

ANALYTIC AND RULE-BASED DECISION SUPPORT TOOL FOR VDT WORKSTATION ADJUSTMENT AND COMPUTER ACCESSORIES ARRANGEMENT

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One important factor that leads to the development of musculoskeletal disorders (MSD) and cumulative trauma disorders (CTD) among visual display terminal (VDT) users is their work posture. While operating a VDT, a user's body posture is strongly influenced by the task, VDT workstation settings, and layout of computer accessories. This paper presents an analytic and rule-based decision support tool called EQ-DeX (an ergonomics and quantitative design expert system) that is developed to provide valid and practical recommendations regarding the adjustment of a VDT workstation and the arrangement of computer accessories. The paper explains the structure and components of EQ-DeX, input data, rules, and adjustment and arrangement algorithms. From input information such as gender, age, body height, task, etc., EQ-DeX uses analytic and rule-based algorithms to estimate quantitative settings of a computer table and a chair, as well as locations of computer accessories such as monitor, document holder, keyboard, and mouse. With the input and output screens that are designed using the concept of usability, the interactions between the user and EQ-DeX are convenient. Examples are also presented to demonstrate the recommendations generated by EQ-DeX.

Key Words: decision support system; VDT workstation; work posture; VDT workstation settings; arrangement of computer accessories

INTRODUCTION

Carpal tunnel syndrome (CTS), neck tension syndrome (NTS), and low back pain have been reported as common occupational injuries found in a large number of visual display terminal (VDT) users. One of the risk factors associated with these injuries is seating with improper posture while interacting with VDT on a prolonged basis. While some VDT users do not develop the above injuries even though their seated postures are improper, their productivity and/or work efficiency may be adversely affected. Improper seated posture may be caused by the following factors: (1) using a non-adjustable poorly designed VDT workstation (i.e., computer table and chair), and (2) using an adjustable VDT workstation but failing to adjust its settings appropriately. Two ergonomic approaches for preventing and controlling CTS (the most common injury reported among VDT users) are to eliminate occupational factors that contribute to the development of the syndrome and to redesign the workstation and/or workplace (Babski and Crumpton, 1997). Workstation redesign is helpful to eliminate or minimize awkward posture of the VDT user. The positioning of a keyboard relative to the user is a crucial factor affecting wrist posture and the risk of cumulative trauma injury (Hedge et al., 1996).

Ergonomic improvements in the design of VDT workstations and tasks have been widely

embraced as a primary measure for preventing musculoskeletal problems in VDT work (Sauter and Schleifer, 1991). Key elements of an ergonomic VDT workstation include height-adjustable work surface, position-adjustable monitor, document holder, detachable keyboard, adjustable seating, wrist support, footrest (if necessary), and appropriate lighting and glare reduction (Gross and Hassel, 1991). Cook et al. (2000) supported the importance of proper VDT workstation design in terms of positions and level heights of computer accessories. There are other studies that also mentioned the computer accessory arrangement but did not propose a solution (Berns and Klusell, 2000; Hastings et al., 2000). Berns and Klusell (2000) mentioned only placing an input device in front of the user as a recommended approach. Another computer accessory that has been widely studied is the monitor. Ankrum and Nemeth (2000) reported that the monitor viewing angle in the range of 35° - 38.5° below eye level is associated with head tilt and head/neck angles consistent with the “comfortable” postures. Straker and Mekhora (2000) categorized monitor positions into two groups: high monitor position (inclined 5° backward with the top of the monitor level with the user’s eyes), and low monitor position (inclined 25° backward with the bottom of the monitor level with the desk). The study shows that VDT users working with a high monitor position have less head, neck, and trunk flexion and less cervical and erector spinae muscle activity than when they work with a low monitor position.

Nanthavanij and Venezia (1999) suggested a set of mathematical formulas that use body height to determine the workstation settings that are appropriate for an individual. However, their formulas emphasize only the vertical heights (from the floor) and horizontal distances (from the VDT user) of the keyboard and monitor. Mekhora et al. (2000) tested the effect of ergonomic intervention on discomfort in VDT users by adjusting their workstation according to the results from Nanthavanij and Venezia’s formulas. Significant improvements were also found in that study. Rurkhamet and Nanthavanij (2000) reported that some computer accessories layout design strongly affects the physical discomforts at the wrist, lower arm, and upper arm, especially when the mouse is predominantly used. They recommended that the adjustment of VDT workstation settings and the arrangement of computer accessories be considered concurrently, and with the consideration of user-related and task-related information. Later, Rurkhamet and Nanthavanij (2004) developed a rule-based algorithm to recommend the location of the monitor, document, keyboard, and mouse on a computer table based on computer task and the user’s typing skill level.

This paper discusses a computerized tool that is developed to assist VDT users in adjusting the workstation and arranging computer accessories so that they can maintain a correct seated posture. EQ-DeX (an ergonomics and quantitative design expert system) is an analytic and rule-based decision support tool that gives not only quantitative recommendations but also line figures that show the resulting body’s seated posture and layout of all computer accessories if the recommendations are followed.

ARCHITECTURE AND COMPONENTS OF EQ-DeX

EQ-DeX is developed using Microsoft Visual Basic (VB) and Visual Rule Studio (VRS) which is a rule-based expert system technology. VRS works as an integral part of VB and appears within VB as an ActiveX Designer. The rule language of VRS, called Production Rule Studio (PRL), is a high level grammar. In VB, VRS is called Rule Machines RuleSet Designer. PRL classes of RuleSet are objects in VB. The designated graphical user interface (GUI) of VB interacts directly with the user by receiving input data and presenting the results (numbers and line figures). While receiving input data from the user, VB works as an error handler. From the input data, both VB and VRS process the data to provide the recommendations (VDT workstation adjustment settings and layout of computer accessories).

The architecture of EQ-DeX is demonstrated in Figure 1.

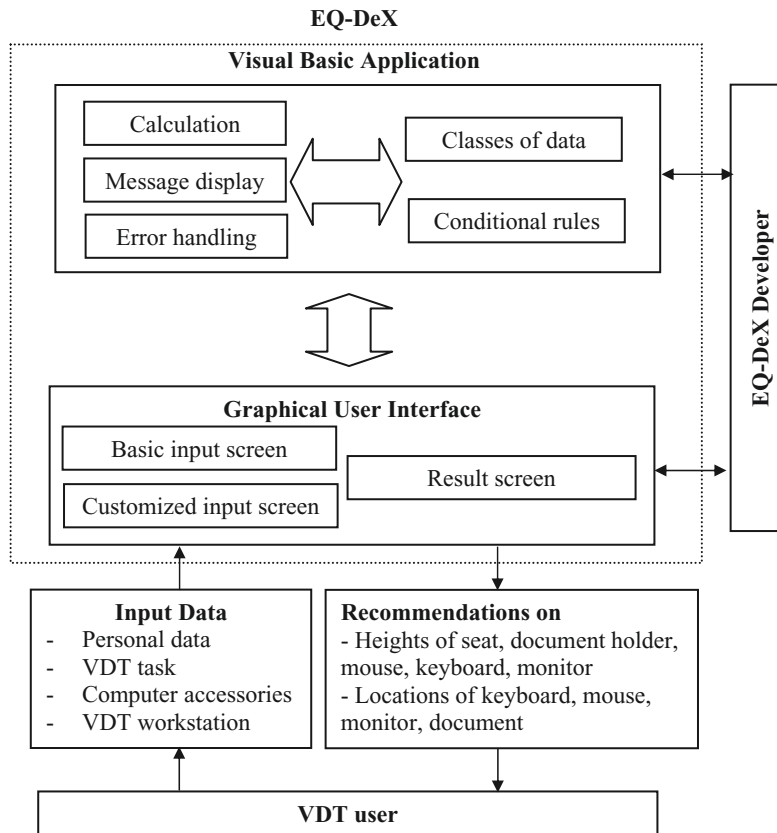


Fig. 1. Architecture of EQ-DeX.

Input data

Input data for EQ-DeX can be categorized into two types, namely, basic input data and customized input data. The basic input data includes a VDT user's personal data (e.g., age, gender, body height, and typing skill level) and usage of computer accessories (percentage of input device usage, percentage of visual display device usage, etc.). The typing skill level is divided into three levels, namely, beginner, intermediate, and professional. The customized input data includes information about adjustment ranges of the user's VDT workstation, dimensions of computer accessories (keyboard, mouse, monitor, and document holder), VDT task, physical interactions between the VDT user and computer accessories (keyboard, mouse, and document holder), and visual interactions between the VDT user and computer accessories (keyboard, monitor, and document holder).

The above mentioned input data can be viewed as quantitative and qualitative data. Quantitative data is processed by the analytic algorithm in EQ-DeX while the qualitative data is processed by the rule statements to rank the placement of computer accessories. Tables 1 and 2 show the physical and visual interactions between a VDT user and computer accessories, respectively. Possible interaction degrees are also shown. According to the physical interaction, VDT users can be divided into three types: (1) keyboard users (those who use the keyboard at least 70% of the task duration), mouse users (those who use the mouse at least 70% of the task duration), and keyboard-mouse users (those who use both the keyboard and mouse relatively equally, i.e., 40-60% of the task duration).

Table 1. Physical interactions between a VDT user and computer accessories.

VDT task	User type	Computer accessory	Degree of interaction
Document preparation	K – Professional	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
	K – Intermediate	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
	K – Beginner	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
Graphics design	M	Keyboard	Weak
		Mouse	Strong
		Document holder	Weak/Moderate
	K-M	Keyboard	Moderate
		Mouse	Moderate
		Document holder	Weak/Moderate
Data entry	K – Professional	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
	K – Intermediate	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
	K – Beginner	Keyboard	Strong
		Mouse	Weak
		Document holder	Weak/Moderate
	M	Keyboard	Weak
		Mouse	Strong
		Document holder	Weak/Moderate
	K-M	Keyboard	Moderate
		Mouse	Moderate
		Document holder	Weak/Moderate

Note: K = keyboard user, M = mouse user, K-M = keyboard-mouse user

Additionally, it is necessary to consider the functional relationships between each pair of computer accessories due to their influence on the relative locations of the devices. Here, we use the conventional concept to express the degree of relationship; that is, A = absolutely important, E = essentially important, I = important, O = ordinary, U = unimportant, and X = not relevant. For example, any pair of devices that receives either “A”, “E”, or “I” for their degree of relationship should be placed close together.

Rules

Rules used in EQ-DeX are created according to ergonomic design principles such as principles for arranging components (the importance principle, the frequency-of-use principle, the functional principle, and the sequence-of-use principle), normal and maximum work areas, and recommended viewing angle and distance. Examples of the rules that EQ-DeX employs to arrange the computer accessories include:

- Rules for comparing percentages of input device usage
- Rules for comparing percentages of visual display device usage

Table 2. Visual interactions between a VDT user and computer accessories.

VDT task	User type	Computer accessory	Degree of interaction
Document preparation	K – Professional	Keyboard	Weak
		Monitor	Moderate/Strong
		Document holder	Weak/Moderate
	K – Intermediate	Keyboard	Moderate
		Monitor	Moderate/Strong
		Document holder	Weak/Moderate
	K – Beginner	Keyboard	Strong
		Monitor	Strong
		Document holder	Strong
Graphics design	M	Keyboard	Weak
		Monitor	Strong
		Document holder	Moderate/Strong
	K-M	Keyboard	Moderate
		Monitor	Strong
		Document holder	Moderate/Strong
Data entry	K – Professional	Keyboard	Weak
		Monitor	Weak/Moderate/Strong
		Document holder	Moderate/Strong
	K – Intermediate	Keyboard	Moderate
		Monitor	Weak/Moderate/Strong
		Document holder	Moderate/Strong
	K – Beginner	Keyboard	Strong
		Monitor	Weak/Moderate/Strong
		Document holder	Moderate/Strong
	M	Keyboard	Weak
		Monitor	Moderate/Strong
		Document holder	Moderate/Strong
	K-M	Keyboard	Moderate
		Monitor	Strong
		Document holder	Moderate/Strong

Note: K = keyboard user, M = mouse user, K-M = keyboard-mouse user

- Rules for classifying user type
- Rules for checking an overlapping condition between the primary and secondary input devices
- Rules for prioritizing the placement of input devices
- Rules for prioritizing the placement of visual displays
- Rules for checking the lower and upper limits of the seat level height
- Rules for checking the lower and upper limits of the keyboard level height
- Rules for checking the lower and upper limits of the monitor level height
- Rules for checking an overlapping condition between visual displays and the primary input device

Adjustment and arrangement algorithms

EQ-DeX utilizes the analytic and rule-based algorithms that consist of sequential mathematical formulas and logic instructions to numerically and logically determine VDT workstation settings and locations of input and display devices based on relevant ergonomic design principles. Briefly, by

assuming that a correct seated posture is maintained, the VDT user's anthropometric data are used to calculate (x, y) coordinates of relevant body reference points, and the reference points of the workstation and computer accessories. Constraints such as the size of computer accessory, user preference, typing skill, and VDT task are also considered in the algorithms to obtain practical and valid results.

The algorithms used in EQ-DeX are based on the following assumptions.

- The VDT user should sit with the back at the upright position, the upper arm hanging naturally along the side, the elbow flexed 90° , the hand and the lower arm forming a straight line, the lower leg forming a right angle with the upper leg, and both feet resting comfortably on the floor (The Human Factors Society, 1988).

- The VDT workstation consists of a fully adjustable computer table and a height-adjustable chair. The range of adjustment is sufficient to accommodate VDT users from the 5th percentile of female population to the 95th percentile of male population.

- Adjustable features of the VDT workstation include: (1) keyboard tray, (2) mouse tray, (3) monitor platform, (4) document holder, and (5) chair seat.

- Computer accessories include: (1) keyboard, (2) mouse, (3) monitor, and (4) document holder.

Initialization: Initially, EQ-DeX will collect data about the VDT user, task, computer accessories, and VDT workstation from the user. It will then define the body reference points (i.e., ankle, knee, hip, shoulder, elbow, fingertip, wrist, and eye). Next, EQ-DeX will define the reference points of computer accessories that the user has to interact with, both physically and visually.

Recommending VDT workstation adjustment settings: From its database on Thai anthropometric data (Thai Industrial Standard Institute, 1994), EQ-DeX is able to estimate the length of key body segments of the VDT user based on the user's gender, age, and body height. From the assumed seated posture, the (x, y) coordinates of body reference points can be determined using the mathematical formulas (shown in the Appendix 1) developed by Nanthavanij and Venezia (1999). Subsequently, the coordinates of the reference points of computer accessories can be next derived.

EQ-DeX will recommend the level heights of chair seat, keyboard tray, mouse tray, monitor platform, and document holder. It is important that the level height of each VDT workstation feature must be within its adjustment range. If not, certain adjustments must be performed.

Figure 2 shows the flow chart of the procedure that recommends the VDT workstation settings.

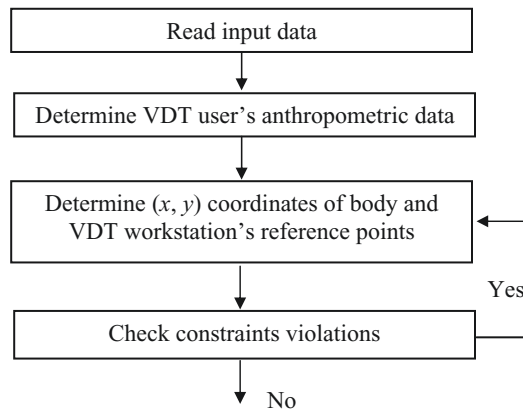


Fig. 2. Procedure for recommending the VDT workstation settings.

Recommending computer accessories layout: For the layout of computer accessories, EQ-DeX starts with the placement of input devices, namely, keyboard and mouse. The percentages of keyboard and mouse usage are compared to determine the primary and secondary input devices. If the keyboard is the primary input device, it is necessary to know whether the alphabet or the numeral section is predominantly used. The optimal locations of the primary and secondary input devices are where the device can be operated most conveniently within the normal working area. If there is a location conflict between the two devices, an alternative location for the secondary input device must be determined. Usually, it should be near the primary input device so that the hand movement between both devices is minimized. Figure 3 summarizes the steps for recommending the locations of both input devices.

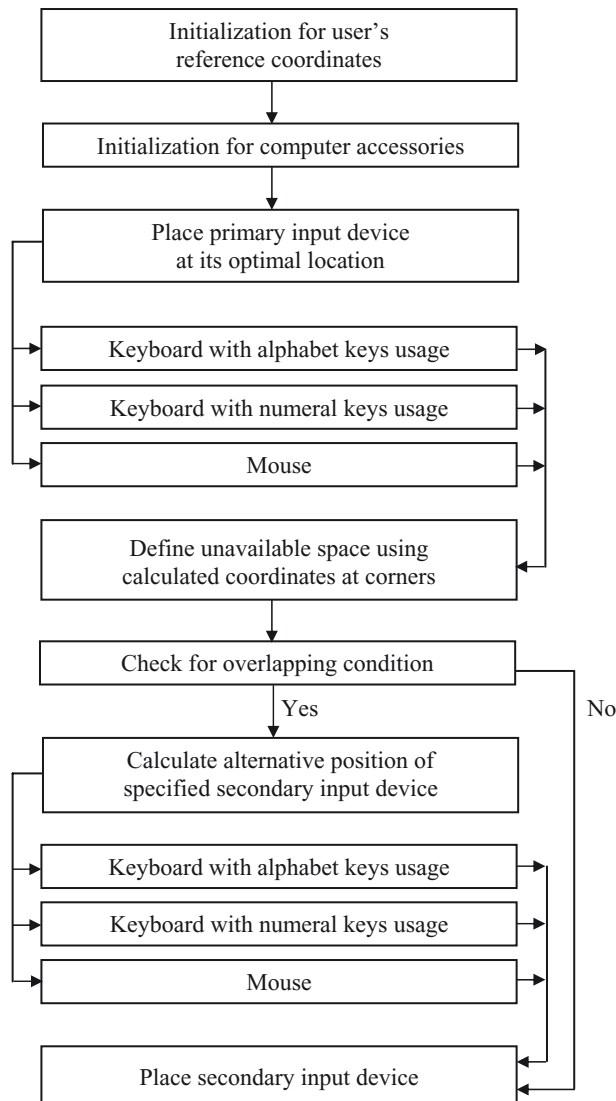


Fig. 3. Procedure for recommending locations of input devices.

The procedure for recommending the locations of visual display devices is shown in Figure 4. Initially, the percentages of monitor and document viewing (depending on the typing skill level of the user or task requirement) are compared to determine the primary and secondary visual display devices. The location of the primary visual display device is determined from the recommended viewing angle and distance. The secondary visual display device is usually placed at its optimal location if it does not obstruct the viewing of the primary display device. Otherwise, an alternative location that is near the primary visual display device so that the head movement is minimized must be determined.

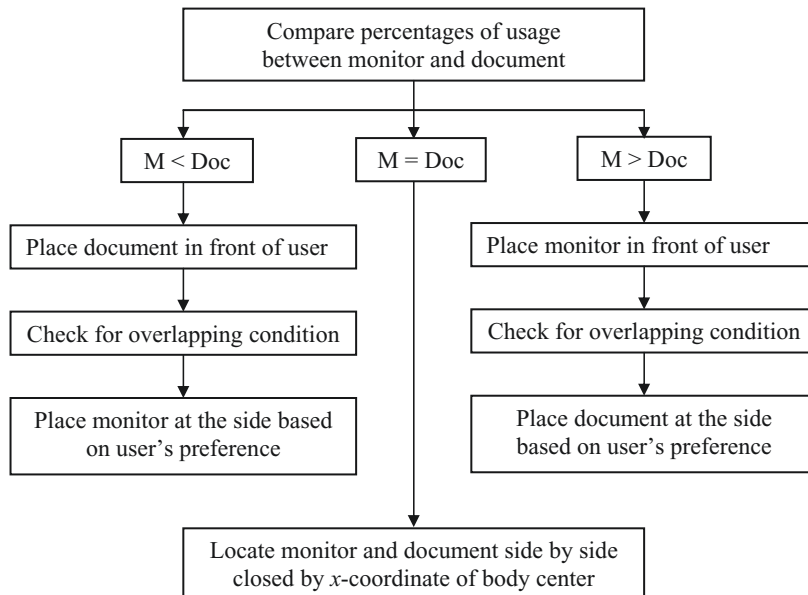


Fig. 4. Procedure for recommending locations of visual display devices (M = monitor, Doc = document).

An example of a rule-based algorithm for placing a monitor in front of the VDT user and obtaining its reference points is given in the Appendix 2. For the details of the adjustment and arrangement algorithms, see Rurkhamet and Nanthavanij (2004).

Graphical user interfaces

To facilitate the user's interactions with EQ-DeX, three screen forms are developed to assist users in entering input data, customizing the data, and viewing the results. These screens are: (1) Input form (2) Customize form, and (3) Result form.

Input form: The Input form allows the user to enter basic input data, to customize input data, and to process input data. The Input form allows the user to enter a new set of input data or retrieve input data from an existing data file. Once the data has been created or retrieved, the user can modify the existing data, save the new data, and print the report of input data. Additionally, the user can choose to customize the default information by clicking on the "Customize Default Information" button or to generate the recommendations by clicking on the "Finish" button. Figure 5 shows the Input form of EQ-DeX.

How to Enter Input Data:

There are two screens for entering input data: (A) Basic Input Data, and (B) Customize Input Data. You need to enter basic input data including personal information and VDT (Visual Display Terminal) task information.

- You are in the screen of **Basic Input Data**
- You can go around the screen by **using Tab button** or clicking at what you want.
- Your Name** can be used as the file name when you save the information.
- Summation of **Input Device** usage should be equal to 100%.
- Summation of **Visual Display** usage should be equal to 100%.

Personal Information

Name

Age years Height cm

Sex Female Male Nationality

Mouse is operated by

Preference of Seating Degree
 Seating with Back Straight
 Leaning Back at 10 Degrees

Typing Skill Level (For Only Document Preparation Work)

VDT (Visual Display Terminal) Task Information

Percentage of Input Device Usage
Keyboard % Mouse %

Percentage of Visual Display Usage
Monitor % Document %

Preferred Location for Monitor when Center Location is not Possible
 Left Side Right Side

Preferred Location for Document when Center Location is not Possible
 Left Side Right Side

When using Keyboard
 I use alphabet keys more than numeric keys
 I use numeric keys more than alphabet keys

Exit Program Customize Default Information Finish

Fig. 5. Input form.

Customize form: In the Customize form, the user will be able to change the default information that EQ-DeX assumes. Specifically, the user can change the default adjustment ranges of the VDT workstation, default dimensions of computer accessories, default percentages of VDT task, and default physical and visual interactions between the user and computer accessories. For the physical and visual interactions, the user can choose the degree of interaction from the given three degrees (i.e., weak, moderate, and strong).

After the altering of default information is finished, the user may choose to return to the Input form by clicking on the “Back” button or to generate the recommendations by clicking on the “Finish” button. When the “Back” button is clicked, the new default information will also be saved. Figure 6 shows the Customize form of EQ-DeX.

Result form: The Result form contains two parts. The left part gives the summary of selected input data and the recommendations for the VDT workstation settings and computer accessories layout. The right part presents two line figures. The top line figure shows a top view of a VDT user and the layout of computer accessories (keyboard, mouse, monitor, and document holder). The accessories are coded with color to differentiate one from the others. The bottom line figure shows a side view of the VDT user’s seated posture if the workstation settings are adjusted according to the recommendations. With the given recommendations and the two line figures, the VDT user is able to visualize what his/her seated posture would look like.

From the Result form, the user can choose to return to the previous form by clicking on the “Back to Previous” button or to exit from EQ-DeX by clicking on the “Exit from Program” button. Additionally, a hardcopy of the recommendations generated by EQ-DeX based on a given set of input data can be obtained by clicking on the “Print” button.

Figure 7 shows the Result form of EQ-DeX.

Customized Form

How to Enter Customized Information

- For adjustable VDT Workstation, enable adjustable check box; otherwise, disable check box.
- The accumulation of work task percentage has to be 100.

Height Ranges of VDT Workstation (in cm)

Adjustable	Minimum	Maximum	
<input type="checkbox"/> Seat Height	<input type="text"/>	<input type="text"/>	<input type="button" value="Default"/>
<input type="checkbox"/> Keyboard Height	<input type="text"/>	<input type="text"/>	<input type="button" value="Clear"/>
<input type="checkbox"/> Monitor Height	<input type="text"/>	<input type="text"/>	

% of Work Task

Document Preparation	<input type="text"/> %	<input type="button" value="Default"/>
Data Entry	<input type="text"/> %	<input type="button" value="Clear"/>
Graphics Design	<input type="text"/> %	<input type="button" value="Clear"/>
Others	<input type="text"/> %	

Computer Accessories (in cm)

	Width	Length	Height	
Keyboard	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Default"/>
Mouse Pad	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Clear"/>
Monitor	<input type="text"/>	<input type="text"/>	<input type="text"/>	
Document	<input type="text"/>	<input type="text"/>	<input type="text"/>	

Remark: Monitor Width is at the Front

Physical Interaction between User and

Keyboard	<input type="text" value="Strong"/>
Mouse	<input type="text" value="Moderate"/>
Document	<input type="text" value="Weak"/>

Visual Interaction between User and

Keyboard	<input type="text" value="Weak"/>
Monitor	<input type="text" value="Strong"/>
Document	<input type="text" value="Moderate"/>

Fig. 6. Customize form.

Top View and Side View of Computer Peripherals and VDT User

Summarized Information for Your Name

Sex **Male** Age **21** years Height **180** cm

with Typing Skill at **Label14** level

Your User Type is **Keyboard**

Monitor Usage > Document Usage

Recommendations for VDT Workstation Settings

Seating at **45** cm height from the floor with Foot Rest **0** cm

Put Keyboard **127** cm from the leftmost of fingertip when streting left arm
49 cm away to the front of the VDT user
70 cm height from the floor

Put Mouse Pad **95** cm from the leftmost of fingertip when streting left arm
37 cm away to the front of the VDT user
70 cm height from the floor

Put Monitor **104** cm from the leftmost of fingertip when streting left
69 cm away to the front of the VDT user
91 cm height from the floor

Put Document **128** cm from the leftmost of fingertip when streting left arm
83 cm away to the front of the VDT user
103 cm height from the floor

TOP VIEW

Legend:
 ■ Monitor
 ■ Document
 ■ Mouse Pad
 ■ Alphabet part of Keyboard
 ■ Numeric part of Keyboard

SIDE VIEW

Legend:
 ■ Monitor
 ■ Document
 ■ Foot rest

Fig. 7. Result form.

EXAMPLES

In this section, we present two examples to show that the recommendations on VDT workstation adjustment and computer accessories arrangement reflect a VDT user's body height, VDT task, and the percentages of usage of input and visual display devices.

Example I

In Example I, the VDT user is assumed to be a 21-year-old Thai male with a body height of 180 cm. The user's dominant VDT task is document preparation and the primary input device is the keyboard. The percentages of input device usage for the keyboard and mouse are 70% and 30%, respectively. While operating the keyboard, the VDT user uses alphabet keys more than numeral keys. His typing skill is at the beginner level. Between the monitor and document, the VDT user spends 70% of his task duration viewing the monitor and 30% viewing the document. The default adjustment ranges of the workstation and default dimensions of computer accessories are used. The input data is entered into EQ-DeX through the Input form (see Figure 8).

Figure 9 shows the Result form that displays the recommendations. From the top line figure at the right side of the form, it is seen that EQ-DeX recommends placing the monitor right in front of the VDT user because the user views the monitor more than the document. The document holder is shown to be at the left side of the monitor due to the user's preference as indicated in Figure 8. From the bottom line figure, it is seen that both the document and monitor screen are at the same level height. This helps to prevent the VDT user from having to look up and down between the two visual display devices.

Between the keyboard and mouse, the keyboard is placed in front of the VDT user since it is his primary input device and it deserves to occupy the best location. The recommended location for the mouse is close to the keyboard to reduce the hand movement between the two devices. However, if the VDT user is not comfortable with the recommended location shown in Figure 9, he can alterna-

How to Enter Input Data:

There are two screens for entering input data: (A) Basic Input Data, and (B) Customize Input Data. You need to enter basic input data including personal information and VDT (Visual Display Terminal) task information.

- You are in the screen of **Basic Input Data**.
- You can go around the screen by using **Tab button** or clicking at what you want.
- Your Name** can be used as the file name when you save the information.
- Summation of **Input Device** usage should be equal to 100%.
- Summation of **Visual Display** usage should be equal to 100%.

Personal Information

Name: Tommy

Age: 21 years Height: 180 cm

Sex: Female Male

Nationality: Thai

Mouse is operated by: Right Hand

Preference of Seating Degree: Seating with Back Straight Leaning Back at 10 Degrees

Typing Skill Level (For Only Document Preparation Work): Beginner Speed < 20 words/min.

VDT (Visual Display Terminal) Task Information

Percentage of Input Device Usage: Keyboard 70% Mouse 30%

Percentage of Visual Display Usage: Monitor 70% Document 30%

Preferred Location for Monitor when Center Location is not Possible: Left Side Right Side

Preferred Location for Document when Center Location is not Possible: Left Side Right Side

When using Keyboard: use alphabet keys more than numeric keys use numeric keys more than alphabet keys

Buttons: Exit Program, Customize Default Information, Finish

Fig. 8. Input data for Example I.

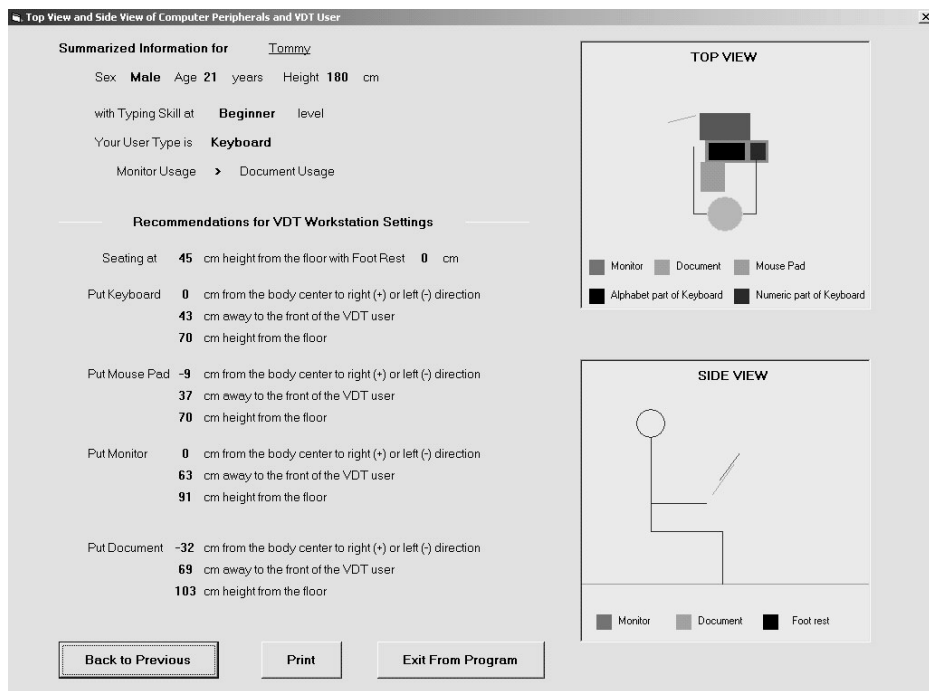


Fig. 9. Recommendations for Example I.

tively place the mouse at the right side of the keyboard (even if it requires greater hand movement than when placing it at the recommended location).

More importantly, the VDT user can work at his VDT workstation with a correct seated posture.

Example II

In this example, we assume that the VDT user is a 27-year-old Thai female with a body height of 150 cm. She is a professional typist. Her dominant VDT task is numerical data entry. As a result, this VDT user uses the keyboard about 70% and the mouse only 30% of her task duration. The primary visual display device is the document (70%) and the secondary one is the monitor (30%). The adjustment ranges of the workstation and the dimensions of computer accessories are according to the default information stored in EQ-DeX. See Figure 10 for the Input form for this example.

From the input data, EQ-DeX recommends placing the document in front of the VDT user (because it is her primary visual display device) and the monitor at its right side. Also, since the VDT user's dominant task is numerical data entry, she tends to use the numeral keys more often than the alphabet keys. As a result, EQ-DeX recommends placing the keyboard such that the numeral keys can be operated conveniently (in front of the user's right hand). For the mouse, EQ-DeX once again recommends placing it close to the numeral keys. At the recommended location, it is seen that the VDT user can move from the numerical keys to the mouse just by sweeping her right lower arm. However, if this location is not preferable, the VDT user can alternatively place the mouse at the right side of the keyboard.

Figure 11 shows the recommendations for the VDT workstation adjustment and computer accessories arrangement for Example II. It is noticed that even though the seat level height is lowered to its lower limit, it is still too high for the VDT user. Thus, EQ-DeX recommends placing a 3-cm footrest under her feet to prevent them from dangling.

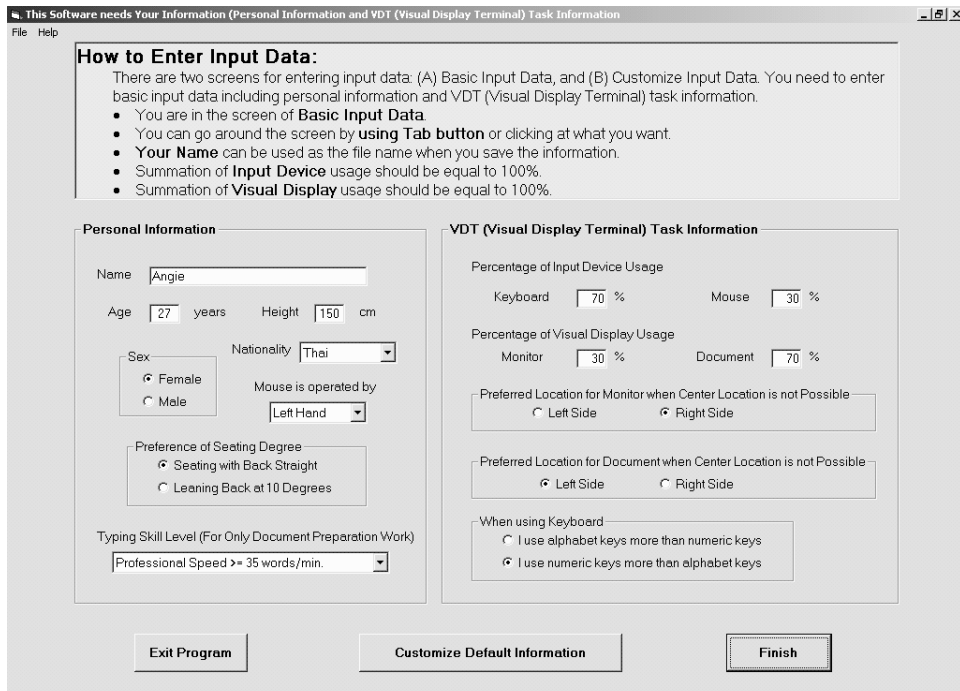


Fig. 10. Input data for Example II.

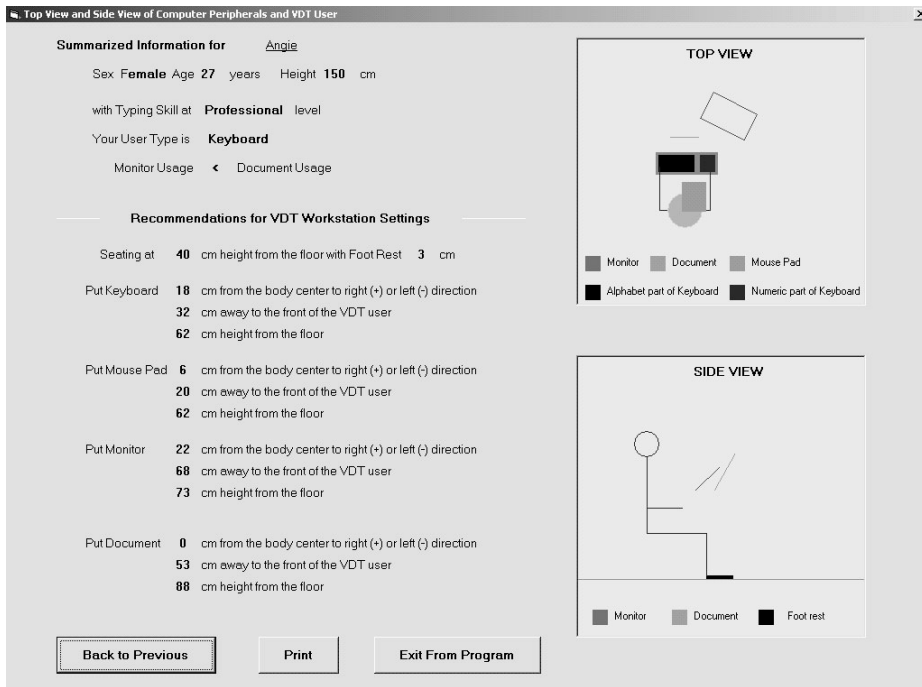


Fig. 11. Recommendations for Example II.

VALIDITY TEST OF EQ-DeX

An experiment to test the validity of the adjustment and arrangement algorithms used in EQ-DeX was conducted (Rurkhamet and Nanthavani, 2004). Twenty university students (15 males and 5 females) participated in the experiment. Their age and body height ranges were 20-22 years and 155-180 cm, respectively. Based on the results of the typing test, the subjects were categorized either as professional-level, intermediate-level, or beginner-level typists. Twelve subjects (four subjects per each category) were assigned to perform the document preparation task. Among the remaining eight subjects, four were assigned the graphics design task while the other four were given the numerical data entry task. Each subject had to perform the given VDT task (which lasted 30 minutes) two times, with at least three days apart between the two trials.

In the first trial, the subjects were asked to adjust the workstation and arrange computer accessories according to their preference. All the settings and accessory locations were recorded and reference points were measured. Additionally, all paired distances between input devices and those between display devices were measured and recorded prior to the test. A video camera was used to record the subject's hand movements.

In the second trial, the subjects used EQ-DeX to recommend the VDT workstation settings and the layout of computer accessories. Then, the computer table, chair, keyboard, mouse, monitor, and document were placed according to the EQ-DeX's recommendations. However, the subjects were allowed to readjust the VDT workstation settings and locations of computer accessories if desired. The instruction, test materials, and test conditions were the same as those used in the first trial. The same video camera was also used to record all hand movements.

The results showed that when adjusting the workstation and arranging computer accessories according to the recommendations from EQ-DeX, the hand movement was found to reduce significantly (at $p = 0.05$). The reductions in average hand movements when performing the document preparation and graphics design tasks were greater than that when performing the numerical data entry task. Table 3 shows the summary of the comparisons between the hand movements from the two trials. Furthermore, the body posture of the subjects was found to be similar to the line figure shown in the Result form.

Table 3. Comparisons between the hand movements from the two trials.

VDT task	Average hand movement (cm)		Average difference (cm)	
	First trial	Second trial	(Second trial – First trial)	% Difference
Document preparation				
- Professional	1914.8	409.4	- 1505.4	- 78.62 %
- Intermediate	1366.6	295.3	- 1071.3	- 78.39 %
- Beginner	927.3	212.3	- 715.0	- 77.11 %
Graphics design	6612.6	1873.4	- 4739.2	- 71.67 %
Numeric data entry	4561.1	3426.6	- 1134.5	- 24.87 %

Note: Adapted from Rurkhamet and Nanthavani (2004)

CONCLUSION

This paper discusses the design, structure, and components of EQ-DeX which is an analytic and rule-based tool for recommending the VDT workstation settings and computer accessories layout so that the VDT user could maintain a correct seated posture. EQ-DeX uses three screen forms to enable

a user to enter input data, customize the adjustment ranges and dimensions of computer accessories, and view and print the report of recommendations. EQ-DeX requires basic input data such as age, gender, and body height of the VDT user. Other input data, for example, VDT task, usage of input and visual display devices, and location preference, are also required by EQ-DeX. From the input data, the adjustment and arrangement algorithms are utilized in sequence to recommend the VDT workstations settings and the arrangement of the input and visual display devices. The quantitative data are processed by a set of mathematical formulas to generate the VDT workstation settings while the qualitative data are processed by a set of rules to recommend the layout of computer accessories.

The recommendations are presented in two forms: (1) numerical values, and (2) line figures. The numerical values assist the VDT user in adjusting the workstation to achieve more precise settings. These numbers also help to eliminate the vagueness of recommendations usually encountered in the literature. The two line figures in the result report enable the VDT user to have a visual feedback of his/her seated posture when the VDT workstation is adjusted according to the recommendations. The locations of input and visual display devices are also displayed in the figures.

EQ-DeX is a decision support tool that will make VDT workstation adjustment and computer accessories arrangement practical and convenient. With EQ-DeX and a fully adjustable VDT workstation, it is anticipated that VDT users will be able to sit with a correct seated posture while operating the VDT. Consequently, the risk of developing MSD and CTD is expected to be reduced.

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APPENDIX 1

Formulas for calculating (x, y) coordinates of body reference points

Ankle (A):	Ax	=	$T\sin [BA] + UL\cos [SA]$
	Ay	=	0
Toe (TO)	TOx	=	Foot + Ax
	TOy	=	0
Knee (K)	Kx	=	Ax
	Ky	=	Ay + LL + TT
Hip (H)	Hx	=	$T\sin [BA]$
	Hy	=	$Ky - UL\sin [SA]$
Shoulder (S)	Sx	=	0
	Sy	=	$Hy + T\cos [BA]$
Elbow (EL)	ELx	=	$U\sin [AA]$
	ELy	=	$Sy - U\cos [AA]$
Fingertip (F)	Fx	=	$ELx + EF\cos [AA]$
	Fy	=	$ELy + EF\sin [AA]$
Wrist (W)	Wx	=	$Fx - F\cos [AA]$
	Wy	=	$Fy - F\sin [AA]$
Eye (E)	Ex	=	5
	Ey	=	$Sy + SE$
Top of head (TH)	THx	=	0
	THy	=	Seated height
Chin (C)	Cx	=	0
	Cy	=	$THy - CT$

Note: AA = arm angle, BA = back angle, SA = seat angle, CT = chin-to-top of head length, EF = elbow-fingertip length, F = forearm length, LL = lower arm length, SE = shoulder-eye length, UA = upper arm length, UL = upper leg length, T = trunk length, TT = thigh thickness

APPENDIX 2

Rule-based algorithm for placing a monitor in front of the user and obtaining its reference points

```

XLowerRight_Monitor = XBodyCenter + (MonitorWidth / 2)
YLowerRight_Monitor = Eye_X + YBodyCenter + (MinVDMonitor *
    Cos(Recommended_Viewing_Angle * DEGTORAD)) -
    (MonitorHeight / 2) * Sin(Recommended_Viewing_Angle
    * DEGTORAD)
ZLowerRight_Monitor = Eye_Y - MinVDMonitor *
    Sin(Recommended_Viewing_Angle * DEGTORAD) -
    (MonitorHeight / 2) * Cos(Recommended_Viewing_Angle
    * DEGTORAD)
If (YLowerRight_Monitor < YUpperRight_PrimaryInput) Then
    YLowerRight_Monitor = YUpperRight_PrimaryInput + 1
End If
If YLowerRight_Monitor < YUpperRight_SecondaryInput Then
    YLowerRight_Monitor = YUpperRight_SecondaryInput + 1
End If
If YLowerRight_Monitor < YUpperRight_AlterSecondaryInput Then
    YLowerRight_Monitor = YUpperRight_AlterSecondaryInput + 1
End If
If ZLowerRight_Monitor > Monitor_Upper Then
    ZLowerRight_Monitor = Monitor_Upper
    YCenter_Monitor = YLowerRight_Monitor + (MonitorHeight / 2) *
        Sin(Recommended_Viewing_Angle * DEGTORAD)
    ZCenter_Monitor = ZLowerLeft_Monitor + (MonitorHeight / 2) *
        Cos(Recommended_Viewing_Angle * DEGTORAD)
    Recommended_Viewing_Angle = Atn((Eye_Y - ZCenter_Monitor) /
        (YCenter_Monitor - Eye_X)) * RADTODEG
Else
    If ZLowerRight_Monitor < Monitor_Lower Then
        ZLowerRight_Monitor = Monitor_Lower
        YCenter_Monitor = YLowerRight_Monitor + (MonitorHeight / 2) *
            Sin(Recommended_Viewing_Angle * DEGTORAD)
        ZCenter_Monitor = ZLowerLeft_Monitor + (MonitorHeight / 2) *
            Cos(Recommended_Viewing_Angle * DEGTORAD)
        Recommended_Viewing_Angle = Atn((Eye_Y - ZCenter_Monitor) /
            (YCenter_Monitor - Eye_X)) * RADTODEG
    End If
End If
If Recommended_Viewing_Angle > 60 Then Recommended_Viewing_Angle = 60
End If
If Recommended_Viewing_Angle < 0 Then Recommended_Viewing_Angle = 0
End If
XLowerLeft_Monitor = XBodyCenter - (MonitorWidth / 2)
YLowerLeft_Monitor = YLowerRight_Monitor
ZLowerLeft_Monitor = ZLowerRight_Monitor
XCenter_Monitor = XBodyCenter
YCenter_Monitor = YLowerRight_Monitor + (MonitorHeight / 2) *
    Sin(Recommended_Viewing_Angle * DEGTORAD)

```


$$\begin{aligned}
Z_{\text{Center_Monitor}} &= Z_{\text{LowerLeft_Monitor}} + (\text{MonitorHeight} / 2) * \\
&\quad \text{Cos}(\text{Recommended_Viewing_Angle} * \text{DEGTORAD}) \\
X_{\text{UpperRight_Monitor}} &= X_{\text{BodyCenter}} + (\text{MonitorWidth} / 2) \\
Y_{\text{UpperRight_Monitor}} &= Y_{\text{LowerRight_Monitor}} + \text{MonitorHeight} * \\
&\quad \text{Sin}(\text{Recommended_Viewing_Angle} * \text{DEGTORAD}) \\
Z_{\text{UpperRight_Monitor}} &= Z_{\text{LowerLeft_Monitor}} + \text{MonitorHeight} * \\
&\quad \text{Cos}(\text{Recommended_Viewing_Angle} * \text{DEGTORAD}) \\
X_{\text{UpperLeft_Monitor}} &= X_{\text{BodyCenter}} - (\text{MonitorWidth} / 2) \\
Y_{\text{UpperLeft_Monitor}} &= Y_{\text{LowerRight_Monitor}} + (\text{MonitorHeight} * \\
&\quad \text{Sin}(\text{Recommended_Viewing_Angle} * \text{DEGTORAD})) \\
Z_{\text{UpperLeft_Monitor}} &= Z_{\text{UpperRight_Monitor}}
\end{aligned}$$

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