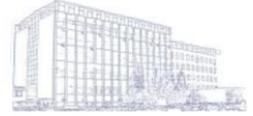




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# Towards a Methodology for CAD program Efficiency Assessment

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**Abstract** — All CAD programs differ when it comes to efficiency. The efficiency of a CAD program depends on its functionality and the user interface. The aim of this research is to investigate possible methodologies for the assessment of efficiency of CAD software in regard to its user interface. Based on an analysis of the interactions between the user and the CAD programs user interface, six elementary user actions were detected. Every user action requires some effort. Efficiency is defined as an inverse value of the total effort that has been invested in the design process. Therefore, to evaluate the efficiency of a CAD program, it is necessary to calculate the total effort. In this paper, four possible methodologies for determining the overall effort during the design process are presented. For each method, process parameters that should be measured in order to calculate the efficiency are defined.

**Keywords**— Computer Aided Design, Productivity, Efficiency, Assessment, Methodology

### I. INTRODUCTION

There are currently over 50 mechanical CAD (Computer Aided Design) programs available on the market [1,2]. Most of these software solutions are commercial products, although there are those that come with licenses that offer free use. The goal of each organization involved in mechanical design, and especially design-driven companies, is to make the design process as productive as possible. In order to achieve this goal those organizations typically acquire CAD programs.

The productivity of the design process based on a CAD program is a measure proportional to the results that a team or an individual can achieve by using a CAD program for a certain period of time. Productivity depends on the following factors:

- the user - knowledge and skills of the person who uses the CAD program, as well as his experience in using the program,
- the program - how efficient the CAD program is,
- the equipment - computers and other equipment involved in the design process (available input / output devices, RAM capacity, processor, computer speed) and
- the organization - management of the design processes inside the organization (team work, collaborative work, synchronization of activities, simultaneous engineering, scheduling, just-in-time,

corporate standards, UDF usage ...), working environment.

Obviously, productivity depends on multiple factors that are difficult to determine. One of the most important ones is the efficiency of the CAD program itself.

The efficiency of a CAD program depends on its functionality (the available tools used for building a geometric model) and the user interface. The existence of a graphical user interface (GUI) is inherent to all CAD programs, but those GUIs are significantly different in their design, structure and functionality. The difference in the GUI makes even the CAD programs that are based on the same graphic kernel different when it comes to efficiency.

The aim of research described in this paper is to explore possible methods for determining the efficiency of the interface of the CAD program, as well as to determine process parameters that should be measured in order to calculate efficiency. The motivation behind this research is twofold. Results of the study can help organizations involved in mechanical design to choose the program that best suits their needs. On the other hand, the results of the analysis can help manufacturers of CAD programs to optimize the user interface.

This study deals primarily with efficiency that is based on the user interface. The next study will address the efficiency that depends on functions available in CAD programs.

In the second chapter, a general definition of efficiency is given first, followed by an analysis of the computer aided design process. It is also analysed how the typical user is using the input devices (keyboard and mouse) during the design procedure, and the recognised actions are classified in regard to the efforts required to complete them. Based on this, the equation for calculating the total effort in the computer aided design process is proposed.

Throughout the third chapter, different ideas behind mathematical and physical models are given together with the different methods needed for expressing the efforts of actions (mouse click, mouse wheel scroll, etc.). This is the basis for data analysis. It is also mentioned what is going to be done next in order to work out the suggested methods and get a system for efficiency assessment that can be practical in real life cases.

## II. EFFICIENCY OF CAD PROGRAMS

According to the Business Dictionary [3], efficiency is “the comparison of what is actually produced or performed with what can be achieved with the same consumption of resources (money, time, labour, etc.). It is an important factor in the determination of productivity”.

Efficiency of a CAD program ( $Ef$ ) may also be defined as the relationship between the cost of design ( $Cd$ ) and the effort invested in design ( $E$ ).

$$Ef = \frac{Cd}{E} \quad (1)$$

Because the price of the design is a category which can be negotiated, the concept of relative efficiency is introduced here. Relative efficiency ( $Er$ ) is the inverse value of effort.

$$Er = \frac{1}{E} \quad (2)$$

Using relative efficiency, the efficiency of a CAD program may be expressed regardless of the project being done.

The use of the user interface of a CAD program during the design process requires physical and mental efforts. In this research only physical efforts were studied, while mental efforts were neglected.

A typical CAD user interface relies on the keyboard and the mouse as the input devices. In order to interact with the input devices, right-handed people use their left hand for occasional keystrokes on Ctrl, Shift, Alt and Esc keys, and the right hand for mouse clicks and mouse wheel scrolls. Also, the right hand moves the mouse. When it is necessary to type in text or numerical values, people let go of the mouse and use their right hand or both hands for typing (Fig 1.).

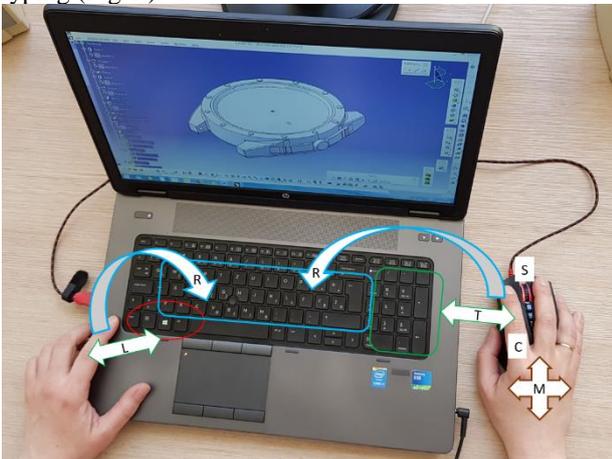


Fig 1. Graphically presented control of input devices

Based on the previous analysis, it can be defined that the physical effort during the design process consists of the following elementary categories of actions:

- **c - Left, right and middle mouse button clicks.** There is no significant difference in efforts that occurs when clicking on the left, middle and right mouse buttons. Therefore, these actions can be classified in the same category;
- **s - Mouse wheel scrolls.** The elemental effort is one rotational step of the mouse wheel;

- **l - Left hand keystrokes.** One elemental effort consists of positioning the finger on the Ctrl, Alt, Shift or Esc key and the keystroke;
- **k - Right and left hand keystrokes.** In this case, the user is using both or one hand to type in one or more alphanumeric characters such as numerical values or the name of the part;
- **m - Movement of the right hand together with the mouse.** The aim of this action is to control the position of the cursor on the screen. It should be borne in mind that the user can adjust the mouse sensitivity by changing the speed of moving the mouse in the control panel of the operating system;
- **t - Transfer (movement) of the right hand from the mouse to the keyboard or vice versa** (number). Each move to the keyboard and each return to the mouse are counted as separate elemental efforts.

The previous analysis is related to right-handed users. A similar analysis can be done for left-handed users, during them the effort should remain approximately the same.

The total effort ( $E$ ) is a sum of the **particular efforts**:

$$E = C+S+L+K+M+T \quad (3)$$

Where:

- **C** – represents the particular effort for left, right and middle mouse button clicks,
- **S** – represents the particular effort for mouse wheel scrolls,
- **L** – represents the particular effort for left hand keystrokes,
- **K** – represents the particular effort for right and left hand keystrokes (the usual typing on the keyboard),
- **M** – represents the particular effort for movements of the right hand together with the mouse in order to control the position of the cursor,
- **T** – represents the particular effort needed to transfer (movement) the right hand from the mouse to the keyboard or vice versa.

## III. METHODOLOGY

In order to determine the overall effort by adding particular efforts, it is necessary to set up a method by which particular efforts can be expressed in the same unit. Also, the method should define how the quantification of elementary efforts will be carried out.

Several methods to express the efforts related to specific actions are explored here in such a way that they can be summated. So far, four different approaches to determine physical effort of design are identified:

1. the click based approach,
2. the time based approach,
3. the path based approach and
4. the energy based approach.

The rest of this chapter is devoted to the closer elaboration of these methods, but their comparison is foreseen in future work.

### A. Click based approach

In order to express the effort needed for performing different actions such as mouse clicks, moving the mouse, transfers of hand and typing, the concept of an atomic effort ( $e_c$ ) is introduced. It is equivalent to one mouse click.

Left, right and middle mouse button clicks are all considered to require the same atomic effort.

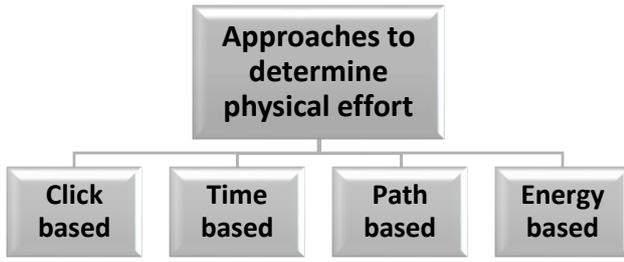


Fig 2. Different approaches to expressing physical effort during a process of computer aided design

The particular effort related to mouse clicks, performed during a design session in a CAD program, may be defined as:

$$C = \sum_{i=0}^{i=c} e_c \quad (4)$$

Where  $e_c$  represents one left, right or middle mouse button click and “c” represents the total number of clicks.

The idea behind the click based approach is to express the effort that an average user makes in order to perform the actions of mouse wheel scrolling, typing, movement of the mouse or transfer of the hand in term of the effort required to perform one mouse click. In this way, the atomic effort for rotating the mouse wheel for one scrolling step,  $e_s$ , can be expressed as:

$$e_s = w_s e_c \quad (5)$$

Where  $w_s$  is the weight coefficient used for the conversion of a mouse wheel scrolling effort to an atomic effort.

Typing on the keyboard, movement of the mouse or the transfer of hand are actions that require different, probably greater, efforts, so the atomic efforts related to those may be defined as:

$$e_l = w_l e_c \quad (6)$$

$$e_k = w_k e_c \quad (7)$$

$$e_m = w_m e_c \quad (8)$$

$$e_t = w_t e_c \quad (9)$$

Where:

- $w_s$  - represents the weight coefficient for the mouse scrolling action,
- $w_l$  - represents the weight coefficient for the action of typing on the keyboard with the left hand,
- $w_k$  - represents the weight coefficient for the action of typing on the keyboard with both hands,
- $w_m$  - represents the weight coefficient for the action of moving the mouse,
- $w_t$  - represents the weight coefficient for transferring the hand from the mouse to the keyboard or vice versa.

Following the analogy, the particular effort for s mouse wheel scrolls may be defined as:

$$S = \sum_{i=0}^{i=s} e_s = w_s \sum_{i=0}^{i=s} e_c \quad (10)$$

The particular effort for l left hand keystrokes is defined as:

$$L = \sum_{i=0}^{i=l} e_l = w_l \sum_{i=0}^{i=l} e_c \quad (11)$$

The particular effort for keyboard typing of k characters with both hands is equal to:

$$K = \sum_{i=0}^{i=k} e_k = w_k \sum_{i=0}^{i=k} e_c \quad (12)$$

The particular effort for m mouse movements with the hand is defined as:

$$M = \sum_{i=0}^{i=m} e_m = w_m \sum_{i=0}^{i=m} e_c \quad (13)$$

The particular effort for t hand transfers from the mouse to the keyboard or vice versa is defined as:

$$T = \sum_{i=0}^{i=t} e_t = w_t \sum_{i=0}^{i=t} e_c \quad (14)$$

The weight coefficients are used to define the ratio between the effort needed for a specific action and the atomic effort, and also to overcome the difference in units in which the partial efforts are expressed. These weight coefficients will be calculated based on some of the following approaches: path, time or energy based approach. The problem with these weight coefficients is the fact that the base unit needs to become one mouse click after we have multiplied the action quantity with the said coefficient. To do so, for example, a number of mouse scrolls must be multiplied by a coefficient which has a unit where the denominator is a mouse scroll, and the numerator is a mouse click. This would apply to all actions, but finding these though theoretically possible is something to work on.

A total value for the effort can be calculated as in equation (3), with the unit of E being a mouse click.

For this approach following events should be measured:

- c - number of left, right and middle mouse button clicks,
- s - number of mouse wheel scrolls,
- l - number of left hand keyboard strokes,
- k - number of characters typed on keyboard,
- m - number of mouse movements together with the hand,
- t - number of hand transfers from the mouse to the keyboard or vice versa.

### B. Time based approach

According to this approach, the effort is proportional to the total time needed for the completion of the design process.

In order to eliminate the influence of an individual users' skills, statistically calculated average values of time required by certain types of actions are used. Therefore, this method requires that an auxiliary experiment be

performed with a large number of users with different characteristics (age, gender, left-handed or right-handed people etc.). The aim of this experiment is to calculate the average times needed to perform a single instance of each action: mouse click, key stroke, mouse scroll, mouse movement and transferring the hand from the mouse to the keyboard or vice versa. For this approach the following data needs to be determined using the auxiliary experiment:

- $t_c$  – the average time required for one left, right or middle mouse click,
- $t_s$  – the average time required for mouse wheel scroll,
- $t_l$  – the average time required for left hand keystrokes (ctrl, alt, left side shift and esc),
- $t_k$  – the average time required for typing with both hands,
- $t_m$  – the average time required for mouse movement together with hand and
- $t_t$  – the average time required for hand transfer from mouse to keyboard or vice versa.

Getting an average time for multiple users will make this method more objective and reliable.

The particular effort (time) related to mouse clicks, performed during a design session in a CAD program, may be defined as:

$$C = \sum_{i=0}^{i=c} t_c \quad (15)$$

Where  $t_c$  is the average time required for one mouse click and “c” is the number of left, right and middle mouse button clicks.

Particular effort for the rest of the actions may be defined as:

$$S = \sum_{i=0}^{i=s} t_s \quad (16)$$

$$L = \sum_{i=0}^{i=l} t_l \quad (17)$$

$$K = \sum_{i=0}^{i=k} t_k \quad (18)$$

$$M = \sum_{i=0}^{i=m} t_m \quad (19)$$

$$T = \sum_{i=0}^{i=t} t_t \quad (20)$$

Therefore, to determine the particular efforts it is necessary to experimentally determine occurrence of c, s, l, k, m and t, like in the case of the click based approach. The total effort for this approach can be calculated as in equation (3), with the unit of E being in seconds.

### C. Path based approach

According to this approach, the effort is equal to the total path traversed by arms or fingers in interaction with GUI during the design session. Next figure represents

typical path of mouse cursor on the display. The user's hand along with the mouse crosses a similar path but downscaled.

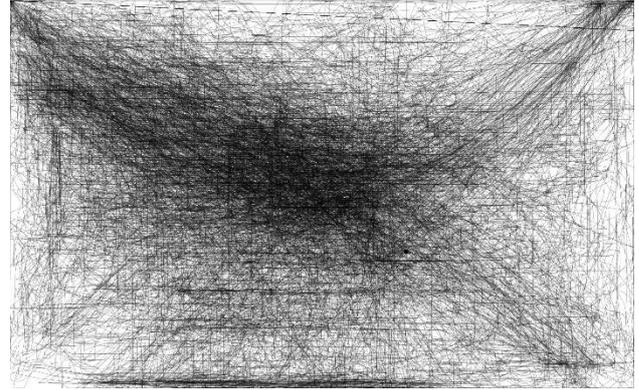


Fig 3. Heat map of my mouse path after 4 hours of casual PC usage [6]

Paths for mouse clicks and mouse wheel scrolls are always the same. Contrary to this, paths required for all other type of input actions are different – context dependent. Therefore, this approach requires an auxiliary experiment in order to determine:

- $p_c$  – The length of path required for completing one mouse click;
- $p_s$  – The length of path required for one mouse wheel scroll (one rotational step). It will be calculated experimentally, using the diameter of the mouse wheel;
- $p_l$  – The average length of path required for left hand keystrokes (ctrl, alt, shift, esc);
- $p_k$  – The average length of path required for typing with both hands;
- $p_m$  – The average length of path required for one mouse movement together with the hand;
- $p_t$  – The average length of path required for a hand transfer from the mouse to the keyboard or vice versa. It will be measured from the centre of the mouse pad to the middle of keyboard (Fig 4.).

$$p_t = \frac{L}{2} + a \quad (17)$$



Fig 4. A graphic display of the dimensions required to calculate the average hand transfer distance

The particular effort (distance) related to mouse clicks, performed during a design session in a CAD program, may be defined as:

$$C = \sum_{i=0}^{i=c} p_c \quad (21)$$

Where  $p_c$  is the path required for one mouse click and “c” is the number of left, right and middle mouse button clicks.

Particular effort for the rest of actions may be defined as:

$$S = \sum_{i=0}^{i=s} p_s \quad (22)$$

$$L = \sum_{i=0}^{i=l} p_l \quad (23)$$

$$K = \sum_{i=0}^{i=k} p_k \quad (24)$$

$$M = \sum_{i=0}^{i=m} p_m \quad (25)$$

$$T = \sum_{i=0}^{i=t} p_t \quad (26)$$

Therefore, to determine the particular efforts it is necessary to experimentally determine occurrence of c, s, l, k, m and t, like in the case of the click based approach. The total effort for this approach can be calculated as in equation (3), with the unit of E being in meters.

Calculating the particular effort for the mouse movement together with the hand in the path based approach can be done also by direct measuring of the mouse path during the session of computer aided design. This method will give a more exact value.

#### D. Energy based approach

The idea behind this approach is to calculate how much energy (e) it takes for a specific action to be completed. The energy needed for some of the actions will be calculated using mechanic laws. For example, in order to move the mouse, the user has to overcome all forces that oppose mouse movement. The first of those is the frictional force caused by static friction. In order to overcome this force, the user needs to act upon the mouse using the force that is higher than the frictional force. While moving the mouse, the user also needs to overcome the inertial force and the force that is the result of the dynamic friction.

To calculate the particular efforts, it is necessary to define the following values:

$e_c$  – the energy required for one left, right or middle mouse click,

$e_s$  – the energy required for one mouse wheel scroll,

$e_l$  – the average energy required for one left hand keystroke (ctrl, alt, shift, esc),

$e_k$  – the average energy required for typing with both hands,

$e_m$  – the average energy required for one mouse movement together with the hand,

$e_t$  – the energy required for an average hand transfer from the centre of the mouse pad to the middle of keyboard.

The particular effort (energy) related to mouse clicks, performed during a design session in a CAD program, may be defined as:

$$C = \sum_{i=0}^{i=c} e_c \quad (27)$$

Where  $e_c$  is the energy required for one left, right or middle mouse click, and “c” is the number of mouse clicks, as determined in click based approach.

The particular efforts for the rest of the actions may be defined as:

$$S = \sum_{i=0}^{i=s} e_s \quad (28)$$

$$L = \sum_{i=0}^{i=l} e_l \quad (29)$$

$$K = \sum_{i=0}^{i=k} e_k \quad (30)$$

$$M = \sum_{i=0}^{i=m} e_m \quad (31)$$

$$T = \sum_{i=0}^{i=t} e_t \quad (32)$$

Again, to determine particular efforts it is necessary to experimentally determine occurrence of c, s, l, k, m and t, like in the case of the click based approach. The total effort for this approach can be calculated as in equation (3), with the unit of E being in joules.

#### IV. CONCLUSION

The efficiency of the user interface of a CAD program can be expressed in terms of total effort that the user invests during the computer aided design process. To determine this effort, four methodologies were identified: the click based approach, the time based approach, the path based approach and the energy based approach. For each methodology, a way of calculating particular efforts has been presented, together with the necessary values that have to be measured or quantified.

In order to choose the best method, in the further work it is necessary to elaborate each of these methodologies, and then compare the results of their application in evaluation of CAD programs efficiency.

#### ACKNOWLEDGMENT

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