Ergonomic Implications of Technological Innovations in the Development of Computer Workstations

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Abstract. Relentless technological progress creates change in the work environment, including that of commonly used computer workstations. Determinants of change in this respect are both the changes in information and communication technologies as well as the more often exhibited concern for the welfare of employees. Technological innovations derive from a multifaceted improvement of a specified element of the technical environment (e.g., contrast, energy consumption for the next generation of computer screens), with the assumption that they will bring a benefit in terms of ergonomic quality of working conditions. Technological innovations can, however, cause a deterioration of identified in advance or often unknown parameters of the working environment, in particular, they can have negative consequences for ergonomic working conditions. The analysis found that technological changes satisfactory from the point of view of ergonomics.

Keywords: Ergonomic design · Heuristic methods · Design · Ergonomics · Devices for the elderly

1 Introduction

Innovations related to the human working environment clearly affect the ergonomic dimension of work systems. In many cases, however, an ergonomic evaluation of the resulting situation is a consequence of irregularities in the functioning of the anthropotechnical system. Innovations include both events of a technical, organizational nature as well as financial – economic. There is therefore a need to consider the ergonomic potential of introduced innovations, particularly in the area of computer workstations as the fundamental work unit of any modern organization. For this purpose, the term innovation must be defined. The broadest and currently classic definition of innovation was presented by J.A. Schumpeter, who interpreted innovation as a discrete undertaking of new combinations of production factors relating to five instances [20]:

- the introduction of a new product,
- the introduction of a new method of production,
- the opening of a new market,

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- the acquisition of new sources of raw materials or half-manufactured products,
- and the conduction of a new method of organization of business processes in production as well as in the sphere of the circulation of goods.

The innovation process is inextricably linked with progressive phenomena of change, reforms and ideas that seek to better exploit existing knowledge, capital, and infrastructure of the information society. Currently, innovation is interpreted in two ways, narrow and broad, i.e. sensu *stricte* and sensu *largo*. In the narrow sense, innovation is defined as a change in manufacturing methods based on new, not previously used, knowledge. One of the proponents of such a narrow interpretation of the concept of innovation was, among others, E. Mansfield, who believes that "innovation is the first application of the invention" [14]. A similar view is expressed by Ch. Freeman, who defined innovation as "the first commercial introduction of a new product, process or machine" [7].

In the broad sense, according to J. A. Allen "innovation is the introduction of new products, processes or procedures to wide application" [1]. P. R. Whitfield stated that innovation is a sequence of complex acts of solving problems, the result of which is some comprehensively developed novelty [23]. In Kotler's broad definition "the concept of innovation refers to any good, which is seen by someone as new" [13], and Rogers' innovation "is an idea, practice or object that is perceived as new by an individual or other receiving entity" [18].

According to the Oslo Manual, used in Europe for research on innovation and which accumulates all created definitions to date, innovation occurs when a new or improved product is introduced to the market, or a new or improved process is used in production, wherein the given product or process is new at least from the point of view of the introducing organization.

Innovation includes all sorts of phenomena and processes related to technological, organizational, economic, social, and psychological progress. Innovations can be created by one person or a group of people or institutions, which is why there are many divisions depending on the type and complexity.

The most frequently proposed breakdown occurring in literature is the division into technological innovations, which include product and process innovations, and non-technological innovations, including marketing and organizational innovations. In addition to the subject criterion in the typology of innovation there can be found a number of divisions based on the criteria:

- originality of changes; pioneering or replicating innovations;
- novelty; new innovations on a global scale, for the market or business;
- magnitude; radical or incremental innovations;
- scope and duration of exposure; revolutionary, evolutionary, strategic or tactical innovations;
- source; foreign, domestic, internal, external, demand or supply innovations;
- complexity; conjugated or not conjugated innovations;
- psychosocial factors; reflective, intentional or unintentional innovations;
- scope of impact; innovation outside the organization or within the organization;
- technological and capital intensity; innovations of advanced or simple technology;
- types of knowledge; tangible or intangible innovations;
- motive for innovative action; autonomous or induced innovation.

In studies devoted to technical progress it is assumed that innovation has an original character, and the main criterion for its distinction is its size, its so-called radicality or groundbreaking nature.

A groundbreaking innovation is defined as the application of a previously unused technical solution that brings about revolutionary change in the way of solving the previously unsolved problem of a particular group of potential recipients – users [21].

One type of "creative destructions" aimed at the recipient – user are ergonomic innovations generated as a result of human creativity, courage and ingenuity. Ergonomic innovation can be defined as the process of introducing a "new solution" to production and use by applying anthropocentric, social, biotic and technical combinations which alter the existing parameters of objects and products in terms of size, quality, novelty and effectiveness. Ergonomic innovation can thus be an approach to design which will allow for obtaining results in the form of solutions that are much more resistant to human error [3] or also resistant to any interference in the process [17] which can lead to a dangerous situation or crisis [2].

One form of innovation can be those that are ergonomic, which collate achievements of many sciences attempting to humanize the living and working environments so that they are friendly to the psycho-physical needs of users, but bring tangible benefits when they completely fulfil the needs of the changing recipient – operator – user. However, they are only a part of the introduced changes, the ergonomic consequences of any innovative changes taking place at computer workstations should also be assessed.

2 Innovations in Operator Workstations

In the era of entrepreneurial culture manifested as a strong attachment of an individual to work, employees devote most of the day to work, which is why it is important to carry out a series of tangible and intangible actions of a scientific, research, technical and organizational character to improve the quality of working life [16]. Ergonomic innovations handle the adaptation of technical tools, positions and methods of work and the material work environment to the biological and psychological needs of the human – operator. The main objective of ergonomic innovations is to ensure healthy and safe working conditions to the human – operator. These activities, which improve the quality of life, are inherent in the pilot concept of the so-called "innovative workplace," which thanks to the commitment of the European Economic and Social Committee will be in the centre of the strategy "Europe 2020."

Rational innovations in the workplace are conducive to social and organizational change which incorporate integrated and sustainable approaches, improve companies' performance and in the long-term reduce operating costs [11]. Striving for improvement can occur in many areas, but the most common are: work processes, work organization, working methods, work tools, physical working environment, professional qualifications, as well as management operating procedures [6].

In the twenty-first century, most work processes are executed by operators – users of different types of machinery, devices and computer equipment. Operators for many hours are performing hard visual and mental work while seated or standing, causing

Fig. 1. Innovative workplace with a computer

eye strain, feeling of fatigue – monotony, as well as pain within the shoulders, back and arms. The complexity of equipment operators' work involves the simultaneous introduction and processing of data – messages, use of preferential equipment, while maintaining a continuity of communication with other employees or superiors. The needs of the stressed, carrying a huge responsibility sector of the market have been noticed by many producers of work equipment, who offer many pioneering and precursory solutions. The most common and most gladly used of them in the Polish economy is presented below.

One of the first innovative solutions from which operators of mobile and computer equipment can benefit is the optimization of seating. The concept of an ergonomic chair for work with a computer was proposed by the company mPosition, which came to the conclusion that the best and safest way is to work in a sitting-lying position, where the line of the vertebral column makes a 135 degree angle with the line of the femur (Fig. 1).

Source: www.officomeble.pl

However, even though all applied ergonomic innovative solutions for improving the quality of working life are subject to criteria and an analysis of the consequences of changes, many of the implemented solutions have not been analyzed in terms of ergonomics, both directly and indirectly.

In view of the large number of various modifications and their variable strength, only an identification of groups of innovations in computer workstations was performed, without indicating the relationship between them. Therefore highlighted were innovations related to:

- logical schema of cooperation between human – computer – e.g. human enters information in machine-readable form – digital encoding,
- software at the workstation – achieving a range of functions at the workstation,
- physical performance of control functions – e.g. speech control,
- hardware components – e.g. different families of processors,
- working environment – e.g. ergonomic seat.

Changes in even one element can belong to multiple groups, additionally the direct motivation for undertaking them (ergonomics of the position) does not eliminate the need for ergonomic assessment of the consequences of the innovation, both because of the uncertainty that assumptions are met as well as due to the possibility of accompanying changes.

3 Ergonomic Assessment Criteria of Consequences of Innovative Changes

The ergonomic evaluation of changes is associated with estimation of the level of quality of use and ergonomic quality before and after the completion of the change. In practice, this assessment is carried out as a form of estimating the future situation and after its occurrence the degree of reaching the initially expected level of performance is assessed. For consequence assessment, different sets of criteria which may be subject to evaluation should be characterized, The following factors can be evaluated [4, 5, 8, 9, 16]:

- (PL) physical load – deviation from the optimal level of load (energy expenditure);
- (MO) motion overload – overload of musculoskeletal system resulting from repetitive and unilateral movements;
- (MS) mental strain – deviation from optimum for a given employee's level of mental strain resulting from factors such as load monotony – described separately, (the term used in this regard corresponds to the effects of stress on the employee as defined in ISO 10075, where strain is – the immediate effect of mental stress within the mentally strained individual (not the long term effect) depending on his or her individual habitual and actual preconditions including individual coping styles, while stress is the total of all assessable influences impinging upon a human from external sources and affecting it mentally);
- (PC) physical conditions – including lighting (luminance, contrast, glare); climatic conditions (temperature, humidity, air movement, atmospheric pressure); noise (sound level, frequency); vibrations (low level vibrations, resonance); weather (rain, storm); odours (disgusting or strongly influencing) – these categories will also have an effect on mental strain;
- (BA) balance – balance between individual factors and a sustainable course of their variability over time limiting overload which would cause a decline in the employee's efficiency;
- (US) usability, which consists of (ISO 9241):

  - *Functionality (Functional completeness, Complexity, Adequacy, Integrity, Traceability, Testability)*
  - *Performance (Execution efficiency, Interaction performance, Stability, Scalability)*
  - *Dependability (Reliability, Error-tolerance, Safety, Security, Testability)*
  - *Satisfaction (Ease of use, Understandability, Learnability, Productivity, Acceptance)*
  - *Flexibility (Portability, Modifiability, Configurability, Ease of testing)*

Some of the elements are considered jointly under the term mental fatigue, which does not allow for analysis because this factor aggregates many others, resulting from:

- (MS-TR) Task requirements;
  - Sustained attention (watching a screen for prolonged periods);
  - Information processing (number and quality of signals to be detected, drawing inferences from incomplete information, deciding among alternative ways of action);
  - Responsibility (for health and safety of co-workers, loss of 1 production);
  - Duration and temporal pattern of action (hours of work, rest pauses, shift work);
  - Task content (controlling, planning, executing, evaluating);
  - Danger (underground working, traffic, handling dangers or valuable objects);
- (MS-SO) Social and organizational factors (which can also may be a consequence of operators' workstation):
  - Conflicts (among groups or individuals);
  - Group factors (group structure, cohesion);
  - Social contacts (work in isolation, customer relations);

It should be added that in the case of factors such as physical load and mental strain, in accordance with ISO 6585 appropriate load is also assessed for an insufficient level – and thus underload.

Therefore, a record of an ergonomic assessment of consequences of innovation in the field of computer workstations can be made as a function of changes in meeting the requirements of specific groups of criteria (PL, MO, MS, PC, BA, US) - (Fig. 2).

The above mentioned groups of criteria can also be evaluated by the directness and indirectness of the change's impact. The reasoning in this regard is made much more difficult due to the complexity of the situation and a repeated inability to isolate it from the others. Thus indicated here are possibilities of using more fuzzy ergonomic assessments – fuzzy index to qualitative and quantitative evaluation [15].

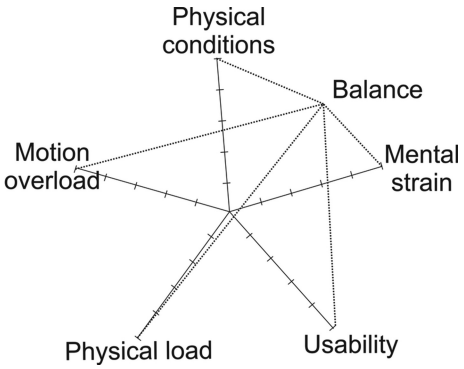

Fig. 2. Functions of changes in meeting the requirements of specific groups of criteria (own preparation).

4 Method Description – Presentation of Innovation Assessment Method with Examples

The author proposes a method of ergonomic evaluation of innovative solutions in terms of the criteria (Fig. 2) along with the application of systematic search methods for the assessment of the possibility of introducing simultaneous pro-ergonomic changes [12]:

1. Identify the components of the problem in question:
   (a) variables which the designer can influence (decisional variables or design parameters). Example – for the change from CRT to LCD technology, physical conditions had to change – the electromagnetic field and usability related to legibility of the provided information, and the decisions which took into account the possibility of setting a different plane of the screen in relation to the plane of work – improving the working position.
   (b) variables which the designer can not influence (contextual variables or independent variables). Example –to change a keyboard in the Dvorak layout content of deep rooted habits of users and content introduced independent of the software,
   (c) variables which are affected by the design (objectives or dependent variables). Example –how will the load on the musculoskeletal system be affected by the use of touch screens.
2. Identify relationships between variables. Example – how will the usefulness of data entry solutions change if the load is transferred from the musculoskeletal system (hand and fingers), to speech organs (voice control).
3. Predict the probable goal values and their threshold values. Example – the threshold values of unloading during the use of intelligent reasoning.
4. Identify constraints or boundary conditions, i.e. the threshold values for each variable. Example – a threshold value for diagonal screen size above which the utility drops significantly during controlling movements.
5. Determine the value of each decisional variable (i.e. try out a range of design decisions), and calculate the values of dependent variables (i.e. calculate the resulting performance). Example – calculating the degree of an increase in efficiency due to the introduction of another type of information display.

The evaluation of innovative solutions regarding workstations must also take into account macroergonomic consequences such as the social effects of physical alienation [19], which, paradoxically, may be due to improvements in the field of communication.

5 Conclusion

The perception of each innovation in a positive light is a significant error. The changing working environment has led to a number of individual and social deviations. Hence the need for the use of a multicriterial evaluation of implemented innovative solutions in the field of computer workstations. The opportunity to evaluate solutions for far

removed effects may in the future allow for adequate prevention of demographic phenomena, which currently seems to be unrealistic. Such far-reaching reasoning brings social engineering closer, still, the proliferation of virtual realities may help to adequately predict the effects of currently observed processes and to appropriately counteract them.

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