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Using the Theory of Technical Systems to Describe the Interaction between Human and Technical Systems within the Ergonomic System

Tomas Gorner*, Michal Simon

University of West Bohemia, Faculty of Mechanical Engineering, Department of Industrial Engineerig and Management, Univerzitni 8, Pilsen, Czech Republic

Abstract

The application of ergonomics in enterprises is gaining in importance. Nowadays ergonomics in enterprises is addressed in a more technical manner. Therefore it is necessary to try to adapt generally applicable ergonomic practices to a technical perception. The result of this is a search for approaches that can be used as a link between technical and ergonomic perspectives of problems in the workplace. The Theory of Technical Systems has been found to be suitable for this. The first part of this article deals with the application of the Theory of Technical Systems to ergonomics. The second part is devoted to the use of the Product Life Cycle according to the Theory of Technical Systems. This theory allows the technically comprehensible analysis of the interaction between the basic elements of the Ergonomic Human-Machine-Environment system. The third part describes the interaction between Human and Technical Systems.

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Keywords: ergonomics; theory of technical system; product lifecycle management; human; workplace

1. Introduction

Ergonomics is a multidisciplinary science with a very wide range. Its main task is to comprehensively and systematically solve the human-machine-environment system. Ergonomics examines and optimizes the relationship between the human and the working conditions using a multidisciplinary approach. This is done by applying the

* Corresponding author. Tel.: +420 377 638 492; fax: +420 377 638 402.
E-mail address: tgorner@kpv.zcu.cz

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latest knowledge of biological, technical and social sciences. The main objective is to optimize the position of human in the working environment. This objective must be achieved while complying with conditions of the human health, human welfare, human safety and optimal performance.

These facts adhere to the definition by the International Ergonomic Association. Ergonomics is a scientific discipline based on understanding the interaction of humans and other system components. By applying the appropriate methods, theory and data we can improve human health, comfort and performance and contribute to the design solution and evaluation of work, tasks, products, environments and systems to make them compatible with the needs, capabilities and performance limitations of the human. Ergonomics is systemically oriented discipline that covers virtually all aspects of human activity. As a holistic approach it includes physical factors, cognitive, social, organizational, environmental and other relevant factors.

The main focus of this article is the application of the ergonomics in the assessment and design of workplaces in engineering companies. From the above facts it is clear that their application is based on the application of a 'proactive' approach. A proactive approach is more appropriate for the following reasons:

- The worker, responsible for the application of ergonomic approaches need not seek ties with an already functioning system. There are no limited by already-established relationships.
- The application of a proactive approach requires fewer financial resources.
- It usually brings greater effects.
- The worker is not exposed to the risk of non-compliance with ergonomic approaches.

The application of ergonomic approaches within companies does not only depend on the theory and knowledge of ergonomic principles. It is also related to the overall system of education of experts in ergonomics. In the Czech Republic there is no coherent educational programme for ergonomists. It is also related to the fact that there is no recognised working position of ergonomist. This gives rise to the major problem and its solution which is presented in this article. It is necessary to find an appropriate procedure for the application of an ergonomic approach suitable for technical staff, and which respects the modern concept of a product. The Innovation for Welfare project (subproject TIAM) also conducts research into the main approaches to applying ergonomics. The problem was the different conditions in the application of ergonomic approaches in five European countries (Spain, Italy, Czech Republic, Austria and Estonia).

Leading Czech ergonomists are engaged in conventional approaches to the application of ergonomics in the Czech Republic. Chundela [1] is representative of the traditional view of project rationalization. At the beginning, the methodology provides the specific objective to be achieved and in what areas. Then the focus is on the determination of the area and depth of rationalization and the schedule. It continues according to the general procedure of the project, i.e. the collection of information, analysis, solution design, implementation and stabilization. Král [2] has a more ergonomic approach. At the beginning of the methodology he presents the formulation and the concept of ergonomic task. Then he continues by collecting information in terms of ergonomics. These data are then sorted. Based on the analysis of this data he sets out various solutions. Then a comprehensive proposal for an ergonomic solution is worked on. Matoušek and Zastávka [3] are representatives of the design approach. They focus on the definition of the design task. The goals are determined on the basis of partial goals while respecting ergonomic sub criteria and technical criteria. Last they select a specific solution according to the procedure. The Refa Methodology [4] presents a general project approach. On the basis of the determined objectives, it sets up alternative systems, from which selects the optimum on is selected. Then follows the process of project implementation, monitoring and adjustments. Hlavenka [5] uses rationalization approach. Problems are exposed by using diagnostics. Then information is collected from documentation. This information is analysed in detail. Then he designs a rationalization proposal to implement it. Bures [6] states specific tasks that must be performed. The general procedure of the ergonomic design includes formulation of objectives, workplace diagnostics, data collection and design of solutions. The author also introduces a new part of the procedure. This is the creation of a digital model of the workplace. Then he designs a selection of optimal variants, documentation, implementation, checking and correcting. ErgoDesign from CEIT SK [7] begins with the collection of data, followed by the creation of the project and design solutions based on the data.

None of those approaches take not into account new trends, regarding the concept of the technical product which relate to the PLM (Product Lifecycle Management). Another fact is that technicians in the Czech Republic are specifically responsible for the application of ergonomic approaches. It is therefore necessary to specify the worker responsible for the administration of the ergonomic approach in companies in the Czech Republic.

2. Specification of the worker responsible for applying the ergonomic approach

The specifications of the worker responsible for the application of ergonomic approach in a an enterprise should be the guiding principle in the development of new methodologies. Technically educated people stand behind the application of ergonomic approaches in practice, especially in manufacturing companies. Their job stands at the level of middle management. In particular they are industrial engineers or workers in occupational health and safety. Given the lack of the working position 'ergonomist', there is no educational system for it. Ergonomics is mostly taught in the form of courses of varying duration and level. The best courses are available at technical faculties at universities. Therefore, if we look at the specification of the worker, they are:

- Secondary or higher education.
- Mostly technical education.
- Central management
- Basic knowledge of ergonomics

These workers usually then have to deal with problems relating to physical and organizational ergonomics, musculoskeletal, or participatory ergonomics. Other areas of ergonomics cannot be ignored, but their solution is necessary by experts in individual branches of ergonomics. Because they are workers with a technical education, it is necessary to find an approach that would allow for a combination of several approaches:

- Ergonomic approach, comprehensively addressing to the ergonomic system of human-machine-environment.
- Technical approach, which would satisfy the engineer.
- One which would respect PLM.

3. The main principles of the Theory of Technical Systems

The whole theory of technical systems is based on the main idea which is the use of transformation to meet needs. There is a need that is satisfied by a transformation. An object is transformed using tools. Because this transformation is controlled and technical tools are used for it, it is a technical transformation. See Fig. 1 (a).

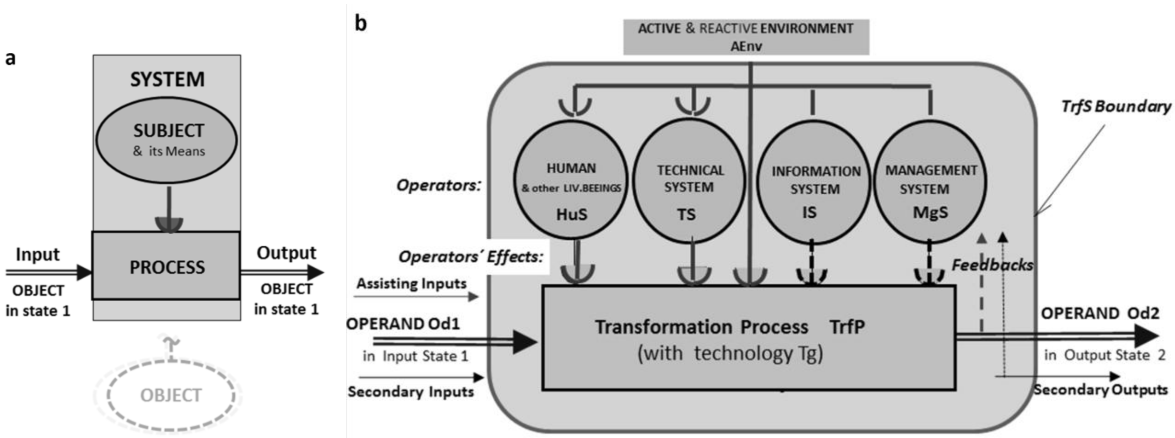

Fig. 1. (a) Paradigmaof the general model of the artificial transformation – Transformation System (TrfS), [9]; (b) General Model of Transformation System (TrfS) with Transformation Process (TrfP), [9].

General model of the transformation system has the following elements - operators:

- Human – HuS
- Technical system – TS
- Active and reactive environment - AEnv
- Information system – IS
- Management system – MgS

The operand enters the transformation system in the input state. During the transformation process an operator acts on the operand and the output condition of the operand in the second state is reached. If we imagine the transformation system in the workshop of a manufacturing company, the major elements of the transformation system are the workers and their technical resources. These act to transform inputs into outputs. This is all under the influence of the environment and with the support of management and information systems. See Fig. 1 (b). A transformation system can be created for any activity in which a transformation takes place. It is therefore possible to create a model that connects individual transformation processes according to individual life cycle phases in the life cycle (LC) of the product. The output of the previous transformation system is then the input for the next transformation process.

4. The lifecycle of a product using the theory of technical systems

Using the theory of technical systems we can create a chain of interconnected transformation systems in the lifecycle. In our case, it is appropriate to link these stages with activities that are necessary for ensuring that a new product can arise. These are the stages of planning, design, technological preparation of production, manufacture, distribution, operation and disposal. If we focus on the workplace and on the production carried out on it, in terms of ergonomics there are two product lifecycles - The workplace lifecycle in the OPERATION phase, OR the product lifecycle in the PRODUCTION phase.

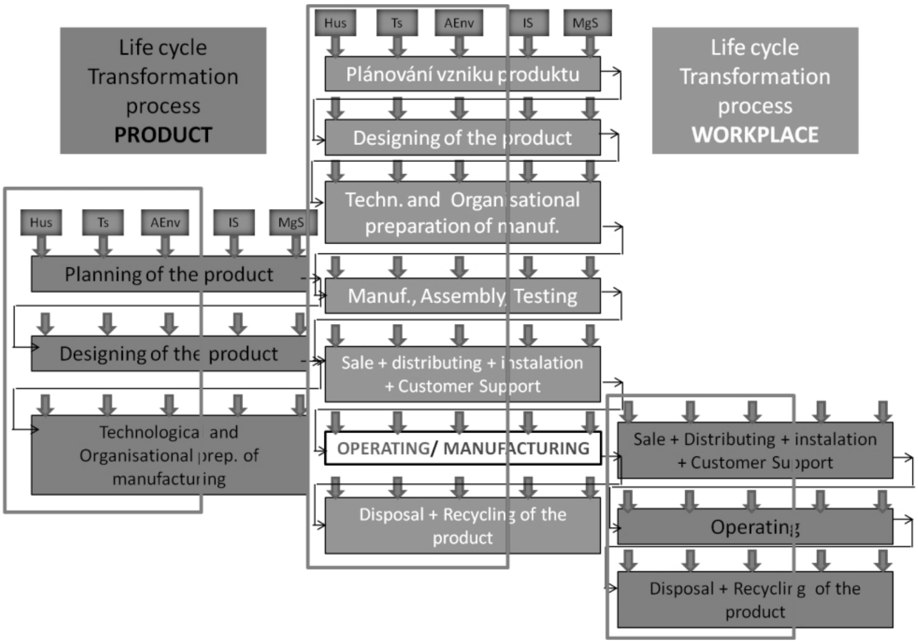

Fig. 2. Linking of the two lifecycles – of the product and of the workplace, on which will be the product produced – the application of transformation systems [12].

The result of this is that the workplace OPERATION leads to PRODUCTION of the product. In both of these phases it is necessary to observe and apply ergonomic principles. A poorly designed product manufactured in the workplace, which does not respect ergonomic principles, also affects employees. A poorly designed product, manufactured in the workplace, which not respect ergonomic principles, also affect employees. See Fig. 2.

The interconnection of the various stages of lifecycles using the theory of technical systems allows the fulfilment of ergonomic approaches to be monitored. However, it is also necessary to know how the various technical systems will behave and, when they are acting on the operand, how they will affect the human system. Generally, the behaviour of the system, or the fulfilment of requirements, is a reflection of its properties.

5. Description of interactions between humans and technical systems

Technical systems must meet certain requirements. These requirements are reflection of the properties. The properties themselves may be numerous, and it is necessary to somehow organize them. Configuration itself, or classification, is addressed by the taxonomy properties. To show individual approaches to classification of properties, and for greater clarity, features not related to ergonomics, are also given, although we will deal further with properties related to ergonomics. There are many approaches to the classification of properties:

- Regulatory classification of properties and requirements for a technical system [8]
- Classification of properties of technical systems according to DIN EN ISO 9000
- Classification of properties of technical systems according to EDS

Two of these classifications show a certain incompleteness and disorder of properties when distinguishing properties. The main function of a technical system is through the transformation acting on the operand. It must also have other properties, as described by [9] or [10]. These include adequate strength, stiffness, etc. These properties are connected with a suitable structure elements, suitable material, forms and so on. These properties are predetermined function principles, etc. The domains of properties are used for classifying properties [10]:

- Domain reflective properties – properties expressing reflection of the technical system on the environment - e.g. graspable, transferable.
- Domain of reactive properties – properties expressing reaction of the technical system to applied loads.
- Domain of descriptive properties – properties giving a description of the technical system or its characteristics - e.g. 1 m high, 30 mm wide, surface roughness, etc.

These properties are further divided into classes of properties of technical systems:

- Classes of reflective properties - according to the life cycle of a technical system (TS) in the form of transformation systems (TrfS).
- Classes of reaction properties - according to the natural and engineering sciences / disciplines that study. Classes descriptive properties – axiomatically divided according to [11]. See Fig. 3.

Because ergonomic approaches applied in enterprises are mainly technical, and approach using ergonomic evaluation ergonomic criteria was chosen. A set of ergonomic evaluation criteria was chosen which corresponds to the workplace in an engineering company. Work is carried out at these workplaces on stationary machines, production lines or there are logistics operations. Ergonomic evaluation criteria are benchmarks enabling assessment and comparison of the suitability of the workplace system as a whole or its various solutions.

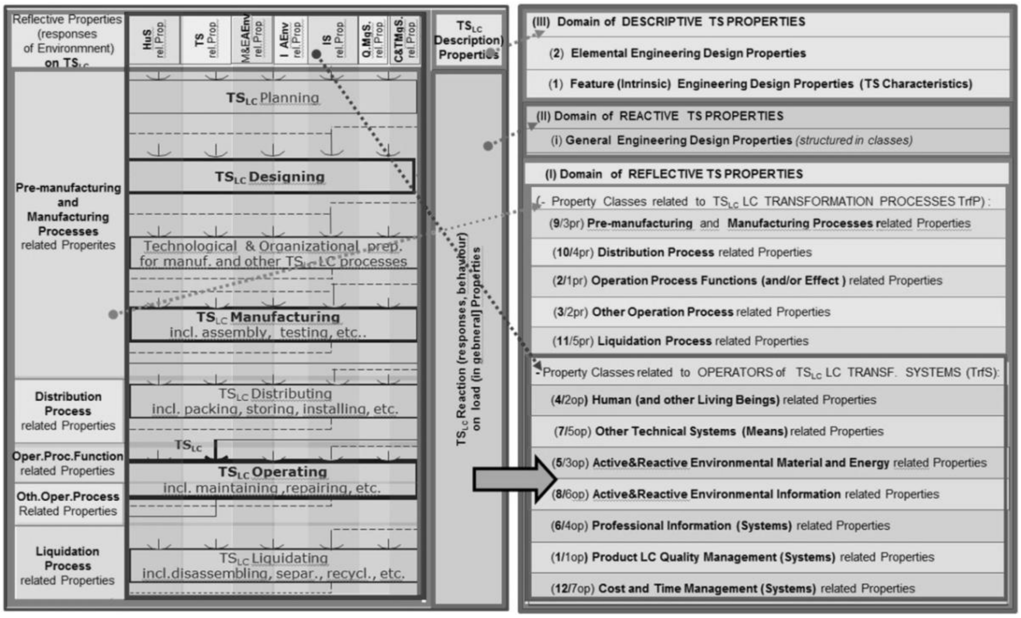

Fig. 3. The relationship between the lifecycle, domain of descriptive properties and classes of properties according to the set of principles, [9].

Ergonomic evaluation criteria and their parameters are considered to be an integral part of product evaluation. Ergonomic evaluation criteria have an impact on operators, which then correspond to the respective properties and their classes. This classification is shown in the following table.

Table 1. Assignment operators and domain of properties selected according to ergonomic criteria and Technical systems theory.

		Criterion	Operator	DREfPro	DReaPro	DDesPro
		Workplace	AEnv	4,5		
	1.1	Size unoccupied floor space	AEnv	4,5		
1	1.2	Clear height	AEnv	4,5		
	1.3	Air cubic capacity	AEnv	4,5		
	1.4	Access to the working place (stairs, platforms)	AEnv	4,5		
	1.5	Freedom of movement at the working place	AEnv	4,5		
		Working position in relation to the movements carried on, physical demands and difficulty of the visual task	HuS	3		
	2.1	Height handling plane above the floor - sitting work	HuS	3		
	2.2	The reaching area of the upper limbs by handling plane by sitting	HuS	3		
2	2.3	The reaching area in the vertical plane by sitting	HuS	3		
	2.4	The reaching area by the standing position at work	HuS	3		
	2.5	The visibility of the place directly sight monitored	HuS	3		
	2.6	The visibility of displays on and out of the machine	HuS	3		
	2.7	The seat for permanent seats, occasional relax	HuS	3		
		Working movements in relation to the exhausting physical	HuS	3		

	3.1	The weight of the manually lifted and transferred burdens	HuS	3	All stages of the lifecycle and the all operators	All stages of the lifecycle and the all operators
	3.2	The vertical distance of the lifting burden	HuS	3		
	3.3	The cumulative weight of burdens per shift	HuS	3		
3	3.4	The gripping options by lifting and moving of the burdens	HuS	3		
	3.5	The location of hand and foot drivers – control forces	HuS	3		
	3.6	The location of the containers with the parts on the working plane	HuS	3		
	3.7	The location of the boxes, containers, etc.	HuS	3		
	3.8	The type of the hand trailer	HuS	3		
	3.9	Handling with the interchangeable parts of machine	HuS	3		
		Vision and hearing displays	TS	2,6		
	4.1	Suitability types of visual display for the monitored functions	TS	2,6		
	4.2	The location of the visual displays with regard to the importance and frequency of the information	TS	2,6		
4	4.3	The legibility of the visual displays	TS	2,6		
	4.4	The method of the evaluation data - symbols, colours	TS	2,6		
	4.5	The visual and hearing signaling exceptional conditions	TS	2,6		
	4.6	The definition audio signal according to the seriousness state	TS	2,6		
	4.7	The arrangement of functionally related displays and drivers	TS	2,6		
		Lighting				
	5.1	The general lighting of the workplace	AEnv	4,5		
	5.2	The local lighting with regard to the visual demand	AEnv	4,5		
5	5.3	The light colour in relation to the colour differentiation	AEnv	4,5		
	5.4	The contrast between the observed location and surroundings	AEnv	4,5		
	5.5	The evenness of the lighting in the workplace	AEnv	4,5		
	5.6	The emergency lighting	AEnv	4,5		
		Noise and vibration	AEnv	4,5		
	6.1	The technical measures to reduce sources of noise - noise barriers, etc.	AEnv	4,5		
	6.2	Soundproof walls and the linings of the ceilings	AEnv	4,5		
6	6.3	Using personal protective working equipment against the noise	AEnv	4,5		
	6.4	Audibility of speech communications in background noise - noise	AEnv	4,5		
	6.5	The technical and routine measures to prevent the transfer of the vibration to the body and to the hands	AEnv	4,5		
		Microclimate – air	AEnv	4,5		
	7.1	The temperature in summer and in winter, with regard to the physical difficulty of work	AEnv	4,5		
	7.2	Airflow	AEnv	4,5		
7	7.3	Relative humidity	AEnv	4,5		
	7.4	The amount of incoming air	AEnv	4,5		
	7.5	Giving of the substitution drinks	AEnv	4,5		
		The risk of the work accidents	HuS	3		
	8.1	Fixed, mobile shields of moving parts and technical equipment	HuS	3		
	8.2	Shields against the flying parts and garbage	HuS	3		
	8.3	The protection against accidental start	HuS	3		
8	8.4	The protection against the risk of cutting, pulling, catching, etc.	HuS	3		
	8.5	The signaling emergency conditions using acoustic displays	HuS	3		

8.6	Color or other identification of risk areas	HuS	3
8.7	Preventing reach the upper limbs in high-risk places	HuS	3
8.8	Protective barriers and barriers to preventing access to the danger zone	HuS	3

In order to identify the properties associated with the ergonomics, it was necessary to clarify the property domains, their classes and subclasses. Their sorting and contents are a part of the Taxonomy of Properties of Technical Systems according to [9]. We begin by assuming that even a designer (who has a technical approach) can solve two types of tasks (new product designs / design modification of an existing product) and therefore offer two activities are offered:

- Design of a completely new product

The designer creates drawings based on an original idea, in which his concepts are transferred, or rather the properties from the domain of descriptive properties – that are created during the design process. Properties from the domain of the reactive properties are thus bound to the properties of the domain of descriptive properties. Properties from the domain of descriptive properties can then be based on the domain of reflective properties.

- Design modification of an existing product

This is first in a series of methods for obtaining as much information as possible about it, e.g. What is the environment in which the machine will operate; How will it work; Why does it have such a drive; What are its characteristics and so on. This is followed by the same processes as used for the designing of a new product. There is only one difference between these processes. The input information exists in the mind of a designer, which is formulated in the design process, or the information must be obtained from an existing condition. The designer tries to sort the properties of the technical system according to the taxonomy of properties. Their sorting is not always simple and straightforward. Non-sorting of properties is considered to be a larger error than sorting them into a different group. It is analogous to the type of problems solved by the staff responsible for application of ergonomic approaches in a company.

- Ergonomic design of a new workplace

Formulation of the ergonomic task: What influences the solution and where its limits; Gathering the necessary documentation to classify them according to needs; Analysis of documents, creation of design guidelines solutions; Processing of proposals on ergonomic solutions; Implementation.

- Ergonomic assessment of an existing workplace

The procedure is similar, but we have to reckon with the existence of much higher limits, which are created mainly by the technologies which are used. This relates to the fundamental rule of ergonomics that there should be an effort to modify the technology for humans. This rule is frequently not observed. As can be seen from the Table 1, the largest number of properties are those, that are sorted into the domain of reflective properties, which is related to the operational phase of the lifecycle of the workplace.

According to [9] of each characteristic property of this domain, must not exceed specified (set, binding, generally implied or their own) limit values and relate to the entire life cycle of TS (individual stages of workplace). In our case, we are in the life cycle focused on the operation of the workplace and the previous stages of the life cycle of the workplace had to go through, and we neglect it, for TS is considered as such equipment and other technical equipment of the workplace. For this to be divided, for the specification of requirements on the properties of TS and evaluation of fulfilment of these requirements, the reflective properties can be divided as follows:

- BD (Before Delivery) properties before delivery TS to users - in our case, before installing the workplace

These are usually pre-production stages (planning, construction, organizational and technological preparation of production), production and distribution. All TS, which are involved in the creation of workplaces (in planning, organizational and technological production and distribution), and also those that will be used for the transition process in the production phase of the product are considered to be TS. The ideal situation would be that ergonomic principles are respected at all stages of the design of the workplace and its creation.

- AD (After Delivery) properties after delivery of TS to users - in our case the installation of the workplace.

This is usually the operation and disposal. In this stage TS are (again we are at a lower hierarchical position) considered to be TS which are involved in the transformation of the operand - in other words, in the manufacture of a product which arises in the workplace. As regards the division (AD, BD) the BD stage properties correspond to the designing of an entirely new workplace and its production, for example, for an external supplier (TS properties are then properties of the workplace and the tools for the workplace). Conversely stage AD would correspond to assessing an existing workplace and tools used thereon. As already mentioned, in practice we are more often tasked with the assessment of an existing workplace than designing a completely new workplace. [9]. A big difference is in how we look at the TS. We can use a technical view of a designed product – e.g. designer´s view of a new component. Or we can use an ergonomic view of the workplace where the product will be manufactured. At this moment, this means mainly the three main elements of the human – machine – environment system, i.e. HuS, TS, Aenv - see the Fig.4.

Criterion	Number of properties according domains	Operators of the Transformation systems	Technical engineer to view product designed		Ergonomic view ergonomists at the workplace where the product is manufactured	
			Product - TS - produced in the workplace		Workplace such as TS	
			Ib Class of reaction properties of the TS		Ib Class of reaction properties of TS	
			Subclass characteristics of the TS	Properties of the TS	Subclass characteristics of the TS	Properties of the TS
2; 3; 8	3	HuS	Suitability for human values	Consistency with social, cultural human values in politics, opinion, conventions	Suitability for human values	Consistency with social, cultural human values in politics, opinion, conventions
			Suitability for human health	Safety for humans, hygiene, ergonomics, etc.	Suitability for human health	Safety for humans, hygiene, ergonomics, etc.
			Suitability for human senses and perception	Appearance, quiteness, fragrance, etc. Sight, hearing, touch, smell, taste, feeling, etc.	Suitability for human senses and perception	Appearance, quiteness, fragrance, etc. Sight, hearing, touch, smell, taste, feeling, etc.
4	2, 6	TS	Suitability for available TS and Tg	Compatibility with the available TS and Tg etc.	Suitability for available TS and Tg	Compatibility with the available TS and Tg etc.
			Suitability for induced TS and Tg	Optimal demands new TS and Tg like.	Suitability for induced TS and Tg	The readiness of the new TS and Tg etc.
1; 5; 6; 7	4, 5	AEnv	Suitability from the viewpoint of environmental, material and energy inputs	Resistance to material and energy effects around etc.	Suitability from the viewpoint of environmental, material and energy inputs	Resistance to material and energy effects around etc.
			Suitability from the viewpoint of environmental, material and energy outputs	Environment friendliness material and energy output	Suitability from the viewpoint of environmental, material and energy outputs	Environment friendliness material and energy output

Fig. 4. Assigning properties subclasses TS and TS operators Ib Property Class of reaction properties.

Properties for operators Information System and Management system can be described as properties defining a framework or conditions in which the ergonomic system of human - machine - environment can function. These are the standards, regulations, documentation, or a variety of management criteria. In the hierarchical structure of properties it is possible to divide properties of technical systems into two basic groups. Project-invariant and variant. It is therefore about project-invariant properties and those which are dependent on the project.

Project invariant properties in ergonomics correspond to ergonomic evaluation criteria. These criteria determine the conditions for evaluating the working system. On this basis it was possible to ergonomic and technical viewpoints to support product life cycle and the theory of technical systems. That technical view of ergonomics can be further developed to the sustainability aspects of the entire system described in [13], or connected to the environmental approaches, mentioned in [14].

Conclusion

This article specified ergonomic workplace evaluation criteria for workplaces in manufacturing companies. In order to find the specifics of a technical approach for describing the properties of technical systems (i.e. the workplace) in relation to ergonomics, as part of any workplace were carried out following steps.

In summary, we reach the following conclusions. By linking the technical and ergonomic approaches we established ergonomic evaluation criteria which determine the elements that must be observed in the design or checking of a workplace. Ergonomic evaluation criteria are expressed by parameters that are assigned a measurable dimension. Ergonomic evaluation criteria are based on ergonomic factors.

The selected technical viewpoint therefore correspond to the situation in the Czech Republic where ergonomics in companies is not solved by ergonomists, but only by people with technical education with basic knowledge of ergonomics.

Further research should be focused on creating simple methodologies and procedures for use in the ergonomic evaluation of workplaces.

Acknowledgements

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