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A FRAMEWORK FOR RESEARCH OF ECONOMIC EVALUATION OF ERGONOMIC INTERVENTIONS

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Abstract. *The systemic aims of ergonomics as in integral discipline of humanization of production labour are in manifold relation to all-comprising and dynamic arrangement of co-operative bounds and occurrences in various industrial systems for purpose of common methodological acting upon practical realization of humane-production solutions.*
To realize these aims, it is necessary to offer true economic argumentation to give the justification for introducing systemic ergonomic solutions in production because it is considered in many organizations rather as a part of altruism than as a profitable investment.
However, even some ergonomists, especially those with traditional determination, avoid the use of economic argumentation partly due to ignorance of techniques and data available for producing economic arguments for justifying ergonomic solutions.
Therefore, the essential intention of this work is to indicate the sources of data and present certain existing methods which can contribute to forming a more authentic argumentation about economic usefulness of ergonomic solutions application in firms.

Key words: *Economic evaluation, ergonomics, cost-benefit model.*

1. INTRODUCTION

In transition between these two centuries some new technologies may be distinguished which present a starting base in reorientation of industrial production systems. These contemporary technologies represent materialization of scientific knowledge and correspond to the high scientific level of development - of automatized industrial production, which as such present extraordinary significant scientific-technical force - which is likely to perform in superautomatized production even better and more complex changes than so far. In addition, this scientific-technologic production synthesis of higher order is substantially different from previous revolutions for it encourages the quick transformation of scientific results in new technologies and their transition into automatized industrial pro-

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duction. Then, it enables wider introduction of information-based flexible production technologies in industrial system, discovers new materials, provides use of new sources of energy, acts on biotechnology development towards production of organ-synthetic chemicals and establishes ecological-technological balance [1].

The increasing growth and the abrupt expansions of modern industrial production have imposed plenty of requirements for an optimum safeguarding and improvement of living and working conditions through efficient organization, rationalization and humanization of production labour.

However, still insufficient application level of science as a production force, especially of "humanization of production labour", in large number of economic organizations - as a consequence of inappropriate multidisciplinary cognition about numerous and various options how to increase business-production efficiency and economic-financial profit - constructively affects establishing firm bonds among ergonomic solutions and their optimum application by the internal production force in a firm.

The very typical professional classifications represent "the expert barrier" constricting a serious approach to developing the organizational-technological conditions and improving the humane-production system. This is the reason why humane-production changes cannot be carried out appropriately without a multidisciplinary team of experts streamlined towards the established and more humane, modern, safeguarding and profitable humane-production aims [2].

Various authors, even 10 and more years ago, encouraged the idea about the necessity of argumentations for justifying ergonomic researches. Alexander (1985) said, "A manager may allow to have ergonomics tested but without any essential improvements (or other equally convincing measures of efficiency), the application of ergonomics will soon decrease and disappear [3].

However, the result of producing a more complete economic argumentation about the necessity of introducing ergonomic solutions to production are still modest although the advocates of these ideas have lately been reinforcing the individual activity, so that Oxenburgh (1991), in his book [4], presented a sequence of short analyses about the profitability of investment in ergonomic researches, and Campbell (1993) pointed out that "safety is not profitable, production is the one that is profitable, but safe production is even more profitable" [5].

In the sense of provability, ergonomic projects do not differ from others and economic usefulness of ergonomic projects or technological process can be assessed in many manners. For instance, Hendric (1996) proved that investments in technical and organizational solutions of ergonomic problems can offer profitable results by means of an increased productivity, decreased absence, improving products quality and declined rate of injury [6].

Riel and Imbean's recent researches (1995) are the first step towards the development of general approach to economic argumentation for justifying ergonomic solutions [7]. They developed the cost function using the model of activity-based costs accounting as a framework and applied it to the costs of health maintenance, safety and insurance, in the Canadian province, Quebec. Dahlen and Wernersoon (1995), using this model and presenting human factors as costs (absence from work and work costs), gave the analysis of a production company in Sweden [8].

2. ECONOMIC EVALUATION OF ERGONOMIC INTERVENTIONS

From the economic view, injury costs can be astonishing. That's the reason why many companies needing creativity and accuracy, high productivity and quality, less amendment and less health insurance slowly tend towards considering ergonomic solution. However, as with any business investment, ergonomic solutions should have to be economically justified. From the traditional view, the role of ergonomics in industry has always been justified on the health and safety basis with occasional and usually vague streamlining towards the improvement of actual production labour. A review of the literature shows an increased scientific interest in providing economic argumentation for necessary ergonomic changes in industry.

In the OECD-countries there is a shift from detailed regulation and inspection towards making employers themselves control the quality of occupational health and safety (OHS), e.g. through the EU directive 89/391 on risk assessment. But this strategy cannot be realized without at least a partially voluntary co-operation of the employers and their managers, whose primary duty is to economize on scarce resources. Luckily more and more studies indicate that OHS investments may also improve the economy of production and that efficient abatement techniques can reduce their costs. Employers, in all types of production, should therefore have a strong interest to improve OHS. Yet, this growing evidence seems not to result in much change. With poor use of opportunities to join profit and OHS interests, conflicts remain high and improvements low. To change this, we need more cost-benefit models (C/B) less than to understand the obstacles which hamper the impact of economic OHS-arguments.

There are many reasons for the slow process of a market driven development of OHS. One is that despite its quantity, the quality of this type of evidence often is poor [9]. The US Congress found that C/B calculations "end to support the vested interests of the sponsors of the estimates". Yet, as economic estimates go, C/B of OHS are no worse than many others used in important management decisions. The inputs and assumptions of all calculations are decided more by arbitration than by science, C/B are more often used to justify decisions already taken than to guide which to take. Like in many other subjects, the importance of C/B on OHS lies therefore less in their net results than in how they emphasize and structure the relation between the OHS and the costs and productivity of labor.

The data which can be resed in ergonomic researches are relatively easy to reach because they are needed in order to carry out production efficiently.

The five sources of information in firms on the basis of which the potential options of achieving economic usefulness are obtained, are the next:

- General Jobs Sector (Absence analysis, Training scheme costs, Injury amendment costs)
- Occupational Safety Sector (Places of potential accidents, Working places needing safety equipment)
- Work Organization Sector (Inappropriate working conditions, Works norms analysis, Quality inspection organization)
- Production Sector (Production failure, Equipment maintenance, Refuse)
- Health Center (Nature of injuries, Type and frequency of minor injuries, Type and frequency of fatigue symptoms)

By analyzing these sources, the following costs can be identified:

- Costs incurred while employers are out of production can be accounted as salary costs plus overhead costs and unprofitable production costs;
- Costs of stoppages due to a poor ergonomic projecting of working places should be established after objective analysis of ergonomic causes of a stoppage;
- Costs of repairs also easily recorded can be significantly reduced because time of repairing is assessed to possibly decrease even by 30% only by improving machines accessibility.

The costing of health and safety issues is often avoided because of the inability to 'cost a life' given the natural ethical and/or moral reservations surrounding such an exercise. However, if one accepts that no organization actually wants to kill its staff and thus work simply on the costs of the organization, then the moral and ethical reservations on costing health and safety disappear, especially if by doing so ergonomists increase the probability of obtaining funding to promote improvements in health and safety.

There are many cost implications to an organization arising from health and safety issues; however the "core costs" are as follows:

- Costs incurred by disruptions in manning from non-work related sickness absence, e.g., influenza.
- Costs incurred by disruptions in manning from work-related, chronic health issues, e.g., back pain, respiratory diseases, dermatitis.
- Costs incurred by disruptions in manning from lost time injuries.
- Costs incurred from compensation payments against injuries, e.g., loss of limbs.
- Costs incurred from compensation payments against health effects, e.g., back pain, hearing loss, tenosynovitis.
- Direct costs in lost production arising from accidents, e.g., time lost in accident recovery, investigations.
- Social costs incurred in sickness benefit payments.

Although generalized costs are usually relatively easy to obtain, it is much more difficult to find information on particular subgroups of the workforce, e.g., a particular job category. However, with some effort a reasonable approximation is often possible.

Seventeen world authorities in industry ergonomics have vacantly offered as the result of the panel discussion, a scheme for research program, comprising a need for developing methods and techniques which would, with respect to costs, justify ergonomic changes [10].

At the panel discussions, a question was brought up: Why managers don't take in the profitability of OHS improvements. This question is a part of the much wider question of organizational behavior. Managers' actions express the basic tension in organizations between a dominating aspiration towards economic objectives on one hand and on the other how the realization of this is obstructed by human limitations and pursuit of individual interests. This creates problems of:

- *Information*, when managers' limited capability results in slow penetration of new knowledge of how to join OHS and profit interests.
- *Structure*, when the necessary organizational backbone of operating procedures obstructs recognition of information on the profitability of OHS.
- *Culture*, when attempts to co-ordinate the individual's perceptions of the organization also conserve a narrow view of the relation between OHS and productivity.
- *Individual interests*, when managers have little interest to recognize OHS-benefits.

3. CURRENT RESEARCHES

There is a growing recognition that only the equipment is not sufficient to prevent employees from being injured but also appropriate assessments and methods of decision making are needed to bring about proper solutions to derived problems.

Establishing such methodologies would significantly ease the work of managing decision makers in firms facing the problem of incapability of justifying interventions in this area from economic view although these investments are justified on the basis of the other criteria.

The purpose of these researches is the study of potential efficient costs of basic ergonomic interventions bringing about the decrease in the number of injuries at work and employees' illnesses but which are constricted by the following:

- socioeconomic and demographic features
- psychosocial factors
- nature of the very intervention
- work risk factors.

Several methods, based on methodologies in the other scientific disciplines currently being improved as an economic support to ergonomic solutions, will be listed. Injury risk probability and that of illnesses at work will be modeled by logistic regression model. The predicted costs model based on empirical data is developed in order to be used as an aid to a decision maker in giving priority to potential investments in ergonomic interventions. Regression methods have always been an integral component of any data analysis and the description of the relation between the average respond variable and one or more changeable predicted variables, but this model, although known for 15 years, only now has its application in direct calculating of one or two variables when allocating cost in the prediction model.

In case of ergonomic profit and costs [11] the application of methods on costs and profit analysis (C/B) is a part of the whole process streamlined towards the assessment of ergonomic interventions in a firm. The benefits and costs are defined as follows: Benefits: f(b) = {favorable outcomes – unfavorable outcomes}. Costs: f(c) = {capital costs + operating and maintenance costs + inefficiencies – revenues}. The proposed cost-benefit analysis process involves the following steps:

1) Identification of the nature of health and safety costs and benefits (i.e. establishment of a typology for both costs and benefits)
2) Detailed cost analysis of ergonomic interventions
3) Detailed benefits analysis of ergonomic interventions
4) Allocation of the costs and benefits of ergonomics-related health and safety initiatives or interventions
5) Assessment of the economic feasibility of investments.

The constraints of the C/B method are the following:

- its inability to define appropriate discount rates
- it does not resolve the problem of who incurs the costs and who gains the profit
- many indicators cannot be translated to money
- it can offer only rough assessments and guidelines easily deformed to decision makers
- it should not be used as the only method

Unless decision makers are aware of serious constants, they can also use the C/B method for supporting economically unjustified projects and business decisions. However, this method is not more unsuitable than many others used while making important decisions in function of alternative investments and ergonomic solutions or about investing and managing, and it can be extremely useful to those who are aware of its ability and constraints. Alberton (1997) proposed a mathematical method of linear programming which comprises that the process of decision eliminate undesired occurrences [12].

As to complete this model, the profits of any potential solutions are established with an option of identifying more efficient solutions from the set of the achieved optimal solutions. The aim of the proposed model is to maximize profits gained by decreasing losses from undesired occurrences.

The proposed model is a multi-period one, where the objective is to maximize the benefits generated by the reduction of losses due to accidents.

The model considers three kinds of restrictions: the budget available, the integrity of the alternatives and the maximum level of risk allowed.

The generic mathematical model can be defined as:

$$\text{Max.}Z = \sum_{j=1}^{T}\sum_{i=1}^{N}\{B_{ij}[(T+1/2)-j]-C_{ij}\}X_{ij} \tag{1}$$

s.a.

1. Budget constraints:

$$\sum_{j=1}^{N} C_{ij}X_{ij} \le D_j \quad j=1,2,...T \tag{2}$$

2. Integrity constraints:

$$\sum_{j=1}^{T} X_{ij}X_{ij} \le 1 \quad i=1,2,...T \tag{3}$$

3. Maximum level of risk allowed:

– For individaul projects:

$$(R_k - R_k\sum_{i=1}^{N}\sum_{j=1}^{T} R_{kij}X_{ij}) - NR_k \le 0 \quad k=1,2,...M \tag{4}$$

– Global:

$$\sum_{k=1}^{M} NR_k \le NRG \tag{5}$$

With

$$Xij = \begin{cases} 0 \\ 1 \quad i=1,2,.....N,\ j=1,2,.....M \end{cases} \tag{6}$$

$$NR_k \ge 0 \tag{7}$$

Where:

i: alternatives, i = 1, 2, ...,N;
N: Total number of alternatives;
j: time period, j = 1, 2, ...,T;
k: Kind of problem, k = 1, 2, ...,M;
B_{ij}: Benefit of alternative I in period j;

C_{ij}: Total cost of alternative i, in period j;
D_j: Budget availability in period j;
R_{kij}: Risk reduction of activity type k, due to alternative i in period j;
R_k: Risk of activity k;
NR_k: Level of risk allowed at activity k;
NRG: Level of risk allowed to all activities type k;
X_{ij}: Decision variable
$X_{ij} = 0$: alternative i in period j will not be implemented
$X_{ij} = 1$: alternative i in period j will be implemented

To perform the analysis of human reliability assessment, human error and preventive engineering and its economics influence are essential as well. Grozdanović proposed the application of the following models:

- Human reliability quantification models [13]
- Human reliability assessment and risk from human error [14]
- Success likelihood index method [15]
- Human error assessment and reduction technique [16]
- Preventive engineering methods [17]

4. EXAMPLES OF ECONOMIC ANALYSIS IN THREE AREAS OF ERGONOMIC ACTIVITY

Previous sections have suggested the type of performance, health and safety issues which can be used to develop an economic case to support ergonomic studies. This section provides example of a number of studies which have included economic analysis. Taken as a whole, they cover each of three areas of ergonomic activity, showing clearly that ergonomics can, and often does, contribute not only to the health and safety of the workforce, but also to the financial health of the organization.

The first example is back pain. This is in many senses the classic example of an ergonomics/health issues which can be treated as a loss of prevention exercise. Manstead presented data which showed that in the UK during 1982 more than six times as many mandays were lost due to back pain than the total lost due to industrial disputes! Hyland has suggested that the total cost to the UK economy arising from back pain related sickness absence is in the order of 9 billion per annum. Moreover, it should be remembered that back pain is by no means restricted to the 'heavy' jobs or those involving manual handling. Lloyd for example, have shown in study which compared miners and office workers, that there was no significant difference in the incidence of back pain in the two groups under the age of 45 years.

Teniswood describes a study of back pain in an Australian mining company. The study covered both surface and underground operations and examined manual handling, workspace and vibration in the drivers' cabs of mobile plant and introduction of new training program. The number of lost time back injuries were halved in two years.

The second example in this section concerns a Norwegian study [19] of the influence of workspace design on musculoskeletal problems, and is one of the most thorough examples published so far showing the economic analysis of ergonomics change. The plant studied was primarily concerned with the assembly and wiring of telephone switching panels.

During 1975 the authors carried out an extensive ergonomics redesign. Particular emphasis was placed on the need to give each operator greater flexibility allowing, for example, for both seated and standing operations. Several other changes were also made, including improved seating, improved tools and major changes to both lighting and ventilation.

Prior to the improvements, musculoskeletal sickness absence was running at 5.3% of the production time available; in the period 1975-82 it had dropped to 3.1%, a difference which was significant. The analysis of labour turnover was even more marked. Prior to 1975 turnover was running at about 30% whereas in the period after the change (to 1982) it had been reduced to an average of slightly over 7.5%. Obviously the labour turnover could have been influenced by many factors other than the ergonomic improvements. However, in interviews with the staff the improved working conditions were the most frequently mentioned issue. These reductions in labour turnover also created additional financial benefits beyond the immediate production improvements, for example, there were attendant savings in terms of both training and recruitment costs, which at a turnover of 30% were considerable.

The third example is a recent study conducted in the mining industry [20] using basic ergonomics principles supplemented by the human error classifications to predict the potential for human error in mining systems. New safety initiatives were then identified by using the potential human errors to target safety activity. Prior to the study, the accident rate at the colliery was over 36 per 100,000 man shifts; one year after the study and the implementation of the initiatives, the rate had reduced to just over 8 per 100,000 man shifts, a reduction of 80%. The savings, when measured against the cost of the study, represent a return on investment of the order of 36:1. Even when an estimate of the cost of implementation of the initiatives is added, the return on investment was of the order of 15:1.

A recent book by Oxenburgh (1991) has presented a collection of short case studies each of which, in one way or another, addresses the question of the return on investment from ergonomics studies and action and which provides an excellent basis for developing a generic argument for the economic viability of ergonomics.

5. CONCLUSION

The evidence of economic profitability of ergonomic solutions given in the previous chapter in this work has not brought about significant changes in this area. As to achieve significant changes, it does not much depend on the number of costs profit models established but more on recognizing obstacles to approval of economic argumentation for ergonomic changes.

There are many reasons why the process of approving ergonomic changes is slow. The first is that the evidence quality of economic justification is still low. The second is that the results from the analyses by C/B methods can be easily adapted to desires of those financing those analyses. The third is that these methods are more frequently used to verify the already made decisions and not to point to the decision to be made. However, there is also a lot of disapproval from the managing factors concerning these ideas. This occurrence was analyzed by Erich (1997) in his paper, "Manners of Preventing Managers from Recognizing Profits from Improved Ergonomics by Organized Conservatism" [21]. If

ergonomics is important for industry as much as ergonomists believe it is, the range of its application indicates that there are shortcomings in the manner it is presented to the management structure.

Management structures, in the current conditions, encounter a lot of problems, so there is little likelihood that they are ready to approve of even new problems, i. e. the problems derived from the ergonomic area have mostly never been heard of. Therefore, a new approach to promoting ergonomics should have to be established.

Firstly, there is not anything called ergonomic problems but there is a whole line of problems comprising occupational safety problems, health problems concerning work, productivity problems and others in which familiarity with ergonomic can be useful.

Secondly, ergonomics should have to be considered as something offering solutions. Once the role of ergonomics is approved of as the one to help in solving accepted problematic regions in industry, the attitude to it will change.

Thirdly, presenting ergonomics as an activity bringing profit by resolving certain problems immediately gives priority to ergonomists to use the language of management structures they are trying to win for ergonomic solutions.

Fourthly, ergonomics should have to be presented as a multidisciplinary area, which it really is, and not to be perceived as a threat to traditional disciplines, because if a "new" discipline is aimed at conquering the failings of designers, managers, occupational safety experts, professional doctors etc., then one can reach a conclusion that those disciplines are unsuccessful.

In conclusion, this paper points out some data and steps which can be used in order to establish appropriate economic argumentation for justifying ergonomic solutions in practice. It also proves, on the basis of the quoted literature, that such analyses are feasible and that they frequently mainly affect approving ergonomic propositions.

What is needed is only that the use of economic argumentation in ergonomic projects and propositions becomes a necessity and a rule as to enable many ergonomists to have the appropriate "tool" for imposing the own ideas and solutions.

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OKVIR ZA ISTRAŽIVANJE EKONOMSKIH PROCENA ERGONOMSKIH INTERVENCIJA

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Sistemski ciljevi ergonomije kao integralne nauke o humanizaciji proizvodnog rada višestruko su vezani za sveobuhvatno proučavanje i dinamičko sređivanje kooperativnih veza i pojava u različitim industrijskim sistemima radi zajedničkog metodološkog delovanja na praktičnom ostvarenju humano - proizvodnih rešenja.

Da bi ovi ciljevi mogli da se realizuju neophodno je da se nađe prava ekonomska argumentacija za opravdanost uvođenja sistemskih ergonomskih rešenja u proizvodnji jer se one u mnogim organizacijama tretiraju kao deo altruizma, a ne kao isplativa investicija.

Međutim i neki ergonomisti, a prvenstveno oni tradicionalne usmerenosti, izbegavaju upotrebu ekonomske argumentacije delimično i zbog nepoznavanja tehnika i podataka koji se mogu koristiti za pravljenje ekonomskih argumenata za opravdanje ergonomskih rešenja.

Zbog toga je i osnovna namena ovog rada da ukače na izvore podataka i prezentira neke postojeće metode koje mogu doprineti formiranju konkretnije argumentacije o mogućnostima ekonomske koristi u preduzećima primenom ergonomskih rešenja.

Ključne reči: *ekonomska procena, ergonomija, model trošak - dobit.*