Chapter 1
Ergonomic Performance and Evaluation of Worksystem: A Few Applications

P.K. Ray, V.K. Tewari and Esha Saha

Abstract Application of ergonomic principles provides a standardized approach for the analysis of a worksystem with emphasis on evaluation of interaction between human(s), machine(s), and environment, as a first step toward exploring the enormous potential and concepts of ergonomics at workplaces. The objectives of the study are manifold: to identify and characterize the ergonomic variables for a given worksystem with regard to work efficiency, operator safety, and working conditions, and to design a comprehensive ergonomic performance indicator (EPI) for quantitative determination of the ergonomic status and maturity of a given worksystem. The study consists of three phases: preparation and data collection, detailed structuring and validation of EPI model. Identification of ergonomic performance factors, development of interaction matrix, design of assessment tool, and testing and validation of assessment tool (EPI) in varied situations are the major steps in these phases. The case study discusses in detail the EPI model and its applications.

Keywords EPI structure · Worksystems · Principal parameters · Normalized total rating

1.1 Introduction

The principles of ergonomics may be applied to the study and design of the components of any worksystem involving human(s) and machine(s) embedded in an environment, and as such its areas of application are not limited by a particular

P.K. Ray (✉) · E. Saha
Department of Industrial Engineering and Management, Indian Institute of Technology Kharagpur, Kharagpur 721302, West Bengal, India
e-mail: pkr@vgsom.iitkgp.ernet.in

V.K. Tewari
Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, West Bengal, India

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technology or by the scale of the system. In essence, application of these principles provides a standardized approach for the analysis of any worksystem with emphasis on consideration of interaction between human(s), machine(s), and environment. In this context, Tata Steel, Jamshedpur has been earnestly striving to apply the ergonomic principles, at its worksystems at different levels in order to ensure safety, health, convenience, and comfort of the personnel at their workplaces at an acceptable level of productivity and reliability of the overall system.

Application of ergonomic principles provides a standardized approach for the analysis of a worksystem with emphasis on evaluation of interaction between human(s), machine(s), and environment, as a first step toward exploring the enormous potential and concepts of ergonomics at workplaces, the management of Tata Steel, the largest steel-making company of India in the private sector, has taken steps to institutionalize the process of implementing ergonomics as a whole and felt the need to develop a framework to determine the levels of ergonomic performance at its different workplaces. As the idea of developing an ergonomic measurement system is quite unique, Tata Steel ventures into the design of a comprehensive approach for determining the ergonomic status of the worksystem.

The factors of performance and/or operations where deficiencies or nonconformances occur should be identified and assessed on a regular basis to improve the performance, productivity, and reliability of any unit of analysis, and application of the concept of "remedial" ergonomics in many areas, operations, and factors of production may lead to substantial improvement in overall system performance. An assessment tool for determination of the status (level of ergonomic maturity) and level of ergonomic intervention to be employed in a given worksystem is all that is needed (Ray and Tewari 2012). The objectives of the project are (i) to identify and characterize the ergonomic variables for a given worksystem with regard to work efficiency, operator safety, and working conditions, (ii) to design a comprehensive ergonomic performance indicator (EPI) for quantitative determination of the ergonomic status (in terms of design requirements and performance leveling) of a given worksystem or unit of analysis, and (iii) to apply the EPI model to assess the degree of ergonomic maturity of a given worksystem or unit of analysis.

1.2 Designing an Ergonomic Performance Indicator (EPI)

In order to design an ergonomic performance indicator (EPI) for determination of the ergonomic status of a given worksystem, modeling a general framework involving all relevant ergonomic factors is the essential first step. Assessing the degree of ergonomic maturity against each identified factor is the next important step. The ergonomic factors to be considered in almost all situations or worksystems are related to four key aspects of worksystems, viz, human characteristics, physical workspace, physical environment, and organizational factors. While assessing the level of an ergonomic factor, three principal parameters need to be looked into, viz., work efficiency, operator safety, and working condition, each of which needs to be defined and interpreted in the widest possible sense during evaluation. The principal parameters are (i) “Operator Safety” refers to either levels of outputs obtained per unit of time, or optimum time utilization, or minimum error rate in tasks, or efficiency in manual handling, or minimum energy expenditure rate by the person(s) concerned in a given worksystem; (ii) “Work Safety” may be interpreted in terms of potential danger to health associated with the tasks, deteriorating fitness of the individual concerned, possibility of injuries and accidents, and hazards of any other kind, and (iii) “Working Condition” refers to the condition or environment in the workplace and its surroundings made available to the satisfaction or dissatisfaction and comfort or discomfort of the person(s) concerned. In essence, the performance of any worksystem is a reflection of the joint effect of performance of the individual components of the worksystem, viz., “human”, “machine”, and “environment”.

It is reasonable to assume that for a worksystem to be capable of performing at its maximum level, each component must also contribute significantly and equally to the overall performance of the worksystem as a necessary condition for an acceptable worksystem. However, the central focus of ergonomics being the human(s) in a worksystem, the main consideration in the design of EPI is to measure and assess the state and the effect of human(s) in the worksystem, as a sufficient condition for sustained ergonomic performance. Hence, in order to assign values to the base parameters in EPI modeling, the effect on each component needs to be considered.

The three major components of “human”, “machine”, and “environment” have been assigned equal weightage while assessing the overall performance of a given worksystem. Against a base parameter, a three-level (L-I, L-II, and L-III) performance rating scale is recommended. For L-I, since the machine and the environment have the highest contribution and the human has the least contribution signifying the level of ergonomic maturity of the system, the total contribution of machine and environment is worked out to be 6.6 in a scale of 0–10. For simplicity and convenience of use, a rounded off figure of 6 has been assigned to this level. Following the same logic, other two levels (L-II and L-III), depending on their ergonomic maturity, have been assigned a maximum score of 12 and 18, respectively.

In the overall assessment of any type of worksystem (manufacturing or non-manufacturing, including service or office activities), various kinds of training programmes on safety may be initiated for the working personnel through safety campaign, and introduction of safe working methods. With regard to such conditions, it is proposed to assign an additional scale rating in a scale of 0–10, on the basis of the intensiveness of safety programmes existing in the worksystem.

1.3 Methodology

The important steps of the methodology leading to the design and development of the EPI assessment tool are as follows:

(i) Identification of ergonomic factors

A general framework involving all relevant factors and sub-factors related to human characteristics, physical workspace, physical environment, and organizational factors is required to be developed including the procedures and norms to be followed for a given unit of analysis (worksystem). A structured data collection form, called EPI data record sheet (version 1) and coded as EPI-DRS-1, has been designed to elicit information and individual judgment from the Tata Steel team members on the ergonomic factors as identified by consultants, and to be included in the design of EPI.

(ii) Identification of design and performance factors, a list of factors related to three specific aspects, viz., operator safety, work efficiency, and working condition including functional requirements, if any, is prepared and standardized at this stage. Wherever feasible and desired, these factors are objectively analyzed with respect to their current levels and/or implications; otherwise, they are subjectively assessed.

Initially, to identify all the possible ergonomic factors so as to have adequate breadth (coverage) and depth (intensiveness) in the EPI model, information on several ergonomic aspects in each factor needs to be considered. With an in-depth understanding of the prevailing situations and requirements of Tata Steel workplaces, several aspects representing depth of each factor, are identified by the consultants.

(iii) Development of interaction matrix

At this stage, the interactions (strong or weak) between the ergonomic and design or performance factors to be ascertained for a given unit of analysis were prepared in order to limit the number of factors with which a given worksystem may be assessed to a reasonable size. The guidelines for the selection of appropriate number of factors were established. The rules for determining the relative weights (reflecting importance or criticality of a factor in the presence of other factors, or on its own) were specified at this stage.

(iv) Design of the assessment tool

On completion of the above three steps, a comprehensive framework for (1) determining the ergonomic performance of a worksystem (the basic EPI model), (2) identification of deficient area(s) in relation to ergonomic factor(s), and (3) setting the priority of improvement actions suggested, is established at this stage. Therefore, a structured methodology for measuring ergonomic performance of a worksystem, called EPI data record sheet (version 2) and coded as EPI-DRS-2, is developed by the consultants for circulation and use among the Tata Steel personnel.

(v) Testing and validation of assessment tool (EPI) in varied situations and worksystems

The proposed tool is to be tested for its verification, validation, and applicability in a number of representative situations as specified and identified by the management of Tata Steel during the course of study. Appropriate modification of the assessment tool is required to be made based on actual observations, review of opinion of Tata Steel personnel, and performance evaluation.

(vi) Data collection and analysis

The entire data collection and analysis was completed by the consultants through (i) meetings with the Tata Steel team members and other concerned personnel at regular and planned intervals, (ii) in-house preparation of required documents (EPI-DRS-1, EPI-DRS-2, and interaction matrix), (iii) visits to the selected and representative worksystems and departments at Tisco plant, (iv) verification and validation of the EPI model by hands-on exercises, and (v) discussion on the EPI model.

1.4 The EPI Model

The details of the EPI model designed and developed for Tata Steel, Jamshedpur, are described in three interrelated parts: Part-I, Part-II, and Part-III. Part-I lists the ergonomic factors to be considered for EPI as well as the guidelines for quantitative assessment of base parameters in the design of EPI. Part-II refers to the tables required to be used to compute the EPI score of a given worksystem. There are five tables listed. The first table provides the definition of scale values for leveling and rating of the ergonomic variables considered; second table shows the details of the scale values under different conditions for assessment of visual environment; the third set of tables present the scale values under different conditions for assessment of thermal environment that requires evaluation of radiant temperature, air speed, and relative humidity, separately; the fourth table presents the details of the scale values under specified conditions and jobs for assessment of auditory environment. The data given in these tables are applicable in acclimatized conditions. The fifth table lists the possible EPI grading of a worksystem under consideration as well as status and actions for improvement. Part-III describes the systematic process of determining the EPI score of a given worksystem.

To understand how the EPI score is computed for a worksystem, the features and working of each part is to be known. The details of the features and working of each part are given below.

Part-I is designed to understand and quantitatively assess the importance of base parameters for a worksystem. In order to help define, assess, and quantify a parameter in the most logical and objective way, each ergonomic factor with its scale value is required to be defined for an objective assessment of base parameters. It is opined that the conditions as described in the guidelines are an exhaustive representation of different working conditions and systems at the present level of technology at Tata Steel.

It is recommended that the analyst studies the prevailing conditions against the following factors considered, with regard to key principal parameters viz., work efficiency, operator safety, and working condition, and matches with those given in the guidelines below. Against each factor, three specific rating scales representing acceptable to unacceptable levels are provided.

1. Pace or speed of work under the control of the operator
2. Adequacy of fatigue allowances for jobs
3. Workers away from their workplace during work
4. Occurrence of "human" errors
5. Frequency of lifting of weights
6. Force required to push or pull objects
7. Movements of human body
8. Assessment of visual environment in the work place
9. Engineering Anthropometry
10. Work Posture
11. Assessment of thermal environment in the work place
12. Workers complain about physical environment in their workplaces
13. Tasks resulting in excessive material wastes
14. Repetitive motions/ frequent use of hand tools/ both hands and feet operating/ same posture/information overload/in sufficient time to sense and respond to signals/ physical fitness/ knowledge of training
15. Assessment of Auditory Environment.

In Part-II, each ergonomic variable or base parameter to be considered should be leveled and quantified, on a predefined scale, once the conditions are known to the analyst. Based on the consideration of the ergonomic effect of the specified conditions on the components of the worksystem, each condition is required to be quantified.

For determining the scale values of a specified ergonomic variable, a three-point scale is found to be applicable, feasible, and easily implementable. Each scale value, for which a level number is given, indicates a numeric ergonomic assessment score of a given situation or worksystem, based on the degree of maturity in the "human" component at the existing level of technology (defined in terms of "machine" and "environment" components). The definition of each level is provided.

While rating a given condition, it is quite probable that the degree of maturity of either "machine" or "environment" or both may also be medium or low. Under such conditions, the scale value is required to be suitably modified towards the lower side.

In Part-III, the steps to be followed for obtaining the EPI score of a worksystem are given. These steps are as follows:

Step-1: Select the principal parameter(s) relevant for the worksystem under consideration.
Step-2: Select the base parameter(s) influencing the identified principal parameter (s) in Step-1.
Step-3: Assess the situation against each base parameter considered (as described in Part-I Sect. 5.1), and assign its scale rating (SR).
Step-4: Repeat Step-3 for all other base parameters selected.
Step-5: Compute the sum of scale ratings (SRs) obtained in Step-3 and Step-4.
Step-6: Assess the intensiveness of safety programmes adopted, and assign an appropriate safety awareness rating in a scale of (0–10).
Step-7: Compute the total ratings obtained in Step-5 and Step-6.
Step-8: Compute the normalized total rating (**NTR**) in a scale of (0–100).

The normalized total rating (NTR), as obtained in Step-8 above for a given worksystem may be graded belonging to one of the five specific classes of worksystems given in Table 1.1. By using the EPI model, a worksystem may be of one of the five types: for Class-I or "excellent worksystem", the prevailing work conditions need to be maintained, for Class-II or "very good worksystem" refers to comparatively acceptable work condition and remedial steps wherever required may be initiated, for Class-III or "good worksystem" refers to acceptable work condition with a great scope for improvement and a time-bound ergonomic intervention is required, for Class-IV or "poor worksystem" refers to work condition not acceptable needing immediate ergonomic intervention, and for Class-V or "very poor worksystem" means a work condition is rejected and large-scale investment with intensive management involvement is required for improving the ergonomic performance.

Table 1.1 EPI grading of worksystems

Type of worksystems	Range of NTR	Grade	Type of worksystems
Class-I	85–100	Excellent	Maintain the prevailing work conditions
Class-II	70–84	Very good	Comparatively acceptable work condition; may initiate remedial steps wherever required
Class-III	50–69	Good	Acceptable work condition with a great scope for improvement; a time-bound ergonomic intervention required
Class-IV	45–49	Poor	Work condition not acceptable; needs immediate ergonomic intervention
Class-V	<45	Very poor	Work condition is rejected; large scale investment and/or intensive management involvement required

1.5 A Few Applications of EPI Model

The EPI model was verified and validated in several workplaces, such as blast furnace raw material division, merchant mill department for long products, LD2 department for flat products, equipment maintenance department, and power house#4 of the steel plant, and also in healthcare settings (Ray and Saha 2016). For illustration purpose, the method of computing EPI score, for two specific types of worksystems, viz., Equipment Maintenance Department (Support Services) and Merchant Mill Department (Long Products) of Tata Steel is explained below.

Application-I

For Equipment Maintenance Department (Support Services), the following factors are considered relevant for the purpose as described in Table 1.2.

The other factors as listed in Part-I are not found to be relevant in this section.

Computation of Normalized Total Rating (NTR)

With the ratings as assigned, the Normalized Total Rating of the emergency section is given by:

$$[\text{NTR}] = \frac{\left[\sum_{i=1}^{n} \text{SR}_i + m\right]}{n \times 18 + 10} \times 100,$$

where SR is the scale rating, i is a factor and n is the total number of factors, and m is the safety awareness (CO-SA) rating (0–10).

Let safety awareness (CO-SA) rating (0–10) = m = 8.

$$\text{Hence, Grand TS} = \left[\sum_{i=1}^{n} \text{SR}_i + m\right] = 87 + 8 = 95$$

Maximum Scale Rating = $n \times 18 = 10 \times 18 = 180$.

Normalized Total Rating (NTR) in 0–100 scale is given by: $[\text{NTR}] = \frac{\left[\sum_{i=1}^{n} \text{SR}_i + m\right]}{n \times 18 + 10} \times 100 = \frac{95}{180 + 10} \times 100 = 52.$

Referring to EPI Grading of worksystems in Table 1.1, it is found that a scale rating of 0.52 refers to a working condition that is “Good” from ergonomic perspective and represents an acceptable work condition with a great scope for improvement and a time-bound ergonomic intervention is required.

Application-II

For Merchant Mill Department (Long Products), the following factors are considered relevant for the purpose as described in Table 1.3.

Table 1.2 EPI factor influenced for equipment maintenance department (support services)

Item	Data collected or information available	EPI factor influenced	Rating
HC-3	Lifting of oil drum, lifting of ladder	F5. Frequency of lifting of weights	12
HC-4	Drawing trolley with motor/weight, pulling of brakes out of service, raising eels rapper motors to esp top, pulling of chain block chain with weight	F6. Force required to push or pull objects	9
HC-5	Dragging of trolley with materials, putting breakers in service position, some valve operation	F7. Movements of human body	6
PE-2	Turbine control at BCD, electrical control at ECR, any job in basement, equipment overhauling	F8. Assessment of visual environment in the workplace	6
PW-2	Esp top gear box, inspection of motors, Tu hall operator, thermal control, BCD operation, electrical operation at electrical control, panel overhauling, boiler control operation, thermal control room operation unit, old thermal room operationTrf overhauling, pump house operation, use of ladder, basement floor movement, etc.	F9. Engineering anthropometry	9
PW-2	ESP emulator changing, changing of pumps and motors, working in shift area	F10. Work posture	9
PE-4	Loco operator's cabin, loco operation in Ld & Bl furnace area	F11. Assessment of thermal environment in the workplace	15
HC-8	Cutting with hacksaw, grinding, use of drill, control room operators-controlling boilers, controller in electrical control room, boiler controllers controlling boiler operation, men at electrical control room, controlling at ECR, boiler control	F14. Repetitive motions/frequent use of hand tools/both hands and feet operating/same posture/information overload/insufficient time to sense and respond to signals/physical fitness/knowledge of training	12
PE-1	Load testing of diesel engine	F15. Assessment of auditory environment	9
Total			87

Table 1.3 EPI factor influenced for merchant mill department (long products)

Item	Data collected or information available	EPI factor influenced	Rating assigned
HC-6	Packing and strapping of furnished base, scale removal from the furnace, removal of cutting from cold shear	F1. Pace or speed of work under the control of the operator	12
HC-7	Pushing out the billets from the furnace, crane drives in finishing and stripping section, pulpit B operates while seeing loop in the bar	F2. Adequacy of fatigue allowances for jobs	6
HC-3	Removal of bullet front and cuttings, removal of scale from mill tunnel, sorting on the hold up bed	F5. Frequency of lifting of weights	6
HC-4	Billet tilting on conveyer roll prior to furnace, putting motor house breaker in or taking out, pulling and pushing oxygen and weight cylinder trolley	F6. Force required to push or pull objects	6
HC-5	Seeing the entry and exit guide setting, alignment of TMT heeding, alignment of pendulum shear with roughing	F7. Movements of human body	6
PE-2	Face area, gas lines water seal, etc., cold shear area, bearing shop for roll assembly, billet yard	F8. Assessment of visual environment in the workplace	9
PW-1	Cleaning and maintenance below gearbox, cleaning below cold sheets and cold sheet 2	F10. Work posture	6
PE-4	Charging bed conveyer roll area prior to furnace, billet pushing cabin, billet withdrawing cabin, crane operator cabin, pushing cabin on the backside of the furnace, crossover bridge for inspection of cooling bed, crane drivers cabin, withdrawal and twist pinch roll operator's cabin, cold sheet operator rear sheet	F11. Assessment of thermal environment in the workplace	9
PE-5	Grinding operation while guides are grinded, face area hydraulic purees platform, TMT heads presume gauge display	F12. Workers complain about physical environment in their workplaces	6

(continued)

Table 1.3 (continued)

Item	Data collected or information available	EPI factor influenced	Rating assigned
HC-8	Cutting from behind near cold sheet bars to be removed and sorted manually, twist pinch roll operator, twist pinch roll operator critically operates control using both hands, changing bed pulpit operator, motor house substation in charge, pulpit operator. This person when asked to tilt the billet which was struck midway inside the furnace, when new system in hydraulic/pneumatic was commissioned, all the people did not have appropriate knowledge of training	F14. Repetitive motions/frequent use of hand tools/both hands and feet operating/same posture/information overload/insufficient time to sense and respond to signals/physical fitness/knowledge of training	9
PE-1	Face area, cold sheet 1, cold sheet 2, roller's cabin where grinding of guides is done, big diameter base moving on the roller from the shuffle bar	F15. Assessment of auditory environment	6
Total			81

The other factors as listed in Part-I are not found to be relevant in this section.

Computation of Normalized Total Rating (NTR)

With the ratings as assigned, the Normalized Total Rating of the emergency section is given by:

$$[\text{NTR}] = \frac{\left[\sum_{i=1}^{n} \text{SR}_i + m\right]}{n \times 18 + 10} \times 100,$$

where SR is the scale rating, i is a factor and n is the total number of factors, and m is the safety awareness (CO-SA) rating (0–10).

Let safety awareness (CO-SA) rating (0–10) = m = 5.

$$\text{Hence, Grand TS} = \left[\sum_{i=1}^{n} \text{SR}_i + m\right] = 81 + 5 = 86$$

Maximum Scale Rating = $n \times 18 = 11 \times 18 = 198$.

Normalized Total Rating (NTR) in 0–100 scale is given by: $[\text{NTR}] = \frac{\left[\sum_{i=1}^{n} \text{SR}_i + m\right]}{n \times 18 + 10} \times 100 = \frac{86}{198 + 10} \times 100 = 45.$

Referring to EPI Grading of worksystems in Table 1.1, it is found that a scale rating of 0.452 refers to a working condition that is "Poor" from ergonomic perspective and represents an unacceptable work condition which needs immediate ergonomic intervention.

With the application of generic EPI model of several worksystems of Tata Steel, a number of observations regarding the usefulness of the model that may be made are (i) the EPI model is applicable to all types of worksystems, (ii) with the use of EPI model on a continuous basis, there is a high probability that the persons at all levels of organization become aware of importance of ergonomic design for sustainable worksystem performance, (iii) as the model is factor specific, ability of the persons concerned to judge the ergonomic performance from several "man–machine" perspectives is expected to improve in near future, (iv) the EPI model is cost-effective in the sense that it mainly suggests preventive measures for improving ergonomic performance and with the implementation of preventive measures, the effect of occupational risk factors get minimized.

1.6 Concluding Remarks

The EPI model has been found to be very effective and a team of qualified ergonomics and human factors professionals from ergonomics and safety department of Tata Steel is responsible for computing EPI score of a given worksystem as and when required. The role of such professionals lies in assessing the present level of ergonomic performance and identifying the deficient areas (the list of factors where the scores are low) and the deficient areas where ergonomic interventions are desired. It has been observed that such ergonomically deficient areas are regularly identified and in terms of ergonomic intervention projects are being undertaken by these professionals. In certain areas, external expertise in the form of hiring consultants is needed for undertaking such improvement initiatives.

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