Ergonomic Performance Measurement and Evaluation for Worksystems in Healthcare

Pradip Kumar Ray and Esha Saha

Abstract The principles of ergonomics can be applied to the study and design for the components of any worksystem involving human(s) and machine(s) embedded in environment. As a first step towards exploring the enormous potential and concept of ergonomics at workplaces, many organizations, including healthcare systems, are required to take steps to institutionalize the process of implementing a framework to determine the level of ergonomic performance at their different workplaces. Relevance ergonomics-related factors of performance 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 or service may lead to substantial improvement in overall system performance. This paper highlights the details of an ergonomic performance measurement system developed for a hospital system in India.

Keywords Ergonomic variables · Ergonomic performance · Worksystems healthcare systems

1 Introduction

The principles of ergonomics can be applied to the study and design for the components of any worksystem involving human(s) and machine(s) embedded in environment, and as such application of these principles is not limited to a particular technology or to the scale of the system. In essence, application of these principles provides a standardized approach to analysis of any system with emphasis on

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consideration of interaction between human(s), machine(s) and environment. As a first step towards exploring the enormous potential and concept of ergonomics at workplaces, many organizations, including healthcare systems, are required to take steps to institutionalize the process of implementing as a whole, and have also felt the need to develop a framework to determine the level of ergonomic performance at their different workplaces. The factors of performance and/or operations where deficiency and nonconformance 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 or service may lead to substantial improvement in overall system performance.

Keeping in view that identification and assessment of effective variables contributing toward overall performance of a human-machine system in healthcare is a primary requirement, the paper highlights the details of an ergonomic performance measurement system developed for a hospital system in India. In specific terms, the objectives of such a performance measurement system are manifold: to identify and characterize the ergonomic variables for a given worksystem in healthcare with regard to work efficiency, operator safety and working condition, to design a comprehensive ergonomic performance measurement system for quantitative evaluation of the ergonomic status (in terms of design requirements and performance labeling) of a given worksystem and unit of analysis, and to apply the performance measurement model to evaluate the degree of ergonomic maturity of a given worksystem or unit of analysis. The methodology leading to the design and development of ergonomic performance measurement systems has a number of steps, viz., identification of ergonomic factors, as well as design and performance factors, development of interaction matrix, design of assessment tool, and testing and validation of the assessment tool in varied situations and worksystems.

The comprehensive performance measurement tool as developed is tested for its verification, validation and applicability in a number of worksystems, such as, outpatient department, inpatient department, emergency department and other related systems of a hospital as specified and identified by the management of the organization. Appropriate modifications of the performance measurement systems are made based on actual observations, review of opinions of the concerned personnel, and performance evaluation. With the help of the measurement systems as developed, the prevailing conditions in a given worksystem are assessed against a number of factors, in respect of key principal parameters, viz., work efficiency, operator safety and working condition. The factors considered are: pace or speed of work under the control of the operator, adequacy of fatigue allowances for jobs, occurrence of human errors, frequency of lifting of weights, movement of human body, assessment of visual environment in workplaces, engineering anthropometry, work postures, assessment of thermal environment in workplaces, operators' complaint regarding physical environment, tasks resulting in excessive material waste, repetitive motions, use of hand tools, information overload and assessment of auditory environment.

The performance of any hospital worksystem is measured with a normalized total rating that may be graded on a five-point scale. Against each of these scale ratings,

such as excellent, very good, good, poor or very poor rating, the corresponding action steps are identified and expected with the implementation of such action steps within a specified time frame. This performance evaluation system is thus considered an effective scientific tool for measuring quality of working life of healthcare personnel, and it may also be used as a benchmark to grade ergonomics maturity of different worksystems in any organization, manufacturing and service. The details of the application of the comprehensive ergonomic performance systems, as per the select criteria, parameters, and methodology, in a hospital in India are provided in this paper.

2 Objectives

Keeping in view that identification and assessment of the effective variables contributing toward the overall performance of a human-machine system is the primary requirement, an Ergonomic Performance Measurement System is proposed to be designed and developed for an organization. Hence, the objectives of the study are set as follows:

(i) To identify and characterize the ergonomic variables for a given worksystem in healthcare with regard to work efficiency, operator safety and working condition,
(ii) To design a comprehensive ergonomic performance measurement system for quantitative evaluation of the ergonomic status (in terms of design requirements and performance labeling) of a given worksystem and unit of analysis, and
(iii) To apply the performance measurement model to evaluate the degree of ergonomic maturity of a given worksystem of healthcare system.

3 Ergonomics Performance Measurement System: Characteristic Features

This section 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 the worksystem considered. It is recommended that the analyst studies the prevailing conditions against the following 15 factors (F1–F15) considered with regard to key principal parameters; viz. work efficiency, operator safety, and working condition, and matches with those given in the guidelines below as suggested in [1].

3.1 F1. Pace or Speed of Work Under the Control of the Operator

(i) The operator has to work with utmost care, attention, high pace, and cannot distract attention; failure results in waste/reworking; continuous flow.
(ii) The operator can work in a relaxed mood; failure may not necessarily result in wastes/reworking; intermittent flow.
(iii) The operator has to work separately in the jobs assigned at a place, and can easily manipulate the pace of work; process pace is not a significant factor for operator pace of working.

3.2 F2. Adequacy of Fatigue Allowances for Jobs

(i) The work results in tiredness very soon; recovery time from fatigue is more; engaged in dangerous and/or heavy work; may result physical and mental stress or both.
(ii) The work results in tiredness when work duration is substantial; recovery time is fast; not engaged in dangerous or heavy work; may result physical and mental stress occasionally.
(iii) The operator feels at ease in coping up with the workload; enjoys the jobs; no evidence to suggest that the worker is mentally or physically stressed or overworked.

3.3 F3. Workers Away from Their Workplace During Work

(i) The operator feels extremely uncomfortable while working; cannot work continuously at the stipulated workplace, and leaves the workplace with virtually no control on his or her movements by the management; actual working time less than or equal to 50 % of the total available working time consistently.
(ii) The operator leaves the workplace at an infrequent interval although the condition at the workplace and the job characteristics may not necessarily compel the operator to do so; the operator is engaged in work, most of the time.
(iii) The operator does not like leaving the workplace at all during the working time.

3.4 F4. Occurrence of "Human" Errors

(i) Human errors may occur due to improper equipment design or performance; may result in catastrophic economic loss, and endanger human life of the self and other persons directly or indirectly affected; elaborate and detailed study as well as alternate technology needs to be employed.
(ii) Human errors may occur with no significant economic loss and no chance of major equipment failure or musculoskeletal injury; the operator may not feel safe in some situations.
(iii) Human errors may occur with no significant economic loss or body injury or accidents; the operator becomes aware about the implication of errors, and is in a position or trained to overcome the problem on his/her own initiative.

3.5 F5. Frequency of Lifting of Weights

(i) The operator has to manually lift a weight at a high frequency at a regular pace as the present level/type of workplace requires; "alternatives are not available".
(ii) The operator has to manually lift a weight at a low frequency at a regular pace as the level/type of technology requires; "better alternatives are not available".
(iii) The operator may have to manually lift weight at an predetermined interval; no physical stress; "alternatives may be available".

3.6 F6. Force Required to Push or Pull Objects

(i) The working condition and the method of doing work make pushing or pulling objects very difficult; the operator has to exert a lot of physical effort either individually or in a group; a permanent feature of the existing working method and condition at the workplace.
(ii) The working condition and working method make pushing or pulling objects somewhat difficult; the operator has to exert physical effort individually; an important feature of the working condition and the method at the workplace.
(iii) The working condition and method of working are such that pushing or pulling objects is not at all difficult for the operator; the type of technology employed makes the job very easy to undertake; indicative of existence of convenient and safe working methods and norms.

3.7 F7. Movements of Human Body

(i) During manual material handling, body movements are primarily bending, or twisting; producing excessive compressive stress on body joints with a high risk of spinal injury.
(ii) During manual material handling, frequency of bending and/or twisting movements is less and under control; there is less risk of musculoskeletal injury.
(iii) The design of the work method is such that no such body movements occur in most cases; chance of musculoskeletal injury is most unlikely.

3.8 F8. Assessment of Visual Environment in the Workplace

(i) The amount of illumination as measured for the job does not conform to the standards: 50 % or more off the standard.
(ii) The amount of illumination as measured for the job does not conform to the standards: within 50 % off the standard.
(iii) The amount of illumination as measured for the job is conforms to the standards.

3.9 F9. Engineering Anthropometry

(i) Mismatch between work system and operators concerned at extreme level with frequent reporting of complaints;
(ii) Mismatch between a few work systems and operators concerned with no apparent reporting of complaints;
(iii) No mismatch whatsoever between the work system and the operators concerned.

3.10 F10. Work Posture

(i) Existing work postures in majority of the cases are unacceptable with serious negative consequences in the long run.
(ii) Existing work postures do create imbalance and discomfort in some situations or jobs in the workplace.
(iii) Working postures do not affect adversely productivity and quality, and are not at all considered a problem.

3.11 F11. Assessment of Thermal Environment in the Workplace

(i) It is concluded that the actual thermal environment of the work system under consideration conforms to the standards with regard to radiant temperature, humidity, and airflow within an acceptable limit.
(ii) It is concluded that the actual thermal environment of the work system under consideration does not exactly conform to the standards with regard to radiant temperature, humidity, and airflow at the workplace on the basis of the deviation from the standards.
(iii) It is firmly concluded that the existing thermal environment of the work system under consideration is judged comfortable for the majority of the persons engaged; a sustained acceptable productive effort in the existing environment is guaranteed.

3.12 F12. Workers' Complaints About Physical Environment in Their Workplaces

(i) In terms of severity of potential hazards in the physical environment, there are high task demands and high risk of musculoskeletal injury; worker complaints are supported by facts; permanent total disability/long term health problems may exist or will occur.
(ii) In terms of severity of potential hazards at the workplace, task requirements exceed the mental and physical capabilities of some workers; complaints of these workers are supported by facts; permanent partial disability is likely.
(iii) Task requirements are difficult for some workers, but within their capabilities; minor injury likely but major injury is very unlikely; there are hardly any complaints reported.

3.13 F13. Tasks Resulting in Excessive Material Wastes

(i) The material wastes generated at the workplace severely restrict the productive effort of the workers concerned; it is also a critical problem in relation to the working environment for almost all jobs.
(ii) The material wastes generated at the workplace restrict the productive effort of the workers concerned in some jobs only; it may not adversely affect the quality of the working condition.
(iii) The material wastes generated at the workplace are not considered a problem; there is no reporting of any adverse effect on the working condition.

3.14 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

(i) It is observed that the productivity of the person(s) concerned is severely affected by one or more of the factors such as repetitive motions, frequent use of hand tools or levers, physical fitness, level of training, fatigue (whole body or local), overexertion, slip/trip and musculoskeletal injury considered as critical problem areas at the workplace for almost all the jobs.
(ii) It is observed that the productivity of the person(s) concerned is restricted by one or more of the factors only for a few jobs, and the problem areas, as mentioned are not at the critical level.
(iii) It is observed that the workplace consideration is not affected, more or less, by such factors as mentioned. The worker(s) concerned is/are mentally and physically fit, and exert(s) productive efforts for the jobs assigned.

3.15 F15. Assessment of Auditory Environment

(i) It is concluded that the existing auditory environment of the workplace under consideration does not conform to the standards established for maximum intensity of sound and total allowable exposure time on the basis of deviation from the standards; there is a strong feeling that permanent hearing loss may occur unless preventive/corrective measures are taken immediately or in near future.
(ii) It is concluded that the existing auditory environment of the workplace under consideration does not conform fully to the prescribed standards.
(iii) It is concluded that the existing auditory environment of the workplace under consideration conforms to the standards established for maximum intensity of sound, and corresponding total allowable exposure time; slight deviation from the standards may occur only sometimes without any adverse effect to the workers engaged/concerned with no complaints whatsoever from the workers.

4 Methodology for Measuring Ergonomic Performance

The important steps of the methodology leading to the design and development of the Ergonomics Performance Management Systems assessment tool are as follows:

4.1 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.

4.2 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.

4.3 Development of Interaction Matrix

At this stage, the interactions (strong or weak) matrix between the ergonomic and design or performance factors to be ascertained for a given unit of analysis is prepared in order to limit the number of factors with which a given work system may be assessed to a reasonable level. The guidelines for the selection of appropriate number of factors are 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) are to be specified at this stage.

4.4 Design of the Assessment Tool

On completion of the above three steps, (i) to (iii), a comprehensive framework for (1) determining the ergonomic performance of a worksystem, (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.

4.5 Testing and Validation of Assessment Tool 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 the organization.

5 Applications in Healthcare

Healthcare industry as a working environment comprises a unique set of characteristics, opportunities and challenges for applying ergonomics. The Ergonomics Performance Management Systems for worksystems in healthcare is especially developed for the hospital settings in the operating rooms, surgical wards, radiology, etc. The purpose and value of using ergonomics to study the divergent medical environments is evident from the literature surveyed. The various methods applicable for the study of human factors and ergonomics in the healthcare setting are explained in detail in the review paper [2]. The human factors and ergonomics area is an expanding field in the healthcare domain and has contributed significantly to the understanding of relationship between ergonomically designed medical devices and work performance, ergonomically designed worksystem and performance, postural stress due to inefficient working conditions of the surgeons during surgery, uncomfort of medical staff in lifting the boxes of medical items from floor to shelf, etc. The hospital worksystem is explained by a simulation model in [3].

As each of the 15 factors considered is generic in nature, they are to be defined in terms of characteristic features and situations prevailing in a healthcare system. The specific ergonomic factors for a given worksystem in healthcare with regard to work efficiency, operator safety and working conditions are highlighted in Table 1.

Table 1 Ergonomic performance-related factors for a worksystem in healthcare

Factor no.	Ergonomic performance-related factors	Description	References
F1	Pace or speed of work under the control of the operator	Medical personnel work with utmost care, attention, high pace, and cannot distract attention	
F2	Adequacy of fatigue allowances for jobs	Postural stress of surgeons during surgery	Bartnicka [4]
F3	Workers away from their workplace during work	Medical personnel feels uncomfortable in the working conditions	
F4	Occurrence of “human” errors	Safety challenges in the use of medical equipment during the training of nurse anaesthetists	Santos et al. [5]
F5	Frequency of lifting of weights	Lifting of boxes of Intravenous fluids from floor to cupboard	Hignett [6]
F6	Force required to push or pull objects	Pushing and pulling on the slope of the switch of surgical scalpels	Wu et al. [7]
F7	Movements of human body	Patient handling tasks	Nelson et al. [8]

(continued)

Table 1 (continued)

Factor no.	Ergonomic performance-related factors	Description	References
F8	Assessment of visual environment in the workplace	Relative balance between monitor light and background reading room lighting is important in determining the degree of radiologist fatigue, efficiency and accuracy	Goyal et al. [9]
F9	Engineering Anthropometry	Stationary position of the patient without the possibility to change it to another during surgery; inadequate height of the surgical table; different anthropometric features of medical staff	Bartnicka [4]
F10	Work Posture	Working posture of surgeons in operating room	Serratos-Perez et al. [10]
F11	Assessment of thermal environment in the workplace	Temperature controls in the working environment of radiology department	Goyal et al. [9]
F12	Workers complain about physical environment in their workplaces	Musculoskeletal injury among the hospital workers	Janowitz et al. [11]
F13	Tasks resulting in excessive material wastes	Medical wastes generated in the hospitals is disposed by the workers	
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	Repetitive movements of the surgeons during operations	Serratos-Perez et al. [10]
F15	Assessment of Auditory Environment	Noise in the working environment of radiology department	Goyal et al. [9]

6 Determination of Ergonomic Performance for a Worksystem in Healthcare

A number of integrated steps in sequence are to be followed for measuring ergonomic performance for a worksystem in healthcare. The specific steps are as follows:

- Step-1: Select the principal parameter(s) relevant for the worksystem in healthcare.

Table 2 Assessment concept of scale rating

Levels	Ergonomic intervention	Rating
Level I	No ergonomic intervention	6
Level II	Lower level of ergonomic intervention	9–12
Level III	Higher level of ergonomic intervention	15–18

- 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 and assign its scale rating (SR) as shown in Table 2.
- 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 rating for safety awareness (CO–SA) 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) by using the following formula:

$$[\mathrm{NTR}] = \frac{\left[\sum_{i=1}^{n} \mathrm{SR_i} + m\right]}{\mathrm{n} \times 18 + 10} \times 100 \tag{1}$$

The performance of the emergency department of a hospital in India has been assessed with the methodology as developed. While assessing the performance, all the 15 factors are considered. The ratings against each of these factors are given in Table 3.

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

$$[\mathrm{NTR}] = \frac{\left[\sum_{i=1}^{n} \mathrm{SR_i} + m\right]}{n \times 18 + 10} \times 100 \tag{2}$$

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.

$$\text{Hence, Grand TS} = \left[\sum_{i=1}^{n} \mathrm{SR_i} + m\right] = 160 + 8 = 168$$

Maximum Scale Rating = n × 18 = 15 × 18 = 270.

Normalized Total Rating (NTR) in 0–100 scale is given by:

$$[\mathrm{NTR}] = \frac{\left[\sum_{i=1}^{n} \mathrm{SR_i} + m\right]}{n \times 18 + 10} \times 100 = \frac{168}{270 + 10} \times 100 = 60 \tag{3}$$

Table 3 Ratings assigned to ergonomic performance-related factors

Factor no.	Ergonomic performance-related factors	Data collected from emergency department of a hospital	Rating assigned
F1	Pace or speed of work under the control of the operator	Medical personnel work with utmost care, attention, high pace, and cannot distract attention	15
F2	Adequacy of fatigue allowances for jobs	Fatigue allowances for medical personnel	10
F3	Workers away from their workplace during work	Medical personnel feels uncomfortable in the working conditions	6
F4	Occurrence of "human" errors	Safety challenges in the use of medical equipment, etc.	11
F5	Frequency of lifting of weights	Lifting of boxes of items required in emergency department	9
F6	Force required to push or pull objects	Force required to push and pull certain medical instruments	6
F7	Movements of human body	Patient handling tasks	10
F8	Assessment of visual environment in the workplace	Lighting in emergency department	6
F9	Engineering anthropometry	Stationary position of the patient; inadequate height of the bed; different anthropometric features of medical personnel	16
F10	Work posture	Working posture of personnel	11
F11	Assessment of thermal environment in the workplace	Temperature controls in the working environment of emergency department	17
F12	Workers complain about physical environment in their workplaces	Musculoskeletal injury among the medical personnel	9
F13	Tasks resulting in excessive material wastes	Medical wastes generated and disposed by the workers	9
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	Repetitive movements of medical personnel in emergency department	15
F15	Assessment of auditory environment	Noise in the working environment of emergency department	10
	Total score		160

According to the ergonomic performance grading, range of NTR values within (85–100) indicates 'excellent' performance; (70–84) 'very good'; (50–69) 'good'; (45–49) 'poor' and less than 45 considered 'very poor'. Using the performance measurement system as developed the ergonomic performance of the emergency

department is found to have a value of 60 grading indicating a 'good' grade. These assessment indicates that the working condition in the emergency department is acceptable; however, there is enough opportunity and scope for improvement in its ergonomic performance and a time bound remedial ergonomic interventions are required wherein work organization-related factors like work norms, shift schedules, occupational hazards, job allocation norms, as well as job design aspects need to be under control.

7 Conclusion

It is essential that a total integrated approach needs to be in place for ergonomics performance measurement and evaluation of any worksystem. The application to the emergency department of the hospital of the proposed ergonomics performance system refers to the level of maturity as achieved by the organization in ergonomic design of the worksystems. The methodology can be applied to any other healthcare worksystems for comparison and improvement purpose.

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