FUZZY-LOGIC-BASED ERGONOMIC ASSESSMENT IN AN AUTOMOTIVE INDUSTRY

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ABSTRACT

The objective of this study was to develop and evaluate a tool for measuring an organisation’s ergonomic level. The study was carried out to fill a research gap in which no attempt had been made to design an index for evaluating a company’s ergonomics. An ergonomic index measuring model with 15 criteria using a fuzzy logic technique was developed during this study. The fuzzy ergonomic index (FEI), which represents the ergonomic level of the company, and the fuzzy performance importance index, which assists in resolving ergonomics barriers, were then calculated. The findings show that the model is capable of analysing ergonomics adequately and has practical application. Application of the methodology presented in this paper will reveal the measures necessary to improve an organisation’s ergonomic level.

OPSOMMING

Die doel van hierdie studie was om 'n instrument te ontwikkel en te evalueer om 'n organisasie se ergonomiese vlak te meet. Die studie is uitgevoer om 'n navorsingsgaping te vul waarin geen poging aangewend is om 'n indeks vir die evaluering van 'n onderneming se ergonomie te ontwerp nie. 'n Ergonomiese indeksmeting model, gebaseer op ‘n wasig logika tegniek, met 15 kriteria is tydens hierdie studie ontwikkel. Die wasige ergonomiese-indeks (WEI), wat die ergonomiese vlak van die maatskappy verteenwoordig, en die wasige werkverrigting-belangrikheidsindeks, wat help om ergonomiese hindernisse op te los, is toe bereken. Die bevindinge toon dat die model in staat is om ergonomie voldoende te analiseer en praktiese toepassing het. Toepassing van die metodologie wat in hierdie artikel aangebied word, sal die maatreëls bepaal wat nodig is om 'n organisasie se ergonomiese vlak te verbeter.

1. INTRODUCTION

Man, machinery, and the environment all make a contribution to the manufacturing industry. In large-scale mass manufacturing, socio-technical difficulties developed as humans and machines worked together. In this context, ergonomics plays a vital role. Ergonomics’ fundamental concepts would be used to improve workplace safety and productivity. The fundamental objective of ergonomics is to create and implement people’s adaptation strategies for their job in effective and safe ways in order to improve their productivity and well-being [1]. Many studies have demonstrated that using ergonomics concepts in machine design, workplaces, job design, environmental design, occupational health and safety, and facility design has a beneficial impact [2]. Organisations’ primary goals have been constantly to enhance efficiency and quality, resulting in increased profitability. Workstations can be designed to enhance performance and lower costs by integrating productivity and ergonomics [3]. There is a growing concern to improve productivity, safety, and quality in manufacturing industries [4]. With the growing age of the workforce, the average duration of illness increases [5]. To develop, design, and manage a new manufacturing technology, produce innovative goods, improve operational efficiency, and enhance health and safety, it is important to have scientific understanding and techniques in ergonomics. Even while manufacturing engineers and managers have traditionally been driven to build technologically automated systems to replace people, there is now a growing recognition that humans are still necessary for diverse tasks, even in fully automated production processes.

From this perspective, two significant research gaps can be identified. The first is that, while there are techniques for assessing a company's leanness, sustainability, and agility, there is no comparable model for ergonomics. The second gap is that there are few research articles on ergonomic assessment, and those that do exist are primarily concerned with conducting ergonomic evaluations of physiological, psychological, or environmental factors. The goal of this research was to develop a conceptual model for evaluating the ergonomics of manufacturing work environments while taking physiological, psychological, environmental, and safety factors into account. In today's production environment, quantifying ergonomics in an organisation has become increasingly important. In this research, the fuzzy logic approach was used.

2. BACKGROUND

The literature review was carried out on ergonomic dimensions and ergonomic assessment tools.

Parsons [6] reviewed the principles, methods, and models used in environmental ergonomics. The evaluation system considered environmental aspects such as heat and cold, vibration, noise, and light on the health, comfort, and performance of people. Grzybowski [7] contributed a method for ergonomic workplace evaluation that considered physical working environment factors (noise, vibration, microclimate, lighting, dust levels, toxicity, electromagnetic radiation), physical strain factors (energy consumption, static strain, repetitiveness of motion), psychological strain factors (information overload, monotony), and technological and organisational factors (factors related to workplace organisation and technical equipment). Ergonomic risks in the workplace can be determined by the movement of work and risks to posture [8]. Different tools have been developed to assess the exposure of risk, based on self-reporting, observational methods, and direct measurement [9]. Rating scales, questionnaires, checklists, and interviews are various forms of the self-reporting method. Initially, an effective rapid-screening instrument [10] was developed to identify cyclical jobs that expose workers to potentially harmful postures in order to determine the presence of the ergonomic risk factors associated with awkward postures of the lower extremities, the trunk, and the neck. Then a self-assessment software package (ErgoTech) [11] was developed to evaluate the ergonomic improvement potential of production systems to achieve excellence in the manufacturing industry. The application of this assessment tool revealed that production managers were able to successfully recognise ergonomic deficiencies on the shop floor. Later, the ErgoSAM tool [12] was used to assist in optimising the workplace in terms of production time and physical load on the operator by detecting high musculoskeletal loads early in the planning process.

Although some organisations use those approaches to ergonomic evaluation, the Occupational Safety and Health Administration (OSHA) checklist, and the Standard Nordic Musculoskeletal Disorders (MSDS) questionnaire [11], are most commonly used. The Standard Nordic MSDS questionnaire has been used in the manufacture of LCD screens and furniture [13]; and the OSHA checklist has been used in the semiconductor manufacturing assessment [14]. The Ovako Working Posture Analysing System (OWAS) [15], the Rapid Upper Limb Assessment (RULA) [16], the Rapid Entire Body Assessment (REBA) [17], the Strain Index [18], and the Occupational Repetitive Actions (OCRA) [19] are examples of observational methods that involve directly observing the worker and the tasks they perform. The RULA technique has been used in a variety of sectors, including garment manufacturing [20], drilling [21], pump manufacturing [22], plastic manufacturing [23], electronic components manufacturing [24], and brick production [25]. REBA has also been used in the analysis of manual picking processes [26] and the development of work rotation schedules [27]. Rosecrance, Paulsen and Murgia [28] used the Strain Index and OCRA to measure the risk index in cheese processing activities. Rapid Office Strain Assessment (ROSA) [29] is a new office risk assessment method used to estimate the hazards connected with computer work. Based on complaints of discomfort connected with office work, this technology would offer information to the user about the need for change. In a call centre workplace, Poochada and Chaiklieng [30] demonstrated the use of ROSA to assess the existence of risk factors for work-related musculoskeletal diseases (WRMSD). Borah [31] carried out a study to determine the drudgery of women cashew nut factory employees in respect of physiological reactions, work-related musculoskeletal problems, and health risk factors. For the evaluation of Advanced Manufacturing Technology (AMT), Macias, Alcaraz, Reyes and Hernández [32] established a list of ergonomic characteristics such as physical workspace compatibility, human skills and training compatibility, usability, physical workspace compatibility, equipment emission requirements, and equipment design organisational requirements. Ergonomic compatibility evaluation on the selection of AMT is done using a fuzzy axiomatic design approach. The Postural Ergonomic Risk Assessment (PERA) technique was introduced by Chander and

Cavatorta [33] to assess the postural ergonomic risk of short cyclic assembly activity. Maman, Yazdi and Cavuoto [34] investigated the direct approach, which allows data to be collected directly from sensors connected to the worker's body. However, it is difficult to apply in real-world settings [35]. Kong [36] has presented a framework model for the ergonomic evaluation of workstations that include both physical and cognitive loads, which is important information for performance prediction, job assignment, operator selection and training, and work organisation.

Despite the fact that there are quantification techniques for ergonomics, according to the literature review, these tools have only been employed to analyse physiological or psychological variables. Ergonomic evaluation appears to make a limited research contribution. A systematic evaluation technique for evaluating workplace ergonomics is thus required.

2.1. Ergonomic assessment model

Table 1 shows the conceptual framework for ergonomic measurement that was used in this study. The ergonomic evaluation model contains 15 criteria, and is divided into three stages. There were four enablers in the first stage. The second stage comprises 15 ergonomic requirements, while the third stage contains 40 ergonomic features [37].

Table 1: Ergonomic evaluation conceptual framework

Factors	Criteria	Variables
EC1 – PHYSIOLOGICAL FACTORS	EC11 – Energy expenditure	EC111 – Basal metabolic rate [31]
		EC112 – Material handling [31]
		EC113 – Worker movement [31]
	EC12 – Biomechanical Aspects	EC121 – Physical work/endurance and design [32]
		EC122 – Postural comfort of design [32]
		EC123 – Vertical reach [32]
		EC124 – Access to machine and clearance [32]
		EC125– Adjustability of design [32]
	EC13 – Usability	EC131 – Visual workplace design [32]
		EC132 – Error tolerance [32]
		EC133 – Compatibility of design and control [32]
		EC134 – Man/machine function allocation of design [32]
		EC135 – Physical distribution of controls [32]
EC2 – PSYCHOLOGICAL FACTORS	EC21 – Communication	EC211 – Speech intelligibility [38,39]
		EC212 – Information flow [38,39]
	EC22 – Human error	EC221 – Design of equipment [38,39]
		EC222 – Worker selection [38,39]
		EC223 – Training [38,39]
	EC23 – Human skills and training capability	EC231 – Training level compatibility [32]
		EC232 – Skill level compatibility [32]
	EC24 – Work rest schedule	EC241 – Heart rate [10]
		EC242 – Work and rest period [10]
		EC243 – Body heat [10]

Table 1: Ergonomic evaluation conceptual framework (cont.)

Factors	Criteria	Variables
EC3 – ENVIRONMENTAL FACTORS	EC31 – Illumination	EC311 – Light distribution [6,39]
		EC312 – Nature of light [6,39]
	EC32 – Motion (vibration)	EC321 – Motion sickness [6]
		EC322 – Interference with activities [6,38]
	EC33 – Temperature/ climate	EC331 – Limits of tolerance [38]
		EC332 – Acclimatisation [6]
	EC34 – Housekeeping	EC341 – Level of cleanliness [6,39]
		EC342 – Maintenance [6,39]
	EC35 – Noise	EC351 – Sound categories [6,39]
		EC352 – Sound intensity [6,39]
EC4 – SAFETY FACTORS	EC41 – Risk management	EC411 – Designing organisational structures, rules [38]
	EC42 – Personal safety	EC421 – Safety training [7]
		EC422 – Person protective equipment [4]
	EC43 – Organisational safety	EC431 – Regulation and norms [41]
		EC432 – Hazards [40]
		EC433 – Stakeholders' investment [38]

3. METHODOLOGY

Figure 1 shows the research methodology used in this study. A conceptual model was established, based on the literature review. It was organised into three levels: enablers, criteria, and attributes. Workers were asked to assess the performance of ergonomic characteristics and their significance weights using linguistic indicators. A triangular fuzzy number was used to approximate the linguistic variables. The fuzzy ergonomic index (FEI) was calculated after three stages of computation had been completed, using fuzzy procedures. Using the Euclidean distance technique, the ergonomic level of the organisation was assessed by matching the FEI with the linguistic terms. The fuzzy performance importance index FPII was used to determine obstacles to further improvement. The case organisation would take the necessary steps to resolve the issues.

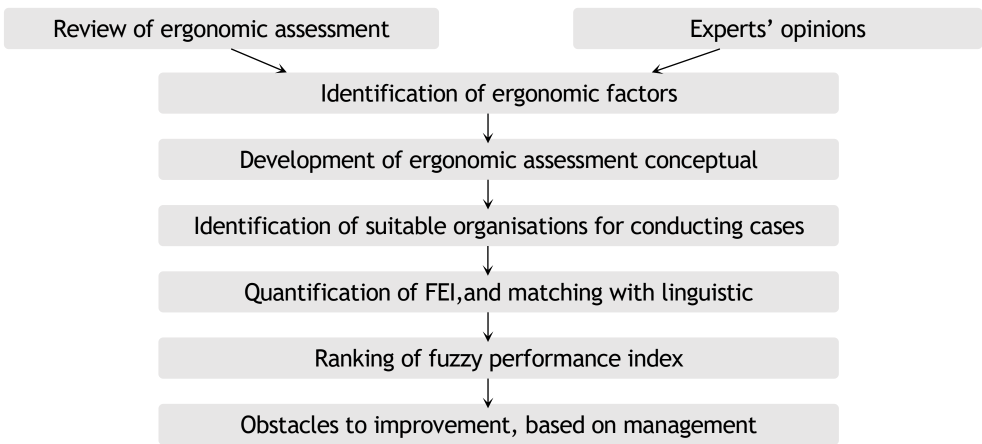

Figure 1: Methodology of the study

4. CASE STUDY

4.1. About the case study

XYZ is a limited liability partnership (LLP) firm manufacturing brake and clutch shoes for two-wheelers. The company operates with three major units: a casting unit, a rubber liner unit, and an assembly unit, all meeting the demand for 70,000 units of brake shoes and clutches. Among the various brake shoe and clutch models offered, the ABC brake shoe was chosen for analysis, as it contributed 56 percent of the company's sales. The study was conducted in the casting unit, which involved the following process: weighing aluminium bars, melting aluminium bars, casting, fettling (the outer and side parts), fettling (the inner part), drilling, and shot blasting.

4.2. Application of fuzzy logic in ergonomic assessment

The fuzzy ergonomic index of an organisation is represented by 'FEI'.

Equation 1 for the ergonomic index is:

$$\boldsymbol{FEI} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{N}} \frac{\boldsymbol{R_i \times W_i}}{\boldsymbol{W_i}} \tag{1}$$

where R_i is the ergonomic capabilities performance index and W_i is the ergonomic capabilities importance weight.

The performance rating of the ergonomic capabilities and the important weights of the ergonomic capabilities were investigated by choosing the linguistic variables. A set of fuzzy integers was developed to estimate the values of the linguistic variables [42], as illustrated in Table 2. Workers used linguistic terms to score their performance and to estimate the significance of their ergonomic capabilities. The workers decided on the ratings and weights after a question-and-answer session. A median operation was used to aggregate the workers' assessments, since it is more consistent with a small sample [42]. Table 3 shows the results, the integrated performance ratings, and the integrated importance weights of the ergonomic capabilities that were examined using linguistic variables to assess the casting unit's aluminium bar process. The linguistic terms in Table 2 were then converted into fuzzy numbers using the connection between the linguistic words and the fuzzy numbers, as illustrated in Table 4.

Table 2: Linguistic variables and their respective fuzzy numbers

Performance rating		**Importance weighting**	
Linguistic variable	**Fuzzy number**	**Linguistic variable**	**Fuzzy number**
(W)Worst	(0,0.5,1.5)	(VL) Very low	(0,0.05,0.15)
(VP) Very poor	(1,2,3)	(L) Low	(0.1,0.2,0.3)
(P) Poor	(2,3.5,5)	(FL) Fairly low	(0.2,0.35,0.5)
(F) Fair	(3,5,7)	(M) Medium	(0.3,0.5,0.7)
(G) Good	(5,6.5,8)	(FH) Fairly high	(0.5,0.65,0.8)
(VG) Very good	(7,8,9)	(H) High	(0.7,0.8,0.9)
(EE) Excellent	(8.5,9.5,10)	(VH) Very high	(0.85,0.95,1.0)

4.2.1. *Evaluation of primary assessment*

Equation 2 was used to calculate the primary assessment EC_{ij} [41]:

$$\boldsymbol{EC_{ij}} = \sum_{\boldsymbol{k=1}}^{\boldsymbol{N}} \frac{\boldsymbol{R_{ijk}} \times \boldsymbol{W_{ijk}}}{\boldsymbol{W_{ijk}}} \tag{2}$$

where

- EC_{ij} is the ergonomic capabilities of jth criterion in ith enabler,
- W_{ijk} is the importance weight of kth attribute in jth criterion in ith enabler and
- R_{ijk} is the performance rating of kth attribute in jth criterion in i.

The following is the model calculation for the 'bio-mechanical aspects' criteria. Here, the values of i and j are 1, and k takes the value 1 to 5. EC11 Ergonomics capability of the first criterion in the first enabler:

$$EC_{11} = \begin{bmatrix} (3,5,7) \otimes (0.85,0.95,1) \oplus \\ (3,5,7) \otimes (0.85,0.95,1) \oplus \\ (3,5,7) \otimes (0.7,0.8,0.9) \oplus \\ (5,6.5,8) \otimes (0.85,0.95,1) \oplus \\ (5,6.5,8) \otimes (0.85,0.95,1) \end{bmatrix} \Bigg/ \begin{bmatrix} (0.85,0.95,1) \oplus \\ (0.85,0.95,1) \oplus \\ (0.7,0.8,0.9) \oplus \\ (0.85,0.95,1) \oplus \\ (0.85,0.95,1) \oplus \end{bmatrix}$$

$$EC_{11} = (3.83, 5.62, 7.41)$$

Using the same principle, the index for the various ergonomic criteria was calculated, and is shown in Table 5.

4.2.2. *Evaluation of secondary assessment*

Equation 2 was used to determine the organisation's secondary assessment. Below is the model calculation for the 'physiological factor' enabler.

EC_1Ergonomic capability of the first enabler

$$EC_1 = \begin{bmatrix} (3.83,5.62,7.41) \otimes (0.85,0.95,1) \oplus \\ (3.70,5.54,7.38) \otimes (0.85,0.95,1) \oplus \\ (3.0,5.0,7.0) \otimes (0.7,0.8,0.9) \oplus \end{bmatrix} \Bigg/ \begin{bmatrix} (0.85,0.95,1) \oplus \\ (0.7,0.8,0.9) \oplus \\ (0.85,0.95,1) \oplus \end{bmatrix}$$

$$EC = (3.50, 5.38, 7.26)$$

The ergonomic indices for the other enablers were computed using the same method, and are listed in Table 5.

4.2.3. *Evaluation of tertiary assessment*

By applying Equation 2, the FEI of the organisation, representing the overall enterprise ergonomic level, was calculated.

$$FEI = \begin{bmatrix} (3.50,5.38,7.26) \otimes (0.7,0.8,0.9) \oplus \\ (4.29,5.91,7.58) \otimes (0.7,0.8,0.9) \oplus \\ (3.09,5.10,7.08) \otimes (0.5,0.65,0.8) \oplus \\ (3.75,5.55,7.36) \otimes (0.7,0.8,0.9) \end{bmatrix} \Bigg/ \begin{bmatrix} (0.7,0.8,09) \oplus \\ (0.7,0.8,0.9) \oplus \\ (0.5,0.65,0.8) \oplus \\ (0.7,0.8,0.9) \end{bmatrix}$$

$$FEI = (3.94, 5.76, 7.53)$$

The appropriate level had to be assigned to the FEI. There were several approaches to determining the ergonomic level; the Euclidean distance approach, piecewise decomposition, and successive approximation were the three main approaches [43]. The most often used distance approach is the Euclidean distance method, which is the geometric distance between two points in a three-dimensional space. The major benefit of the Euclidean technique over other methods is that the distance between any two items remains unchanged when additional objects are added to the analysis.

Using the Euclidean distance method, the natural-language expression set LL= {excellent [EE], very good [VG], good [G], fair [F], poor [P]} was selected for labelling [42]. Figure 2 shows the linguistic and associated membership functions. The Euclidean distance D from the FEI to each member in set LL was then computed as follows, using the Euclidean distance technique (Equation 3):

$$D(FEI, EL_i) = \sqrt{\sum_{i=0}^{n} \left(f_{FEI(X)} - F_{LLI(x)}\right)^2} \tag{3}$$

where:

- D(FEI,ELi) is the Euclidean distance between FEI and ELi,
- FEI is the fuzzy ergonomic index,
- LL_i is the corresponding fuzzy number for natural language expression,
- $f_{FEI(x)}$ is the FEI triangular fuzzy number,
- $f_{LLI(x)}$ is the LL_i triangular fuzzy number and
- x is the lower, middle, and upper triangular numbers.

$$D(FEI, EE) = \{(3.94 - 7)^2 + (5.76 - 8.5)^2 + (7.53 - 10)^2\}^{\frac{1}{2}} = 4.81$$
$$D(FEI, VG) = 2.23$$
$$D(FEI, G) = 1.33$$
$$D(FEI, F) = 4.75$$
$$D(FEI, P) = 7.36$$

Table 3: Excerpt of ergonomic capability linguistic terms

Factors	Criteria	Variables	Factors	Criteria	Variables	RIJ
		EC111			VH	F
		EC112			VH	F
	EC11	EC113		VH	H	F
		EC114			VH	G
		EC115			VH	G
		EC121			H	G
EC1		EC122	H		H	F
	EC12	EC123		H	VH	F
		EC124			H	F
		EC125			FH	G
		EC131			VH	F
	EC13	EC132		VH	H	F
		EC133			H	F

Table 3: Excerpt of ergonomic capability linguistic terms (cont.)

Factors	Criteria	Variables	Factors	Criteria	Variables	RIJ
EC2	EC21	EC211	H	VH	FH	F
		EC212			H	G
		EC213			VH	G
	EC22	EC221		H	M	G
		EC222			M	G
	EC23	EC231		FH	M	F
		EC232			FL	F
		EC233			FH	F
	EC24	EC241		M	FH	F
		EC242			H	G
EC3	EC31	EC311	FH	VH	H	F
		EC312			H	F
	EC32	EC321		FH	FH	F
		EC322			M	F
	EC33	EC331		H	H	F
		EC332			FL	F
	EC34	EC341		H	FH	F
		EC342			H	F
	EC35	EC351		M	FL	G
		EC352			FL	F
EC4	EC41	EC411	H	M	FL	G
		EC412			L	G
	EC42	EC421		FL	H	F
		EC422			FH	F
		EC423			H	F
	EC43	EC431		M	H	F
		EC432			FH	F

Table 4: Excerpt of ergonomic capability – fuzzy numbers

Factors	Criteria	Variables	W_i	W_{ij}	W_{ijk}	R_{ijk}
EC1	EC11	EC111	(0.7,0.8,0.9)	(0.85,0.95,1)	(0.85,0.95,1)	(3,5,7)
		EC112			(0.85,0.95,1)	(3,5,7)
		EC113			(0.7,0.8,0.9)	(3,5,7)
		EC114			(0.85,0.95,1)	(5,6.5,8)
		EC115			(0.85,0.95,1)	(5,6.5,8)

Table 4: Excerpt of ergonomic capability – fuzzy numbers (cont.)

Factors	Criteria	Variables	W_i	W_{ij}	W_{ijk}	R_{ijk}
EC1 (cont.)	EC12	EC121	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(5,6.5,8)
		EC122			(0.7,0.8,0.9)	(3,5,7)
		EC123			(0.85,0.95,1)	(3,5,7)
		EC124			(0.7,0.8,0.9)	(3,5,7)
		EC125			(0.5,0.65,0.8)	(5,6.5,8)
	EC13	EC131		(0.85,0.95,1)	(0.85,0.95,1)	(3,5,7)
		EC132			(0.7,0.8,0.9)	(3,5,7)
		EC133			(0.7,0.8,0.9)	(3,5,7)
EC2	EC21	EC211	(0.7,0.8,0.9)	(0.85,0.95,1)	(0.5,0.65,0.8)	(3,5,7)
		EC212			(0.7,0.8,0.9)	(5,6.5,8)
		EC213			(0.85,0.95,1)	(5,6.5,8)
	EC22	EC221		(0.7,0.8,0.9)	(0.3,0.5,0.7)	(5,6.5,8)
		EC222			(0.3,0.5,0.7)	(5,6.5,8)
	EC23	EC231		(0.5,0.65,0.8)	(0.3,0.5,0.7)	(3,5,7)
		EC232			(0.2,0.35,0.5)	(3,5,7)
		EC233			(0.5,0.65,0.8)	(3,5,7)
	EC24	EC241		(0.3,0.5,0.7)	(0.5,0.65,0.8)	(3,5,7)
		EC242			(0.7,0.8,0.9)	(5,6.5,8)
EC3	EC31	EC311	(0.5,0.65,0.8)	(0.85,0.95,1)	(0.7,0.8,0.9)	(3,5,7)
		EC312			(0.7,0.8,0.9)	(3,5,7)
	EC32	EC321		0.5,0.65,0.8)	(0.5,0.65,0.8)	(3,5,7)
		EC322			(0.3,0.5,0.7)	(3,5,7)
	EC33	EC331		(0.7,0.8,0.9)	(0.7,0.8,0.9)	(3,5,7)
		EC332			(0.2,0.35,0.5)	(3,5,7)
	EC34	EC341		(0.7,0.8,0.9)	(0.5,0.65,0.8)	(3,5,7)
		EC342			(0.7,0.8,0.9)	(3,5,7)
	EC35	EC351		(0.3,0.5,0.7)	(0.2,0.35,0.5)	(5,6.5,8)
		EC352			(0.2,0.35,0.5)	(3,5,7)
EC4	EC41	EC411	(0.7,0.8,0.9)	(0.3,0.5,0.7)	(0.2,0.35,0.5)	(5,6.5,8)
		EC412			(0.1,0.2,0.3)	(5,6.5,8)
	EC42	EC421		(0.2,0.35,0.5)	(0.7,0.8,0.9)	(3,5,7)
		EC422			(0.7,0.8,0.9)	(3,5,7)
		EC423			(0.5,0.65,0.8)	(3,5,7)
	EC43	EC431		(0.3,0.5,0.7)	(0.5,0.65,0.8)	(3,5,7)
		EC432			(0.7,0.8,0.9)	(3,5,7)

Table 5: Excerpt of ergonomic capabilities – fuzzy index

Factors	Criteria	Variables	R_{ij}	R_{ijk}
EC1	EC11	EC111	(3.83,6.62,7.41)	(3.50,5.38,7.26)
		EC112		
		EC113		
		EC114		
		EC115		
	EC12	EC121	(3.70,5.54,7.38)	
		EC122		
		EC123		
		EC124		
		EC125		
	EC13	EC131	(3.0,5.0,7.0)	
		EC132		
		EC133		
EC2	EC21	EC211	(4.51,6.09,7.70)	(4.29,5.91,7.58)
		EC212		
		EC213		
	EC22	EC221	(5.0,6.50,8.0)	
		EC222		
	EC23	EC231	(3.0,5.0,7.0)	
		EC232		
		EC233		
	EC24	EC241	(4.17,5.83,7.53)	
		EC242		
EC3	EC31	EC311	(3.0,5.00,7.00)	(3.098,5.101,7.081)
		EC312		
	EC32	EC321	(3.0,5.00,7.00)	
		EC322		
	EC33	EC331	(3.0,5.00,7.00)	
		EC332		
	EC34	EC341	(3.0,5.00,7.00)	
		EC342		
	EC35	EC351	(4.00,5.75,7.50)	
		EC352		

Table 5: Excerpt of ergonomic capabilities – fuzzy index (cont.)

Factors	Criteria	Variables	R_{ij}	R_{ijk}
EC4	EC41	EC411	(5.00,6.50,8.00)	(3.75,5.55,7.36)
		EC412		
	EC42	EC421	(3.0,5.00,7.00)	
		EC422		
		EC423		
	EC43	EC431	(3.0,5.00,7.00)	
		EC422		
		EC423		
	EC43	EC431	(3.0,5.00,7.00)	
		EC432		

Table 6: Excerpt of fuzzy performance importance index

Variables	R_{ijk}	(1,1,1)- W_{ijk}	FPII	Score
EC111	(3,5,7)	(0,0.05,0.15)	(0,0.25,1.05)	0.34
EC112	(3,5,7)	(0,0.05,0.15)	(0,0.25,1.05)	0.34
EC113	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC114	(5,6.5,8)	(0,0.05,0.15)	(0,0.325,1.2)	0.42
EC115	(5,6.5,8)	(0,0.05,0.15)	(0,0.325,1.2)	0.42
EC121	(5,6.5,8)	(0.1,0.2,0.3)	(0.5,1.3,2.4)	1.35
EC122	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC123	(3,5,7)	(0,0.05,0.15)	(0,0.25,1.05)	0.34
EC124	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC125	(5,6.5,8)	(0.1,0.2,0.3)	1,2.275,4)	2.35
EC131	(3,5,7)	(0,0.05,0.15)	(0,0.25,1.05)	0.34
EC132	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC133	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC211	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC212	(5,6.5,8)	(0.1,0.2,0.3)	(0.5,1.3,2.4)	1.35
EC213	(5,6.5,8)	(0,0.05,0.15)	(0,0.25,1.05)	0.42
EC221*	(5,6.5,8)	(0.3,0.5,0.7)	(1.5,3.25,5.6)	3.35
EC222*	(5,6.5,8)	(0.3,0.5,0.7)	(1.5,3.25,5.6)	3.35
EC231	(3,5,7)	(0.3,0.5,0.7)	(0.9,2.5,4.9)	2.63
EC232*	(3,5,7)	(0.5,0.65,0.8)	(1.5,3.25,5.6)	3.35
EC233	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC241	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC242	(5,6.5,8)	(0.1,0.2,0.3)	(0.5,1.3,2.4)	1.35

Table 6: Excerpt of fuzzy performance importance index (cont.)

Variables	R_{ijk}	(1,1,1)- W_{ijk}	FPII	Score
EC311	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC312	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC321	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC322	(3,5,7)	(0.3,0.5,0.7)	(0.9,2.5,4.9)	2.63
EC331	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC332*	(3,5,7)	(0.5,0.65,0.8)	(1.5,3.25,5.6)	3.35
EC341	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC342	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC351*	(5,6.5,8)	(0.5,0.65,0.8)	(2.5,4.225,6.4)	4.30
EC352*	(3,5,7)	(0.5,0.65,0.8)	(1.5,3.25,5.6)	3.35
EC411*	(5,6.5,8)	(0.5,0.65,0.8)	(2.5,4.225,6.4)	4.30
EC412*	(5,6.5,8)	(0.7,0.8,0.9)	(3.5,5.2,7.2)	5.25
EC421	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC422	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07
EC423	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC431	(3,5,7)	(0.2,0.35,0.5)	(0.6,1.75,3.5)	1.85
EC432	(3,5,7)	(0.1,0.2,0.3)	(0.3,1,2.1)	1.07

5. RESULTS AND DISCUSSION

The ergonomics level was classified as 'good' by matching the linguistic variables with a minimal D. The approach presented above was used to determine not just the ergonomic level, but also the major barriers. The FPII of the ergonomic capability, which combined the performance rating and the important weight of each ergonomic element capability, provided an effect that would contribute to the ergonomic level of an organisation. The smaller a factor's FPII, the less it contributed [17]. The transformation [(1, 1, 1) - W_{ijk}] was low when W'_{ijk} was large. As a result, the $FPII_{ijk}$ for each ergonomic element capability was defined as:

$$FPII_{ijk} = W_{ijk} \otimes R_{ijk} \tag{4}$$

where:

- $FPII_{ijk}$ is the FPII for the ijkth attribute,
- W_{ijk} is the complement of ijkth attribute's importance weight,
- and W'_{ijk} = [(1, 1, 1)−W_{ijk}] where W_{ijk}s are the fuzzy importance weight of the EC_{ijk} [41].

Then the FPIIs of each ergonomic element capability were computed using Equation 4. The model calculation for the $FPII_{111}$attribute is shown below:

$$FPII_{111} = (3,5,7) \otimes (0,0.05,0.15)$$
$$FPII_{111} = (0,0.25,1.05)$$

The remaining attributes' FPIIs were determined using the same method and is presented in Table 6. Because fuzzy numbers may not always provide a completely ordered collection in the same way that real numbers do, all FPIIs must be rated [44,45]. The fuzzy number was ranked using the centroid technique for membership function (a, b, c) in Equation 5, where a, b, and c are the lower, middle, and upper values of the triangle fuzzy number respectively.

$$Ranking\ score = \frac{a + 4b + c}{6} \tag{5}$$

The model calculation for the $FPII_{111}$ attribute is shown below:

$$Ranking\ score = \frac{1 + 4 \times 0.25 + 1.05}{6} = 0.34$$

Table 6 gives the ranking score for four enablers, based on the above-mentioned concept for the remaining attributes. The management threshold of scale three was created to determine which major barriers needed to be improved in order to identify the important obstacles. After calculating the results, it was revealed that eight capabilities performed worse than the management threshold limit. Table 7 shows the overall fuzzy score for the process, and the result is shown in Figure 2.

Table 7: Fuzzy score - process

S.No	Process	Fuzzy score	Defuzzy
1	Weighing aluminium bars (a)	(4.18,5.94,7.65)	G
2	Melting aluminium bars(b)	(4.11,5.89,7.62)	G
3	Casting (c)	(4.24,5.96,7.66)	G
4	Fettling (outer and sideparts) (d)	(4.34,6.05,7.72)	VG
5	Fettling (inner part) (e)	(4.30,6.01,7.69)	G
6	Drilling (f)	(4.27,5.98,7.68)	G
7	Shot blasting(g)	(4.12,5.65,7.54)	G

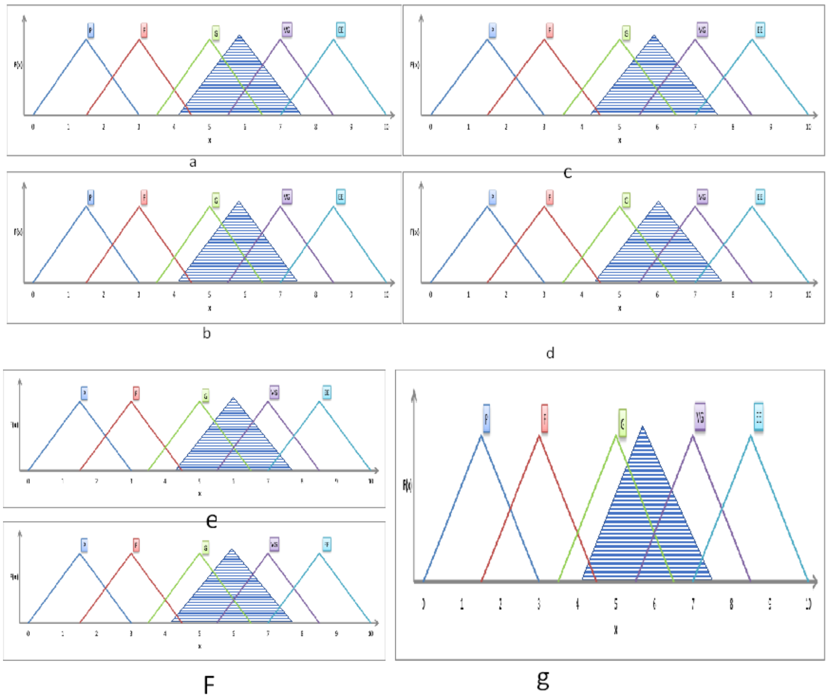

Figure 2 a-g: Fuzzy ergonomic index to match linguistic levels

Table 8 shows the problem that was identified and the suggested solutions. The case organisation has since taken appropriate steps to enhance the weaker capabilities. Ergonomic performance indicators such as the productivity rate are measured before and after the ergonomic assessment task is implemented, as shown in Table 9. The findings in Table 9 show a substantial improvement in ergonomics following the implementation of the identified changes.

Table 8: Problem identification and suggested solutions

S.No	Process	Problem	Solution
1	Weighing aluminium bars	Frequent movements in the upper part of the body with heavy weights create severe hand and back pain.	Frequent movements in the upper part of the body for lifting each bar are eliminated by introducing slider and bins.
		Creates musculo-skeletal disorder as a large number of aluminium bars are lifted using bins.	Transportation of bars by trolley makes the work easier, and the operator will feel less fatigue.
2	Melting aluminium bars	The operator feels the heat of the furnace and feels fatigue quickly.	The melting furnace is covered with a smart shield furnace insulating sheet that protects the workers from the hot working environment.
3	Casting	Removal of projections is carried out with gloves that are not enough to handle the heat of casted parts. Frequent handling of these parts may cause burns in hands.	A bin is placed between the fettling (outer) and fettling (inner) machines, which avoids the manual lifting of parts.
4	Fettling (outer and sideparts)	After the completion of 200 parts, the bin is lifted manually and carried to the fettling (inner) process. This causes lower back pain and hand pain for the workers carrying heavy weights.	A bin is placed between the fettling (inner) and drilling machines, which avoids the manual lifting of parts.
5	Fettling (inner part)	After the completion of 200 parts, the bin is lifted manually and carried to the drilling process. This causes lower back pain and hand pain for the workers carrying heavy weights.	A bin is placed between the fettling (inner) and drilling machines, which avoids the manual lifting of parts.
6	Drilling	After the completion of 200 parts, the bin is lifted manually and carried to the Shot blasting process. This creates lower back pain and hand pain for the workers carrying heavy weights.	After the completion of 200 parts, the bin is lifted manually and carried to the shot blasting process.
7	Shot blasting	Frequent movements in the upper part of the body with heavy weights creating severe hand and back pain	Frequent movements in the upper part of the body are eliminated, saving the workers from severe hand and back pain.

Table 9: Before and after implementation

Units	Process	Cycle time (S)		Production rate (units)	
		Before implementation	After implementation	Before implementation	After implementation
Casting	Weighing aluminium bars	33.2	28.2	881	911
	Fettling (outer)	33.2	21		
	Fettling (inner)	23.33	13.33		
	Transportation	148.65	68.18		

6. CONCLUSION

Ergonomics is the study of how to design systems so that humans may interact with them in a comfortable way. Since the 1950s, the number of workers in secondary industries has increased dramatically, currently accounting for more than 60% of all workers. The need for ergonomics has evolved over time as the industrial structure has changed drastically. Ergonomics enhances output quality and productivity. A failure to use ergonomics in the workplace not only decreases productivity but also leaves employees' health and safety at risk. A conceptual model for ergonomic evaluation was created as a result of the research that was carried out. Manufacturing companies could use the ergonomic assessment to establish their score on the ergonomic scale, and to identify areas where improvements could be made. To address disadvantages such as vagueness, uncertainty, and ambiguity, a fuzzy logic method was used. The ergonomic level of the organisation was determined using the FEI and the Euclidean distance technique; FPII was used to determine the weaker characteristics in addition to FEI. Our study found eight out of 40 characteristics to be inadequate. The improvement measures are being implemented in the organisation. Also, before and after executing the ergonomic assessment exercise, improvements in performance indicators such as cycle time and production rate were measured. Following the implementation of the recommendations for improvement, there was a significant improvement. The 15-criteria ergonomic model was implemented in a single manufacturing company, indicating that similar techniques might be used in an industrial scenario. In the future, further research across many manufacturing companies might be done to increase the model's performance.

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