Energy Expenditure and Ergonomic Risk Assessment in the Industry Using TOPSIS

I IBERIAN CONFERENCE ON MCDM/A (IMCDM/A)
University of Coimbra, 2025

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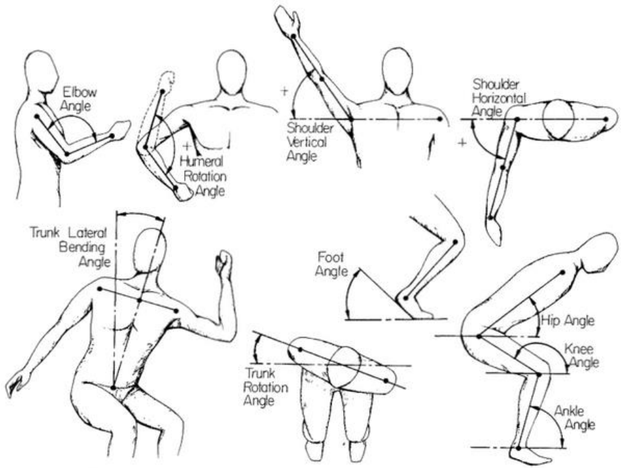
Introduction
Ergonomic challenges in the industry

Work-related Musculoskeletal Disorders (WMSDs)

Impact worker health and result in significant organizational costs.



Primary risk factors

- Prolonged hand tool use.
- Mechanical pressure on the upper limbs.
- Repetitive movements.
- Awkward postures.

Assessment challenge

Quantitative methods are needed. The systematic hazard identification is required.

Difficult to determine which approach best suits a given context.

Background
Ergonomic Assessment Tools

Multiple ergonomic assessment tools

- Each method evaluates specific risk factors.
- Often in isolation, making them difficult to integrate.

Difficult to prioritize tasks effectively

- When tasks present different types of risks, it becomes challenging to objectively compare them and determine which requires immediate attention.

Need for an integrated data-driven approach

- Combining multiple ergonomic indicators into a single framework supports more informed decision-making on the shop floor.

Table 1: Mapping of Ergonomic Assessment Methods to evaluated criteria.

Method	Lifting of heavy loads	Awkward postures	Repetitive work	Psychological comfort
NIOSH Lifting Index	X			
Job Strain Index (JSI)			X	
Occupational Repetitive Actions (OCRA)		X	X	
European Assembly Worksheet (EAWS)	X	X	X	
Energy Expenditure (EE)	X		X	
Ovako Working Posture Analysis System (OWAS)		X		
Rapid Upper Limb Assessment (RULA)		X		
Rapid Entire Body Assessment (REBA)		X		
Quick Exposure Check (QEC)		X	X	
Daily Noise Dosage (DND)				X
Copenhagen Psychosocial Questionnaire (COPSOQ)				X
LEST Method				X

Background

MCDM in Ergonomics

- Ergonomic risks are multi-dimensional.
- Conflicting ergonomic criteria must be evaluated together.

MCDM enables a structured, consistent method to synthesize diverse risk factors into actionable rankings.

Research gap

- Current tools isolate individual risk factors.
- Fragmented assessments → No holistic task prioritization

This study:

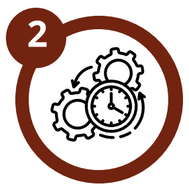
Combines different indicators to support both ergonomics and efficiency.

Aims to guide task redesign and worker allocation.

Background
Research Objectives

Combine complementary ergonomic risk indicators

- Postural strain (REBA)
- Metabolic energy expenditure (Garg et al.)
- Task duration (MTM standard)



Integrate diverse measures into a unified model

- Normalize and harmonize different types of ergonomic data
- Compare common industrial manual tasks

Apply the TOPSIS method as a decision-support tool

- Rank tasks based on proximity to an "ideal" ergonomic profile
- Include both physical and time-efficiency factors

Improve task prioritization and worker allocation

- Identify high-risk tasks that require ergonomic intervention
- Support more balanced task assignments to reduce WMSDs

Methodology
Framework steps

1. Task Observation and Decomposition
2. Time Assignment - MTM Standard
3. Metabolic Cost Estimation
4. Postural Risk Evaluation (REBA)

TOPSIS method

5. Normalization of criteria
6. Weight assignment and sensitivity analysis
7. Task Ranking and Prioritization

Methodology
MTM (Methods-Time Measurement)

Elemental motion decomposition - MTM

- Tasks are decomposed into elemental motions
- For precision analysis, accurate time and ergonomic assessment are performed per micro-movement.

Practical implications

- Allow to compare tasks by motion effort and time requirement.
- Provides a foundation for metabolic cost estimation and productivity analysis.

Motion Length (cm)				≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class				1	2	3
Get and Place			Code	1	2	3
	Case of get	Case of place		TMU	TMU	TMU
≤ 1 kg	easy	approx.	AA	20	35	50
		loose	AB	30	45	60
		tight	AC	40	55	70
	difficult	approx.	AD	20	45	60
		loose	AE	30	55	70
		tight	AF	40	65	80
	handful	approx.	AG	40	65	80
> 1 kg to ≤ 8 kg		approx.	AH	25	45	55
		loose	AJ	40	65	75
		tight	AK	50	75	85
> 8 kg to ≤ 22 kg		approx.	AL	80	105	115
		loose	AM	95	120	130
		tight	AN	120	145	160

Place	Code	1	2	3
		TMU	TMU	TMU
approx.	PA	10	20	25
loose	PB	20	30	35
tight	PC	30	40	45

Motion Length (cm)	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	1	2	3

Handle Tool	Code	1	2	3
		TMU	TMU	TMU
approx.	HA	25	45	65
loose	HB	40	60	75
tight	HC	50	70	85

Operate	Code	1	2	3
simple	BA	10	25	40
compound	BB	30	45	60

Motion Cycles	Code	1	2	3
one motion	ZA	5	15	20
motion sequence	ZB	10	30	40
re-position and one motion	ZC	30	45	55
tighten or loosen	ZD		20	

Body Motions	Code	TMU
walk / m	KA	25
bend, stoop, kneel	KB	60
sit and stand	KC	110

Visual Control	VA	15

MTM-UAS - Standard Times for Basic Operations (LP Montagetechnik, 2025)

Methodology
Energy Expenditure

Inputs

- Movement Type (e.g., arm lift, carrying)
- Body Weight (kg)
- Load Handled (kg)
- Others (gender, average pushing/pulling force, walking speed, distances, heights…)

Output

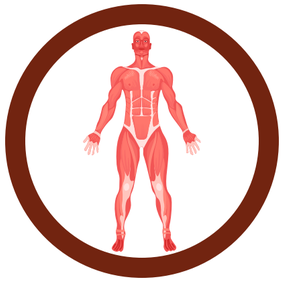
- Energy expenditure (kcal per motion)
- Enables objective comparison of task demands (in terms of fatigue)

Predictive equations for net metabolic cost of tasks:

- Introduced by Garg et al., 1978
- One of the most common methods to estimate energy expenditure in line balancing ergonomics

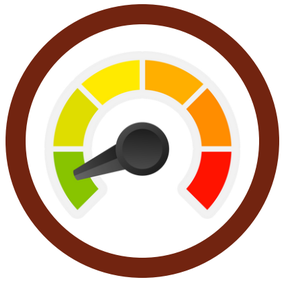
Methodology

Postural Risk – REBA (Rapid Entire Body Assessment)



Body Segmentation

- Evaluates neck, trunk, arms, legs separately
- Sensitive to asymmetries, loads, and joint angles

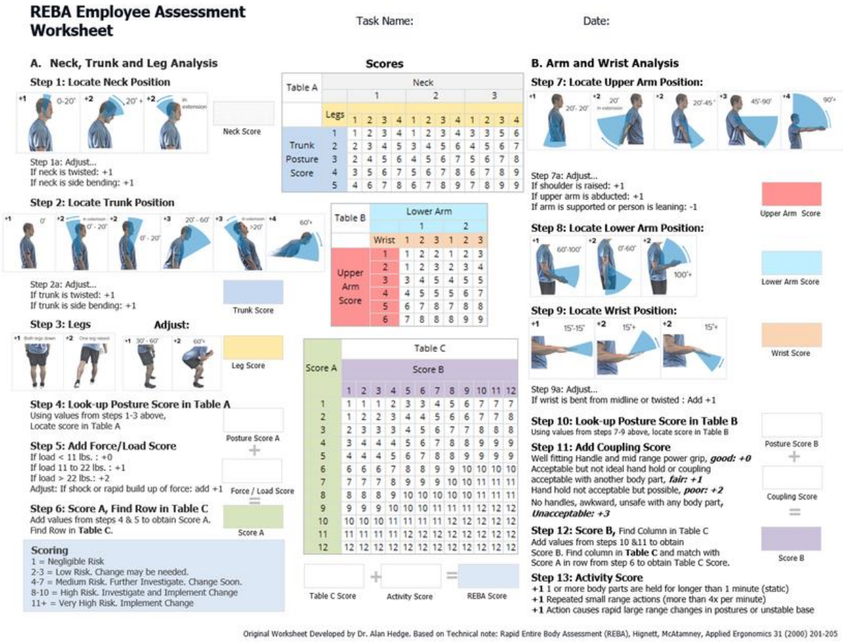


REBA Scores

- Reflect musculoskeletal strain levels
- Higher score = higher ergonomic risk

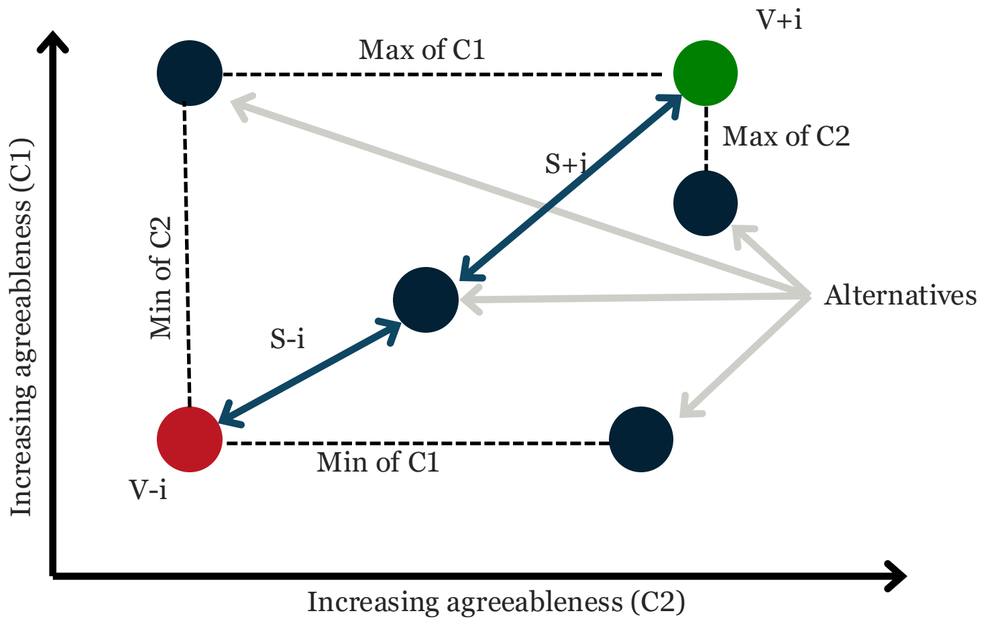
Robust Assessment

- 3 evaluations per task (e.g., 3 different workers or task variants)
- Increases consistency and accounts for individual variability



Methodology

TOPSIS - Technique for Order Preference by Similarity to Ideal Solution



Ranks alternatives based on proximity to:

- Ideal solution
- Negative-ideal solution

Create a decision matrix

Define the alternatives and criteria.

Normalize Matrix

Transform values to comparable units.

Apply criteria weights

Assign importance to each factor.

Calculate similarity

Measure distance to ideal solution. Rank tasks by risk level.

Results

Raw Ergonomic Metrics

1) Create a decision matrix

Define the alternatives and criteria.

Alternatives: Manual tasks performed on the assembly line (e.g., riveting, screwing, assemble brackets, cable laying, etc.)

Criteria:

- REBA score (postural strain) → minimize
- Energy expenditure (metabolic cost in kcal) → minimize
- Cycle time using MTM (in seconds) → minimize

Table 2: Task-wise energy expenditure and ergonomic risk evaluation.

Task ID	Movement	EE (kcal)	Time (sec)	REBA score
T1	Trolley movement	0.950	10.29	4
T2		0.457	8.64	3
T3		0.601	9.54	3
T4	Riveting	0.362	20.32	5
T5		0.132	13.30	5
T6		0.348	6.94	7
T7	Assemble brackets	0.111	8.28	2
T8		0.135	6.12	2
T9		0.127	5.04	5
T10	Laying cables	0.310	16.38	5
T11		0.360	18.90	5
T12		0.310	5.22	1
T13	Screwing	0.481	28.51	6
T14		0.326	12.52	6
T15		0.726	14.88	2
T16	Install seals	0.269	8.64	1
T17		0.255	12.42	1
T18		0.122	4.32	1
T19	Hand threading	0.319	5.04	4
T20		0.122	6.66	3
T21		0.356	11.34	3
T22	Packaging	0.752	14.22	6
T23		0.361	10.26	4
T24		0.504	6.48	3

Results

Weighted Normalized Matrix

2) Normalize Matrix

Transform values to comparable units.

3) Apply criteria weights

Assign importance to each factor.

4) Calculate similarity

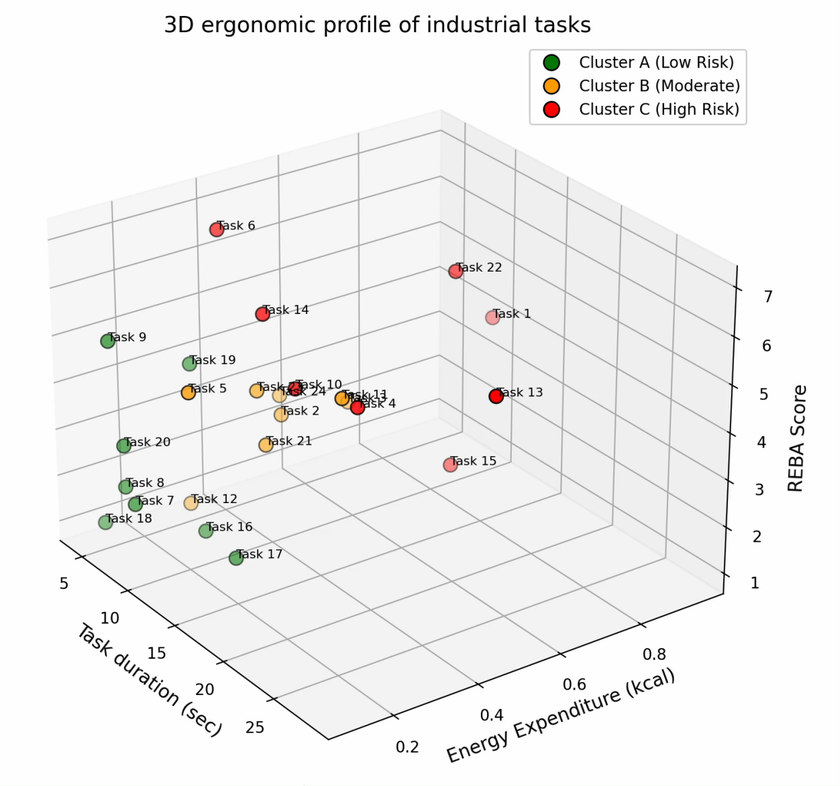
Measure distance to ideal solution. Rank tasks by risk level.

Table 3: Weighted Normalised Matrix of tasks considering energy expenditure, task duration, and ergonomic risk.

Task	Movement	EE	Time	REBA	S_{i+}	S_{i-}	P_i	Rank
1		0.152	0.057	0.067	0.148	0.112	0.432	22
2	Trolley movement	0.073	0.047	0.051	0.069	0.151	0.685	10
3		0.096	0.052	0.051	0.090	0.136	0.601	16
4		0.058	0.112	0.084	0.118	0.110	0.482	21
5	Riveting	0.021	0.073	0.084	0.084	0.159	0.656	13
6		0.056	0.038	0.118	0.109	0.153	0.584	17
7		0.018	0.045	0.034	0.028	0.194	0.876	3
8	Assemble brackets	0.022	0.034	0.034	0.020	0.198	0.909	2
9		0.020	0.028	0.084	0.068	0.188	0.735	8
10		0.049	0.090	0.084	0.100	0.128	0.562	19
11	Laying cables	0.057	0.104	0.017	0.089	0.149	0.625	15
12		0.050	0.029	0.101	0.090	0.165	0.646	14
13		0.077	0.157	0.101	0.168	0.077	0.314	24
14	Screwing	0.052	0.069	0.101	0.102	0.134	0.569	18
15		0.116	0.082	0.034	0.116	0.118	0.506	20
16		0.043	0.047	0.017	0.035	0.185	0.842	4
17	Install seals	0.041	0.068	0.017	0.050	0.175	0.777	6
18		0.020	0.024	0.017	0.002	0.213	0.991	1
19		0.051	0.028	0.067	0.061	0.172	0.739	7
20	Hand threading	0.020	0.037	0.051	0.036	0.191	0.841	5
21		0.057	0.062	0.051	0.065	0.150	0.699	9
22		0.121	0.078	0.101	0.144	0.086	0.375	23
23	Packaging	0.058	0.056	0.067	0.072	0.147	0.670	12
24		0.081	0.036	0.051	0.073	0.156	0.683	11

Results
Cluster Analysis

Tasks grouped into 3 clusters:



Cluster A: Low risk

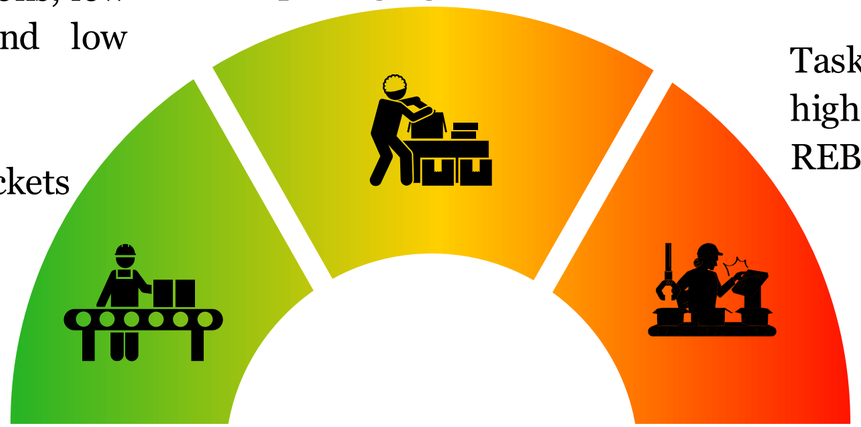
Tasks with short durations, low energy expenditure and low REBA scores:

- Installing seals
- Assembling brackets
- Hand threading

Cluster B: Moderate risk

Tasks with medium durations, energy expenditure and REBA scores:

- Trolley movement
- laying cables
- packaging



Cluster C: High risk

Tasks with longer durations, high energy expenditure and REBA scores:

- Riveting
- Screwing

Results
Sensitive analysis

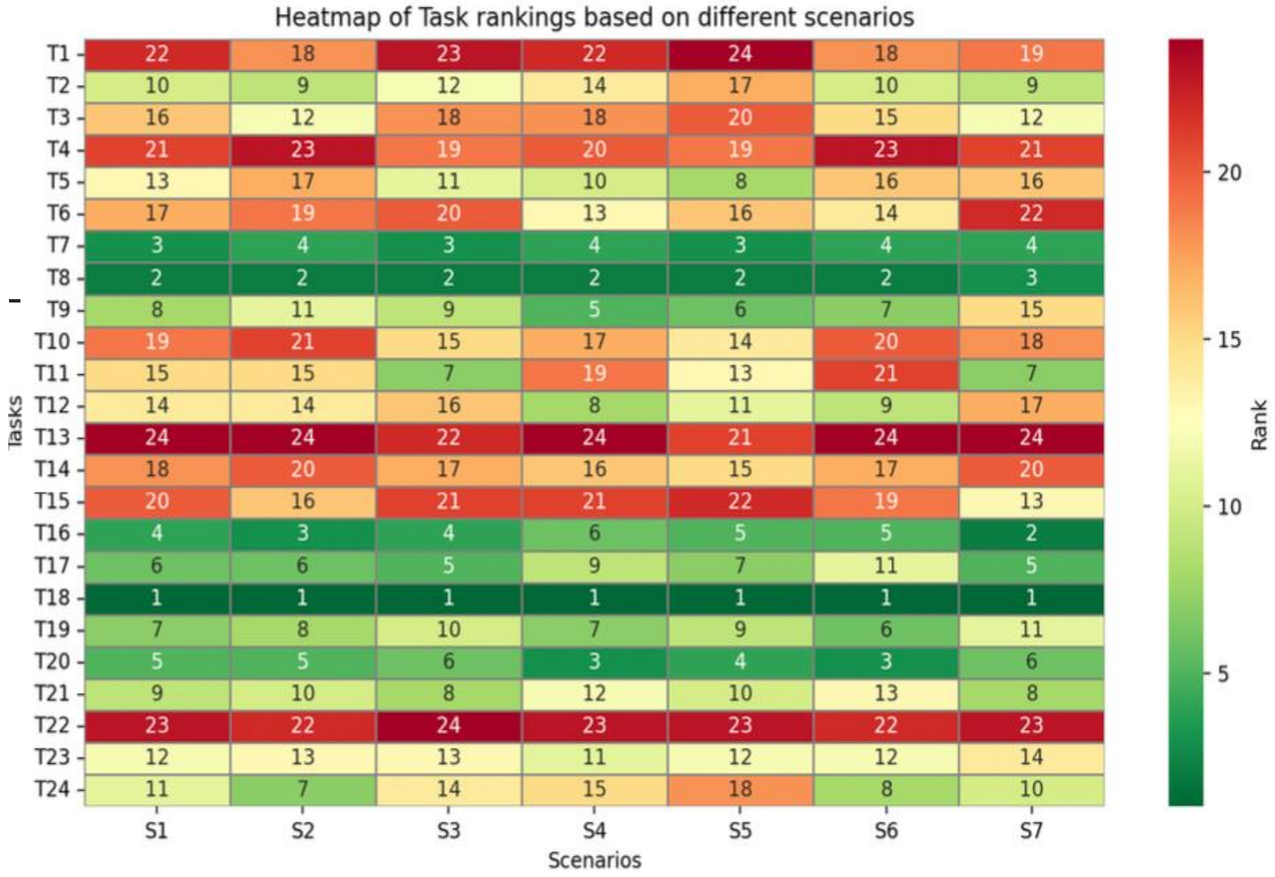
Assessing the impact of different priorities on task ranking

Criteria weighting tests

- Evaluate how changing the criteria's importance (weights) - posture, energy, and time - affects task rankings.
- Identify robust tasks (ranked consistently high/low)

Robust Rankings

Task priorities remained stable across weight variations.



Conclusion
Practical applications

Proposed methodology

A new framework evaluates and ranks manual assembly tasks based on:

- Task duration (MTM time)
- Energy expenditure (metabolic cost)
- Postural risk (REBA score)

Final output: a ranked list of tasks guiding ergonomic decision-making.

Workplace design improvements

Prioritize redesign efforts for high-risk tasks.
Target interventions where needed most.

Job rotation optimization

Structure rotations based on risk rankings. Balance metabolic and postural loads.

Prevent cumulative strain through appropriate scheduling.

Strategic task allocation

Assign workers based on ergonomic profiles.
Match tasks to physical capabilities.
Reduce injury risk through informed placement decisions.

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