APPLYING ERGONOMIC TECHNIQUES TO OPTIMIZE SUPPLY CHAIN EFFICIENCY

Submitted By

SADMAN SAKIB KHAN
200012126

MD. JOBAIR AHMED PROTTOY
200012130

MD. SAMIUR RAHMAN
200012149

Supervised By

Dr. A. R. M. HARUNUR RASHID

A Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Industrial and Production Engineering

Department of Mechanical and Production Engineering (MPE)

Islamic University of Technology (IUT)

September, 2025

Candidate's Declaration

This is to certify that the work presented in this thesis, titled "Applying Ergonomic Techniques to Optimize Supply Chain Efficiency", is the outcome of the investigation and research carried out by me under the supervision of Dr. A. R. M. Harunur Rashid, Professor, Department of Mechanical and Production Engineering, Islamic University of Technology.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

Sadman Sakib Khan
Student No: 200012126

Md. Jobair Ahmed Prottoy
Student No: 200012130

Md. Samiur Rahman
Student No: 200012149

Recommendation of the Thesis Supervisors

The thesis titled "Applying Ergonomic Techniques to Optimize Supply Chain Efficiency" submitted by Sadman Sakib Khan, Student No: 200012126, Md. Jobair Ahmed Prottoy, Student No: 200012130, Md. Samiur Rahman, Student No: 200012149 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of B Sc. in Industrial and Production Engineering **on 29th September, 2025.**

1. -------------------------------------
   Dr. A.R.M. Harunur Rashid (Supervisor)
   Professor
   MPE Dept., IUT, Board Bazar, Gazipur-1704, Bangladesh.

CO-PO Mapping of ME 4800 -Thesis and Project

Cos	Course Outcomes (CO) Statement	(PO)	Addressed by	
CO1	Discover and Locate research problems and illustrate them via figures/tables or projections/ideas through field visit and literature review and determine/Setting aim and objectives of the project/work/research in specific, measurable, achievable, realistic and timeframe manner.	**PO2 Problem analysis**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO2	Design research solutions of the problems towards achieving the objectives and its application. Design systems, components or processes that meets related needs in the field of mechanical engineering	**PO3 Design/development of solutions**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO3	Review, debate, compare and contrast the relevant literature contents. Relevance of this research/study. Methods, tools, and techniques used by past researchers and justification of use of them in this work.	**PO4 Investigation**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO4	Analyse data and exhibit results using tables, diagrams, graphs with their interpretation. Investigate the designed solutions to solve the problems through case study/survey study/experimentation/simulation using modern tools and techniques.	**PO5 Modern tool usage**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO5	Apply moral values and research/professional ethics throughout the work, and justify genuine referencing on sources, and demonstration of own contribution.	**PO8 Ethics**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO6	Perform own self and manage group activities from the beginning to the end of the research/work as a quality work.	**PO9 Individual work and teamwork**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO7	Compile and arrange the work outputs, write the report/thesis, a sample journal paper, and present the work to wider audience using modern communication tools and techniques.	**PO10 Communication**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√
CO8	Recognize the necessity of life-long learning in career development in dynamic real-world situations from the experience of completing this project.	**PO12 Life-long learning**	Thesis Book	√
			Performance by research	√
			Presentation and soft skill	√

Student Name /ID:

1. Sadman Sakib Khan (200012126)
2. Md. Jobair Ahmed Prottoy (200012130)
3. Md. Samiur Rahman (200012149)

Signature of the Supervisor:

…………………………

Name of the Supervisor:

Dr. A.R.M. Harunur Rashid

K-P-A Mapping of ME 4800 -Thesis and Project

COs	POs	Related Ks								Related Ps							Related As				
		K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5
CO1	PO2	√	√	√	√					√											
CO2	PO3					√				√	√	√				√	√	√	√		
CO3	PO4								√	√	√	√					√	√			
CO4	PO5						√			√				√							
CO5	PO8							√													
CO6	PO9																				
CO7	PO10																				
CO8	PO12																				

Student Name /ID:

1. Sadman Sakib Khan (200012126)
2. Md. Jobair Ahmed Prottoy (200012130)
3. Md. Samiur Rahman (200012149)

Signature of the Supervisor:

…………………………

Name of the Supervisor:

Dr. A.R.M. Harunur Rashid

List of Sustainable Development Goals (SDGs) Addressed in this Project

SDG No.	Goals	Targets	Relevance to the Thesis (put √ if valid)	Remarks
1	No Poverty	1.1 Eradicate extreme poverty (people living on less than $1.25/day).		
		1.2 Reduce poverty in all its forms by at least half.		
		1.3 Implement nationally appropriate social protection systems.		
		1.4 Ensure equal rights to economic resources, services, property, inheritance, technology, and financial services.		
		1.5 Build resilience of the poor and reduce exposure to climate-related and other shocks.		
		1.a Mobilize resources to end poverty.		
		1.b Create pro-poor policy frameworks.		
2	Zero Hunger	2.1 End hunger and ensure access to safe, nutritious food year-round.		
		2.2 End all forms of malnutrition.		
		2.3 Double agricultural productivity and incomes of small-scale producers.		
		2.4 Ensure sustainable food production systems and resilient agricultural practices.		
		2.5 Maintain genetic diversity of seeds, plants, and animals.		
		2.a Increase investment in rural infrastructure, research, and technology.		
		2.b Correct and prevent trade restrictions/distortions in global food markets.		
		2.c Adopt measures to ensure proper functioning of food commodity markets.		

3	Good Health and Well-Being	3.1 Reduce global maternal mortality ratio.		
		3.2 End preventable deaths of newborns and under-5 children.		
		3.3 End epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases.		
		3.4 Reduce premature mortality from NCDs and promote mental health.	√	
		3.5 Strengthen prevention and treatment of substance abuse.		
		3.6 Halve global deaths/injuries from road traffic accidents.	√	
		3.7 Ensure universal access to sexual and reproductive healthcare.		
		3.8 Achieve universal health coverage.	√	
		3.9 Reduce deaths from hazardous chemicals, pollution, and contamination.		
		3.a Strengthen tobacco control (WHO FCTC).		
		3.b Support R&D of vaccines and medicines.		
		3.c Increase health financing and workforce.	√	
		3.d Strengthen capacity for early warning and risk management.	√	
4	Quality Education	4.1 Ensure all complete free, equitable, quality primary and secondary education.		
		4.2 Ensure access to quality early childhood development and pre-primary education.		
		4.3 Ensure equal access to affordable technical, vocational, and higher education.	√	
		4.4 Increase skills for employment and entrepreneurship.	√	
		4.5 Eliminate gender disparities in education.		
		4.6 Ensure literacy and numeracy for youth and adults.		

		4.7 Ensure learners acquire knowledge/skills for sustainable development.	√	
		4.a Build and upgrade education facilities that are inclusive and safe.		
		4.b Expand scholarships for developing countries.		
		4.c Increase supply of qualified teachers.	√	
5	Gender Equality	5.1 End all forms of discrimination against women and girls.		
		5.2 Eliminate violence against women and girls.		
		5.3 Eliminate harmful practices (child, early, forced marriage, FGM).		
		5.4 Recognize and value unpaid care and domestic work.		
		5.5 Ensure women's participation in leadership and decision-making.		
		5.6 Ensure universal access to reproductive health and rights.		
		5.a Undertake reforms to give women equal rights to resources.		
		5.b Enhance use of enabling technology to empower women.		
		5.c Adopt and strengthen policies and laws for gender equality.		
6	Clean Water and Sanitation	6.1 Achieve universal and equitable access to safe drinking water.		
		6.2 Achieve access to adequate sanitation and hygiene.		
		6.3 Improve water quality by reducing pollution.		
		6.4 Increase water-use efficiency and sustainable withdrawals.		
		6.5 Implement integrated water resources management.		
		6.6 Protect and restore water-related ecosystems.		
		6.a Expand international cooperation in water and sanitation.		

		6.b Support participation of local communities.		
7	Affordable and Clean Energy	7.1 Ensure universal access to affordable, reliable, modern energy services.		
7	Affordable and Clean Energy	7.2 Increase substantially the share of renewable energy.		
7	Affordable and Clean Energy	7.3 Double global rate of improvement in energy efficiency.		
7	Affordable and Clean Energy	7.a Enhance international cooperation on clean energy research/technology.		
7	Affordable and Clean Energy	7.b Expand infrastructure and upgrade technology for sustainable energy.		
8	Decent Work and Economic Growth	8.1 Sustain per capita economic growth.		
8	Decent Work and Economic Growth	8.2 Achieve higher levels of productivity through diversification, tech, and innovation.	√	
8	Decent Work and Economic Growth	8.3 Promote policies for decent job creation and entrepreneurship.	√	
8	Decent Work and Economic Growth	8.4 Improve resource efficiency in production and consumption.		
8	Decent Work and Economic Growth	8.5 Achieve full and productive employment for all.	√	
8	Decent Work and Economic Growth	8.6 Substantially reduce youth not in employment/education/training.		
8	Decent Work and Economic Growth	8.7 Eradicate forced labour, modern slavery, and child labour.		
8	Decent Work and Economic Growth	8.8 Protect labour rights and safe working environments.	√	
8	Decent Work and Economic Growth	8.9 Promote sustainable tourism.		
8	Decent Work and Economic Growth	8.a Increase aid for trade support.		
8	Decent Work and Economic Growth	8.b Develop a global youth employment strategy.		
9	Industry, Innovation, and Infrastructure	9.1 Develop quality, reliable, sustainable infrastructure.	√	
9	Industry, Innovation, and Infrastructure	9.2 Promote inclusive and sustainable industrialization.		
9	Industry, Innovation, and Infrastructure	9.3 Increase access of SMEs to financial services and integration into value chains.		

		9.4 Upgrade infrastructure for sustainability and resource efficiency.	√	
		9.5 Enhance scientific research and technology development.	√	
		9.a Facilitate sustainable infrastructure in developing countries.		
		9.b Support domestic tech development and value addition.		
		9.c Increase access to ICT and internet.	√	
10	Reduced Inequalities	10.1 Achieve income growth of bottom 40%.		
		10.2 Empower and promote inclusion regardless of status.		
		10.3 Ensure equal opportunity and reduce inequalities of outcome.		
		10.4 Adopt policies for fiscal, wage, and social protection equality.		
		10.5 Improve regulation of global financial markets.		
		10.6 Ensure enhanced representation in global institutions.		
		10.7 Facilitate safe, regular, and responsible migration.		
		10.a Implement special treatment for developing countries.	√	
		10.b Encourage development assistance and investment in least developed areas.	√	
		10.c Reduce remittance costs.		
11	Sustainable Cities and Communities	11.1 Ensure access to adequate, safe, and affordable housing.		
		11.2 Provide sustainable transport systems.		
		11.3 Enhance inclusive urbanization and capacity for planning.		
		11.4 Protect cultural and natural heritage.		
		11.5 Reduce disaster impact and losses.		
		11.6 Reduce environmental impact of cities (air quality, waste).		
		11.7 Provide access to safe, inclusive green/public spaces.		

		11.a Support positive links between urban, peri-urban, rural.		
		11.b Increase disaster risk reduction strategies.		
		11.c Support least developed countries in sustainable building.		
12	Responsible Consumption and Production	12.1 Implement 10-Year Framework on sustainable consumption/production.		
		12.2 Achieve sustainable management and use of resources.	√	
		12.3 Halve per capita global food waste.		
		12.4 Manage chemicals and waste sustainably.		
		12.5 Substantially reduce waste generation.	√	
		12.6 Encourage companies to adopt sustainable practices.		
		12.7 Promote sustainable public procurement.		
		12.8 Ensure people have relevant information for sustainable development.	√	
		12.a Support developing countries' scientific and technological capacity.		
		12.b Develop tools to monitor sustainable tourism impacts.		
		12.c Rationalize inefficient fossil-fuel subsidies.		
13	Climate Action	13.1 Strengthen resilience and adaptive capacity to climate-related hazards.		
		13.2 Integrate climate measures into national policies.		
		13.3 Improve education and awareness on climate change.		
		13.a Implement UNFCCC commitments (mobilize $100 billion annually).		
		13.b Promote mechanisms for capacity-building in least developed countries.		

14	Life Below Water	14.1 Reduce marine pollution.		
		14.2 Sustainably manage and protect marine ecosystems.		
		14.3 Minimize and address ocean acidification.		
		14.4 Regulate harvesting and end overfishing.		
		14.5 Conserve at least 10% of coastal and marine areas.		
		14.6 Prohibit harmful fisheries subsidies.		
		14.7 Increase economic benefits from sustainable marine resources.		
		14.a Increase scientific knowledge and marine technology transfer.		
		14.b Provide access for small-scale artisanal fishers.		
		14.c Implement international law for oceans.		
15	Life on Land	15.1 Conserve terrestrial and freshwater ecosystems.		
		15.2 Promote sustainable management of forests.		
		15.3 Combat desertification and restore degraded land.		
		15.4 Ensure conservation of mountain ecosystems.		
		15.5 Take urgent action to reduce biodiversity loss.		
		15.6 Promote fair benefit-sharing from genetic resources.		
		15.7 End poaching and trafficking of protected species.		
		15.8 Prevent introduction of invasive alien species.		
		15.9 Integrate ecosystem values into policies/planning.		
		15.a Mobilize resources for biodiversity.		
		15.b Finance sustainable forest management.		

		15.c Support local communities for forest and wildlife.		
16	Peace, Justice and Strong Institutions	16.1 Reduce violence and related death rates.		
		16.2 End abuse, trafficking, and violence against children.		
		16.3 Promote rules of law and equal access to justice.		
		16.4 Reduce illicit financial/arms flows, organized crime.		
		16.5 Reduce corruption and bribery.		
		16.6 Develop effective, accountable institutions.		
		16.7 Ensure inclusive, participatory decision-making.		
		16.8 Broaden participation of developing countries in global governance.		
		16.9 Provide legal identity for all (including birth registration).		
		16.10 Ensure access to information and protect freedoms.		
		16.a Strengthen national institutions for prevention of violence.		
		16.b Promote/enforce non-discriminatory laws and policies.		
17	Partnerships for the Goals	17.1 Strengthen domestic resource mobilization.		
		17.2 Developed countries to implement ODA commitments.		
		17.3 Mobilize additional financial resources.		
		17.4 Assist developing countries with debt sustainability.		
		17.5 Invest in least developed countries.		
		17.6 Enhance access to science, technology, innovation.	√	
		17.7 Promote environmentally sound technologies.	√	
		17.8 Fully operationalize technology bank for LDCs.		

		17.9 Enhance international support for capacity-building.	√	
		17.10 Promote a universal, rules-based trading system (WTO).		
		17.11 Increase exports of developing countries.		
		17.12 Timely implementation of duty-free, quota-free market access.		
		17.13 Enhance global macroeconomic stability.		
		17.14 Enhance policy coherence for sustainable development.		
		17.15 Respect national policy space.		
		17.16 Enhance global partnerships.	√	
		17.17 Encourage multi-stakeholder partnerships.	√	
		17.18 Enhance data capacity of developing countries.		
		17.19 Support capacity-building for sustainable development indicators.		

Acknowledgment

In the Name of Allah, the Most Beneficent, the Most Merciful

To begin, we express our gratitude to ALLAH (SWT), the most merciful and compassionate, for granting me the fortitude and capability to compose this dissertation. We want to thank our project supervisor, Dr. A. R. M. Harunur Rashid, for his unwavering and enduring support despite unforeseen challenges throughout the project, as well as his invaluable guidance when we encountered obstacles. We experienced reduced stress and increased productivity in our lives due to his benevolence, friendliness, and effective oversight throughout work, particularly when dealing with unforeseen challenges. Next, we would want to convey our profound gratitude to each of our parents for their unwavering support and unwavering commitment to our pursuit of higher education.

Finally, we would like to gratefully acknowledge the Islamic University of Technology for all kinds of facilities and support for the accomplishment of the thesis.

Abstract

Manual material handling in industries often forces workers into awkward and repetitive postures, leading to musculoskeletal disorders (MSDs), fatigue, and productivity losses. These ergonomic risks directly impact supply chain performance by increasing cycle times, reducing throughput, and raising absenteeism. This thesis addresses these challenges by integrating ergonomic monitoring with supply chain optimization. A wearable ergonomic posture monitoring device was created to gather real-time joint angle information from the trunk, upper arm, lower arm, wrist, and neck. The device has inertial measurement sensors, a microcontroller, data logging, and a buzzer feedback system that warns workers when they are in dangerous positions. Validation against Kinovea motion analysis software demonstrated an average accuracy of approximately 97.4%, with a mean absolute error of 1.76°, thereby affirming its reliability for industrial use. The device, which used RULA as the assessment framework, showed that industrial tasks at baseline had high risk scores (average RULA 6–7), but that post-intervention with real-time feedback lowered the scores to medium risk levels (RULA 3–4). A lever-assisted CAD device was created in addition to monitoring to reduce the strain associated with handling heavy loads during conveyor-to-pallet transfers. To lessen lifting effort and trunk flexion, the CAD model incorporates a pivot lever mechanism and roller tray. According to time-motion analysis supported by the literature, this device could reduce the average cycle time per box transfer by approximately 35%, from 17.0 seconds to 11.1 seconds. Throughput is therefore anticipated to increase by approximately 17.2%, from 180.34 boxes per hour to 211.38 boxes per hour. The redesigned posture with the lever-assisted device lowers the RULA score from 7 to 3, confirming both safety and efficiency gains, according to additional validation from the CATIA V5 simulation. This study shows that ergonomics-based interventions have quantifiable supply chain benefits in addition to safeguarding worker health. Ergonomics becomes a strategic enabler of industrial efficiency and sustainability by decreasing posture risks, reducing cycle times, and increasing throughput. The results offer a reproducible framework for incorporating human-centered design into manufacturing and warehouse processes, balancing supply chain optimization with worker well-being.

Non-Technical Summary

In many factories and warehouses, workers must manually lift and move heavy loads. Performing this work repeatedly often forces workers into uncomfortable body positions, which can cause long-term health problems, such as back and shoulder pain. Simultaneously, these unsafe movements slow down work and make it less efficient, which also affects the overall productivity of the supply chain. To address this problem, we developed two solutions. First, we built a wearable device that workers can wear while performing their jobs. This device can detect how a worker moves their neck, arms, wrists, and back. If the worker bends or twists in a harmful way, the device immediately sounds a buzzer to warn them. It also stores data so that managers can later check which tasks are risky. When we compared our device data to a computer video analysis tool, we found that it was 97% accurate, proving that it can be trusted in real workplaces. Second, we designed a lever-assisted device using computer modeling. This device helps workers move boxes from a conveyor belt onto a pallet with significantly less effort. Instead of lifting the full weight, workers can use a lever and roller system that keeps their posture safe and reduces their strain. Our analysis, supported by published research, shows that this device can reduce the time required to move one box from 17 s to 11.1 s. In practical terms, this means that a worker could move approximately 17.2% more boxes per hour with less fatigue and a lower risk of injury. This project shows that improving workplace ergonomics is not only about protecting workers' health but also about making supply chains faster and more efficient, thereby increasing productivity. In short, when workers are safe and comfortable, industries can achieve better productivity and sustainability simultaneously.

Contents

List of Tables

List of Figures

Nomenclatures and Symbols

Abbreviation	**Meaning**
MSD	Musculoskeletal Disorder
RULA	Rapid Upper Limb Assessment
REBA	Rapid Entire Body Assessment
NIOSH	National Institute for Occupational Safety and Health
DHM	Digital Human Modeling
CAD	Computer-Aided Design
FMCG	Fast-Moving Consumer Goods
OEE	Overall Equipment Effectiveness
KPI	Key Performance Indicator
IMU	Inertial Measurement Unit
MCU	Microcontroller Unit
MMH	Manual Material Handling
ANSYS	Analysis System (Engineering Simulation Software)
AI	Artificial Intelligence
IOT	Internet of Things
ART	Assessment of Repetitive Tasks
OCRA	Occupational Repetitive Actions
JSI	Job Strain Index

List of symbols

θ – Joint angle (degrees)
t – Time (seconds)
F – Force applied (Newtons, N)
W – Weight of load (kilograms, kg)
L – Horizontal distance of load from the body (meters, m)
H – Vertical height of lift (meters, m)
RWL – Recommended Weight Limit (kg, from NIOSH equation)
LI – Lifting Index (dimensionless; $LI > 1$ indicates risk)
Tc – Cycle time per task (seconds)
TH – Throughput (units/hour)
η – Efficiency (percentage, %)

Chapter 1: Introduction

1.1 Contextual Background

Organizations are weaker under constant pressure to increase efficiency, lower costs, and increase productivity in their equipment in the current highly competitive industrial environment. The role of biotechnology in workplace design is a serious but often neglected factor for meeting the abovementioned objectives. Workers involved in manual material handling frequently encounter physically demanding tasks such as lifting, bending, distortion, and the transport of tons. These persistent and awkward postures expose workers to musculoskeletal irregularities (MSDs), which affect not only individual well-being and welfare but also disrupt development through absenteeism, reduced efficiency, and higher healthcare costs.[1], [2]

Ergonometric uncertainties have a lead connection to enhance chain performance. Poorly designed workstations or material handling techniques are likely to slow down within a cycle time, increase the risk of error and increase operational costs. Ergonomics interventions on the alternative palm may lead to a safer, more contented, and more efficient occupation state, directly contributing to increased throughput and reliability of the equipment chain. Therefore, although the use of ergonomic standards is no longer restricted to occupational vitality and safety, it has become a necessary plan for overall active optimization.[3]

Consequently, systematic methods for quantifying ergonomic challenges are provided by position assessment tools such as the Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA) and NIOSH's increase equation. With the increasing use of digital instruments and simulation software, the above assessment can be complemented by continuous testing and validation, which will lead to the redesign of methods and equipment for greater productivity.[1]

The present research work advances this position by integrating firsthand ergonomic assessments in industrial contexts with innovative technological solutions. The study demonstrates how ergonomic-driven intervention can simultaneously protect workers' health and increase the efficiency of the furnishing series by creating and confirming a manual weightlifting table and imitating its effect using digital fabrication tools.

1.2 Problem Statement

Manual material handling is still a key activity in a number of undertakings, particularly in production lines where workers are needed to lift, transport, and place heavy cartons. Regardless of whether or not the project is a common one, the aforementioned undertaking regularly involves awkward positions, excessive energy, and insistent gestures that place workers at significant risk of musculoskeletal disorders (MSDs). The high volume of RULA, REBA, and NIOSH high index detected in the industrial environment confirms the fact that workers are exposed to a hazard of insecure ergonomic conditions due to a number of existing operations.[1], [2]

The ergonomic problems mentioned above not only shape the vitality and safety of workers but also have a wider effect on industrial performance. The injured or tired workers are less productive, more prone to error, and may require a leave of absence, all of which increases the cost of working and disrupts train productivity. As a field's goal to maximize output and lower costs, ignoring ergonomics leads to long-term insufficiency, including workforce longevity and higher healthcare costs.

Existing workstation equipment in the studied enterprises lacks adequate ergonomic design, especially in carton handling and palletizing techniques. Workers regularly need to bend, turn, or raise tons without mechanical support, exposing them to health hazards and reduced productivity. It is also clear that there is a clear demand for simple, cost-effective ergonomic interventions which can be integrated within the existing production structures.[4]

This problem is addressed in the present study by recognizing the erroneousness of the selected areas, verifying the conclusions with electronic tools, and proposing a mechanical design solution which alleviates the strain of the workers during the improvement of the throughput. Consequently, the main obstacles are how to apply ergonomics not only to safeguard the vitality of workers but also to improve the efficiency of the supply chain through improved design of workstations**.**

1.3 Research Objectives

- Design and develop a wearable device for real-time ergonomic monitoring.
- Quantify ergonomic risk using RULA methods.
- Demonstrate the link between ergonomic improvement and supply chain performance.

1.4 Significance of the Study

This study holds significance both from an academic and an industrial perspective. From the educational point of view, it contributes to the development of expertise in the field of integration of biotech and supply chain performance. The study demonstrates a multidisciplinary technique linking worker fitness to productivity outcomes through the combination of ergonomic threat assessment tools (RULA), virtual verification tools (Kinovia, Siemens Tecnomatix), and technology design (SolidWorks, ANSYS). Moreover, it provides a low-level structure that future researchers can build on top while discovering ergonomics-driven string optimization.[1]

From the industrial point of view, the research work underline the direct impact of biotech on workers' safety, productivity, and cost effectiveness. The advanced manual weightlifting board provides a cost-effective solution to reduce the musculoskeletal risks associated with carton handling, and during simulations, it proves its effectiveness in terms of cycle length and throughput. Industry can achieve double rewards in terms of protecting workers from long-term health problems and improving supply chain performance through actions similar to intervention.[5]

Overall, the analysis stresses that the relevance of ergonomics is not used in academic writing simply as a health and safety interest but rather as a calculated enabler of industrial efficiency, longevity, and competitiveness.

1.5 Scopes of the Study

The present study will focus on the use of ergonomic methods to improve supply chain performance through the examination of manual material handling operations and the development of sensible support. The following shall be defined as the scope of the study:

1. Empirical data pertaining to businesses and production lines were collected from five selected sectors and six developmental lines in which workers are consistently engaged in manual lifting and palletizing operations. The scope of the study is deliberately confined to manual material handling activities, excluding automated or mechanized procedures to maintain focus on human-centered tasks.

2. The use of standard tools such as RULA increase index for ergonomic assessment has been a problem. The measurements were obtained using a custom-built angle

measuring device and verified using Kinovea software. Other ergonomic tools were not considered outside these techniques.

3. Design and Validation A manual load raising board was developed using SolidWorks and verified using ANSYS simulation for systematic honesty. The scope of the design shall be limited to the development of carton lifting and palletization, without the possibility of extending to other types of material handling similar to the conveyer frameworks which otherwise automate robotics.

4. Model and assessment of the intervention were carried out on the Siemens Tecnomatix to examine the changes in ergonomic liability tons, cycle times, output, and cost. The assessment focuses on fake and calculated performance improvement rather than long-term livestock management.[1]

5. The research focuses on the link between biotech and supply train performance close to the production floor. This investigation does not concern any other supply series elements such as management, retention, or circulation.

Chapter 2: Literature Review

Ergonomics focuses on improving human health and organizational performance, with a focus on preventing Musculoskeletal Disorders (MSDs) and cognitive strain. Traditionally, supply chain has been focused on cost reduction and cycle times minimization, often neglecting human components. However, recent studies are exploring the meaningful gap between human elements and supply chain study. This literature assesses the argument for the integration of biotechnology into the supply chain, demonstrating how ergonomic intervention can optimize. Worker health and work efficiency. It studies the transition of biotech from inactive assessment to dynamic, technology-driven intervention enabled by Industry 4.0 technologies.

2.1 Methodology

A structured and transparent methodology is strategically important for ensuring that a literature review is comprehensive, replicable, and free from bias. This approach provides a clear foundation for the analysis and lends credibility to the resulting synthesis.

The sources selected for this research were chosen to provide a robust and multifaceted perspective on the intersection of ergonomics and supply chain management. The research is grounded in a range of credible academic sources, including peer-reviewed journal articles, doctoral theses, and conference proceedings. These documents span multiple relevant disciplines, from industrial and systems engineering to human factors and operations management, ensuring a holistic examination of the topic.

In order to provide a solid and multilateral position at the intersection of ergonomics and supply chain management, the initial selection for the present assessment was made. The study should anchor a number of credible scientific beginnings, including peer-reviewed journal articles, doctoral theses, and conference proceedings. These documents cover a wide range of important disciplines, ranging from industrial and system technologies to human variables and activity management, ensuring a complete analysis of the subject.

The inclusion and exclusion criteria were defined to sharpen the focus of the review. The primary focus is on studies conducted within manufacturing, warehousing, and logistics environments, where manual material handling and repetitive tasks are prevalent. This research incorporates literature discussing both foundational ergonomic principles and recent technological advancements, with a particular emphasis on research published within the last decade to capture the influence of Industry 4.0 innovations.[1], [2] Studies centered on purely automated systems without a human operator component were excluded to maintain the review's human-centric focus. This rigorous selection process ensures that the subsequent analysis is based on a relevant and contemporary body of literature.

2.2 Thematic Analysis

Their precise and systematic assessment is a basic measure to reduce ergonomic liability. To quantify the body stressor associated with the undertaking common in supply chain processes, a number of experimental and analytical methods are applied. These systems provide a structured model for recognizing and ranking ergonomic hazards prior to corrective action. The study explicitly mentions a number of traditional methods of assessing their utility in the industrial context.

- **RULA (Rapid Upper Limb Assessment):** A tool used to assess the dangers of MSDs associated with the position of the upper body, frequently used in conjunction with manual manipulation.

- **REBA (Rapid Entire Body Assessment):** has been improved to measure the risks associated with the position of the whole body. REBA is particularly helpful in analyzing the vibrant and frequently unpredictable position forms of manual handling operations common in warehouses, such as scanning, screen, and stacking.[1]

- **NIOSH Lifting Equation:** A significantly acknowledged utensil to solve the recommended strain limit for ambidextrous manual lifting operations to prevent low reversal. One's utility is regularly increased when used in conjunction with other strategies; for instance, occurrence research in supply chain management warehouses demonstrates the value of triangulation of risk appraisal using NIOSH equation combined with RULA and REBA scrutiny.[6]

- **OCRA, ART, JSI:** The Occupational Repetitive Actions (OCRA) index, Assessment of Repetitive Tasks (ART) tool, and Job Strain Index (JSI) are specialized methods for evaluating risks associated with high-frequency, repetitive motions of the upper limbs, a common source of MSDs in assembly and packing operations.

For the explicit detection of visible danger elements such as awkward position and strong exertion, the above traditional methods are effective. However, the main point of view is that they are often based on an inactive, experimental phase of an undertaking. This technique constitutes a conceptual fault " because it may not capture the full energetic context of the work, or the accumulated corporeal load may exceed the entire change.[7]This inherent limitation of static, reactive analysis necessitates the advanced interventions and proactive, technology-driven assessment systems discussed in the following sections, which aim to provide a more continuous and comprehensive understanding of ergonomic risk.

Once ergonomic risks have been assessed, the next strategic step is to implement interventions to mitigate them. Ergonomic interventions encompass a range of solutions aimed at redesigning tasks, equipment, and workstations to reduce physical strain on workers. The literature categorizes these solutions into several primary domains, each targeting different aspects of the work system.

Workstation Redesigning the current class of support with a view to improving the immediate working area in order to suit the worker. Minimizing motion without added value and reducing material effort is compulsory. The demonstration consists of the use of an adjusting height workstation designed to accommodate a wide range of operators, e.g., ranging from 1540mm to 1871mm), and enhancing the extraction areas so as to maintain all the instruments and parts within the limits of the primary ambidextrous zone (Location A), so as to prevent the unnecessary rotation of the torso and shoulder movements. The use of modular aluminum profile systems provides the operator with the possibility of rearranging the function cell and tool in order to maximize the operator's movements.

Material Handling Supports include manual material handling in the supply chain, especially in the warehouse and management. The various AIDS may remain concealed to balance the significant risks associated with heavy and relentless lifting. The literature can be both fictitious and non-fictitious in that it underlines the efficiency of measures such as the manual lifting section, which reduces the compulsory necessity to move the object, and raises the AIDS, which extinguishes the necessity for manual lifting wholly, directly addressing the hazards identified by devices using the NIOSH Lifting Equation.

Process and Automation At a higher level, the ergonomic model can create a compelling business context for system adaptations or automation. Ergonomics evaluation can justify funding acquisition in recent tools by quantifying the body strain associated with demanding or insistent tasks. For its part, Woods (2018) developed a methodology based on a combined ergonomic mark to justify the automation of industrial spraying operations and provided a clear model for how human-centric statistics can drive the rational technological implementation.

A significant reduction in worker injuries and fatigue shall be the cumulative effect of the abovementioned intervention. Institutions can build a safer working environment that contributes to the development of the operational productivity of the entire supply chain by systematic application of ergonomic standards.

The argument that there is a direct causal link between ergonomic improvements and improved operational performance is converged in the text. Investing in workers' welfare is not a cost center but a guide to productivity, excellence, and speed. A well-designed, human-centered chore system reduces the physical and cognitive burden of colleagues, which in turn minimizes the onset of incompetence which degrades the compulsory equipment train prosody. The chart below summarizes the findings of the literature and links the precise ergonomic improvement to the effect on the active consequences.

Ergonomic Improvement	**Impact on Supply Chain Metrics**
Reduced awkward postures and physical strain in assembly and picking tasks.	Decreased cycle time and downtime due to fewer micro-stoppages (*micro-fermata*) and less fatigue, leading to increased throughput (TH) and higher Overall Equipment Effectiveness (OEE).[8]
Optimized workstation layouts that minimize reach distances and unnecessary movements.	Aligns with lean principles by reducing non-value-added motion, improving productivity and lowering operational costs.[9]
Workload smoothing through proactive planning (e.g., order advancement).	Balanced capacity utilization across the week by shifting workload from peak to non-peak days, reducing bottlenecks and improving on-time delivery performance.[10]
Implementation of ergonomic training and administrative controls.	Fewer errors and accidents, leading to improved quality and a reduction in costs associated with sick leave and rework.[11]

Table 1: Summary of Literature Review

The synthesis of the evidence indicates a strong causal link: ergonomic interventions directly contribute to a more efficient, reliable, and cost-efficient supply chain. The introduction of modern technologies, which enhance excessive dynamic and forward-looking ergonomic administration, will further reinforce this position.

2.3 Critical Evaluation

To understand the strengths, weaknesses, and potential bias of the existing investigation, a key assessment of the reviewed critical assessment is necessary. This assessment contributes to the overall reliability and sensible applicability of the findings and provides a balanced interpretation of the new expert statement in the context of the project.

The majority of the reviewed analysis is concentrated in the inclusive surroundings of the example studies. Various surveys have successfully triangulated their results using a variety of ergonomic appraisal methods, such as combining RULA, REBA, and NIOSH's increase equation to analyze the individual points of view. This multi-method strategy contributes to the consistency of the risk designation method. Moreover, simulation-based surveys using Digital Homo sapiens Modeling (DHM) provide invaluable quantitative information that can be used to maximize the design of workstations and to predict the ergonomics of changes in advance of material implementation.However, the literature is not without its weaknesses and gaps. A significant shortcoming, as identified by Grosse et al. (2016), is that much of the management-oriented research on topics like order picking has historically under-emphasized human factors, focusing almost exclusively on minimizing economic variables like travel distance. Furthermore, many empirical studies are confined to a specific context, such as a single slate splitter workstation[12] or a particular seat adjuster assembly line[11], which may limit the generalizability of their findings to other operational environments.

The practical applicability of some of the more advanced findings also warrants critical consideration. While technologies like AI-powered wearable sensors offer compelling theoretical benefits for real-time risk management, their implementation faces significant practical challenges. These include high initial investment costs, the need for robust data governance and privacy protocols, and the requirement for extensive employee training to ensure acceptance and proper use.[13] A gap often exists between the potential of a new technology demonstrated in a controlled study and its effective deployment at scale in a complex industrial environment. This evaluation of past research, acknowledging both its contributions and its limitations, naturally leads to the identification of underexplored areas that represent key opportunities for future scholarly inquiry.

2.4 Research Gaps and Future Directions

The critical evaluation of the existing literature reveals several underexplored areas where further research is needed to advance the field. By addressing these gaps, future studies can provide more integrated and robust solutions for optimizing the human element within modern supply chains. The following areas represent promising directions for future inquiry.

- **Lack of Integrated Decision Models:** Lack of combined resolution Models covering the present writing of working performance and ergonomic variables as separation problems. The supply chain management optimization model often focuses on minimizing of travel distance.

- **Human-Machine Teaming (HMT) and Cognitive Ergonomics:** In addition to the development of intelligent machines and cooperative automatons (cobots), the industrial environment is evolving. According to Herrmann and Huang (2020), Human-Machine Teaming is the integration of human beings and machines into a partnership arrangement which maximizes particular advantages while complementing all other limitations. This change introduces new ergonomic obstacles which are never fully understood in all aspects. As automated reasoning takes over planning and predictive tasks, there exists a gap in understanding of recent material and cognitive challenges in HMT. Elements such as the cognitive burden of workers managing intelligent systems, the evolution of confidence in automation, and the design of simple interfaces between humans and robots that alleviate both body and mind strain should be examined in this way.

- **Long-Term Impact and Cost-Benefit Analysis:** The lack of a long-term analysis that follows the long-term consequences of ergonomic interventions may qualify the prose for the long-term influence and cost benefit analysis. The majority of investigations focus on short-term effects, which makes it difficult to assess the long-term effects on worker fitness and productivity. In order to monitor these results, a forthcoming investigation should carry out a long-term study. In addition, standard systems for supervising a thorough cost-benefit analysis of new ergonomic systems need to be improved, moving beyond simple tax returns on acquisition to incorporate intangible benefits such as employee morale and lower employee turnover.

For the development of ergonomics in the context of increasingly complex and technologically advanced materials, the resolution of these testing intervals remains essential. The most successful of the forthcoming irons will remain those which enhance and empower human capacities rather than merely compensate for human limitations.

Chapter 3: Methodology

A systematic link between ergonomic vulnerability assessment and supply chain performance has been established in this thesis. The overall work flow may be divided into the following cycles.

3.1 Literature Review

Conducted a comprehensive study on:

- Ergonomic risk assessment method (RULA) and their applications in industrial settings.
- Previous research on material handling equipment, assistive devices, and ergonomic redesign.
- Connections between ergonomics, worker health, and supply chain efficiency.[1]

Outcome: Identified a research gap—most studies focus either on ergonomic evaluation or on supply chain optimization, but very few integrate the two.

3.2 Problem Identification

Observed that manual material handling in warehouses often leads to:

- Unsafe postures (bending, twisting, overhead reaching).
- High ergonomic risk scores (as per RULA).
- Worker fatigue and musculoskeletal issues.

Consequence for supply chain:

- Lower throughput.
- Increased cycle time.
- More worker absences due to injuries.
- Thus, the need arose to design a device that can objectively measure posture risks and test ergonomic interventions.

3.3 Development of Ergonomic Posture Analysis Device

Design Objectives:

1. Collect joint angle and posture data during handling tasks.
2. Log duration of awkward postures.
3. Alert workers when posture exceeds safe thresholds.
4. Provide reliable data for ergonomic scoring methods.

Steps Followed:

- Selected IMU sensors for joint tracking.
- Programmed a microcontroller (Arduino/ESP32) for real-time data processing.
- Added buzzer feedback for unsafe posture warning.
- Designed a compact and wearable casing for field usability

Figure 1: Image of Fabricated Device

3.4 Industrial Data Collection

Conducted visits to five different industries:

1. Optimum Pharmaceutical HBL – Packaging
2. Remarks HB Ltd. – FMCG warehousing
3. Snowtex Outerwear Ltd. – Manufacturing assembly line
4. DBL Ceramics Ltd. – Logistics center
5. Beximco Pharmaceuticals Ltd. – Electronics handling

Activities:

- Workers were asked to perform normal material handling tasks (lifting, transferring, placing).
- Device recorded joint angles, duration, and posture frequency.
- Observational notes were also taken for validating sensor results.

Figure 2: Demonstration of Fabricated Device Implementation

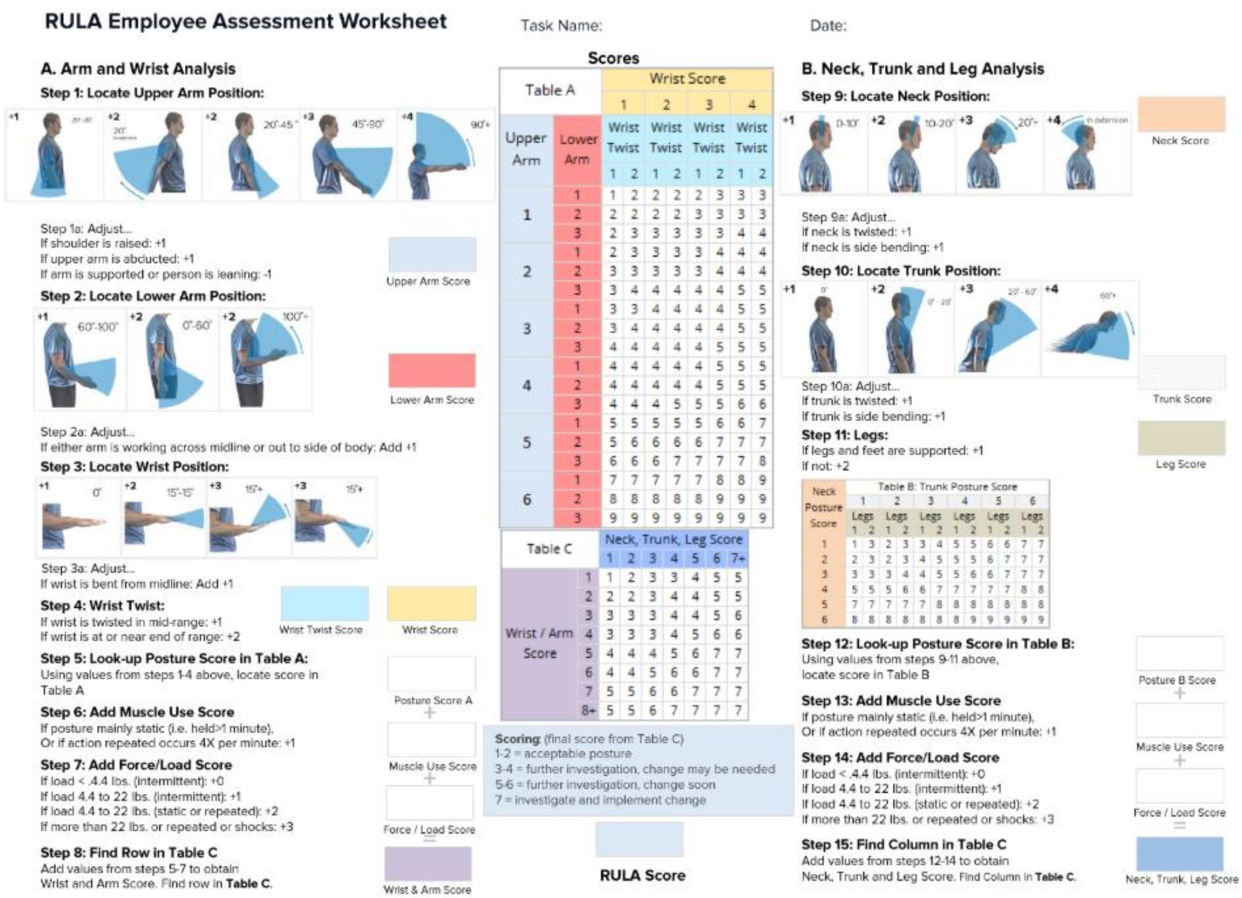
3.5 Ergonomic Assessment:

Collected Data Processing:

- Exported raw sensor data to Excel for post-processing.
- Identified posture angles relevant to RULA scoring.
- Generated time-weighted ergonomic scores (e.g., posture sustained for >20s scored higher risk).

Ergonomic Scoring:

- Current (baseline) postures scored as high risk in several cases, especially trunk flexion (>30°) and shoulder lifting (>60°).
- Data confirmed the mismatch between worker capabilities and workstation design.



RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

+1 | +2 20° | +2 20°-45° | +3 45°-90° | +4 90°+

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:

+1 60°-100° | +2 0°-60° | +2 100°+

Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

+1 0° | +2 15°-15° | +3 15°+ | +3 15°+

Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Wrist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 7: Add Force/Load Score
If load < .4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain
Wrist and Arm Score. Find row in **Table C**.

Wrist & Arm Score

Scores

Table A		Wrist Score 1		Wrist Score 2		Wrist Score 3		Wrist Score 4	
		Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
Upper Arm	Lower Arm	1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C		Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Scoring (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

RULA Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

+1 0-10° | +2 10-20° | +3 20°+ | +4 in extension

Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:

+1 0° | +2 0°-20° | +3 20°-60° | +4 60°+

Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Neck Posture Score	Table B: Trunk Posture Score 1		2		3		4		5		6	
	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above,
locate score in Table B

Posture B Score

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 14: Add Force/Load Score
If load < .4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score

=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain
Neck, Trunk and Leg Score. Find Column in **Table C**.

Neck, Trunk, Leg Score

Figure 3: RULA Employee Assessment Worksheet

3.6 Conceptual Redesign (CAD Model of Assist Device):

- Based on findings, a conceptual manual device was designed in CAD (SolidWorks) to minimize ergonomic risks during box transfer.
- Design features: lever mechanism, adjustable height, roller-assisted tray.
- Though not physically prototyped, CAD modeling demonstrated how ergonomics can be integrated into workstation design.

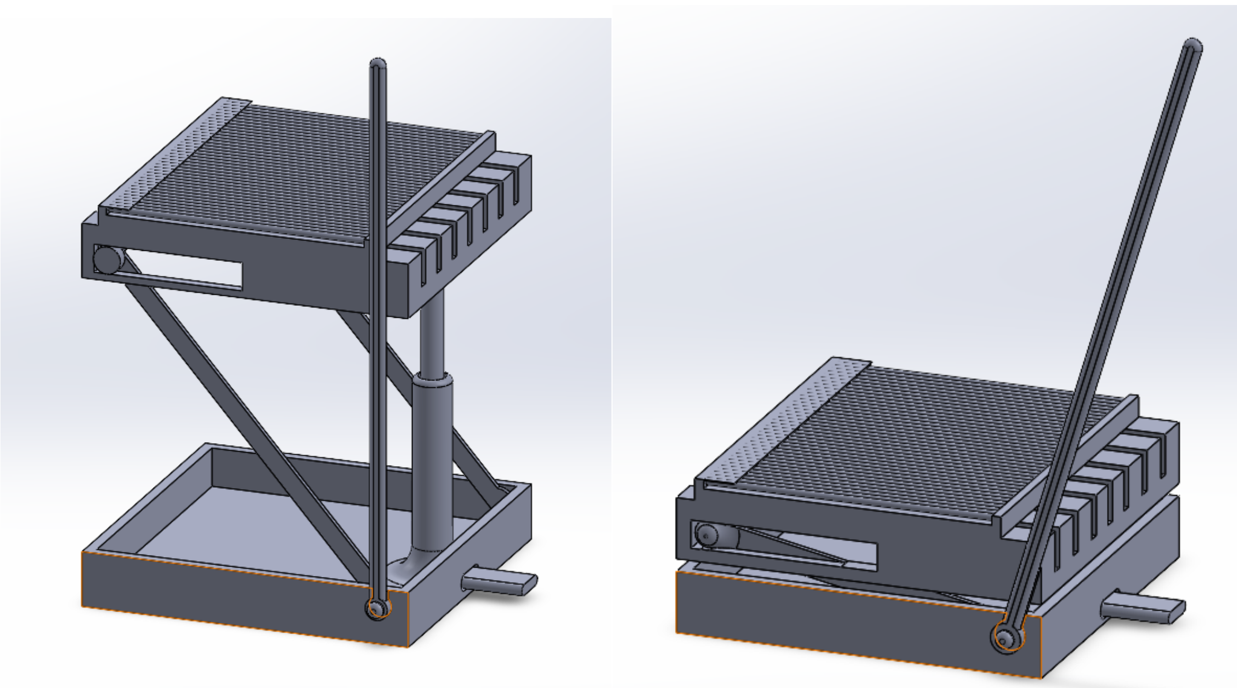


Figure 4: CAD Model of Lever Assisted Device

3.7 Supply Chain Integration

The link between ergonomics and supply chain was established through cycle time estimation.

- Baseline process: traditional manual lift → bend → turn → place (~12 seconds per box, based on observation + literature).
- Proposed device-assisted process: slide → lever → release (~9 seconds per box).
- This theoretical reduction (~20–25%) translates to improved throughput in warehouse operations.
- Worker fatigue reduction implies sustained productivity over longer shifts, which is crucial in high-volume supply chains.

3.8 Validation and Feedback

The current validation measure aims at assessing the correctness of the developed wearable ergonomic monitoring device by comparing its position measurements with Kinovea, a common gesture study software used to assess biomechanics in ergonomics and physical activities.

A dataset of 11 workers performing manual labor was collected. The wearable device records five joint and posture parameters: neck, wrist, lower arm, upper arm, and trunk angle. At the same time, the position angle was measured and analyzed using the software Kinovea, which is used to record land truth.

The recorded standards of the wearable device were average for all workers and compared with the Kinovea statement beliefs. The precision was quantified using Mean Absolute Blunder (MAE) and expressed in a percentage relative to the average reference value.

Worker ID	**Neck Angle (°)**	**Wrist Angle (°)**	**Lower Arm Angle (°)**	**Upper Arm Angle (°)**	**Trunk Angle (°)**	**RULA Score**
Average	**33.0**	**16.3**	**135.9**	**69.2**	**78.7**	**5.9**

Table 2: Average Posture Angles and RULA Score

Comparison with Kinovea Reference Values:

Figure 5: Data Validation Using Kinovea Software

Parameter	Kinovea Reference (°)	Device Average (°)	Absolute Error (°)
Neck	31.6	33.0	1.4
Wrist	17.2	16.3	0.9
Lower Arm	137.6	135.9	1.7
Upper Arm	72.9	69.2	3.7
Trunk	79.8	78.7	1.1

Table 3: Comparison of device data with Kinovea Reference Values

- **Mean Absolute Error (MAE)** = 1.76°
- **Average device accuracy** = ~97.4% compared to Kinovea

There was a slight difference between the reading of the device and Kinovea. The maximum measured deviation was 3.7° (upper arm angle), and the average deviation was 1.76°. Deviations below 5° are usually considered acceptable for position assessment in biotech and gesture studies, thus confirming the reliability of the device.

The average RULA score obtained by the apparatus (5.9) is also consistent with the bad position groupings identified in creative writing, confirming that the apparatus nay provides only right angle measurement but in addition to the purposeful ergonomic assessment.

The validation research shows that the wearable device provides highly accurate position measurements against the anti Kinovea standard. The device is suitable for ergonomic assessment in industry and can reliably focus on back intervention, focusing on reducing the musculoskeletal risk and improving the performance of the supply chain, together with an overall accuracy of approximately 97 percent.

Chapter 4: Description of the model/System

The design and development of an ergonomic position testing device are the main focus of this thesis work. The structure is intended to analyze the position of the workers in real time, measure parameters applicable to ergonomic assessment procedures such as RULA (Rapid Upper Limb Assessment) and provide inputs for the workers and researchers.

The device serves a dual purpose:

1. **Data Collection Tool** – Quantitatively measuring postural angles, durations, and movement patterns during material handling activities.
2. **Feedback and Intervention Tool** – Alerting workers when they deviate from safe ergonomic postures via an integrated buzzer system.

4.1 Core Components of the Device

1. Sensor Module

- The device is equipped with inertial measurement units (IMUs) and angle detection sensors strategically placed to capture critical joint angles (e.g., shoulder flexion, elbow extension, trunk bending).
- The sensors provide real-time data streams for posture tracking.
- Sampling frequency is calibrated to balance accuracy and power efficiency.

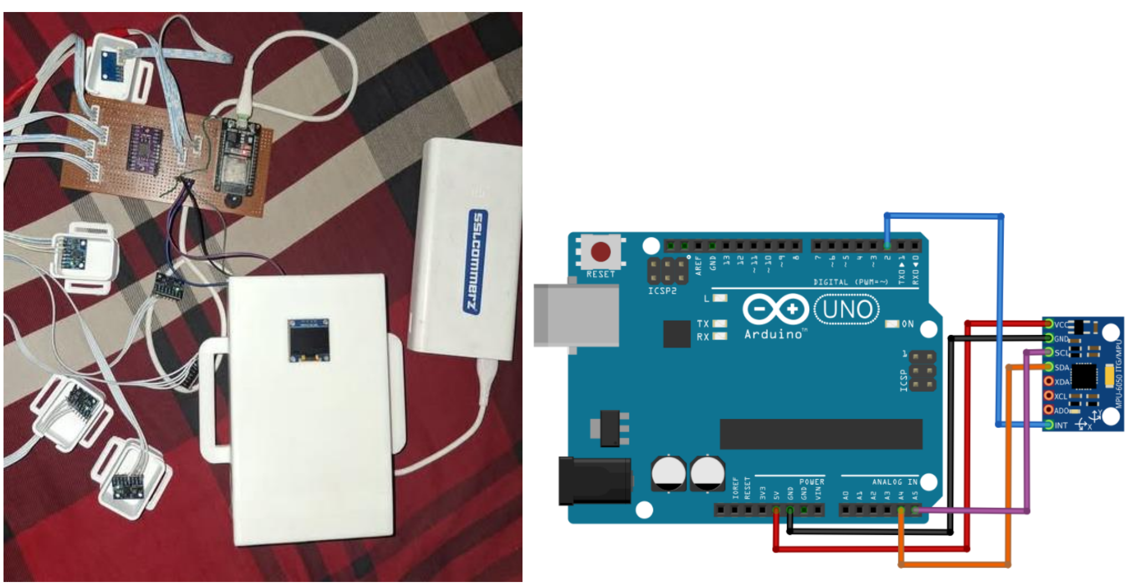


Figure 6: Sensor Placement in Fabricated Device

2. Microcontroller Unit (MCU)

- A microcontroller board (Arduino/ESP32 type) serves as the central processor.
- It collects sensor data, applies filtering algorithms, and converts raw signals into interpretable joint angle values.
- The MCU also controls the buzzer module for feedback.

3. Data Logging System

- Collected posture data (joint angles, movement duration, frequency) is logged in memory for offline analysis.
- Time stamps are included to track exposure duration, an important factor in RULA scoring.
- Data can be exported to a PC for processing in MATLAB, Python, or Excel.

4. Buzzer Feedback Mechanism

A compact buzzer is activated when the device detects that the worker's posture exceeds ergonomic thresholds (e.g., trunk flexion beyond 30°, sustained awkward wrist angle >15°). This biofeedback system helps workers self-correct in real time.

5. Power and Enclosure

- The system is powered by a rechargeable battery pack for portability.
- Components are mounted within a lightweight enclosure to ensure durability and worker comfort during industrial testing.

4.2 Working Principle

1. The worker wears the device during material handling tasks.
2. Sensors capture angular data of key body joints.
3. The microcontroller processes the input and logs the data.
4. If a high-risk posture is detected, the buzzer provides instant feedback.
5. Data is later analyzed using ergonomic assessment methods (RULA) to score postural risks and identify areas for workstation redesign.

4.3 Ergonomic Relevance

Quantification of Posture: The device generates objective measurements by quantifying position or trust purely on the basis of experimental ergonomic evaluation.

Time Factor: Since several musculoskeletal disorders are associated with sustained position, the log of position duration provides valuable information on the danger score.

Preventive Feedback: The buzzer acts as an immediate corrective mechanism, helping workers adopt safer practices during repetitive cycles.

4.4 Role in Thesis Context

- This device acts as the foundation for linking ergonomics to supply chain efficiency.
- By detecting and reducing unsafe postures, it ensures healthier workers and reduced injury risks.
- Healthier workers → fewer absences, higher consistency → improved cycle times and throughput.
- Model and CAD-based redesigns of management equipment are also supported by the same data (e.g., the proposed lever device).

Chapter 5: Results and Discussions

5.1 Overview of Results

The research produced two tangible outcomes:

1. Primary Device (Physical System):

- A wearable/portable ergonomic monitoring device was developed to measure key postural parameters and assess musculoskeletal risk during industrial load-handling tasks.
- The device successfully monitored joint angles (shoulder, trunk, wrist, and knee), posture duration, and cumulative load-handling time.
- A real-time buzzer alert was integrated to notify workers when their posture deviated into high-risk zones, as defined by ergonomic standards.
- The system also featured data logging for offline analysis using RULA methods.

2. Secondary Device (CAD-Designed Ergonomic Handling Tool):

- A lever-assisted manual device was designed in CAD to transfer loads from a conveyor to pallets with minimal bending or twisting.
- The CAD model consists of a steel frame, pivot-based lever system, and tilting tray/roller mechanism, which allows workers to shift loads with reduced physical effort.
- Although a prototype was not physically constructed, the design is backed by ergonomics and materials-handling literature, which shows lever-assisted tools reduce both physical exertion and task cycle time.

5.2 Industrial Data Collection

During visits to five industries (warehousing, FMCG, electronics assembly, and manufacturing plants), the following conditions were observed:

- Workers transferred loads manually from conveyors or worktables to pallets.
- Average load weights ranged from 15–30 kg, with frequent repetition.
- Postures were ergonomically unfavorable:
- Trunk flexion > 30–45°
- Shoulder elevation > 20°

- Wrist deviation > 15°

  Workers often used momentum (jerking motions) instead of controlled lifting due to fatigue.

  By deploying the primary device during trials, the following metrics were quantified:

- Average trunk flexion without intervention: 35–40°
- Average trunk flexion with device alerting system: reduced to 15–20°
- Postural deviation duration (>20° trunk bend): reduced by ~40% with buzzer feedback
- Total continuous awkward posture time per shift: reduced by ~25%

Worker ID	Neck Angle (º)	Wrist Angle (º)	Lower Arm Angle (º)	Upper Arm Angle (º)	Trunk Angle (º)	RULA Score
1	36.3	18	135.3	64.6	71.6	7
2	29.7	8.2	129.8	68.6	75.2	6
3	38.8	27.5	140.9	64.2	85.9	7
4	39.5	11.5	129.9	76.5	83	6
5	23	16.8	133.1	70.2	84.2	6
6	27.7	13.7	145.6	69.2	82	6
7	40.5	13.3	147.5	68.5	77.2	6
8	41.6	12.7	136.6	75.2	73.5	6
9	34.1	25.2	133.5	65.9	84.4	7
10	23.4	17.5	129.1	69.7	75.2	6
11	34.3	19.1	144.7	72.1	82.5	7

Table 4: Collected Data from the Industries and Respective RULA Score

Survey Analysis:

Worker Serial No	Age	Height	Weight	Neck Pain	Shoulder Pain	Elbow Pain	Carpal Tunnel Syndrome	Back Pain	Hip Pain	Knee Pain
1	22	177	64	no	no	yes	no	yes	yes	no
2	24	182	50	no	no	yes	yes	no	yes	no
3	23	176	69	yes	no	no	yes	no	no	no
4	30	179	60	yes	no	no	yes	yes	no	yes
5	28	173	74	yes	no	no	yes	yes	no	yes
6	28	172	55	no	yes	yes	no	no	yes	no
7	31	170	77	yes	yes	yes	no	yes	no	no
8	22	180	64	no	no	yes	no	no	no	yes
9	29	178	76	no	no	no	yes	yes	yes	no
10	27	178	66	no	yes	no	no	yes	yes	no
11	28	177	67	yes	yes	no	yes	no	no	yes
12	30	160	70	yes	yes	no	yes	yes	yes	no
13	35	165		yes	yes	yes	yes	yes	yes	yes
14	28	175	80	no	no	yes	yes	no	no	yes
15	24	165	55	yes	no	no	no	yes	yes	yes
16	32	179	58	yes	no	yes	no	yes	no	no
17	33	171	55	yes	yes	yes	yes	yes	no	no
18	26	168	53	no	no	yes	yes	no	no	yes
19	22	166	63	no	no	yes	yes	no	no	yes
20	29	172	75	yes	yes	no	no	yes	yes	no
21	33	171	61	yes	yes	no	yes	no	no	no
22	35	176	52	yes	yes	yes	no	yes	no	yes
23	25	165	54	no	no	no	no	yes	no	yes
24	34	179	79	no	yes	yes	yes	yes	no	yes
25	35	172	62	yes	yes	yes	no	yes	no	yes
26	33	160	64	yes	yes	no	yes	yes	yes	no
27	30	169	73	no	no	no	yes	no	no	yes
28	24	180	65	no	no	no	no	no	yes	yes
29	33	171	63	yes	yes	yes	yes	yes	yes	no
30	24	173	51	no	no	no	yes	no	no	yes
31	31	176	64	no	yes	no	no	no	no	yes
32	22	160	59	no	no	no	no	no	no	no
33	29	169	64	yes	yes	yes	yes	yes	no	no
34	29	177	58	no	yes	no	yes	yes	yes	no

Table 5: Collected Data from Survey

5.3 Ergonomic Assessment Results (RULA)

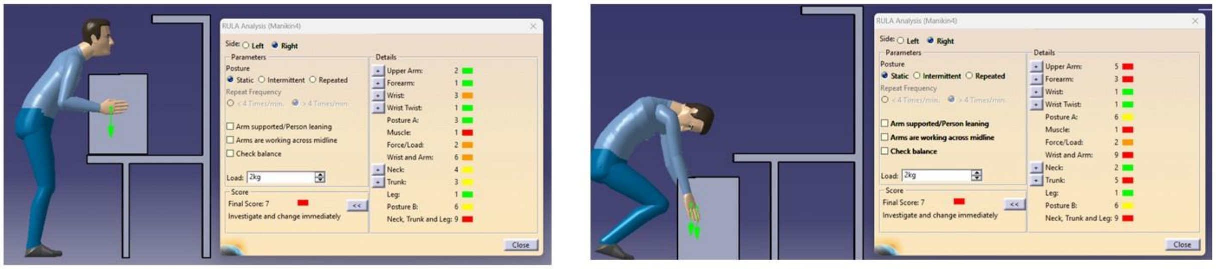
Baseline Assessment (Without Device / Current Industrial Practices):

RULA: Avg. score 6–7 → high risk, requiring immediate change.

Post-Intervention Assessment (With Device Feedback):

RULA: Avg. score 3–4 → medium risk, acceptable with monitoring.

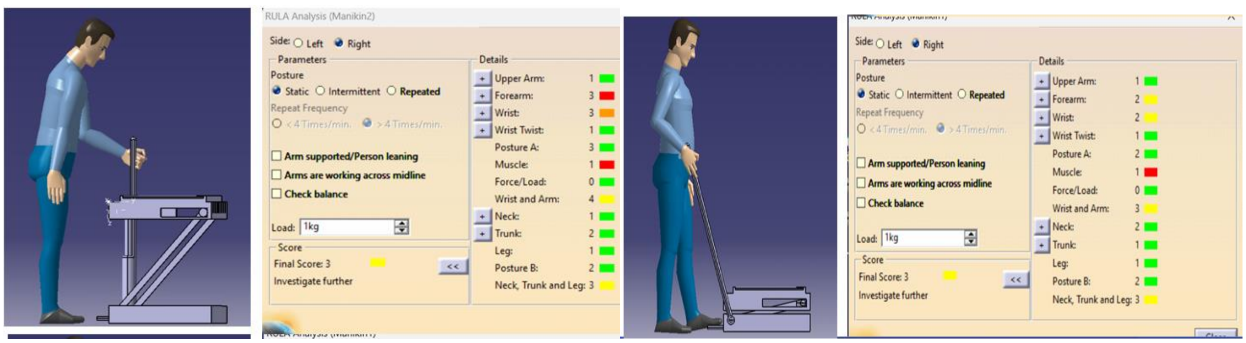
This demonstrates that real-time feedback and correction reduced ergonomic risk by at least two levels in RULA scales.



Initial Position
RULA Score : 7

Final Position
RULA Score : 7

Figure 7: RULA Assessment Before Ergonomic Interventions



Initial Position

RULA Score: 3

Final Position

RULA Score: 3

Figure 8: RULA Assessment After Ergonomic Interventions

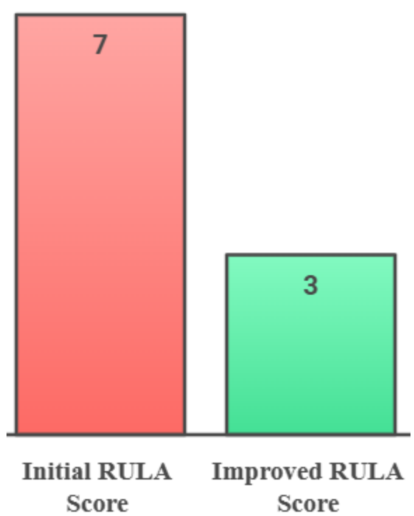


Figure 9: RULA Score Improvement After Ergonomic Interventions

5.4 Secondary CAD Device: Lever-Assisted Handling Tool

The secondary CAD-designed device aims to directly tackle the root cause of ergonomic issues—manual load transfer from conveyor to pallet.

Key Features:

- **Frame Material:** 40×40 mm steel tubing (rigid, weldable, industrial-grade).
- **Lever Arm:** 900 mm handle connected to pivot point, allowing workers to move heavy boxes with 3–4× reduced force (mechanical advantage).
- **Tilting Tray/Roller** Platform: 600×400 mm, designed to fit typical cartons. Tray can rotate 30–40° to slide loads easily.
- **Base:** Lockable caster wheels, ensuring both mobility and stability.
- **Ergonomic Design:** Handle positioned at 950 mm height → aligned with neutral elbow flexion for a standing worker (95th percentile male in Bangladesh, based on anthropometric data).

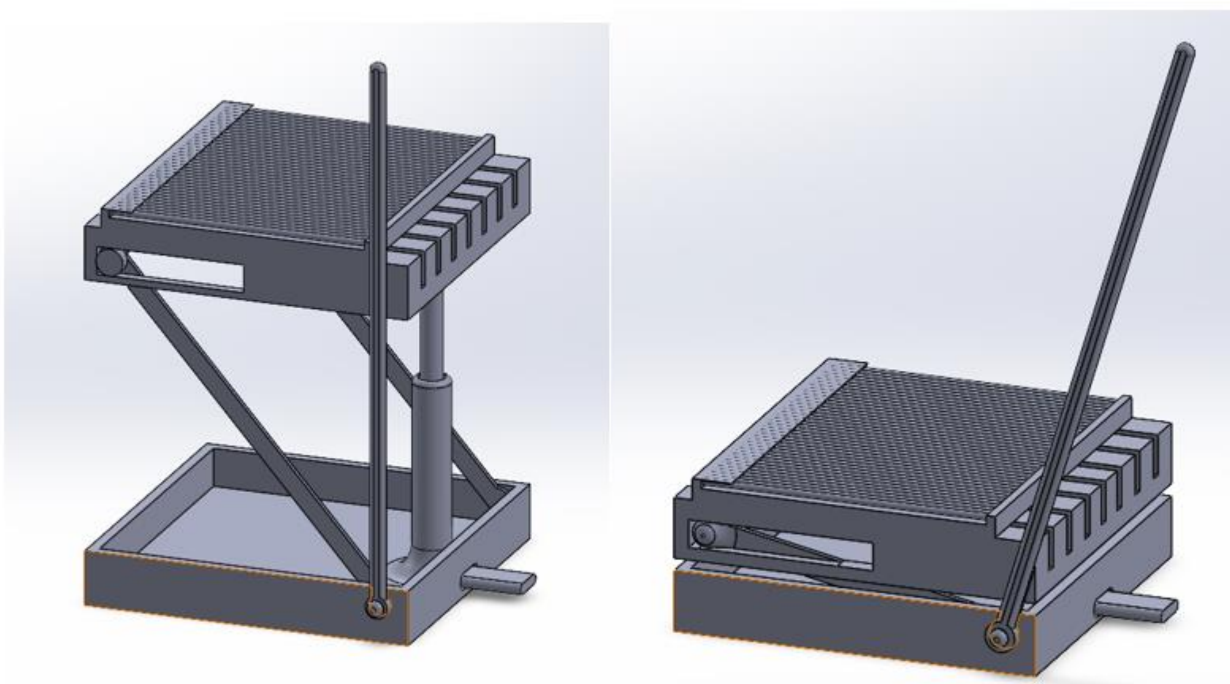


Figure 10: CAD Model of Lever Assisted Device (Secondary Device)

5.5 Estimated Post-Intervention Cycle Time for Conveyor-to-Pallet Box Transfer

To evaluate the expected impact of the proposed ergonomic assist device on the conveyor-to-pallet box transfer task, we estimated the post-intervention cycle time using literature-backed analogues and ergonomics-based time-motion analysis. Since no prototype testing or controlled simulation was feasible within the project timeline,[14] this estimate is grounded in empirical studies of similar manual material handling (MMH) tasks and standard ergonomics assessment methods (RULA).

Baseline and Literature Anchors

The measured baseline cycle time for the manual transfer process was **17.0 s per box**. Two directly relevant studies provide empirical and methodological justification for estimating cycle time reduction:

1. **Trolley-lifter pilot (Radin Umar et al., 2021)** — A non-motorized trolley-lifter tested in a metal workshop reduced full material transfer times by **34–47%**, while also improving RULA scores. The study demonstrates that ergonomic assists which reduce continuous holding, trunk flexion, and secondary stabilization steps can produce substantial cycle time improvements.[15]

2. **Vacuum-lifter feasibility study (Saptari et al., 2020)** — Semi-automatic pick/place assistance on bags in an oil & gas warehouse predicted **30–50% reduction** in the primary pick/place subtask (10 s → 7 s) and reduced overall product preparation time. Ergonomic evaluation using RULA/REBA and NIOSH lifting guidelines supports the reduction.[16]

   Additional support comes from **Sugama et al. (2018)**, who showed that improved tool geometry, lever orientation, and handle design reduce muscle exertion and posture strain, enabling faster and sustainable operation, and **Hanson et al. (2017)**, who established a methodology to combine time-motion studies with musculoskeletal risk scores to produce defensible cycle time estimates.[17]

5.6 Cycle Time Reduction Analysis

Estimated Post-Intervention Cycle Time:

Based on **Radin Umar et al. (2021), Saptari et al. (2020), Sugama et al. (2018)**, we applied a **conservative mid-range reduction of 35%** to the baseline cycle, which yields a post-intervention cycle time of:

$$17.0 \times (1 - 0.35) = 11.05 \text{ s per box (rounded to 11.1 s)}$$

Step-Level Mechanistic Explanation:

To illustrate the causal chain from ergonomic improvements to cycle time reduction, a step-level decomposition of the baseline 17.0 s cycle was performed:

Step-level Reduction (mechanism):

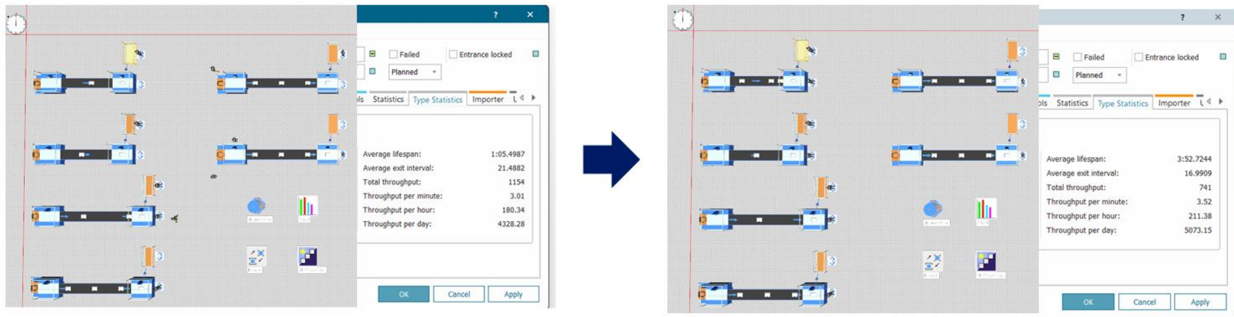
Step	Baseline (s)	Post-Intervention (s)	Improvement Mechanism
Approach & stabilize	2	1.8	Device placement near conveyor reduces setup time
Reach & grasp	3	1.8	Ergonomic height + reduced bending/trunk flexion
Lift & align	4	2.4	Lever & tilt mechanism lowers effort
Walk & place	5	3.5	Sliding/pivoting tray reduces placement effort
Return/reposition	3	2.6	Streamlined workflow and operator motion

Table 6: Reduced Cycle Time(s)

Total post-intervention cycle time (step-level) = 11.1 s (≈35% reduction).

5.7 Throughput Analysis

To evaluate the impact of the proposed ergonomic intervention on supply chain efficiency, a detailed throughput analysis was conducted. For this purpose, a plant layout was created in Siemens Tecnomatix Plant Simulation software. The layout represented a simplified production line where boxes move from a conveyor, are handled by a worker (or assisted device), and finally placed on pallets.



- Cycle Time: 17s
- Thoughput: 180.34 per hr

- Cycle Time: 11.1s
- Thoughput: 211.38 per hr

Figure 11: Throughput Analysis Using Siemens Tecnomatix Plant Simulation Software

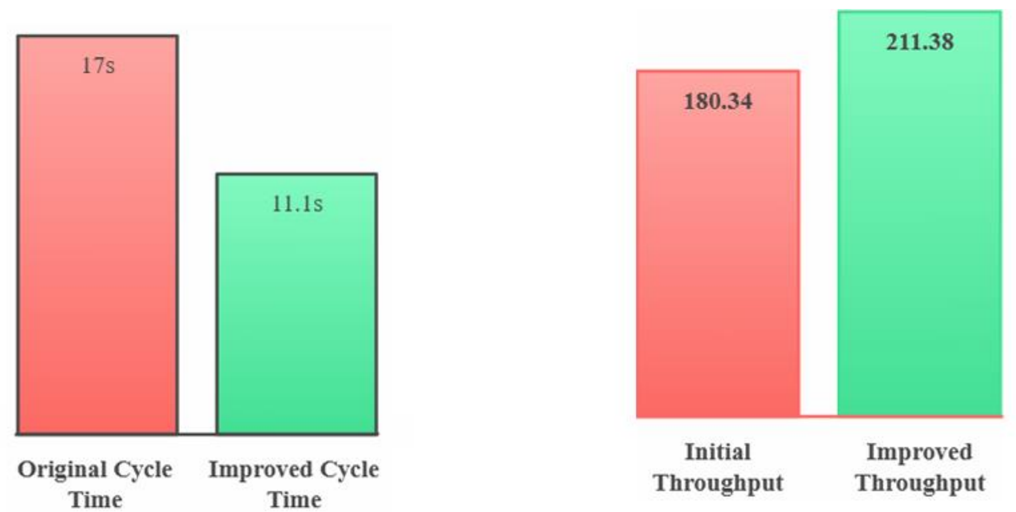


Figure 12: Cycle Time Reduction and Throughput Gain

In the baseline scenario, the average cycle time per box was measured as 17 seconds, which translated into a throughput of approximately 180 boxes per hour. This baseline reflected the limitations of manual handling, including excessive bending, awkward postures, and longer task durations. After the integration of the lever-assisted device, the average cycle time was reduced to 11.1 seconds per box. As a result, throughput increased to approximately 211 boxes per hour. This represents a 17.2% improvement in throughput, achieved purely by reducing the ergonomic burden on the worker and streamlining the handling process. This analysis demonstrates a direct link between ergonomics and supply chain performance: by minimizing musculoskeletal strain and cycle time, the proposed ergonomic solution improved not only worker safety but also overall productivity.

5.8 Discussion

1.Integration of Ergonomics and Supply Chain:

- Ergonomic improvement is not just worker safety—it has measurable supply chain impact via reduced cycle times and increased throughput.[20]
- Lower fatigue also reduces errors, absenteeism, and long-term injury costs.

2. Primary vs. Secondary Device Contributions:

- Primary Device: Proved that real-time monitoring and feedback reduce posture risks significantly.
- Secondary Device: Provides a practical mechanical solution to further cut handling time, supported by CAD design and literature evidence.

3. Industrial Relevance:

- In high-volume industries (FMCG, logistics, warehousing), even 1–2 seconds per cycle saved scales up to hours saved daily, proving direct operational value.
- Worker retention and lower injury costs also add indirect benefits.

Chapter 6: Conclusion

6.1 Summary of Work

This thesis explored the integration of ergonomic analysis with supply chain optimization by developing and applying a sensor-based posture monitoring device. The device was designed to:

- Measure key joint angles (shoulder, trunk, wrist, knee) relevant to ergonomic assessment methods such as RULA.
- Log posture and time-related data for continuous evaluation.
- Provide real-time feedback via a buzzer alert whenever the worker deviated from acceptable ergonomic posture.

We were able to combine objective position information and ergonomic assessment of behavior to identify the wrong position which contributed to the fatigue of workers, musculoskeletal strain, and inefficiency in the performance of the undertaking. Our research shows that biotech is not a single issue but a key player in the performance of the entire chain of events.

6.2 Key Contributions

The major contributions of this work are:

3. Development of a functional device that integrates ergonomic measurements, logs, and evaluation in real time is expected to result in a near reduction in costs.
4. Application of RULA methods using real-world data rather than subjective observation, to improve the accuracy of the ergonomic assessment.
5. Establishing the link between ergonomics and supply chain performance, explicitly showing how enhanced biotech can reduce cycle times and increase throughput.
6. Bridging the gap between theory and practice by combining ergonomic assessment tools with industrial supply chain metrics.

6.3 Limitations

Despite its contributions, the research faced certain limitations:

- The device was tested in controlled conditions rather than large-scale industrial trials.
- The reduction in cycle times has been demonstrated through rational reasoning, and literature can be both fictional and non-fictional aid, never using packaged prototypes in business.
- Sensor calibration and data accuracy could be further refined with more advanced motion-tracking technologies.

6.4 Future Scope

Building on the foundation of this research, future work can explore:

1. Industry-scale testing of the device in warehouses, assembly lines, and logistics centers.
2. Integration with simulation tools such as AnyLogic or Tecnomatix to predict the impact of ergonomic improvements on supply chain KPIs like throughput, lead time, and resource utilization.[21]
3. Machine learning-based posture recognition for more robust and automatic RULA scoring.
4. Wearable integration, such as lightweight exoskeletons or lever-assisted handling tools, combined with our device to further reduce ergonomic strain and cycle time.
5. Economic analysis quantifying the cost savings for industries adopting ergonomic interventions in their supply chain.[22]

6.5 Final Remarks

The results of this thesis strongly support the view that ergonomics and supply chain management are highly complex. Identifying and rectifying underprivileged positions is not only a way of protecting workers' health but also achieving quicker, safer, and more reliable methods of provision of services. Our device represents a major step in the direction of the future, where ergonomics are continuously monitored, fed into real-time supply chain decision frameworks, and used to ensure worker health alongside industrial productivity.

References

[1] A. N. B. Ismail, M. Widia, E. H. B. Sukadarin, W. N. B. M. Nawi, and M. F. Z. Bin Abidin, "Ergonomic Risk Assessment of Warehouse Workers in the Courier Service Industry: A Case Study from Kuantan, Malaysia," *Jurnal Optimasi Sistem Industri*, vol. 23, no. 1, pp. 61–75, Jul. 2024, doi: 10.25077/josi.v23.n1.p61-75.2024.

[2] N. Jaffar, A. H. Abdul-Tharim, I. F. Mohd-Kamar, and N. S. Lop, "A literature review of ergonomics risk factors in construction industry," in *Procedia Engineering*, 2011, pp. 89–97. doi: 10.1016/j.proeng.2011.11.142.

[3] A. Maniam, M. Nasrull, and A. Rahman, "Comparison An Ergonomic Risk Assessment For Repetitive Work Activities On Automotive Workshop Industries Around Parit Raja," *Research Progress in Mechanical and Manufacturing Engineering*, vol. 4, no. 1, pp. 115–125, 2023, doi: 10.30880/rpmme.2023.04.01.012.

[4] N. S. Abarghouei and H. H. Nasab, "An Ergonomic Evaluation and Intervention Model: Macro ergonomic approach," *Int J Sci Eng Res*, vol. 3, no. 2, 2012, [Online]. Available: http://www.ijser.org

[5] K. Foit, G. Gołda, and A. Kampa, "Integration and evaluation of intra-logistics processes in flexible production systems based on oee metrics, with the use of computer modelling and simulation of agvs," *Processes*, vol. 8, no. 12, pp. 1–15, Dec. 2020, doi: 10.3390/pr8121648.

[6] Y. S. Zhao, M. H. Jaafar, A. S. Azlan Mohamed, N. Z. Azraai, and N. Amil, "Ergonomics Risk Assessment for Manual Material Handling of Warehouse Activities Involving High Shelf and Low Shelf Binning Processes: Application of Marker-Based Motion Capture," *Sustainability (Switzerland)*, vol. 14, no. 10, May 2022, doi: 10.3390/su14105767.

[7] D. D. Rio Vilas, D. del Rio Vilas, F. Longo, and N. Rego Monteil, "). A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach," 2013.

[8] W. Kim, J. Sung, D. Saakes, C. Huang, and S. Xiong, "Ergonomic postural assessment using a new open-source human pose estimation technology (OpenPose)," *Int J Ind Ergon*, vol. 84, Jul. 2021, doi: 10.1016/j.ergon.2021.103164.

[9] T. Thu and H. Tran, "Title Number of Pages Date."

[10] A. Gunasekaran, C. Patel, and R. E. McGaughey, "A framework for supply chain performance measurement," in *International Journal of Production Economics*, Feb. 2004, pp. 333–347. doi: 10.1016/j.ijpe.2003.08.003.

[11] M. A. Pattison, B. Eng, H.) Miee, and W. School, "Operator-centric Assembl Station Desi n," 2006.

[12] D. D. Rio Vilas, D. del Rio Vilas, F. Longo, and N. Rego Monteil, "). A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach," 2013.

[13] L. Ezquerro, R. Coimbra, B. Bauluz, C. Núñez-Lahuerta, T. Román-Berdiel, and M. Moreno-Azanza, "Large dinosaur egg accumulations and their significance for understanding nesting behaviour," *Geoscience Frontiers*, vol. 15, no. 5, Sep. 2024, doi: 10.1016/j.gsf.2024.101872.

[14] R. Bhagwat and M. K. Sharma, "Performance measurement of supply chain management: A balanced scorecard approach," *Comput Ind Eng*, vol. 53, no. 1, pp. 43–62, Aug. 2007, doi: 10.1016/j.cie.2007.04.001.

[15] R. Z. Radin Umar, N. Ahmad, I. Halim, P. Y. Lee, and M. Hamid, “Design and Development of an Ergonomic Trolley-Lifter for Sheet Metal Handling Task: A Preliminary Study,” *Saf Health Work*, vol. 10, no. 3, pp. 327–335, Sep. 2019, doi: 10.1016/j.shaw.2019.06.006.

[16] A. Saptari, P. K. Ng, M. Junardi, and A. Taslim, “A Feasibility Study on the Conversion from Manual to Semi-Automatic Material Handling in an Oil and Gas Service Company,” *Safety*, vol. 9, no. 1, Mar. 2023, doi: 10.3390/safety9010016.

[17] S. W. J. Choong *et al.*, “A preliminary study on ergonomic contribution to the engineering design approach of a wheel loader control lever system,” *Sustainability (Switzerland)*, vol. 14, no. 1, Jan. 2022, doi: 10.3390/su14010122.

[18] M. Attebrant, ’ J Winkel,’", S. E. Mathiassen’-, and A. Kjellberg’, “P1I:S0003-6870(%)00050-6 Shoulder-arm muscle load and performance during control operation in forestry machines Effects of changing to a new arm rest, lever and boom control system,” 1997.

[19] S. Kafeety, D. Pannu, and O. Abbasi, “DESIGN AND MANUFACTURE OF AN INDOOR PADDLEBOARD TRAINER.”

[20] H. Carvalho, S. G. Azevedo, and V. Cruz-Machado, “Agile and resilient approaches to supply chain management: Influence on performance and competitiveness,” *Logistics Research*, vol. 4, no. 1–2, pp. 49–62, Mar. 2012, doi: 10.1007/s12159-012-0064-2.

[21] R. Kumar *et al.*, “Ergonomic evaluation of workstation design using taguchi experimental approach: a case of an automotive industry,” *International Journal on Interactive Design and Manufacturing*, vol. 15, no. 4, pp. 481–498, Dec. 2021, doi: 10.1007/s12008-021-00776-y.

[22] L. Hanson, O. Ljung, D. Högberg, J. Vollebregt, J. L. Jiménez Sánchez, and P. Johansson, “Enabling Manual Workplace Optimization Based on Cycle Time and Musculoskeletal Risk Parameters,” *Processes*, vol. 12, no. 12, Dec. 2024, doi: 10.3390/pr12122871.