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Enhancement of Material Handling System for Optimized Safety Measures

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ABSTRACT

Material handling is a fundamental operation in industrial environments, especially among small and medium-sized enterprises (SMEs) like FAMAX Technology (M) Sdn. Bhd., where reliance on manual labor is high due to budget constraints. This study aims to enhance the safety and efficiency of material handling at FAMAX by optimized material handling and safety measures. The method that is used in this study is by site observation and layout mapping to identify current material handling activities. The analyzed time-motion studies, ergonomic assessments (RULA) and simulation FlexSim to identify physical strain of the workers. The result shows long-distance trolley handling and improper lifting postures. Practical and cost-effective solutions were proposed and validated, including the implementation of Autonomous Mobile Robots (AMRs) for long-distance transport and standardized safe work methods at critical points like the band saw cutting station. The interventions were validated through improved RULA scores, NIOSH lifting index calculations, and cost-benefit analysis. The results contributed directly to FAMAX by reducing ergonomic risk, improving workflow efficiency, and demonstrating a favorable return on investment. Overall, this study presents a scalable ergonomic improvement model for SMEs with similar resource constraints.

1. Introduction

Material handling, defined as the movement, protection, storage, and control of materials, is a core element in manufacturing industries. In small and medium-sized enterprises (SMEs), particularly in the semiconductor sector, manual material handling dominates due to cost and

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space limitations, often leading to productivity issues, workplace fatigue, and increased injury rates. These operations frequently involve lifting heavy items, transporting materials over long distances, and repetitive tasks, all of which expose workers to ergonomic risks such as musculoskeletal disorders. SMEs like FAMAX Technology (M) Sdn. Bhd. face compounded challenges due to a lack of mechanized handling systems, structured safety protocols, and ergonomic considerations. In these environments, operators are often expected to perform tasks that exceed safe physical limits, such as pushing trolleys loaded with heavy bins over extended distances or handling long and unbalanced rods. In addition to worker strain, these inefficient practices disrupt production flow and reduce overall operational performance.

Literature reviews consistently highlight that ergonomic tools, layout optimization, and automation technologies such as Autonomous Mobile Robots (AMRs), can significantly improve safety, productivity, and operational efficiency in manufacturing environments. However, small and medium-sized enterprises (SMEs) often face financial and technical constraints that limit the adoption of such solutions. Significant reductions in musculoskeletal risks and handling inefficiencies can be achieved through modest ergonomic redesigns and simulation-based assessments [1-3]. Enhancements in material flow and space utilization can be effectively achieved through systematic layout planning [4,5]. Value stream mapping has been shown to play a critical role in improving assembly and handling operations [6]. Collectively, these findings reinforce the importance of integrating ergonomic and automation strategies like AMRs into SME operations to overcome traditional limitations and achieve sustainable improvements [7]. This study want to address the identified research and practical gaps by systematically evaluating the current material handling practices at FAMAX and proposing feasible, evidence-based improvements tailored to the context of small and medium-sized enterprises (SMEs).The study aims to identify and characterize existing material handling activities and operational constraints, analyze ergonomic and process inefficiencies using time-motion studies, Rapid Upper Limb Assessment (RULA), and FlexSim-based simulation modeling, and develop and validate improvement strategies through ergonomic performance metrics and cost-effectiveness analysis.

2. Methodology

The methodology employed a systematic, three-phase approach Problem Identification, Analysis, and Solution Development to optimize the material handling system at FAMAX Technology (M) Sdn. Bhd., a semiconductor SME. The Problem Identification Phase involved site observations, layout mapping, and data collection to determine current material handling activities. FlexSim simulation software was used to create a visual representation and validate the existing material flow, movement paths, and potential congestion points.

The Analysis Phase focused on quantifying inefficiencies and risks. This involved Time-motion studies to measure task durations (like loading and travel time) and the administration of the Nordic Musculoskeletal Questionnaire (NMQ) to assess worker discomfort. Ergonomic risks were evaluated using the Rapid Upper Limb Assessment (RULA) method. Data analysis utilized Microsoft Excel for time studies and CATIA software to perform detailed RULA simulations.

The Solution Development Phase focused on recommending practical, cost-effective interventions. Proposed solutions included the development of a Standard Work Method for manual handling and the introduction of automated material handling equipment, such as Autonomous Mobile Robots (AMRs). Solutions were validated using CATIA RULA simulation (before and after comparison), safety assessment via the NIOSH Lifting Equation to calculate the Lifting Index (LI), and a basic cost-benefit analysis to assess financial feasibility

3. Results

Overview of Current Material Handling Activities: Figure 1 presents the complete manufacturing process of a selected component at FAMAX Technology (M) Sdn. Bhd. The figure maps out each production stage from raw material input to final dispatch, including cutting, turning, stamping, and outsourced plating.

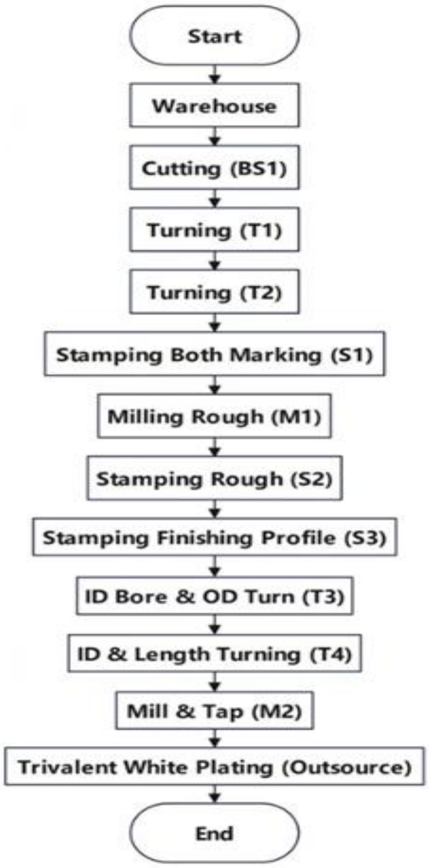

Fig 1. The Manufacturing Process of the Selected Component

3.1 Layout and Material Flow Analysis

FlexSim software was used to simulate material flow across the observed workstations.The simulation model was constructed based on actual process flow, layout, and movement paths gathered during the site visit. The maximum walking speed of the workers was set using calculated values from the time-motion study, where travel distances and actual travel times were recorded. This allowed the simulation to reflect realistic cycle times for each material handling transition. Figure 2 shows the FlexSim simulation of the current material handling flow.

3.2 Material Handling Analysis

Table 1 presents the time-motion study conducted at FAMAX Technology (M) Sdn. Bhd. for various stages of the material handling process. Material handling activities primarily involved manual transfer of 30 kg bins via trolleys and lifting long raw rods up to 6 meters in length. Time-motion studies showed excessive setup (17.6 minutes) and unloading time (16 minutes) for long rod handling, while trolley pushing over distances up to 75 meters caused physical fatigue.

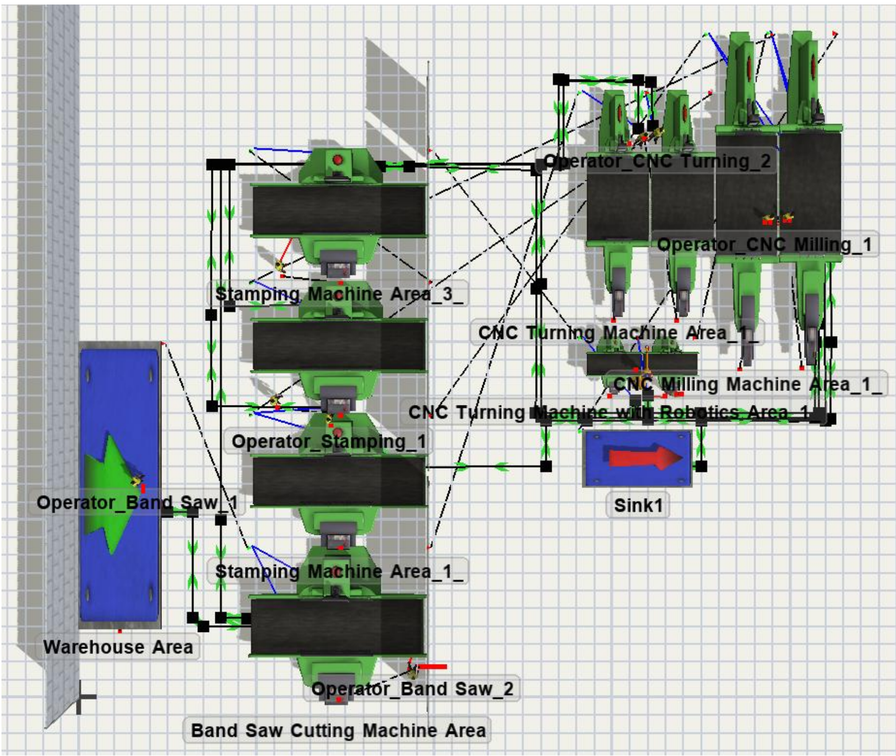

Fig. 2. Layout of the factory and existing material handling flow (FlexSim)

3.3 Determination of Material Handling Activities

The initial phase identified that material handling processes, spanning across stages like cutting, turning, stamping, and milling, rely heavily on manual handling due to the SME's budget constraints.

- Process Flow and Handling Methods: The raw material, a Cold Drawn Round Bar - S20C (6000 mm in length), is transferred from the warehouse to the cutting station using a combination of forklifts, manual work, and trolleys. Subsequent inter-process movement primarily relies on operators manually pushing trolleys loaded with storage bins. Each bin weighs approximately 30 kg, and trolleys often carry three bins, equating to around 90 kg per trip.
- Efficiency Contrast: A specific transition between the ID Bore & OD Turn process and ID & Length Turning (T4) utilizes a robotic arm, which demonstrated enhanced safety and efficiency by eliminating manual lifting for that segment.
- Initial Safety Concerns: Observations highlighted a significant safety hazard at the band saw cutting machine, where raw materials were fed from both sides, increasing the likelihood of mishandling.

Table 1
Summary of time-motion study for material transition

Material	From Process	To Process	Handling Method	Setup Time (min)	Loading Time (min)	Travel Time (min)	Unloading Time (min)	Total Time (min)	Travel Distance (m)	Bottlenecks / Observations
Cold Drawn Round Bar - S20C	Warehouse	Cutting (BS1)	Forklift, Manual Work and Trolley	1.700	17.617	0.800	16.083	36.200	30	Handling 6-meter heavy rods is time-consuming, demanding coordination, and physically strenuous.
	Cutting (BS1)	Turning (T1)	Trolley with Storage Bins	-	0.297	1.983	0.301	2.581	65	Cutting is slower than transport; batching does not cause a bottleneck.
	Turning (T1)	Turning (T2)	Manual Lifting	-	0.062	0.170	0.060	0.292	3	Machines are side-by-side; simple, quick transfer.
	Turning (T2)	Stamping Both Marking (S1)	Trolley with Storage Bins	-	0.297	0.622	0.301	1.220	55	Each bin ~30 kg; 3 bins per trolley.
	Stamping (S1)	Milling Rough (M1)	Trolley with Storage Bins	-	0.297	1.395	0.301	1.993	45	Each bin ~30 kg; 3 bins per trolley.
	Milling Rough (M1)	Stamping Rough (S2)	Trolley with Storage Bins	-	0.297	1.405	0.301	2.003	75	Long distance travel; causes fatigue.
	Stamping Rough (S2)	Stamping Finishing Profile (S3)	Manual Lifting	-	0.068	0.267	0.060	0.395	5	Side-by-side transfer; no bottleneck.
	Stamping Finishing (S3)	ID Bore & OD Turn (T3)	Trolley with Storage Bins	-	0.297	0.517	0.301	1.115	40	Each bin ~30 kg; 3 bins per trolley.
	ID Bore & OD Turn (T3)	ID & Length Turning (T4)	Robotic Arm	-	0.033	0.092	0.033	0.158	3	Robotic transfer reduces cycle time and eliminates manual handling.
	ID & Length Turning (T4)	Milling & Tap (M2)	Trolley with Storage Bins	-	0.297	0.140	0.301	0.738	20	Each bin ~30 kg; 3 bins per trolley.
	Milling & Tap (M2)	Trivalent White Plating (Outsource)	Trolley with Storage Bins	-	0.297	0.270	0.301	0.868	25	Each bin ~30 kg; 3 bins per trolley.

3.4 Analysis of Worker Inefficiencies

Structured analysis quantified the time penalties and ergonomic risks associated with manual handling. Time-Motion Study Findings:

- The most time-consuming transition was from the Warehouse to Cutting (BS1), totalling approximately 36.2 minutes, largely due to the challenging manual adjustment and precise alignment of the 6-meter long, heavy rods during band saw loading.
- The physical effort required to push 90 kg loads over long distances, particularly between Milling Rough and Stamping Rough, prolonged the travel time and contributed to worker fatigue.
- The most efficient movement was the automated transfer using the robotic arm, which took just 0.158 minutes (approximately 3 seconds).

3.5 Ergonomic Risk (RULA)

Table 2 summarizes the ergonomic risk scores from the RULA (Rapid Upper Limb Assessment) analysis of various material handling tasks observed in the production area. Transitions such as Milling Rough to Stamping Rough and Warehouse to Cutting scored 6-7, indicating urgent need for intervention. Tasks involving robotic assistance (e.g., ID Bore to T4) scored as low as 2, highlighting the value of automation.

Table 2
RULA assessment results across different transitions.

From Process	To Process	Wrist/ Arm Score	Neck/ Trunk/Leg Score	Final RULA Score	Risk Level
Warehouse	Cutting	6	3	5	Investigate and change soon
Cutting	Turning (T1)	6	4	6	Investigate and change soon
Turning (T1)	Turning (T2)	2	2	2	Acceptable
Turning (T2)	Stamping Both Marking (S1)	6	6	7	Investigate and implement change
Stamping Both Marking (S1)	Milling Rough (M1)	6	6	7	Investigate and implement change
Milling Rough (M1)	Stamping Rough (S2)	6	6	7	Investigate and implement change
Stamping Rough (S2)	Stamping Finishing Profile (S3)	2	2	2	Acceptable
Stamping Finishing Profile (S3)	ID Bore & OD Turn (T3)	6	6	7	Investigate and implement change
ID Bore & OD Turn (T3)	ID & Length Turning (T4)	-	-	-	Using Robot Arm
ID & Length Turning (T4)	Milling & Tap (M2)	6	6	7	Investigate and implement change
Milling & Tap (M2)	Trivalent White Plating (Outsource)	6	6	7	Investigate and implement change

3.5.1 RULA Ergonomic Assessment Findings

The Rapid Upper Limb Assessment (RULA) revealed high ergonomic risks in manual handling tasks.

- Several transitions involving pushing heavy trolleys and awkward postures were classified as high risk, receiving a RULA score of 7 (meaning "Investigate and Implement Change").
- Tasks involving short-distance manual lifting or the use of the robotic arm received acceptable RULA scores (as low as 2).

3.5.2 Worker Feedback (Nordic Musculoskeletal Questionnaire):

Workers reported consistent discomfort, particularly in the lower back, neck, knees, and shoulders, associated with repetitive lifting and pushing duties. Feedback also confirmed a lack of formal safety training specific to material handling, with workers relying only on informal guidance.

3.6 Recommended Solutions and Validation

Solutions were proposed and validated to ensure they were both effective and feasible within the SME's resource constraints.

3.6.1 Proposed Solution: Implementation of AGV/AMR for Material Handling

The current material handling system causes workers fatigue due to manually pushing heavy bins over long distances. To address this, Autonomous Mobile Robots (AMRs) are proposed to automate high-strain material transfers, reducing physical effort and ergonomic risks. AMRs were chosen over AGVs and conveyors for their flexibility and adaptability in dynamic factory environments. The selected AMR is the Mecalux AMR 100 which is designed to transport boxes, totes, bins, and trays. It is equipped with a configurable upper conveyor for load transfers. Table 3 lists the technical specifications of the Mecalux AMR 100 Box unit, chosen as the proposed automation solution for improving handling safety.

3.6.2 Proposed Solution: Standardized Safe Work Method for Material Loading at Band Saw Cutting Machine

Developed for loading at the band saw station; includes visual guidelines and ergonomic techniques to reduce upper limb stress. Figure 3 shows the Standard Work Method for material loading and band saw cutting machine.

3.7 Simulation Insights of the Proposed Solution

Figure 4 displays the improved simulation layout in FlexSim software after integrating the proposed Autonomous Mobile Robot (AMR) pathway. This simulation shows how the AMR replaces manual transport between long-distance zones such as the Raw Material Area and the Cutting Machine. The dedicated AMR route reduces worker fatigue and shortens the handling time significantly, while allowing human operators to focus on value-added tasks.

Table 3
Technical specifications Mecalux AMR 100

MECALUX

Name	AMR 100 Box
Maximum Speed	1.6 m/s
Robot Weight	130 kg
Maximum Load Weight	100 kg
Battery type	Li-Ion NMC 51.8 V / 29 Ah (1.5 kWh)
Battery runtime	8 hours with payload, 10 hours without payload
Charge time	< 60 minutes
Runtime ratio	10:1
Turning radius	0 mm (can rotate in place)
Dimensions	Width: 640 mm Length: 780 mm Height: 750 mm
Navigation	Autonomous
Functionality	Load transfer

Fig. 3. Standard work method for material loading direction at band saw machine

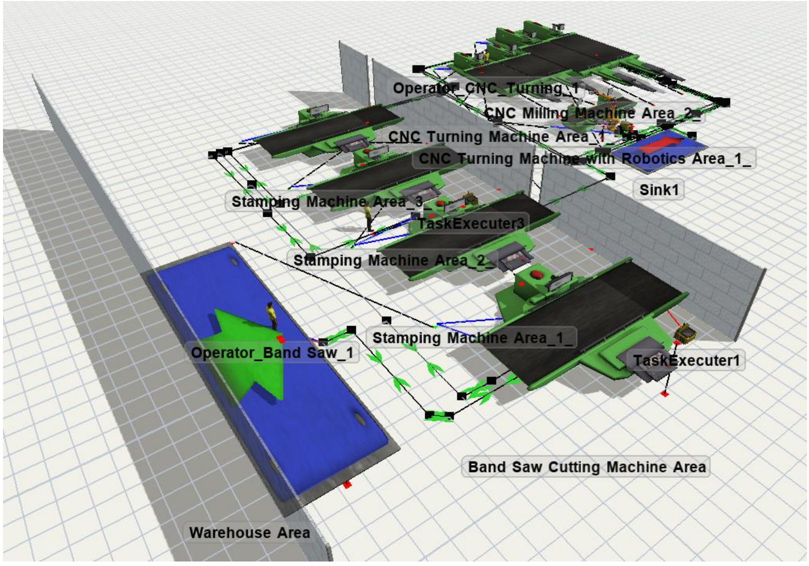

Fig. 4. FlexSim simulation of the improvement material handling flow

3.8 Validation (Ergonomic & Safety)

CATIA Ergonomics Design & Analysis module was used to simulate two key scenarios based on site observation and proposed changes; Before AMR (Pushing Trolley & Lifting Bin from Trolley to Table) and After AMR (Lifting from AMR Flat Surface to Table)

3.8.1 Before AMR (Pushing Trolley & Lifting Bin from Trolley to Table)

Figures 5 to 7 illustrate the RULA (Rapid Upper Limb Assessment) ergonomic evaluations conducted using CATIA software for different manual handling postures at FAMAX Technology (M) Sdn. Bhd. Figure 5 shows the posture of an operator pushing a fully loaded trolley. The RULA result yielded a score of 7, indicating Action Level 4, which demands immediate corrective action due to high strain on the upper arms, wrists, and shoulders. In Figure 6, the worker is depicted lifting items from the trolley to a workstation. This posture, involving trunk flexion and unsupported arm movement, resulted in a RULA score of 6 (Action Level 3), suggesting that changes are required soon to reduce musculoskeletal risk. Lastly, Figure 7 shows the after lifting posture on to the table.

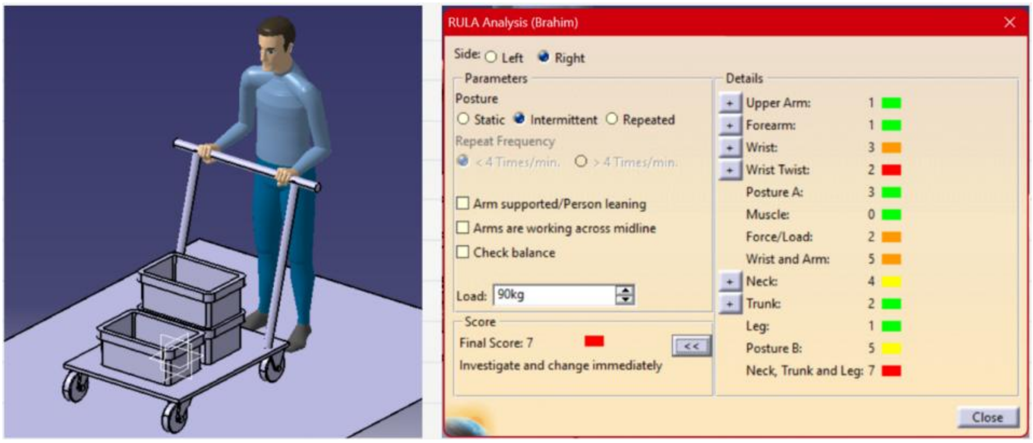

Fig. 5. CATIA RULA analysis before AMR (Pushing Trolley)

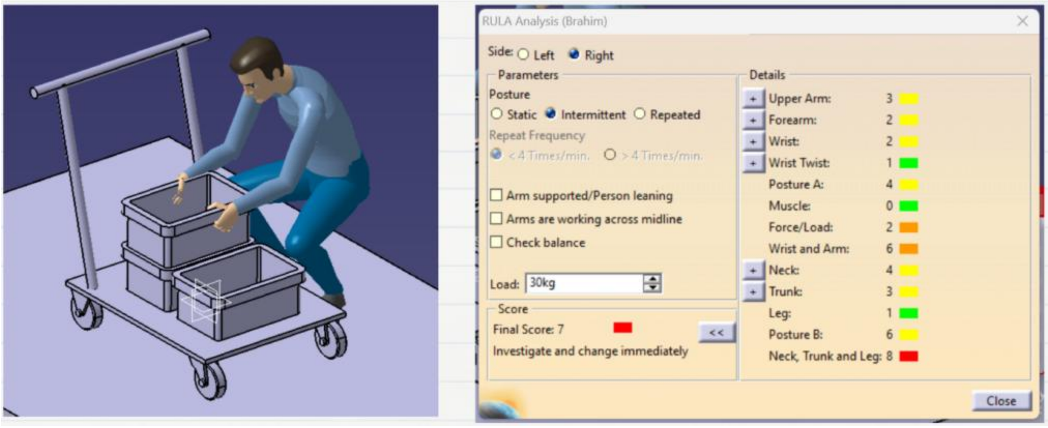

Fig. 6 CATIA RULA analysis before AMR (Before lifting posture)

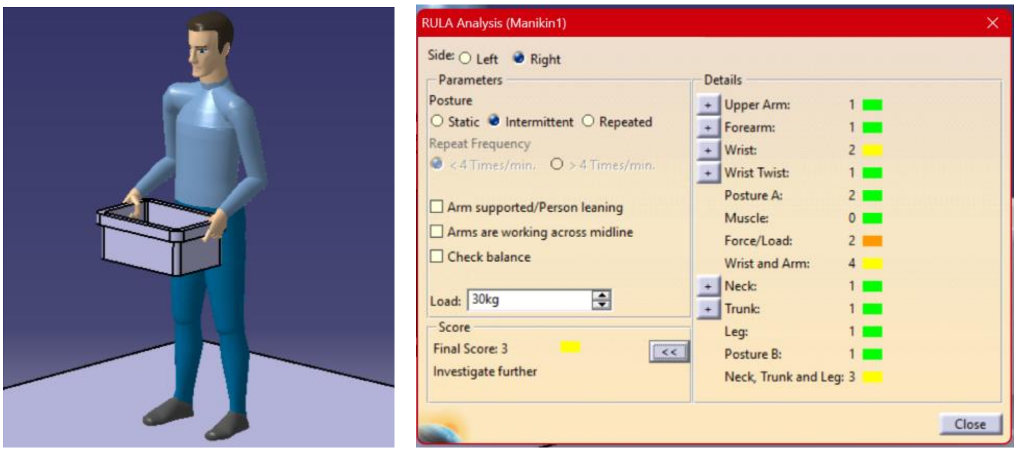

Fig. 7 CATIA RULA analysis before AMR (After lifting posture)

3.8.2 After AMR (Lifting from AMR Flat Surface to Table)

Figure 8 shows operator now lifts the bin directly from the AMR surface with minimal vertical movement and no trunk bending. Only one upright posture was simulated for this scenario.

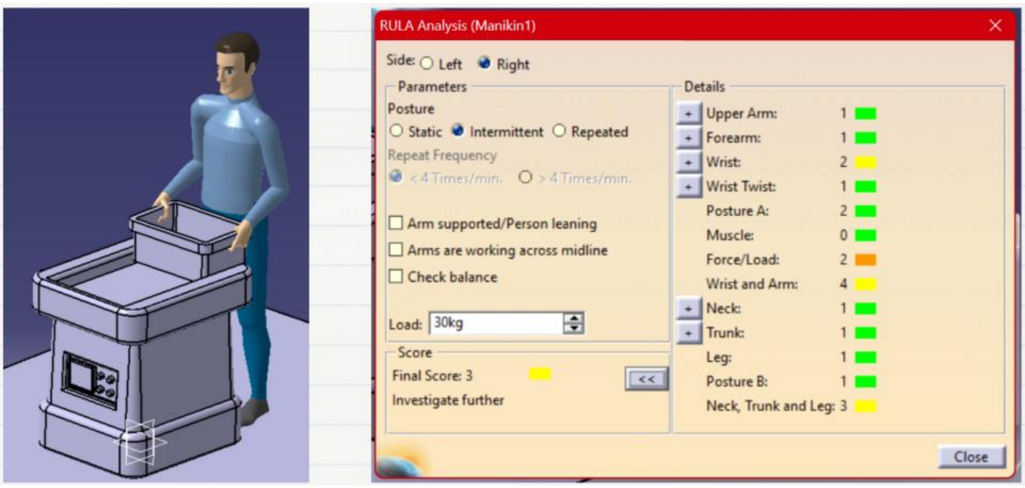

Fig. 8. CATIA RULA analysis after AMR (Lifting from AMR)

3.9 Safety Validations using NIOSH Lifting Equation

NIOSH Lifting Equation was used to evaluate the safety level of the same lifting task. This equation estimates the Recommended Weight Limit (RWL) and Lifting Index (LI) based on multiple variables such as lifting geometry, load characteristics, and task frequency. Table 4 and 5 shows the NIOSH Lifting Equation Before AMR (From Trolley to Table) and After AMR (From AMR to Table).

Table 4
NIOSH lifting equation before AMR (From Trolley to Table)

	Origin	Destination	M_Origin	M_Destination
1. Load Weight	30	30	30	30
Load Constant	23	23	23	23
2. Horizontal Location (H)	52	25	0.480769231	1
3. Vertical Location (V)	53	90	0.934	0.955
4. Vertical Travel Distance (D)	37	37	0.941621622	0.941621622
5. Asymmetry Angle (A)	90	90	0.712	0.712
6. Lifting Frequency	3	3	0.88	0.88
8. Coupling Classification	Good	Good	1	1
RWL (Recommended Weight Limit)			6.093270599	12.95896437
Lifting Index			4.923464257	2.314999807

Table 5
NIOSH lifting equation after AMR (From AMR to Table)

	Origin	Destination	M_Origin	M_Destination
1. Load Weight (kg)	30	30	30	30
Load Constant (kg)	23	23	23	23
2. Horizontal Location (H) (cm)	25	25	1	1
3. Vertical Location (V) (cm)	90	90	0.955	0.955
4. Vertical Travel Distance (D) (cm)	5	5	1.72	1.72
5. Asymmetry Angle (A) (∠)	0	0	1	1
6. Lifting Frequency	3	3	0.88	0.88
8. Coupling Classification	Good	Good	1	1
RWL (Recommended Weight Limit)			33.246224	33.246224
Lifting Index			0.902358114	0.902358114

3.10 Validation (Cost Analysis)

Tables 6 and 7 show the Capital Cost Breakdown for the Mecalux 100 Box Implementation and Estimated Operational Savings and ROI Drivers from AMR Implementation. Implementation of AMR showed potential ROI within 2.5 years, with projected reduction in injury-related downtime and improved task consistency.

Table 6
Capital cost breakdown for Mecalux AMR 100 Box Implementation

Item	Estimated Cost (RM)
AMR Unit Hardware	80,000
Software Setup & Integration	10,000
Charging Station & Infrastructure	5,000
Training & Commissioning	5,000
Total Initial Investment	100,000

Table 7
Estimated Operational Savings and ROI Drivers from AMR Implementation

Benefit Area	Estimated Annual Value (RM)	Explanation
Reduced Labor & Overtime	25,000	Increased productivity by reducing non-value-added tasks for machine operators
Insurance & Health Claim Savings	5,000	Fewer ergonomic injuries may reduce premiums and worker compensation payouts
Material Handling Accuracy	Qualitative	AMRs reduce product damage and rework from unstable trolley movement
Maintenance Cost (AMR)	-2,000	Estimated annual servicing cost
Net Annual Benefit	28,000	Approximate annual savings after expenses

3.11 Discussion and Justification of Proposed Solutions

The implementation of Autonomous Mobile Robots (AMRs) at FAMAX Technology was rigorously assessed from ergonomic, safety, and cost perspectives. Ergonomic evaluation showed a significant reduction in RULA scores (from 7 to 3), and safety assessment using the NIOSH Lifting Equation reduced the lifting index from 4.92 to below 1.0. Financial analysis estimated RM 28,000/year savings on a RM 100,000 investment, yielding a 3–4-year payback.

Our findings are consistent with recent studies in material-handling automation. In semiconductor smart factories, digitalized automated material-handling systems markedly improve throughput and process adaptability by integrating real-time data with flexible robotic vehicles [7]. Similarly, A comprehensive model outlining the cost and organizational factors influencing autonomous robot adoption in supply chains has underscored perceived cost as a primary barrier, consistent with our observation that robots improved safety ROI with minimal capital impact, as reported by Shamout *et al.* [8] and Naumann *et al.* [9]. These ergonomic enhancements mirror earlier findings showing that postural-assist exoskeletons can significantly decrease upper-limb strain in SME manual-handling activities, reinforcing the risk reduction achieved through our AMR-assisted workflow, as reported by Ogunseiju *et al.* [10] and Vargas-Pardo & Giraldo-Ramos [11]. Furthermore, optimized layout design using a Firefly Algorithm has been shown to significantly reduce travel distances and handling times in SMEs, aligning with the gains achieved in our standardized band-saw area and further strengthened by AMR deployment to enhance automation and ergonomic outcomes, as reported by Bechtsis *et al.* [12]. Whereas prior research emphasized pure ergonomic training in poultry operations, our approach expands these principles through AMR integration to better balance human-centered design with automation [13-15]. The success of our implementation at FAMAX, which relied on top-management support and trained operators, reflects the importance of organizational and managerial backing in adoption processes, as highlighted by Shamout *et al.* [8].

4. Conclusions

This study successfully achieved its objective of enhancing the material handling system at FAMAX Technology (M) Sdn. Bhd. by integrating ergonomic principles with cost-effective technological solutions to optimize safety and efficiency. The investigation revealed that the company's heavy reliance on manual handling, such as repetitive lifting of 30 kg bins and pushing 90 kg trolleys resulted in high ergonomic risk, operational delays, and reduced worker well-being.

Time-motion and RULA analyses, supported by CATIA simulation, confirmed critical postural stresses (RULA score = 7) and prolonged handling durations, while worker feedback corroborated widespread musculoskeletal discomfort.

The implementation of ergonomic interventions and partial automation through Autonomous Mobile Robots (AMRs) demonstrated substantial improvements across safety, performance, and financial indicators. Ergonomic validation showed a reduction in RULA scores from 7 to 3, and the NIOSH Lifting Index decreased from 4.92 to 0.90, indicating a transition from hazardous to acceptable working conditions. Financial evaluation confirmed feasibility, with an estimated payback period of 3–4 years for the RM 100,000 investment.

In conclusion, the research underscores that structured ergonomic assessment combined with affordable automation can significantly mitigate manual handling risks, enhance operator safety, and improve productivity in small and medium-sized enterprises (SMEs). The outcomes not only provide a validated framework for ergonomic redesign within FAMAX but also contribute practical, transferable strategies for other SMEs seeking to advance workplace safety and sustainable manufacturing performance under resource constraints.

The findings demonstrate that integrating structured ergonomic analysis and practical design improvements with targeted, cost-effective automation offers a viable strategy for enhancing safety and performance in resource-constrained environments. The proposed standard work methods and the implementation of AMRs successfully mitigate manual handling risks, reduce physical strain, and align the company with sustainable, safer manufacturing practices. This research offers actionable, low-cost strategies that can be adapted and applied by other SMEs facing similar material handling challenges.

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References

[1] S. Anwer, H. Li, M.F. Antwi-Afari and A.Y.L. Wong, "Associations Between Physical or Psychosocial Risk Factors and Work-Related Musculoskeletal Disorders in Construction Workers Based on Literature in the Last 20 Years: A Systematic Review," International Journal of Industrial Ergonomics, (2021):83. https://doi.org/10.1016/j.ergon.2021.103113

[2] Y. Harari, A. Bechar and R. Riemer, "Simulation-Based Optimization Methodology for a Manual Material Handling Task Design That Maximizes Productivity while Considering Ergonomic Constraints," IEEE Transactions on Human-Machine Systems 49, no. 5(2019): 440–448. https://doi.org/10.1109/THMS.2019.2900294

[3] M. Waseem, U. Ghani, T. Habib, S. Noor and T. Ahmed, "Productivity Enhancement with Material Handling System Design and Human Factors Analysis – a Case Study," Mehran University Research Journal of Engineering and Technology 40, no.3(2021): 556–569. https://doi.org/10.22581/muet1982.2103.10

[4] A.N. Ariq Ms, B.A. Bimasakti, F.F. Laureng, S. Ady Wicaksono, R. Nurcahyo and A. Nurdini, "Optimizing the Facility Layout and Material Handling System Using the Systematic Layout Planning Method: A Case Study at PT EDS Manufacturing Indonesia," Proceedings of the International Conference on Industrial Engineering and Operations Management, June 6 (2024). https://doi.org/10.46254/AN14.20240495

[5] D. Derrell Forest and G.H. Massiha, " Material Handling and Assembly Process Optimization using Value Stream Mapping," IAES International Journal of Robotics and Automation (IJRA) 6, no. 1 (2017): 59. https://doi.org/10.11591/ijra.v6i1.pp59-68 59

[6] E. Charistheo, T.D. Sofianti and A.T. Pratama, "Material Handling System Improvement in Injection Section of Automotive Manufacturing Company," ACM International Conference Proceeding Series, (2020). https://dl.acm.org/doi/epdf/10.1145/3429789.3429803

[7] R. Wang, "Digitalization Solutions for Automated Material Handling Systems in Semiconductor Smart Factories," Proceedings of 2024 Conference of Science and Technology for Integrated Circuits, (2024): 1–4. https://doi.org/10.1109/cstic61820.2024.10531903

[8] Mohamed Shamout, Rabeb Ben-Abdallah, Muhammad Alshurideh, Haitham Alzoubi, Barween Al Kurdi and Samer Hamadneh, "A Conceptual Model for the Adoption of Autonomous Robots in Supply Chain and Logistics Industry Growing Science," Journal Uncertain Supply Chain Management 10, no. 2(2022): 577–592. https://doi.org/10.5267/j.uscm.2021.11.006

[9] F. Naumann, V. Gottschalk, B. Burchard and F. Altmann, "Reliability Evaluation of Si-dies due to Assembly Issues," Microelectronics Reliability 64, (2016): 266–269. https://doi.org/10.1016/j.microrel.2016.07.065

[10] O. Ogunseiju, J. Olayiwola, AAkanmu and O.A. Olatunji, "Evaluation of Postural-Assist Exoskeleton for Manual Material Handling," Engineering, Construction and Architectural Management 29, no. 3(2022): 1358–1375. https://doi.org/10.1108/ecam-07-2020-0491

[11] Vargas-Pardo, Luisa and Giraldo-Ramos, Frank, "Firefly Algorithm for Facility Layout Problem Optimization," Visión Electrónica 15, (2021): 218-225. https://doi.org/10.14483/22484728.17474

[12] D. Bechtsis, N. Tsolakis, D. Vlachos and E. Iakovou, "Sustainable Supply Chain Management in the Digitalisation Era: The Impact of Automated Guided Vehicles," University of Cambridge Repository, (2017). https://doi.org/10.17863/CAM.6888

[13] M.S. Denadai, S.R. Alouche, D.P. Valentim and R.S. Padula, "An Ergonomics Educational Training Program to Prevent Work-Related Musculoskeletal Disorders to Novice and Experienced Workers in the Poultry Processing Industry: A Quasi-Experimental Study," Applied Ergonomics 90, (2021): 103234. https://doi.org/10.1016/j.apergo.2020.103234

[14] S.S. Zulkifly, N. Yaakub and N. S. Mohamad Zahir, "Assessing the Level of Employees' Safety Performance in Northern Malaysian Small & Medium Manufacturings," International Journal of Research and Innovation in Social Science 8, no. 1(2024): 2061-2066. https://doi.org/10.47772/IJRISS.2024.801152

[15] C. L. Chang, R. Y. Xu and J. Y. Ke, "Design and Implementation of an AI-Driven Mobile Robot for Managing Poultry Tasks, "2024 International Automatic Control Conference (CACS)," (Taoyuan, Taiwan, 2024): 1-6. https://doi.org/10.1109/CACS63404.2024.10773178