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Design Enhancement of Hose Rolling Tool for Firefighters Using DFMA

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Abstract

Firefighting operations depend significantly on effective equipment, with hose rolling tools being crucial for the swift deployment and recovery of fire hoses. Existing hose rolling tool designs frequently exhibit significant component counts, intricate assembly, and elevated manufacturing costs, which hinder operational efficiency and escalate manufacture expenses. This project seeks to improve the design of a hose rolling tool for firefighters by utilizing Design for Manufacturing and Assembly (DFMA) principles to decrease part complexity and cost. The project entailed evaluating the current hose rolling tool design, highlighting inefficiencies, and methodically improving the tool through SolidWorks modelling and manual Design for Assembly (DFA) analysis such as Boothroyd-Dewhurst DFA worksheet method. Comparative evaluations were performed to analyze part quantity, material expenses, and assembly durations between the original and revised models. The findings indicated a substantial decrease in total components from 40 to 25, an 11% reduction in production expenses, and a 48% enhancement in assembly efficiency. These findings underscore the efficacy of DFMA in enhancing product design for manufacturing and assembly, resulting in more economical and user-centric firefighting equipment. In summary, the implementation of DFMA principles significantly enhanced the manufacturability and operational efficacy of the hose rolling tool, offering a viable framework for future advancements in firefighting equipment.

1. Introduction

In recent decades, technology breakthroughs have significantly transformed society, facilitating the creation of more efficient tools and systems for public safety and emergency response. Firefighting, specifically, depended on specialized tools to guarantee swift and efficient response during crises. The hose rolling tool was essential for the deployment and retrieval of hoses, significantly influencing the efficiency and safety of firefighting operations [1].

Considering continuous advancements in engineering technology, numerous hoses rolling tool tools continue to exhibit complexity, featuring a multitude of components and extensive assemblies. This complexity frequently led to elevated production costs, extended assembly durations, and heightened risk of operational failure [2,3]. Previous studies emphasized the significance of Design for Manufacturing and Assembly (DFMA) as a methodical

strategy to streamline product design; nevertheless, its implementation in firefighting equipment has been restricted [4,5]. The absence of cost analysis and inadequate emphasis on manufacturability further constrained the practical improvement of these instruments.

The project primarily focused on the inefficiencies and elevated costs linked to the traditional hose rolling tool. The current design incorporated excessive complexity, resulting in manufacturing difficulties and higher costs. If neglected, these factors may impede the operational preparedness and dependability of firefighting units. Consequently, it was essential to reengineer the hose rolling tool to streamline its design, minimize component quantity, and decrease manufacturing expenses while maintaining performance [1,6].

The current project concentrated on improving the hose rolling tools for firefighters through the application of design for DFMA principles. The project intends to address the enhancement of hose rolling tool focusing on efficiency and cost effectiveness by employing DFMA method. The aim was to enhance an innovative concept that reduced the quantity of components and assembly procedures, thereby yielding a more durable, dependable, and economical equipment for firefighting activities [3,7].

2. Methodology

This section describes the methodology used to redesign and evaluate the hose rolling tool. The approach combined material selection, DFMA principles, 3D modeling, and cost analysis to improve efficiency and reduce manufacturing costs. The following subsections outline the materials, tools, and procedures applied throughout the project.

2.1 Materials

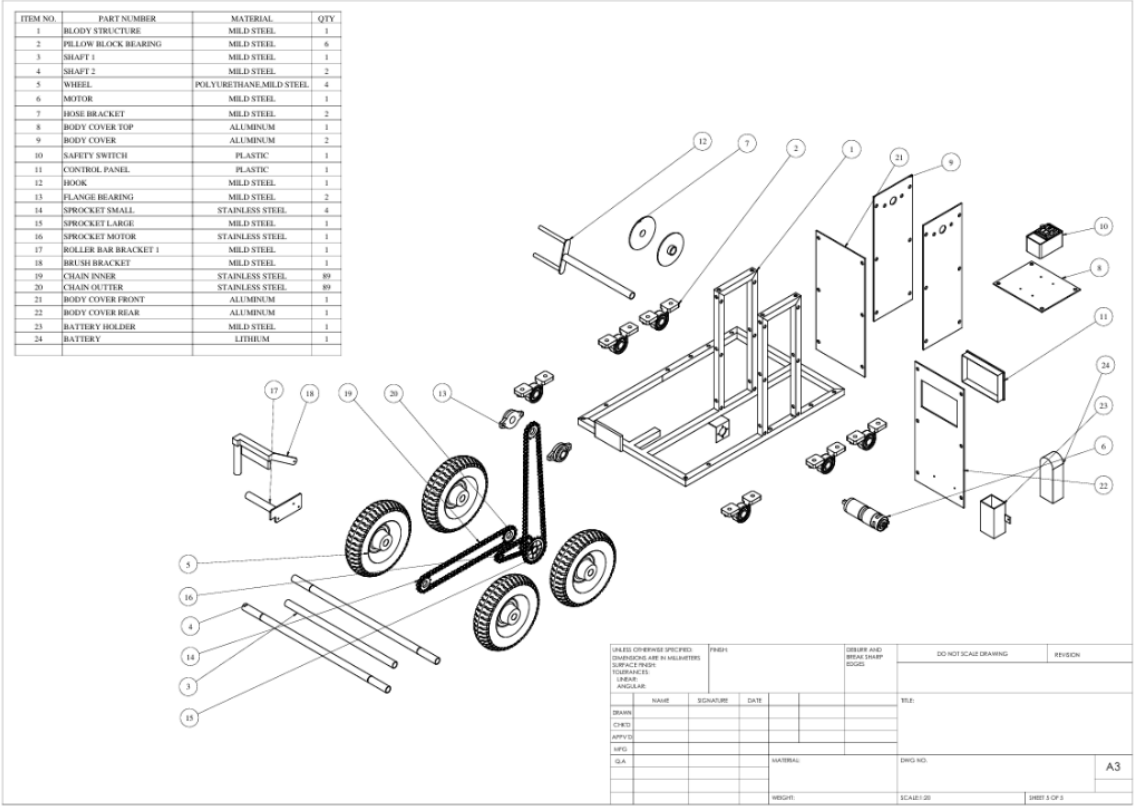
The original hose rolling tool was acquired and utilized as the reference for evaluation and development. Standard mechanical fasteners, including bolts and nuts, were procured from trustworthy suppliers to guarantee compatibility and facilitate assembly. Mild steel and aluminum were chosen as the principal materials because of their advantageous combination of strength, manufacturability, and cost-efficiency [2].

2.2 Design and Analytical Tools

The hose rolling tool's redesign utilized the concepts of DFMA. DFMA is an engineering approach that streamlines product design by minimizing part count and enhancing assembly procedures [8]. This strategy sought to improve manufacturability, reduce assembly duration, and decrease manufacturing expenses for the hose rolling tool. The DFMA principles inspired every phase of the redesign, from the initial concept to the final assessment.

SolidWorks software served as the principal instrument for three-dimensional modelling and visualisation. The original and updated hose rolling tool tools were meticulously modelled to guarantee precise measurement and analysis of each component [9]. The software facilitated iterative adjustments, permitting the incorporation of components and the removal of redundancies. Fig. 1 illustrates the exploded view of the original hose rolling tool tools, emphasising the decrease in part count and complexity needed via the implementation of DFMA.

J. of Advanced Industrial Technology and Application Vol. 6 No. 2 (2025) p. 27-36



ITEM NO.	PART NUMBER	MATERIAL	QTY
1	BLODY STRUCTURE	MILD STEEL	1
2	PILLOW BLOCK BEARING	MILD STEEL	6
3	SHAFT 1	MILD STEEL	1
4	SHAFT 2	MILD STEEL	2
5	WHEEL	POLYURETHANE,MILD STEEL	4
6	MOTOR	MILD STEEL	1
7	HOSE BRACKET	MILD STEEL	2
8	BODY COVER TOP	ALUMINUM	1
9	BODY COVER	ALUMINUM	2
10	SAFETY SWITCH	PLASTIC	1
11	CONTROL PANEL	PLASTIC	1
12	HOOK	MILD STEEL	1
13	FLANGE BEARING	MILD STEEL	2
14	SPROCKET SMALL	STAINLESS STEEL	4
15	SPROCKET LARGE	MILD STEEL	1
16	SPROCKET MOTOR	STAINLESS STEEL	1
17	ROLLER BAR BRACKET 1	MILD STEEL	1
18	BRUSH BRACKET	MILD STEEL	1
19	CHAIN INNER	STAINLESS STEEL	89
20	CHAIN OUTTER	STAINLESS STEEL	89
21	BODY COVER FRONT	ALUMINUM	1
22	BODY COVER REAR	ALUMINUM	1
23	BATTERY HOLDER	MILD STEEL	1
24	BATTERY	LITHIUM	1

Fig. 1 *Exploded views of old design hose rolling tool tool* [1]

The Boothroyd-Dewhurst manual Design for Assembly (DFA) worksheet was employed to assess assembly efficiency. This worksheet offered a methodical approach to evaluate handling and insertion durations for each component, grounded in empirical data and component geometry. The DFA index, which measures assembly efficiency, was computed for both the original and revised tools. Fig. 2 presents the DFA worksheet example for manual assessment.

0	1	2	3	4	5	6	7	8	9
Name of Part	Part ID #	# of times the operation is carried out consecutively	two-digit manual handling code	manual handling time per part	two-digit manual insertion code	manual insertion time per part	operation time, sec, (2) x [(4) + (6)]	operation cost, cents, 0.4 x (7)	estimation of theoretical minimum # of parts, 0 or 1
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
	20								
							TM	CM	NM

Fig. 2 *Example of manual DFA worksheet* [10]

Quantitative data analysis was performed during the redesign process. The quantity of components, projected assembly durations, and overall production expenses were documented and contrasted between the original and reengineered tools. Supplier quotations and standardised engineering cost models facilitated the cost analysis [11]. The integration of sophisticated CAD modelling, methodical DFA assessment, and quantitative analysis guaranteed that the reengineered hose rolling tool tool was both distinctive and functional for realistic firefighting applications [12].

2.3 Redesign Procedure

The project proceeded with a comprehensive disassembly and analysis of the original hose rolling tool. Every component was documented and its purpose evaluated to pinpoint sources of needless complexity and inefficiency. Measurements were obtained and documented for all components to establish a baseline for comparison during the redesign phase.

The redesign procedure was executed utilizing SolidWorks software. The design concentrated on incorporating various components, removing unnecessary components, and standardizing fasteners and materials. Multiple design iterations were generated, with each variant assessed for manufacturability and ease of assembly. The most prospective design was chosen for further analysis [13].

A cost analysis was conducted by gathering supplier quotations for materials and components. The cumulative production cost of the original and distinct hose rolling tool tools was computed and analyzed. Data from the DFA worksheet and cost analysis were employed to corroborate the efficacy of the redesign in diminishing part count, assembly duration, and total cost [11,14].

The Boothroyd-Dewhurst manual DFA worksheet was subsequently utilized for both the original and revised tools. This entailed assessing the handling and insertion durations for each component and computing the DFA index to measure assembly efficiency. The worksheet offered a systematic framework for pinpointing assembly inefficiencies and enhancement potential [2].

2.4 Data Analysis

A quantitative data analysis was conducted to assess the efficacy of the revised hose rolling tool tool. The primary data gathered encompassed the quantity of components, projected assembly durations, and overall production expenses for both the original and reengineered equipment. All measurements were recorded during the disassembly, redesign, and evaluation phases.

$$EM = 3\frac{NM}{TM} \tag{1}$$

The assembly efficiency was evaluated by computing the Design for Assembly (DFA) index utilizing the Boothroyd-Dewhurst worksheet. The handling and insertion durations for each component were assessed using empirical charts and the shape of the parts. Formula (1) presents the formula for calculating efficiency during DFA worksheet analysis subsequent to the computation of handling and insertion times where EM is the total efficiency in percentage, NM is the theoretical minimum number of parts and TM is the total manual assembly time in seconds. The gathered data were systematically arranged and presented for comparison in the results section, facilitating a clear evaluation of the enhancements realized using the DFMA methodology [10].

3. Results and Discussion

The outcomes of the redesign process are presented and analyzed in this section. The discussion focuses on the impact of DFMA principles on the hose rolling tool, specifically regarding part reduction, cost savings, and assembly efficiency. Comparative data between the original and revised designs are provided to highlight the tangible improvements achieved through the reengineering effort. The following subsections detail the quantitative and qualitative results of the project, offering insights into the effectiveness of the applied methodologies.

3.1 Total Parts

The simplification made to the hose rolling tool tools was achieved by reducing the total number of components from 40 in the old design to 25 in the new design, as shown in Table 1. This reduction was accomplished by integrating several parts into single multifunctional components and eliminating unnecessary features specific to the hose rolling tool. For example, the belt system, which previously required multiple brackets and fasteners as a chain system, was redesigned as an integrated unit, reducing the need for separate mounting hardware. The frame structure was also consolidated, combining previously separate support and body covers into fewer, more robust parts. Additionally, the number of auxiliary parts, such as wheels and bushings, was minimized by

J. of Advanced Industrial Technology and Application Vol. 6 No. 2 (2025) p. 27-36

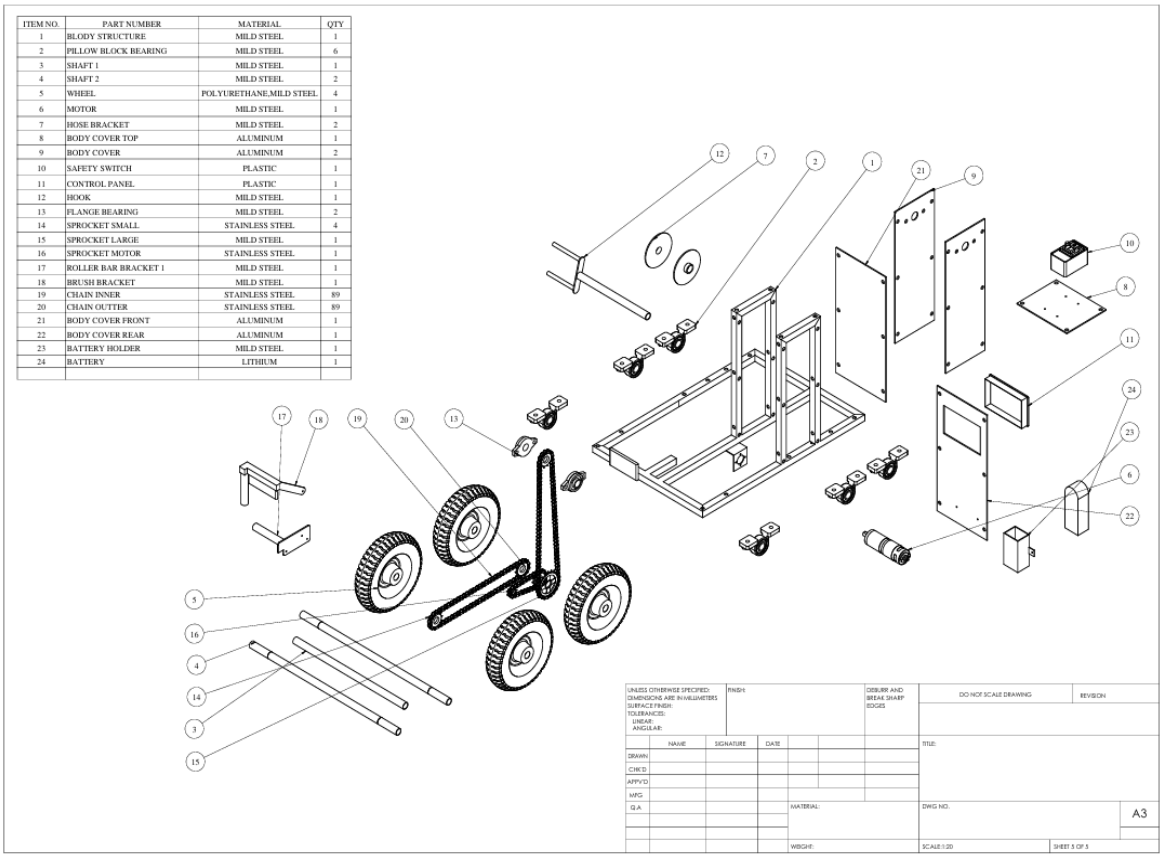
redesigning the roller assembly to require fewer supporting elements. The new proposed design is represented by Fig. 3. These changes not only simplified the assembly process but also improved the tool's reliability and reduced production costs, making the hose rolling tool more efficient and user-friendly for firefighting operations.

Table 1 *Total parts comparison for old and new designs*

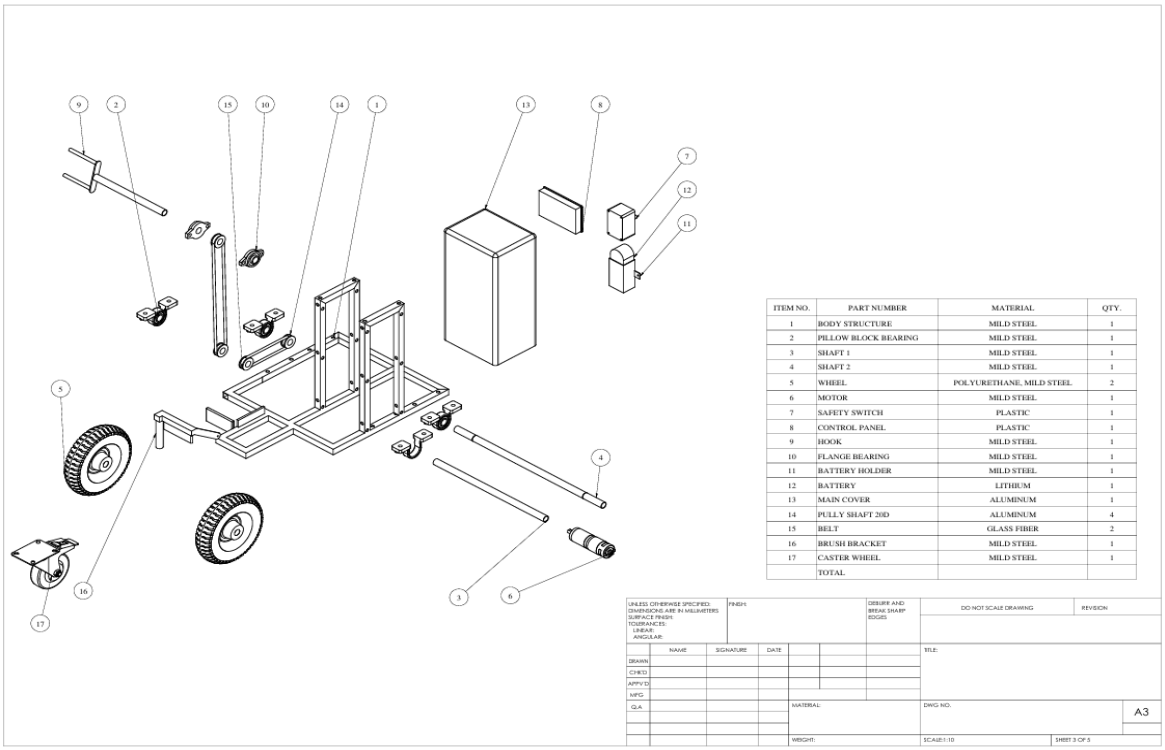
Category	Quantity (Old design)	Quantity (New design)
Structural components	10	6
Mechanical subsystems	19	13
Auxiliary parts	11	6
Total	**40**	**25**

The decrease in component quantity is noteworthy for multiple reasons. A reduced number of components typically results in diminished assembly mistake risk, decreased inventory demands, and streamlined maintenance for end users. In firefighting, when reliability and swift deployment are essential, reducing part complexity directly enhances operational efficacy. The revised design not only decreased the physical components but also streamlined the assembly process, enhancing the tool's intuitiveness [15].

The results correspond with other studies on DFMA, such as the assertion that component integration and simplification are essential for enhancing product manufacturability and reliability [2]. In a related vein, showing the same patterns, indicating that a reduction in part count within mechanical assemblies resulted in quantifiable enhancements in product performance and customer satisfaction [3]. Nonetheless, the process encountered obstacles. Certain components could not be merged due to functional or safety constraints, which restricted the degree of simplicity. Future projects should explore new materials or innovative joining procedures that may provide greater integration without sacrificing the tool's performance or safety.



(a)



(b)

Fig. 3 *Exploded views of the (a) current design; (b) new design hose rolling tool proposed*

3.2 Costing

The cost analysis indicated that the revised hose rolling tool was 11% more economical to manufacture than the original. The decrease was mostly attributable to the diminished quantity of components and the utilization of standardized, readily accessible materials and fasteners. For instance, the redesign eliminated the need for body brackets and integrated these functions into other existing structural components. Other minor components, such as sprockets, wheels and redundant fasteners, were also removed, reduced or consolidated. By reducing the number and variety of unique parts, the redesign minimized procurement complexity and allowed for more efficient inventory management. The overall simplification of the assembly process further contributed to lower labor costs, as fewer steps and less handling were required during production. Table 2 highlights the comparative production costs, offering a brief envision of the financial effects of the redesign.

Table 2 *Simple cost comparison [16]*

	Old design	New design
Cost	RM 4132	RM 3693

Reduced production costs yield direct advantages for both producers and consumers. Manufacturers can enhance profit margins and competitiveness through decreased material and labour costs. For firefighting organizations, cost-effective equipment enables more efficient resource allocation, perhaps facilitating wider distribution and enhanced preparation. The cost savings identified in this project align with prior DFMA project. The substantial cost reductions resulting from the systematic application of DFMA concepts in product development were documented [3,4].

The results underscore the significance of DFMA in enhancing both performance and cost feasibility in specialized tools. Regardless, there were constraints in the cost analysis. Supplier prices for estimating material and component costs may vary over time, and the analysis excluded potential costs associated with tooling modifications or large-scale production. The subsequent project should include a sensitivity analysis with empirical production data to deliver a more thorough economic evaluation.

3.3 Design Efficiency

The modification significantly enhanced assembly efficiency. The analysis of the Boothroyd-Dewhurst DFA worksheet indicated a 48% decrease in total assembly time for the revised design relative to the original. This enhancement was accomplished by the standardization of fasteners, the reduction of assembly stages, and the consolidation of subassemblies. The DFA index, which measures assembly efficiency, improved correspondingly, validating the practical advantages of the DFMA methodology.

The decrease in assembling time has numerous practical consequences. For manufacturers, streamlined assembly results in reduced labour expenses and abbreviated production timelines. A tool that is simpler to construct and maintain can improve preparedness and save downtime for firefighters during crucial operations. The optimized assembly procedure diminishes the probability of human error, hence enhancing the tool's reliability. Table 3 presents the comparative proportion between the old and new designs.

Table 3 *DFA efficiency comparison*

	Old design	New design
Efficiency	25.21%	37.18%

These results align with the existing literature. An indication that the implementation of DFMA concepts in product design consistently results in reduced assembly times and enhanced efficiency [2,5]. This project expands these findings to specialized firefighting equipment, illustrating that DFMA can provide significant advantages even in challenging operational environments.

Although these enhancements were made, the assembly evaluation depended on manual DFA worksheet analysis, potentially introducing subjective bias. Automated assembly analysis tools or practical assembly trials may yield more objective and thorough evaluations in the next project.

3.4 Recommendation

The findings of this project suggest that producers of firefighting equipment should implement DFMA principles to enhance design and production efficiency. Future project is advised to concentrate on the integration of automated DFA tools, the execution of field trials with end users, and the investigation of improved materials or joining techniques for enhanced simplicity. Addressing these aspects will facilitate the surmounting of existing constraints and improve the dependability, efficacy, and cost-effectiveness of firefighting equipment.

4. Conclusion

This project successfully applied DFMA principles to redesign a firefighter hose rolling tool, reducing parts from 40 to 25, cutting production costs by 11%, and improving assembly efficiency by 48%. By analyzing the original design and using 3D modeling and DFA techniques, the project confirmed that DFMA effectively streamlines complex tools while maintaining functionality. Although results are promising, limitations such as cost variability and manual assessment methods suggest future work should include automated analysis, ergonomic testing, and exploration of new materials to further optimize design. Overall, this project highlights DFMA's potential to enhance the efficiency, affordability, and reliability of firefighting equipment, providing a foundation for continued innovation in emergency response tools.

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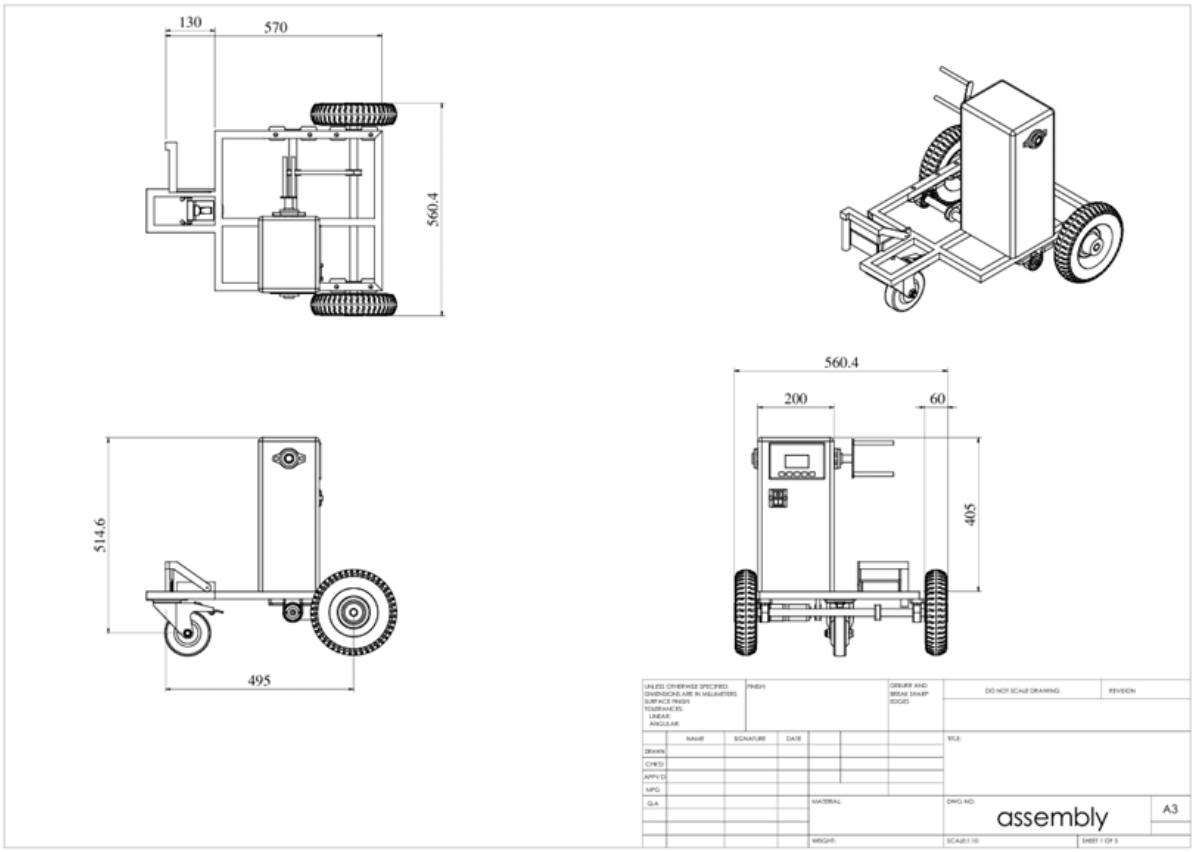
Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***project conception and design:*** *Adam Danial Zailani, Salwa Mahmood, Ismail Abdul Rahman;* ***data collection:*** *Adam Danial Zailani;* ***analysis and interpretation of results:*** *Adam Danial Zailani, Salwa Mahmood, Azli Nawawi;* ***draft manuscript preparation:*** *Adam Danial Zailani, Salwa Mahmood. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A: Assembly View of the New Hose Rolling Tool



Appendix B: Old Design DFA Analysis

Old design DFA worksheet analysis									
c1	c2	c3	c4	c5	c6	c7	c8	c9	Assembly Name
Part ID	No of times the operations is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	Manual insertion time per part	Operation time c2(c4+c6)	Operation cost 0.4(c7)	Estimation for theoretical minimum parts	MOTORIZED HOSE ROLLER
1	1	95	4	00	1.5	5.5	2.2	1	Body structure
2	6	20	1.8	08	6.5	49.8	19.92	3	Pillow block bearing
3	1	80	4.1	07	6.5	10.6	4.24	1	Shaft 1
4	2	80	4.1	07	6.5	21.2	8.48	1	Shaft 2
5	4	80	4.1	00	1.5	22.4	8.96	3	Wheel
6	1	10	1.5	09	7.5	9	3.6	1	Motor
7	2	12	2.25	11	5	14.5	5.8	0	Hose bracket
8	1	12	2.25	08	6.5	8.75	3.5	1	Body cover top
9	2	22	2.55	08	6.5	18.1	7.24	0	Body cover
10	1	30	1.95	06	5.5	7.45	2.98	1	Safety switch
11	1	30	1.95	00	1.5	3.45	1.38	1	Control panel
12	1	10	1.5	29	11.5	13	5.2	1	Hook
13	2	20	1.8	28	10.5	24.6	9.84	2	Flange bearing
14	4	00	1.13	08	6.5	30.52	12.208	4	Sprocket small
15	1	00	1.13	08	6.5	7.63	3.052	1	Sprocket large
16	1	00	1.13	18	9	10.13	4.052	1	Sprocket motor
17	1	30	1.95	08	6.5	8.45	3.38	1	Roller bar bracket 1
18	1	30	1.95	08	6.5	8.45	3.38	0	Brush bracket
19	3	02	1.88	13	6	23.64	9.456	3	Chain
21	1	10	1.5	08	6.5	8	3.2	0	Body cover front
22	1	20	1.8	08	6.5	8.3	3.32	0	Body cover rear
23	1	30	1.95	28	10.5	12.45	4.98	1	Battery holder
24	1	20	1.8	20	5.5	7.3	2.92	1	Battery
Total	40					333.22	133.288	28	
						TM	CM	NM	Design efficiency: 3 NM/TM = 0.25208

J. of Advanced Industrial Technology and Application Vol. 6 No. 2 (2025) p. 27-36

Appendix C: New Design DFA Analysis

New design DFA worksheet analysis									
c1	c2	c3	c4	c5	c6	c7	c8	c9	Assembly Name
Part ID	No of times the operations is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	Manual insertion time per part	Operation time c2(c4+c6)	Operation cost 0.4(c7)	Estimation for theoretical minimum parts	MOTORIZED HOSE ROLLER
1	1	95	4	00	1.5	5.5	2.2	1	Body structure
2	3	20	1.8	08	6.5	24.9	9.96	3	Pillow block bearing
3	1	80	4.1	07	6.5	10.6	4.24	1	Shaft 1
4	1	80	4.1	07	6.5	10.6	4.24	1	Shaft 2
5	2	80	4.1	00	1.5	11.2	4.48	2	Wheel
6	1	10	1.5	09	7.5	9	3.6	1	Motor
7	1	30	1.95	06	5.5	7.45	2.98	1	Safety switch
8	1	30	1.95	00	1.5	3.45	1.38	1	Control panel
9	1	10	1.5	29	11.5	13	5.2	1	Hook
10	2	20	1.8	28	10.5	24.6	9.84	2	Flange bearing
11	1	30	1.95	28	10.5	12.45	4.98	1	Battery holder
12	1	20	1.8	20	5.5	7.3	2.92	1	Battery
13	1	25	2.57	01	2.5	5.07	2.028	1	Main cover
14	4	00	1.13	13	6	28.52	11.408	4	Pully shaft 20D
15	2	03	1.69	03	3.5	10.38	4.152	2	Belt
16	1	35	2.73	08	6.5	9.23	3.692	1	Brush Bracket
17	1	30	1.95	08	6.5	8.45	3.38	1	Caster wheel
Total	25					201.7	80.68	25	
						TM	**CM**	**NM**	**Design efficiency:** 3 NM/TM = 0.3718

References

[1] Mustapha, M. L. H. B. (2024). *Ergonomic Hose rolling tool Tool Design for Firefighters: Fabrication and Low Back Disorder Risks Analysis*. Universiti Tun Hussein Onn Malaysia.

[2] Boothroyd, G., Dewhurst, P., & Knight, W. A. (2018). Product Design for Manufacture and Assembly. In *CRC Press eBooks*. https://doi.org/10.1201/9781420089288

[3] Formentini, G., Rodríguez, N. B., & Favi, C. (2022). Design for manufacturing and assembly methods in the product development process of mechanical products: a systematic literature review. *The International Journal of Advanced Manufacturing Technology,* 120(7–8), 4307–4334. https://doi.org/10.1007/s00170-022-08837-6

[4] Gonzalez, R., et al. (2022). Application of Design for Manufacturing and Assembly Principles in Product Development. *International Journal of Advanced Manufacturing Technology*, 95(1-4), 123-134. https://doi.org/10.1007/s00170-018-0279-0

[5] Mohammad, N. N., Rosli, M. F., Fadzly, M. K., Salikan, N. S. M., & Effendi, M. S. M. (2020). Design for Manufacturing and Assembly (DFMA): Redesign of Joystick. *IOP Conference Series Materials Science and Engineering*, 864(1), 012212. https://doi.org/10.1088/1757 899x/864/1/012212

[6] Rasu, S. (2024). Enhancing Manufacturing Feasibility through Design for Manufacturability (DFM) and Design for Assembly (DFA). *International Research Journal of Innovations in Engineering and Technology,* 08(09), 302-307. https://doi.org/10.47001/irjiet/2024.809037

[7] Naiju C.D. (2021). DFMA for product designers: a review. *Materials Today: Proceedings*, 46(17), 7473-7478. https://doi.org/10.1016/j.matpr.2021.01.134

[8] Sild, S. (2024, January 26). *Design for Manufacturing and Assembly*. Fractory. https://fractory.com/design-for-manufacturing-and assembly-dfma/

[9] SolidWorks. (2018). 3D CAD Design Software. https://www.solidworks.com/

[10] Nawawi, A. (2019). *Calculation of Manual Assembly in DFMA*. Universiti Tun Hussein Onn Malaysia. https://www.youtube.com/@AzliNawawi

[11] Benneker, B. (2022). Development of a Cost Price Model to Support Bid Price Estimation. http://essay.utwente.nl/87763/1/Benneker_BA_BMS.pdf

[12] Widanage, C., & Kim, K. P. (2024). Integrating Design for Manufacture and Assembly (DfMA) with BIM for infrastructure. *Automation in Construction*, 167, 105705. https://doi.org/10.1016/j.autcon.2024.105705

[13] Subbaiah, A., & Antony, K. M. (2021). Integration of DFMA and sustainability - A case study. International Journal of Sustainable Engineering, 14(3), 343–356. https://doi.org/10.1080/19397038.2020.1871443

[14] Sanmina. (2024). How to Boost Cost Savings: Combining DFMA with the VAVE Approach. https://www.sanmina.com/pdf/resources/how_to_boost_cost_-savings.pdf

[15] Newstreaming. (2024, March 11). 5 Strategies for Streamlining Your Assembly Process. https://www.newstreaming.com/5-strategies-for streamlining-your-assembly-process/

[16] MISUMI. (2025). *MISUMI | Configurable Components | Distributor & Manufacturer* https://us.misumi-ec.com/