MG2040
ASSEMBLY TECHNOLOGY

RC CAR

PROJECT REPORT

Group G

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1. Introduction

Assembly is the most important and crucial stage in the production process where mechanical, electrical and electronic components are assembled together to achieve the product's functionality. A well designed assembly process helps engineers to streamline workflows, balance assembly lines, reduce assembly time and increase efficiency of the overall process. It also helps to identify potential bottlenecks, opportunities for automation, minimize errors and increase the quality of the product.

In this report we focus on applying theoretical principles to a practical task to assemble a remote-controlled (RC) car. This hands-on project not only demonstrates the technical importance of assembly in product realization but also highlights how analytical tools are used in real-world manufacturing to ensure performance, consistency, and cost-effectiveness.

2. Product Description

Remote-controlled (RC) cars are a source of entertainment and excitement for several people, especially for kids, hobbyists, collectors or even future engineers. This diversity in the target audience for RC cars is justified by the product's ability to serve different purposes, which is related to its specifications. For instance, the car's performance and durability is something that interests hobbyists, while the user-friendly controls and robust design allow children to easily explore the world of RC cars. Furthermore, by being a small and interactive product it can also serve educational purposes by allowing teachers to explain the principles of mechanics, electronics and physics in an engaging way.

The RC car model that is going to be analysed in this project is a Land Monster, especially designed for anyone older than 8 years old and built for adventure, speed and fun. This product is made up of several components, including structural, electrical, mechanical and control elements, that work together to provide a seamless experience.

Through a powerful drive system this product is able to reach a speed of 15 km/h, which make it a perfect fit for racing purposes, by being both rapid and manageable. Moreover, its design, with large wheels and a shock-absorption suspension, offers stability and the opportunity to be driven on several types of terrain, such as street, lawn and sand. Finally, this product comes with an intuitive and user-friendly remote control that, by being connected to the steering system, enables the user to easily control the direction of the RC car.

3. Exploded View

The following drawings in figure 1 and figure 2 shows the exploded view of the car and the controller. As well as exploded drawings with lists of components in figure 3.

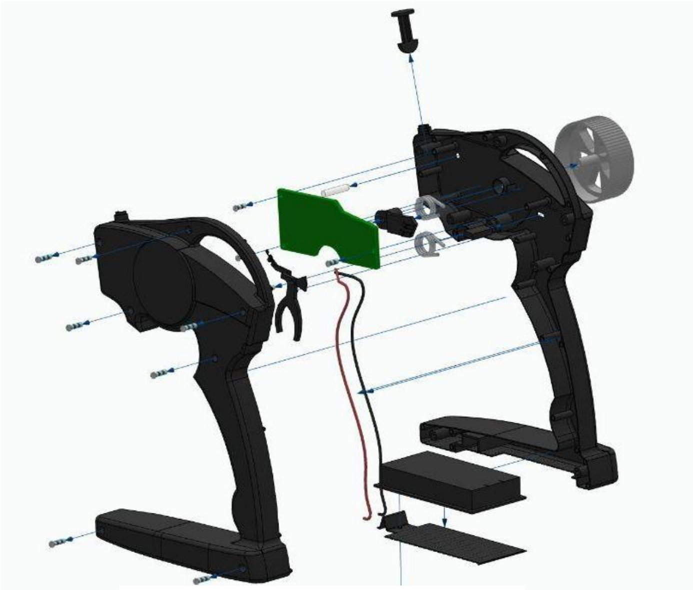


Figure 1 Exploded view of RC-controller.

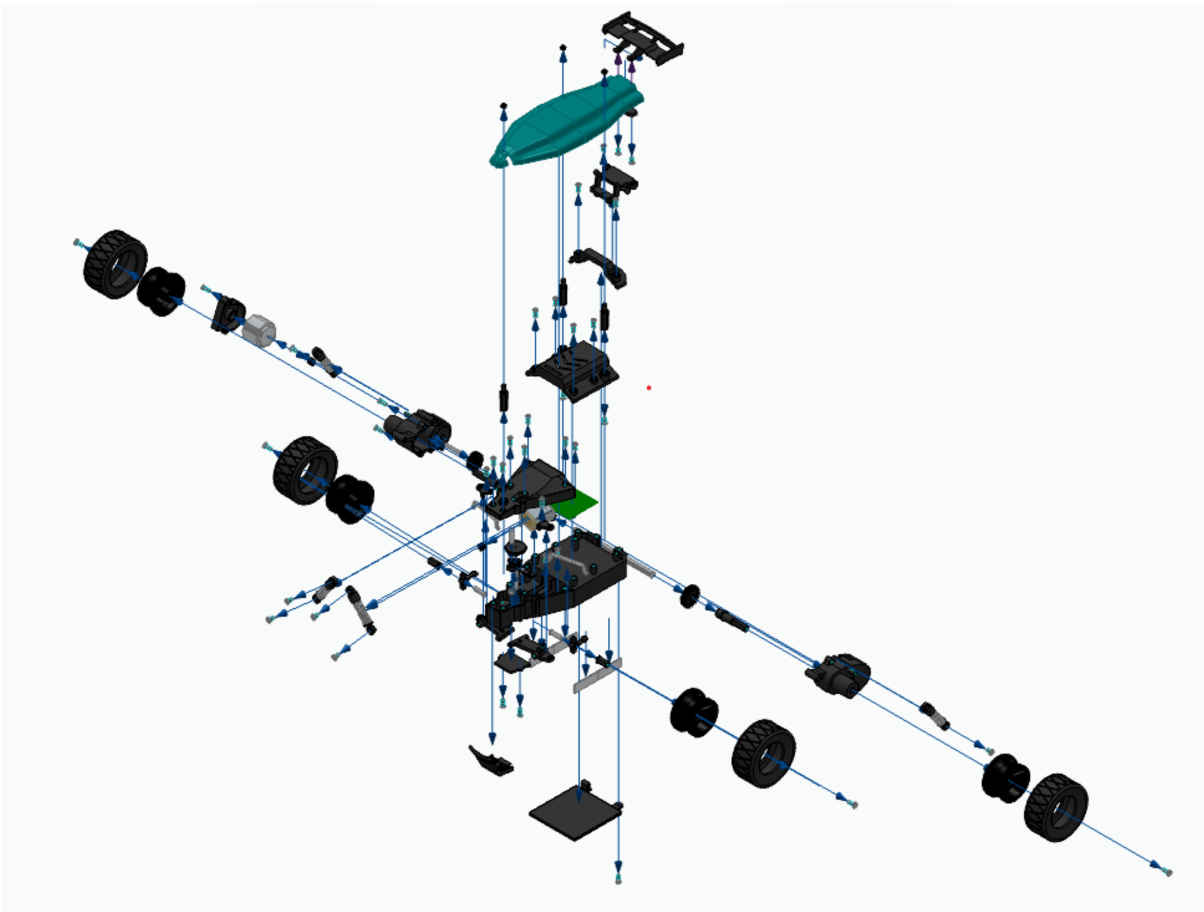


Figure 2 Exploded view of the RC-car

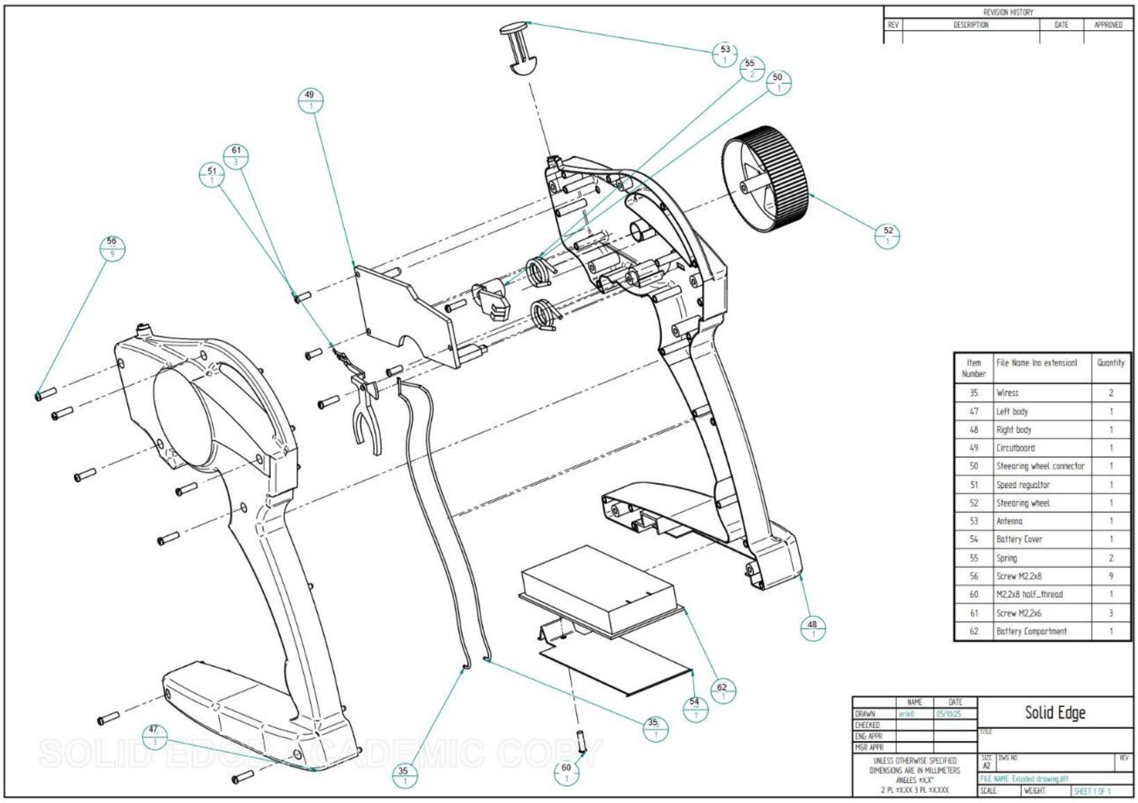


Figure 3 Explode drawing with component description for the RC-controller

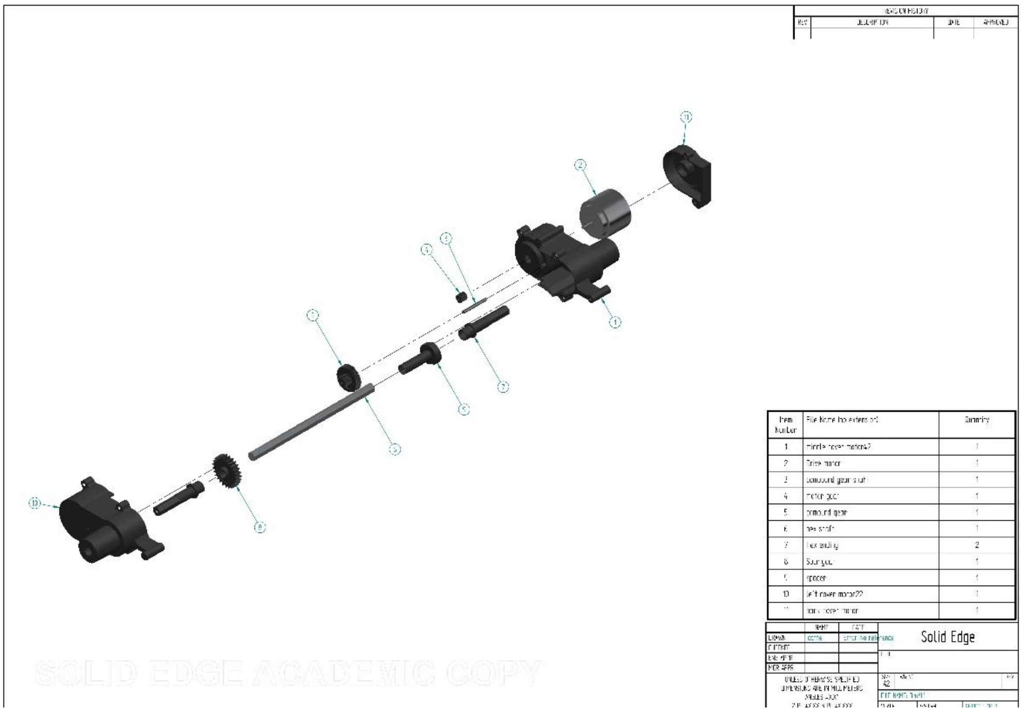


Figure 4. Exploded View of Motor and Main shaft subassembly

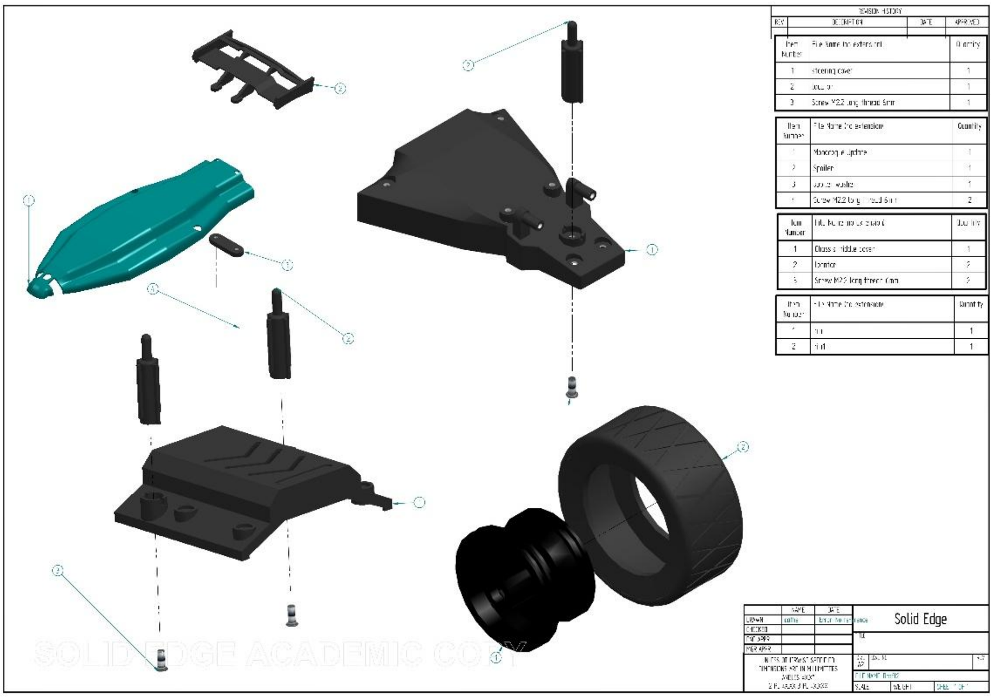
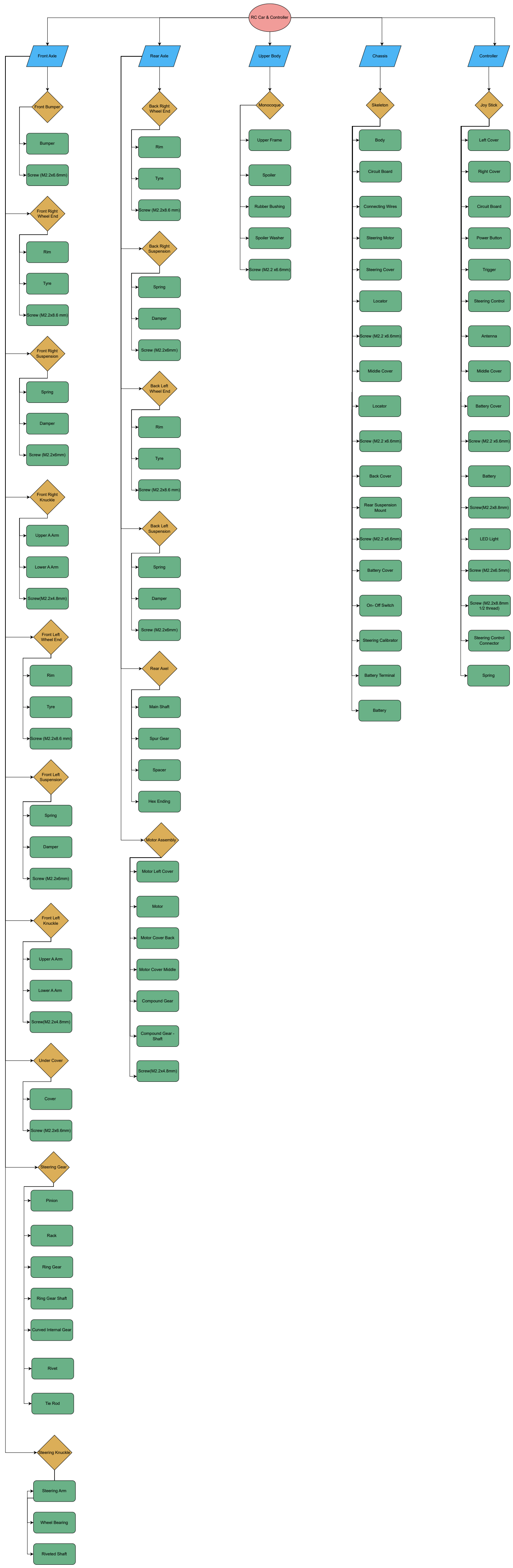


Figure 5. Exploded view of wheel ,monocoque, middle cover and steering cover subassemblies

4. Bill of Materials (BOM)

The Bill of Materials is a schematic representation of all the subassemblies, and the components that are used in each, necessary to produce the final product. The Flow Chart illustrates the Bill of Materials for the RC car, where the subassemblies are represented in green and the components in yellow.

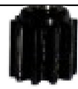

RC Car & Controller
Front Axle
Rear Axle
Upper Body
Chassis
Controller
Front Bumper
Bumper
Screw (M2.2x6.6mm)
Front Right Wheel End
Rim
Tyre
Screw (M2.2x8.6 mm)
Front Right Suspension
Spring
Damper
Screw (M2.2x6mm)
Front Right Knuckle
Upper A Arm
Lower A Arm
Screw(M2.2x4.8mm)
Front Left Wheel End
Rim
Tyre
Screw (M2.2x8.6 mm)
Front Left Suspension
Spring
Damper
Screw (M2.2x6mm)
Front Left Knuckle
Upper A Arm
Lower A Arm
Screw(M2.2x4.8mm)
Under Cover
Cover
Screw (M2.2x6.6mm)
Steering Gear
Pinion
Rack
Ring Gear
Ring Gear Shaft
Curved Internal Gear
Rivet
Tie Rod
Steering Knuckle
Steering Arm
Wheel Bearing
Riveted Shaft
Back Right Wheel End
Rim
Tyre
Screw (M2.2x8.6 mm)
Back Right Suspension
Spring
Damper
Screw (M2.2x6mm)
Back Left Wheel End
Rim
Tyre
Screw (M2.2x8.6 mm)
Back Left Suspension
Spring
Damper
Screw (M2.2x6mm)
Rear Axel
Main Shaft
Spur Gear
Spacer
Hex Ending
Motor Assembly
Motor Left Cover
Motor
Motor Cover Back
Motor Cover Middle
Compound Gear
Compound Gear - Shaft
Screw(M2.2x4.8mm)
Monocoque
Upper Frame
Spoiler
Rubber Bushing
Spoiler Washer
Screw (M2.2 x6.6mm)
Skeleton
Body
Circuit Board
Connecting Wires
Steering Motor
Steering Cover
Locator
Screw (M2.2 x6.6mm)
Middle Cover
Locator
Screw (M2.2 x6.6mm)
Back Cover
Rear Suspension Mount
Screw (M2.2 x6.6mm)
Battery Cover
On- Off Switch
Steering Calibrator
Battery Terminal
Battery
Joy Stick
Left Cover
Right Cover
Circuit Board
Power Button
Trigger
Steering Control
Antenna
Middle Cover
Battery Cover
Screw (M2.2 x6.6mm)
Battery
Screw(M2.2x8.8mm)
LED Light
Screw (M2.2x6.5mm)
Screw (M2.2x8.8mm 1/2 thread)
Steering Control Connector
Spring

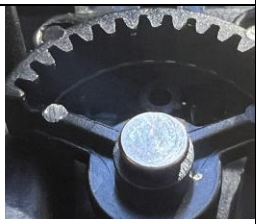
5. Parts List and their functionalities

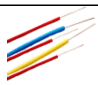
Table 1 contains information about all the parts, including part number, name, functionality, size and angle of rotation. This Table is divided in two sections, one for the RC car and one for the controller, and in total there are 63 components.

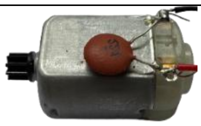
Table 1 Parts List

NR	Part Name	Functional Description	Quantity	Picture	Total Angle of Symmetry	Dimension(Length * Thickness)
1	Upper Frame, Monocoque	For Decorative purpose and to cover the internal parts	1		α = 360° β = 360° α + β = 720°	16.5 * 4.3
2	Spoiler	For aesthetic purposes	1		α = 360° β = 360° α + β = 720°	6.7 * 1.8
3	Rubber Bushing	to fix the upper frame in position	3		α = 180° β = 0° α + β = 180°	0.6 * 0.3
4	Spoiler Washer	to hold the spoiler in the frame	1		α = 360° β = 180° α + β = 540°	2.1 * 0.4
5	Bumper	for Passive Safety Purpose	1		α = 360° β = 360° α + β = 720°	3.4 * 1.4
6	Rim	To connect the tyre and the shaft	4		α = 360° β = 0° α + β = 360°	3.9 * 2.4
7	Tyre	Transfer the rotation motion to the ground and make the car	4		α = 180° β = 0° α + β = 180°	5.5 * 2.4

		to move forward				
8	Spring & Damper	Absorbs and stores the energy from the shocks on the road & dissipates the energy and reduce the Oscillation caused due to vibration	4		α = 360° β = 180° α + β = 540°	4.2 * 0.8
9	Upper A Arm	Controls camber, stabilizes wheel movement, and helps manage lateral forces.	2		α = 360° β = 360° α + β = 720°	1.4 * 0.5
10	Lower A Arm	Supports most of the load, connects to the spring/damper, and provides a foundation for suspension movement.	2		α = 360° β = 360° α + β = 720°	3.9 * 1.1
11	Under Cover	Supports the Lower A Arm connection to the car	1		α = 360° β = 0° α + β = 360°	3.2 * 0.3
12	Pinion	Transfers rotational motion to rack	2		α = 180° β = 0° α + β = 180°	0.6 * 0.5
13	Rack	Converts rotational motion into linear motion for steering	1		α = 360° β = 360° α + β = 720°	2.2 * 0.3
14	Ring Gear	Engages with other gears to transmit motion	1		α = 360° β = 0° α + β = 360°	1.8 * 0.9
15	Ring Gear Shaft	Supports ring gear and ensures	1		α = 180° β = 0°	1.9 * 0.2

		smooth rotation			α + β = 180°		
16	Curved Internal Gear	Curved internal gear could mesh with a pinion attached to the servo motor, allowing precise angular movement of the wheels.	1		α = 360° β = 360° α + β = 720°	2 * 0.9
18	Rivet	To hold the sector gear in place	1		α = 0° β = 360° α + β = 360°	1 * 0.4
19	Tie Rod	Connects the rack and steering arm also transfers the steering angle	2		α = 180° β = 360° α + β = 540°	4.1 * 0.7
20	Steering Arm	Transfers the Steering angle to the wheel	2		α = 360° β = 360° α + β = 720°	1.7 * 1.5
21	Wheel Bearing	Connect the Wheel to the car			α = 0° β = 360° α + β = 360°	1.2 * 1.5
22	Riveted Shaft	The Shafts go through wheel bearing to connect the wheel			α = 0° β = 360° α + β = 360°	2 * 0.4
23	Main Shaft	Transfers power from the motor to the wheels	1		α = 180 β = 0 α + β = 180	8.6 * 0.3
24	Spur Gear	Engage with gears to control speed and torque transmission	1		α = 360 β = 0 α + β = 360	1.9 * 0.8
25	Spacer	Maintains proper distance	2		α = 360° β = 0° α + β = 360°	2.6 * 1.4

		between rotating parts				
26	Hex ending	Ensures secure attachment to the wheel hub	2		α = 360° β = 0° α + β = 360°	3.7 * 0.9
27	Motor Cover Left	Protects the motor and supports mounting	1		α = 360° β = 360° α + β = 720°	6.6 * 3.8
28	Main Motor	Generates rotational motion to drive the vehicle	1		α = 360° β = 360° α + β = 720°	3.7 * 2.4
29	Motor Cover Back	Protects the motor and supports mounting	1		α = 360° β = 360° α + β = 720°	4 * 1.2
30	Motor Cover Middle	Provides protection and structural support	1		α = 360° β = 360° α + β = 720°	6.6 * 4.6
31	Compound Gear	Transfers and modifies torque from the motor	1		α = 360° β = 0° α + β = 360°	1.7 * 0.9
32	Compound Gear - shaft	Holds compound gears in place	1		α = 180° β = 0° α + β = 180°	1.7 * 0.1
33	Body	Provides structural support and protection	1		α = 360° β = 360° α + β = 720°	14.1 * 2.6
34	Circuit Board	Controls and processes signals for motor and steering control	1		α = 360° β = 360° α + β = 720°	3.4 * 0.1
35	Connecting Wires	Transfers electrical power and	7		α = 180° β = 0° α + β = 180°	12 * 0.1

		signals between components				
36	Steering Motor	Gives rotational motion to steer the car	1		α = 360° β = 360° α + β = 720°	3.5 * 1.5
37	Steering Cover	Protects the steering mechanism	1		α = 360° β = 360° α + β = 720°	6.8 * 2.2
38	Locator	To place the monocoque to the body	3		α = 180° β = 0° α + β = 180°	2.4 * 0.7
39	Middle Body Cover	Protects components	1		α = 360° β = 360°	6 * 2
40	Back Body Cover	Protects the rear section of the car	1		α = 360° β = 360° α + β = 720°	6 * 1.7
41	Rear Suspensi on Mount	Holds the suspension system securely	1		α = 360° β = 360° α + β = 720°	4.3 * 1.9
42	Battery cover	Protects the battery from external damages	1		α = 360° β = 360° α + β = 720°	7.3 * 0.4
43	On - Off switch	Controls the power supply	2		α = 360° β = 360° α + β = 720°	1.9 * 1.4
44	Steering Calibrat or	Adjusts steering accuracy and responsivene ss	1		α = 360° β = 360° α + β = 720°	1.1 * 0.1
45	Battery Termina l	Send electricity to the circuit board	1		α = 360° β = 360° α + β = 720°	6.1 * 1.7
46	Battery	Provide electrical	6		α = 360° β = 0°	

		power to the system			α + β = 360°	
47	Left Cover	Protects the internal components of the joystick	1		α = 360° β = 360° α + β = 720°	16.5 * 2.1
48	Right Cover	Protects the internal components of the joystick	1		α = 360° β = 360° α + β = 720°	16.5 * 3.7
49	Circuit Board	Processes user inputs and sends signals to the car circuit board	1		α = 360° β = 360° α + β = 720°	6.9 * 0.1
50	Steering wheel connect or	translates movement in the wheel to electric signals	1		α = 360° β = 360° α + β = 720°	3 * 1.5
51	Trigger & connect or	To control forward and backward movement & connects the Steering control to the right cover	1		α = 360° β = 360° α + β = 720°	5 * 1
52	Steering Control	To control the direction	1		α = 360° β = 0° α + β = 360°	4.1 * 1.5
53	Antenna	To connect with the car	1		α = 360° β = 180° α + β = 540°	2 * 0.7
54	Battery Cover	To protect the joystick battery	1		α = 360° β = 360° α + β = 720°	7.8 * 1.1
55	spring	For steering, throttle and trigger	2		α = 180° β = 360° α + β = 540°	1.6 * 0.3
56	Screw M2.2 Long	Main body controller fastener	9		α = 360° β = 0°	0.8 * 0.4

	Thread 8 mm				α + β = 360°	
57	Screw(M2.2x 8.8mm) Wide top	Connects Wheels to the body	4		α = 360° β = 0° α + β = 360°	0.8 * 0.6
58	Screw (M2.2x 4.8mm) wide top	Connects Suspenion to the body	7		α = 360° β = 0° α + β = 360°	0.4 * 0.6
59	Screw M2.2 Long Thread 6 mm	Connects Covers to the body	8		α = 360° β = 0° α + β = 360°	0.6 * 0.4
60	Screw M2.2 Long Thread 4 mm	Battery hatch	1		α = 360° β = 0° α + β = 360°	0.8 * 0.46
61	Screw(M2.2 x 6.5mm)	Controller circuit board fastener	3		α = 360° β = 0° α + β = 360°	0.6 * 0.3
62	Battery compart ment	secures the batteries	1		α = 360° β = 360° α + β = 720°	8 * 1
63	Steering Spring	Makes the Rack to return to its position	1		α = 360° β = 360° α + β = 720°	0.14 * 0.3

6. Liaison Diagram

The liaison diagram helps us to visually represent the functional and physical connections within the RC car assembly. By clearly distinguishing between screw fits and snap fits, the diagram highlights the interaction between components and shows how sub-assemblies are formed and related with each other to create the complete product. The connections make it easier to create the build logic, identify critical parts, and understand how assembly operations can be grouped and sequenced. This understanding of part relationship provides a structured foundation for further steps like precedence planning and station balancing.

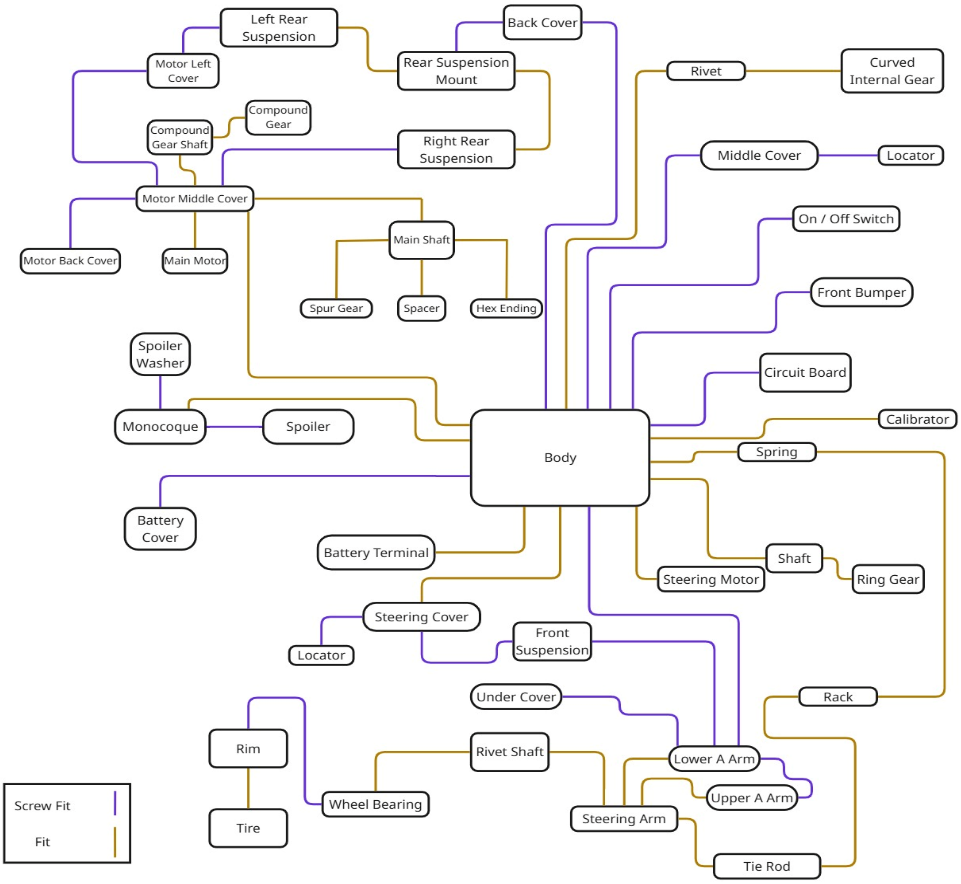


Figure 6 Liaison Diagram

7. Operations and Precedence Table

7.1. Operations and assembly times

We recorded each operator's handling and insertion time to analyse the natural variability in how different people perform the same task. The 92 assembly operations were analysed by 3 different operators; by recording each operator's cycle time and then taking the simple average, we arrived at a "standard" time which neutralizes the occasional fast or slow performing actions. The averaged time becomes the basis for line balancing calculations without over-relying on any one individual's pace.

Considering multiple operators to get an average time is important because no two people work exactly alike. The difference in operator's strength, experience, fatigue can all affect the operator's performance. By recording different operator's and their average value, we build a margin that creates a real world scenario and protects against unrealistic standards.

Table 2 Time Comparission between Assembly Time of Different Operators

Subassembly	Operation	Operator 1 (sec.)	Operator 2 (sec.)	Operator 3 (sec.)	Average(sec.)
Rear Axle	1	3,1	2,7	3,1	3
	2	3,2	3,3	4,0	3,5
	3	2,6	2,3	2,6	2,5
	4	3,4	2,6	3,0	3
	5	3,8	3,4	3,4	3,5
Motor	6	3,0	2,8	3,2	3
	7	3,0	3,0	3,0	3
	8	4,2	3,9	4,0	4
	9	3,2	3,4	3,9	3,5
	10	3,9	3,9	4,3	4
	11	3,9	3,9	4,2	4
	12	4,2	3,4	4,4	4
	13	13,4	13,6	13,5	13,5
	14	3,2	2,6	3,3	3
	15	9,2	8,1	9,8	9
Monocoque	16	3,6	2,7	2,7	3
	17	3,5	3,4	3,6	3,5
	18	4,8	4,0	4,2	4,5
	19	4,3	4,4	4,4	4,25
Chassis	20	2,0	1,9	2,0	2
	21	18,0	18,0	18,0	18
	22	4,2	4,4	4,9	4,5
	23	4,6	4,3	4,7	4,5
Front knuckle	24	4,8	5,0	5,2	5
	25	3,0	3,0	3,0	2,9
	26	9,2	9,4	9,4	9
	27	2,8	2,8	2,8	2,9
	28	8,0	7,8	8,1	7,95
Steering cover	29	3,2	2,8	3,0	3
	30	3,4	3,7	3,4	3,5
	31	4,0	4,8	4,7	4,5
Middle cover	32	2,7	3,0	2,9	3
	33	3,5	3,5	3,5	3,5
	34	3,0	2,9	3,0	3
	35	4,5	4,5	4,5	4,5
	36	3,0	3,0	3,0	3
Steering gear	37	3,4	3,5	3,6	3,5
	38	3,3	3,4	3,3	3,5
	39	7,3	7,1	6,6	7
	40	4,4	4,7	4,5	4,5
	41	3,5	3,5	3,5	3,5
	42	4,0	4,2	4,3	4,25
Circuit Board	43	5,6	6,0	6,4	6
	44	6,3	5,6	5,1	6
	45	5,5	5,8	6,8	6
	46	5,9	6,5	5,6	6
	47	5,4	6,3	6,4	6
Steering System	48	5,0	5,0	5,0	5
	49	5,3	4,9	4,8	5
	50	8,4	9,0	9,2	9
	51	6,0	6,0	6,0	6
	52	4,9	6,0	5,2	6
Rear suspension mount	53	3,4	2,6	3,0	3
	54	3,1	2,6	2,8	3
	55	2,9	2,7	3,3	3
Main body	56	3,0	3,1	2,9	3
	57	3,6	3,4	3,5	3,5
	58	4,3	4,2	3,5	4
	59	3,6	3,8	4,6	4
	60	4,4	3,8	3,8	4
	61	4,6	4,7	5,0	4,75
Rear Suspension	62	2,8	2,2	2,5	2,5
	63	3,5	3,4	2,7	3,5
	64	2,5	3,2	3,3	3
	65	2,4	2,7	2,8	3
Ackermann	66	3,2	2,6	3,2	3
	67	3,2	3,4	3,1	3,5
	68	2,7	3,2	2,7	3
	69	2,7	3,2	2,9	3
	70	3,1	2,6	3,4	3
	71	3,2	3,4	3,1	3,5
	72	2,4	2,2	3,0	2,5
	73	2,8	2,7	2,5	3
	74	2,6	2,7	3,1	3
	75	3,0	2,7	3,0	3
Front suspension	76	5,5	5,8	5,2	5,5
	77	2,6	3,1	3,4	3
	78	2,8	3,1	3,0	3
	79	12,0	12,0	12,0	12
Wheels and tires	80	2,8	3,4	2,8	3
	81	9,4	8,6	10,4	9,5
	82	2,9	3,4	2,7	3
	83	10,2	8,6	9,7	9,5
	84	3,2	2,8	3,0	3
	85	9,6	8,2	10,8	9,5
	86	3,4	2,7	3,0	3
	87	9,8	10,0	8,8	9,5
	88	5,2	5,3	4,5	5
	89	4,8	5,4	4,8	5
	90	15,6	18,9	19,5	18
Final Assembly	91	3,9	4,7	4,8	4,5
	92	8,7	10,0	8,4	9

Tables 3 and 4 illustrate the assembly operations sequence in order to properly assemble the RC car and its controller, respectively. This table includes both handling and insertion operations, with its respective times, as well as the total time to perform each operation, which is given by the sum of the times previously mentioned. Besides this, it is also possible to observe which parts are required for each operation and, most importantly, what is the required precedence to successfully assemble both products.

Table 3 Precedence Table

Subassembly	Operation	Parts involved	Handling Operation	Handling Time	Insertion Operation	Insertion Time	Total Time	Subassembly total time	Precedence
Rear Axel	1	23	Pick up the main shaft	1,5	Place the main shaft on the working table	1,5	3	15,5	
	2	23, 26	Pick up one hex ending	1,5	Fix the hex ending into the main shaft	2	3,5		1
	3	25, 26	Pick up and orient the spacer	1,5	Insert the spacer into the main shaft	1	2,5		2
	4	24, 26	Pick up the spur gear	1,5	Insert the spur gear into the main shaft	1,5	3		3
	5	23, 26	Pick up the hex ending	1,5	Fix the hex ending into the main shaft	2	3,5		4
Motor	6	30	Pick up the middle cover	1,5	Place the middle cover on the working table	1,5	3	51	
	7	12, 28, 30	Pick up and orient the motor (including the pinion)	1,5	Insert the motor inside the middle cover	1,5	3		6
	8	30, 35	Grab motor wire	1	Insert the motor wire	3	4		7
	9	30, 32	Pick up the motor shaft	2	Insert the motor shaft into the motor cover	1,5	3,5		8
	10	31, 32	Pick up and orient the compound gear	2	Insert the compound gear inside the shaft	2	4		9
	11	23, 24, 25, 26, 30	Pick up the rear axel subassembly	1,5	Insert rear axel subassembly into the motor middle cover	2,5	4		5, 10
	12	27, 30	Pick up the left motor cover and orient it according to the middle cover	1,5	Insert the left motor cover into the middle cover	2,5	4		11
	13		Pick up and orient 3 screws	6	Insert and tighten screws	7,5	13,5		12
	14	29, 30	Pick up and orient the motor back cover	1,5	Insert the motor back cover to the middle cover	1,5	3		13
	15		Pick up and orient 2 screws	4	Insert and tighten screws	5	9		14
Monocoque	16	1	Pick up the monocoque	1,5	Place monocoque in the working table	1,5	3	20	
	17	1, 2	Pick up and orient the spoiler	1,5	Insert the spoiler into the monocoque	3	4,5		16
	18	2, 4	Pick up the spoiler washer	1,5	Insert the spoiler washer into the spoiler	2	3,5		17
	19		Pick up and orient the screws	4	Insert and tighten screws	5	9		18
Chassis	20	33	Pick up the body	1	Place the body on the working table	1	2	29	
	21	33, 45, 46	Pick up the battery terminal and pick up and orient the batteries (4)	8	Insert each battery inside the battery terminal	10	18		20
	22	33, 42	Pick up and orient the battery cover	2,5	Assemble battery cover to the body	2	4,5		21
	23		Pick up and orient the screw	2	Insert and tighten screws	2,5	4,5		22
Front knuckle	24	10, 33	Pick up and orient the lower A Arms	3	Insert one A Arm one each side of the body	2	5	29	23
	25	5	Pick up and orient the front bumper	1	Place the front bumper over the body	2	3		24
	26		Pick up and orient 2 screws for front bumper	4	Insert and tighten screws to the front bumper	5	9		25
	27	10, 11	Pick up and orient the under cover	1,5	Place the under cover by covering the lower A Arms	1,5	3		26
	28		Pick up and orient screws	4	Insert and tighten screws	5	9		27
Steering cover	29	37	Pick up the steering cover	2	Place the steering cover on the working table	2	4	15	
	30	37, 38	Pick up and orient the locator	1,5	Insert locator inside the steering cover	5	6,5		29
	31		Pick up and orient screw	2	Insert and tighten screws	2,5	4,5		30
Middle cover	32	39	Pick up the middle cover	2	Place the middle cover on the working table	2	4	26	
	33	37, 39	Pick up and orient the locator	1,5	Insert locator inside the middle cover	5	6,5		32
	34		Pick up and orient the screw	2	Insert and tighten screws inside the holes	2,5	4,5		33
	35	37, 39	Pick up and orient the locator	1,5	Insert locator inside the middle cover	5	6,5		34
	36		Pick up and orient the screw	2	Insert and tighten screws	2,5	4,5		35
Steering gear	37	33	Pick up the body.	2	Place the chassis subassembly on the working table	1	3	24,5	
	38	33, 44	Pick up the calibrator.	1,5	Insert calibrator inside the body	2	3,5		37
	39	8, 33	Pick up the spring and rotate the body	3	Insert spring inside the body	2	5		38
	40	13, 33	Pick up the rack	1,5	Insert rack inside the body	2	3,5		39
	41	16, 33	Pick up the curved internal gear	1,5	Insert curved internal gear to the body above the rack	2	3,5		40
	42	18, 33	Pick up the rivet	2	Insert the rivet to the body	4	6		41
Circuit Board	43	33, 34	Pick up the circuit board	2	Insert the circuit board inside the body	4	6	148	23
	44		Pick up the screw.	2	Insert and tighten screw inside the hole	2,5	4,5		43
	45	33, 43	Pick up on /off switch.	1,5	Insert on/off switch inside the body.	3	4,5		44
	46		Pick up the screw for the on /off switch.	4	Insert and tighten screw	6	10		45
	47	35	Pick up the soldering tool.	3	Solder the circuit board wires.	120	123		46
Steering System	48	33, 36	Pick up the steering motor.	2	Place steering motor in the body	1	3	24,5	42
	49	15, 33	Pick up the shaft.	2	Insert shaft inside the body	1,5	3,5		48
	50	14, 15	Pick up the ring gear.	2	Place ring gear on the shaft	2	4		49
	51	19, 13	Pick up the right tie rod.	3	Insert the right tie rod to the rack	4	7		50
	52	19, 13	Pick up the left tie rod.	3	Insert the left tie rod to the rack	4	7		51
Rear suspension mount	53	40	Pick up the back cover.	1,5	Place the back cover on the working table	1,5	3	10,5	
	54	40, 41	Pick up the rear suspension mount.	1,5	Lock the rear suspension mount to the back cover	1,5	3		53
	55		Pick up the screw.	2	Insert and tighten screws to the rear suspension mount	2,5	4,5		54
Main body	56	13, 14, 15, 19, 33, 36, 37, 38	Pick up the steering cover subassembly.	2	Place the steering cover subassembly over the steering system	3	5	74	31,52
	57		Pick up the screws.	12	Insert and tighten screws	15	27		56
	58	33, 37, 39	Pick up the middle cover subassembly.	2	Assemble the middle cover to the body	3	5		36,47
	59		Pick up the screws	8	Insert and tighten screws to the middle cover	10	18		58
	60	23, 24, 25, 26, 27, 28, 29, 30, 32, 33, 35, 40, 41	Pick up the motor and the rear suspension mount subassemblies	5	Assemble the motor and the rear suspension mount subassemblies to the body	5	10		15
	61		Pick up the screws.	4	Insert and tighten screws	5	9		60
Rear Suspension	62	8	Pick up the right spring and damper	1,5	Insert right spring and damper into the body	2	3,5	25	15,23,55
	63		Pick up the screw	4	Insert and tighten screws	5	9		62
	64	8	Pick up the left spring and damper	1,5	Insert left spring and damper into the body	2	3,5		63
	65		Pick up the screw	4	Insert and tighten screws	5	9		64
Ackeramen	66	20	Pick up the right steering arm.	1,5	Place the right steering arm on the working table	1,5	3	42	
	67	20, 22	Pick up the shaft.	2	Insert the shaft in the steering arm	2	4		66
	68	19, 21	Pick up the wheel bearing.	1,5	Insert the wheel bearing into the body by connecting it to the tie rod	5	6,5		28,67
	69	9, 33	Pick up the right upper A arm.	1,5	Insert the right upper A arm into the body	2	3,5		68
	70		Pick up the screws.	2	Insert and tighten screws	2,5	4,5		69
	71	20	Pick up the left steering arm.	1,5	Place the left steering arm on the working table	1,5	3		
	72	20, 22	Pick up the riveted shaft.	2	Insert the riveted shaft in the steering arm	2	4		70,71
	73	19, 21	Pick up the wheel bearing.	1,5	Insert the wheel bearing into the body by connecting it to the tie rod	5	6,5		28,72
	74	9, 33	Pick up the left upper A arm.	1,5	Insert the left upper A arm into the body	2	3,5		73
	75		Pick up the screws.	2	Insert and tighten screws	1,5	3,5		74
Front suspension	76	8	Pick up the right spring and damper	1,5	Insert the right spring and dumper into the front body	3,5	5	34	31,75
	77		Pick up the screw	4	Insert and tighten screws	8	12		76
	78	8	Pick up the left spring and dumper	1,5	Insert the left spring and dumper into the front body	3,5	5		31,75
	79		Pick up the screw	4	Insert and tighten screws	8	12		78

Table 4 Operations and Precedence table for the RC car

Wheels and tires	80	6	Pick up the right front rim	1,5	Place the right front rim on the working table	1,5	3	78	
	81	6, 7	Pick up the right front tire.	1,5	Insert the right front tire around the rim	8	9,5		80
	82	6	Pick up the left front rim	1,5	Place the left front rim on the working table	1,5	3		
	83	6, 7	Pick up the left front tire.	1,5	Insert the left front tire around the rim	8	9,5		82
	84	6	Pick up the right back rim	1,5	Place the right back rim on the working table	1,5	3		
	85	6, 7	Pick up the right back tire.	1,5	Insert the right back tire around the rim	8	9,5		84
	86	6	Pick up the left back rim	1,5	Place the left back rim on the working table	1,5	3		
	87	6, 7	Pick up the left back tire.	1,5	Insert the left back tire around the rim	8	9,5		86
	88	6, 7 ,9, 19, 20, 21, 22, 33	Pick up right and left front wheel assemblies (rim and tire).	3	Insert the front wheel subassembly into the Ackeramen subassembly	2	5		81,83,75
	89	6, 7 ,9, 19, 20, 21, 22, 33	Pick up right and left back wheel assemblies (rim and tire).	3	Insert the back wheel subassembly into the motor subassembly	2	5		85,87,15
	90		Pick up the screws	8	Insert and tighten screws	10	18		88,89
Final Assembly	91	1, 2, 4, 33	Pick up the monocoque assembly	1,5	Insert the monocoque subassembly into the body	3	4,5	13,5	19,61,65,77,79,90
	92	3, 33	Pick up the rubber bush.	4,5	Insert rubber bush into the body	4,5	9		91
						TOTAL TIME	659,5		

Table 5 Operations and Precedence table for the controller

Subassembly	Operation	Parts involved	Handling Operation	Insertion Operation	Total Time	Precedence
Circuit Board and battery	1	49	Pick up circuit board	Place on the working table	10	
	2	35	Pick up wires	Solder wires to circuit board	30	1
	3	62	Pick up battery holder	Solder battery holder to wiers	30	2
Right side controller	4	48	Pick up component	Place on the working table	2	
	5	55	Pick up steering springs	Insert springs into the body	24	4
	6	52	Picking up the steering wheel	Insert into the body	12	5
	7	51	Picking up the Wheel controller	Insert it into the steering wheel and spring	11	5
	8	56	Pick up the screw	Insert into the wheel connector	4	7
	9			Tighten Screw	10	8
	10	51	Pick up the trigger	Insert into the body and spring	4	5
	11	57	Pick up screw	Insert into the trigger	8	10
	12			Tighten screws	15	11
	13	Circuit Board Subassembly	Pick up circuit board subassembly	Place on studs and insert led and switch	4	12 & 3 & 9
	14	61	Pick up screws	Insert all 3 screws	10	13
	15			Tighten screws	40	14
	16	Circuit Board Subassembly	Pick up the battery compartment	Place in the body	8	15
	17	Circuit Board Subassembly	Pick up wiress	Place wiress inside the stem of the body	5	15
	18	53	Pick up antenna	Place antenna in the body	6	4
	19	54	Pick up battery cover	Place battery cover on the body	6	16
Final assembly	20	47	Pick up right controller body	Place right body on left body	28	19
	21	56	Pick up screws	Insert screws	30	20
	22			Tighten screws	60	21
	23	60	Pickup Battery latch screw	Insert screw	5	22
	24			Fasten screw	10	23
				TOTAL TIME	372	

8. Precedence diagrams

Figures 5 and 6 illustrate the precedence diagrams for the RC car and the controller, respectively, which are a visual representation of the previous tables. In order to facilitate the understanding of the RC car diagram we decided to attribute a different color to each subassembly, as it is also represented in Table 3.

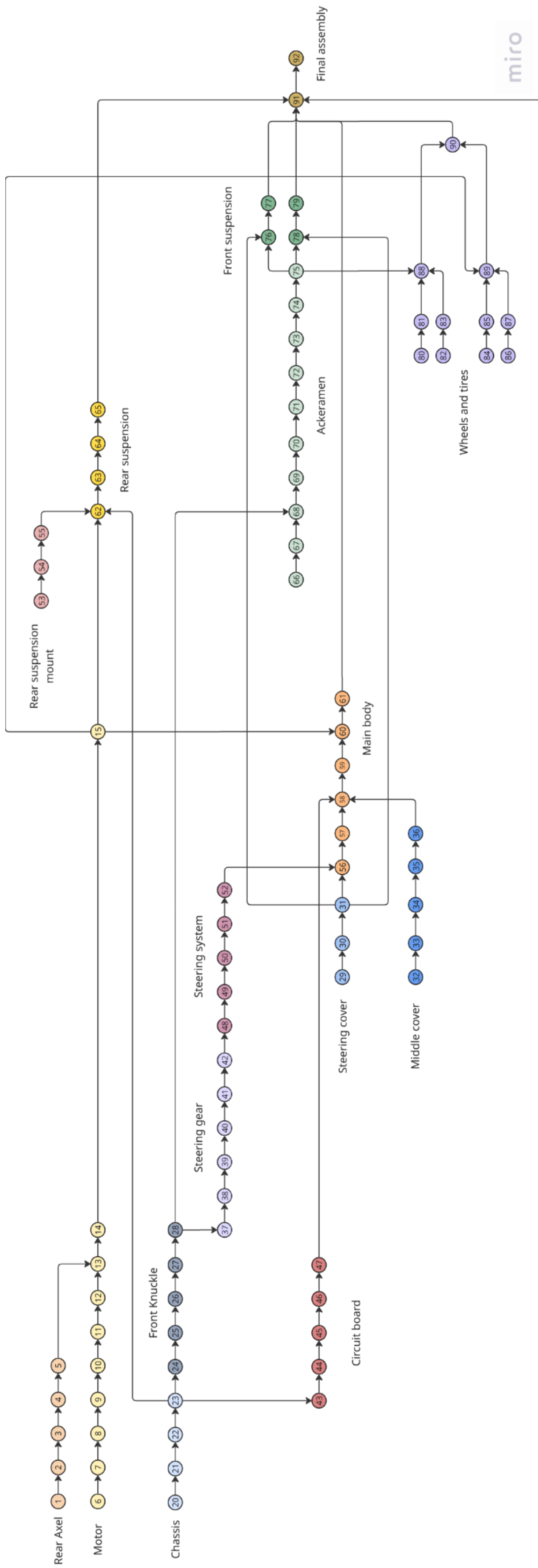


Figure 7 Precedence diagram for RC-Car.

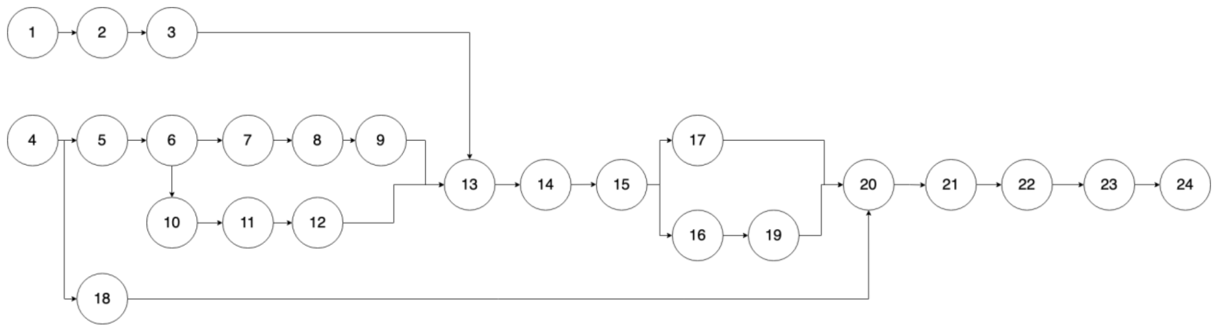


Figure 8 Precedence diagram for rc-controller

9. Liaison Sequence Diagram (LSD)

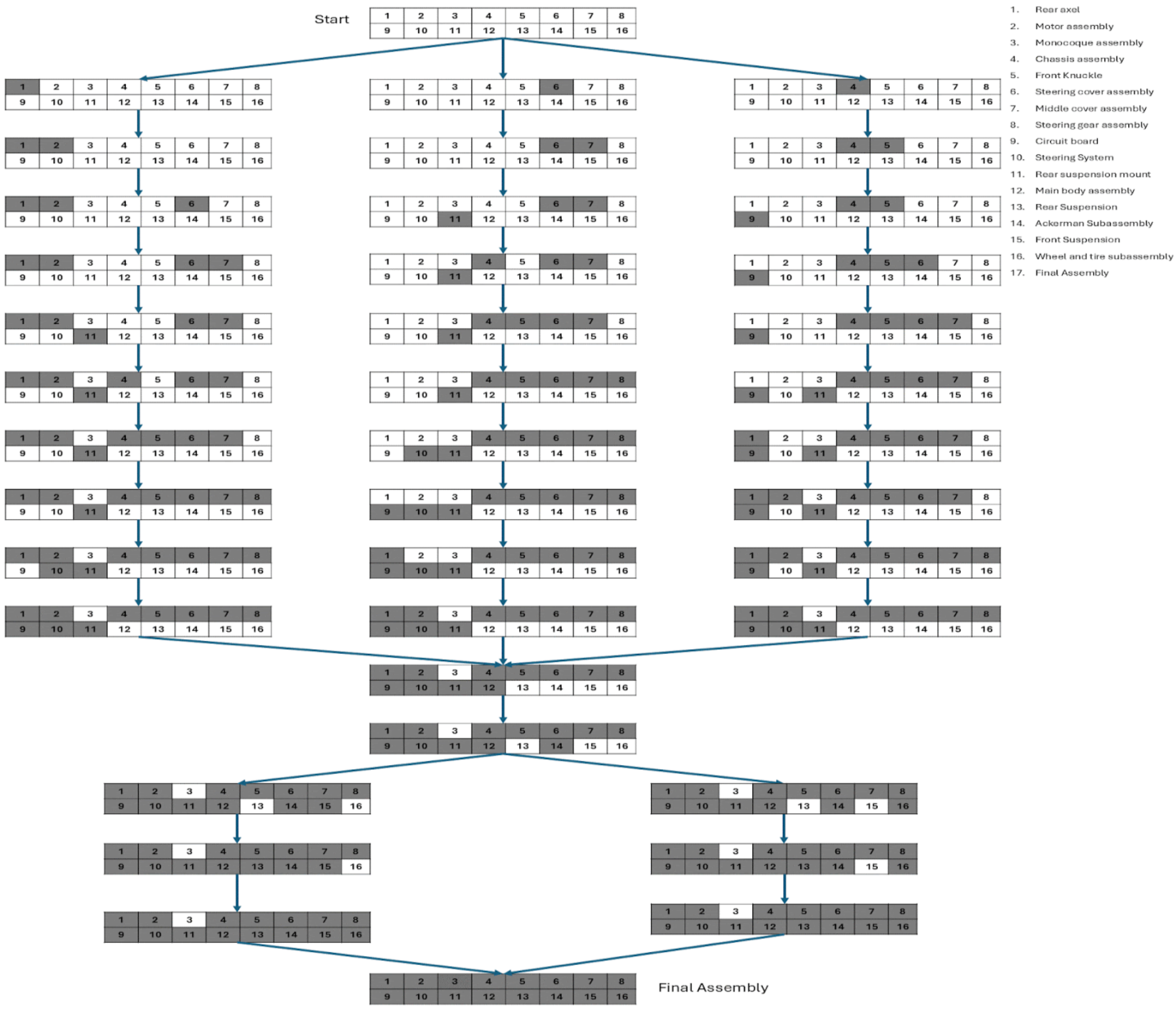


Figure 9 Liaison sequence diagram.

The liaison sequence diagram was created for our sub assemblies to analyze the precedence constraints which means that no component can be installed until all upstream liaisons are complete. The liaison sequence diagram shown in the above figure consists of the best possible 3 cases where the first 10 sub assemblies can be performed in different sequences.
The subassemblies 12 and 14 are the common sequences for all the 3 cases which should be performed before assembling subassemblies 13, 15 and 16. The last and common sub assembly is the monocoque subassembly which is done at last after all the sub assemblies.

The liaison sequence diagram helped us to perform the assembly workflow better. It helped to

1) The subassemblies which block others and nothing is assembled out of order.
2) Derive possible assembly sequences which ensures no subassembly is inaccessible at the point of its assembly.
3) Optimize workstations.
4) Compare alternative sequences and arrive at best strategies.

10. Production planning

Since market and production data analysis is fundamental to properly perform an assembly line balancing, this chapter will include all the calculations and assumptions regarding production planning.

We started by doing a market analysis in order to determine the annual demand for a RC car.[1] This research process followed a top-down approach, meaning that the final value was found by decomposing a broader demand value. Therefore, the global market value for RC cars was calculated according to both the market value for Diecast cars market and the value for the remaining markets excluding RC cars, as it is demonstrated by the following formula:

$$\begin{aligned} Global\ demand\ for\ RC\ cars \\ &= Global\ value\ for\ the\ toy\ market \\ &- Global\ value\ for\ Diecast\ car\ market \\ &- Gloabal\ value\ for\ the\ remaining\ market \end{aligned}$$

$$Global\ demand\ for\ RC\ cars = 442.5\ million\ dollars$$

Where,

- Global value for the toy market = 4.5 billion dollars (value representative of 2023, [1])
- Global value for Diecast cars market = 3.9 billion dollars
- Remaining market value, excluding the RC cars = 3,5% of the global demand = 157.5 million dollars

[1] During the demand calculations the expression "RC car" refers to both the RC car and the RC controller.

The global demand for RC cars in terms of number of products was calculated based on the selling price for our RC car, which is 199.90 SEK in Clas Ohlson, and corresponds to 21 dollars. [2]

The following formula demonstrates this step:

$$Global\ demand\ for\ RC\ cars\ (number\ of\ products) = Global\ demand\ for\ RC\ cars\ (value, \$)\ /\ Selling\ price$$

$$Global\ demand\ for\ RC\ cars\ (number\ of\ products) = 21\ 071\ 429 = 21\ million$$

The next step of this process was to calculate the European market size for RC cars, which was found to be around 30% of the global demand for this product. [3]

$$European\ demand\ for\ RC\ cars = 30\% * Global\ demand\ for\ RC\ cars$$

$$European\ demand\ for\ RC\ cars = 6\ 321\ 429 = 6.3\ million$$

The last step was then to calculate the Swedish market size, which is the one used for the entire project. This value was calculated according to the Swedish population rate, as demonstrated by the following formula:

$$Swedish\ demand\ for\ RC\ cars = Swedish\ Population\ Proportion * European\ demand\ for\ RC\ cars$$

Where,

$$Swedish\ population\ proportion = \frac{Swedish\ population}{European\ population} = \frac{10\ 656\ 633}{744\ 552\ 477} = 1{,}43\%$$

Therefore,

$$Swedish\ demand\ for\ RC\ cars = 1{,}43\ \% * 6.3\ million = 90\ 477$$

Besides the annual demand, other parameters needed to be calculated.

The first parameter to calculate was the total available time, which is given by the following formula:

$$\begin{aligned} Available\ time &= Working\ weeks * Working\ days\ per\ week * Shifts\ per\ day \\ &* Working\ hours\ per\ shift = 5376 \end{aligned}$$

Where,

$$Working\ weeks = 48$$
$$Working\ days\ per\ week = 7$$
$$Shifts\ per\ day = 2$$
$$Working\ hours\ per\ shift = 8$$

With the annual demand and the total available time it was possible to calculate the Theoretical Production Rate (Rp), given by,

$$Theoretical\ Production\ Rate\ (Rp) = \frac{Demand}{Total\ Available\ Time} = 16{,}83\ units/hour$$

With this value we can calculate the $Takt\ time$, which is given by,

$$Takt\ time = \frac{60}{Rp} = 3{,}57\ min$$

In order to calculate the $Cycle\ Time$ we had to take in consideration the line efficiency, which was assumed to be 95%, therefore assuming 5% of downtime.

$$Cycle\ Time\ (Tc) = Takt\ time * Efficiency\ (E) = 3{,}39\ min$$

In order to determine the ideal number of working stations we had in consideration the total time it takes to produce one unit. It is important to note that this step was made separately for the RC-car and its controller, since they will be assembled in different lines.

For the RC-car,

$$\begin{aligned} Total\ production\ time\ per\ unit\ (Tp) &= \sum_{op=1}^{op=92} (Handling\ time + Insertion\ time) \\ &= 659{,}5\ sec = 10{,}99\ min \end{aligned}$$

$$Ideal\ number\ of\ working\ stations\ (RC\ car) = \frac{Tp}{Tc} = \frac{10{,}99}{3{,}39} = 4$$

For the RC-controller,

$$Total\ production\ time\ per\ unit\ (Tp)\ = \sum_{op=1}^{op=24} (Handling\ time + \ Insertion\ time)$$
$$= \ 372\ sec\ = \ 6{,}2\ min$$

$$Ideal\ number\ of\ working\ stations\ (RC\ controller)\ = \frac{Tp}{Tc} = \frac{6{,}2}{3{,}39} = 2$$

Therefore,

$$Total\ number\ of\ working\ stations\ = \ 6$$

In order to calculate the maximum time for each working station, we took into consideration the $Repositioning\ time\ (Tr)$, which is defined by the safety factor and it was assumed to be $3\ seconds$, corresponding to $0{,}05\ minutes$. Therefore, the maximum available time to assemble parts in each station is defined by the following formula:

$$Maximum\ available\ time\ per\ station\ (Tmax)\ = Tc\ -\ Tr\ =\ 3{,}39\ -\ 0{,}05$$
$$=\ 3{,}34\ min\ =\ 200{,}21\ seconds$$

With these values it was possible to calculate the repositioning efficiency, given by,

$$Repositioning\ efficiency\ = \frac{Tmax}{Tc} = \frac{3{,}34}{3{,}39} = 98{,}5\%$$

Another parameter that was considered in order to determine the overall efficiency was the balancing loss efficiency, which was calculated separately for the RC-car and RC-controller, according to the following formula,

$$Balancing\ loss\ efficiency\ = \frac{Tp}{Ideal\ number\ of\ working\ stations\ *\ Tmax}$$

$$Balancing\ loss\ efficiency\ (RC\ car) = \frac{10{,}99}{4\ *\ 3{,}34} = 82{,}4\%$$

$$Balancing\ loss\ efficiency\ (RC\ controller) = \frac{6{,}2}{2 *\ 3{,}34} = 92{,}9\%$$

With all of these efficiencies we could calculate the overall efficiency for each assembly line.

$$Overall\ efficiency$$
$$= Line\ efficiency\ *\ Repositioning\ efficiency$$
$$*\ Balancing\ loss\ efficiency$$

$$Overall\ efficiency\ (RC\ car) = 95\% * 98{,}5\% * 82{,}4\% = 77{,}1\%$$
$$Overall\ efficiency\ (RC\ controller) = 95\% * 98{,}5\% * 92{,}9\% = 87\%$$

Lastly, based on the previous calculations we determined the final number of working stations for both assembly lines using the following formula,

$$Final\ number\ of\ working\ stations = \frac{Rp * Tp}{60 * Overall\ efficiency}$$

$$Final\ number\ of\ working\ stations\ for\ RC\ car = \frac{16{,}83 * 10{,}99}{60 * 77{,}1\%} = 4$$

$$Final\ number\ of\ working\ stations\ for\ RC\ controller = \frac{16{,}83 * 6{,}2}{60 * 87\%} = 2$$

To conclude, these calculations indicate that the final number of working stations that fit our production planning, including annual demand and total assembly time, should be 6.

11. Assembly Line Balancing

The main goal of performing a line balancing analysis for the assembly line is to minimize the total idle time, therefore maximizing the line efficiency. In order to determine the optimal solution for the assembly line balancing several methods were applied, such as the LCR, the Kilbridge and Wester and the RPW. It is important to note that we choose to do the assembly line balancing considering the subassemblies previously presented, instead of individual operations. This decision was based on the logical flow of the assembly process, since we considered that assembling the subassemblies inside the same working station would simplify the entire assembly process. For all the methods, the maximum time available per station (Tmax) is 200,21 seconds, which means that the total sum of the assembling time for all the subassemblies attributed to the same station cannot exceed 200,21 seconds.

11.1.LCR method

This method follows the principle of the Last Candidate Rule, which states that we assemble components according to their respective operation's assembly time, starting from the one with the highest value until the ones with the lowest. Therefore, the first step was to organize all the subassemblies according to their total assembling time, as shown in Table X.

Table 6 Subassemblies' list organized by descending order regarding the total assembling time

Subassembly	Total time to assemble
Circuit board	148
Wheels and tires	78
Main body	74
Motor	51
Ackerman	42
Front suspension	34
Front knuckle	29
Chassis	29
Middle cover	26
Rear suspension	25
Steering system	24,5
Steering gear	24,5
Monocoque	20
Rear axel	15,5
Steering cover	15
Final assembly	13,5
Rear suspension mount	10,5

Based on this sequence and by respecting both the precedence constraints for each subassembly and the station time limit (maximum available time per station), all the assemblies were divided by the four working stations. These results are presented in Tables 6 and 7.

Table 7 LCR Results

LCR				
Station	**Subassemblies**	**Tek**	**Total time**	**Idle time**
1	Chassis	29	177	23,21
	Circuit board	148		
2	Front knuckle	29	196,5	3,71
	Ackerman	42		
	Middle cover	26		
	Steering gear	24,5		
	Steering system	24,5		
	Monocoque	20		
	Rear axel	15,5		
	Steering cover	15		
3	Motor	51	173,5	26,71
	Wheels and tires	78		
	Front suspension	34		
	Rear suspension mount	10,5		
4	Main body	74	112,5	87,71
	Rear suspension	25		
	Final assembly	13,5		

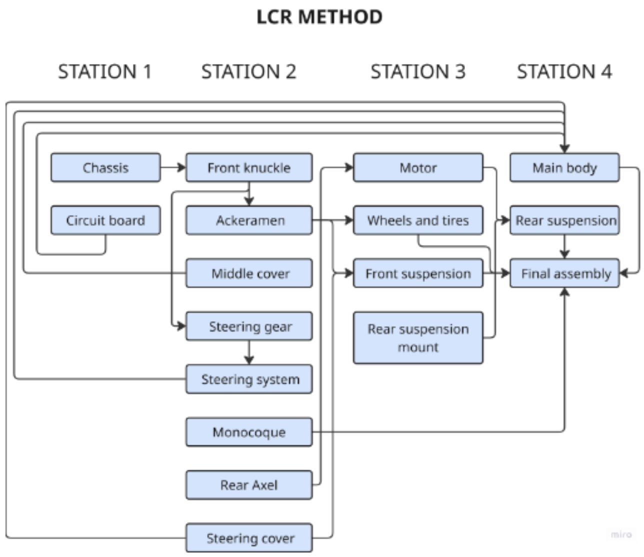


Figure 10 LCR results with precedence flow

11.2 Kilbridge and Wester's method

Kilbridge and Wester's is another line balancing method that prioritizes task sequence over time since it is based on the position of each component in the assembly line. Figure X illustrates the precedence diagram used for this method, which is organized by columns. The rule to follow is to assign tasks according to the column where they belong, starting by assigning those subassemblies that do not have predecessors (column 1). In this method it is also required to respect the maximum time available for each station and the precedence constraints.

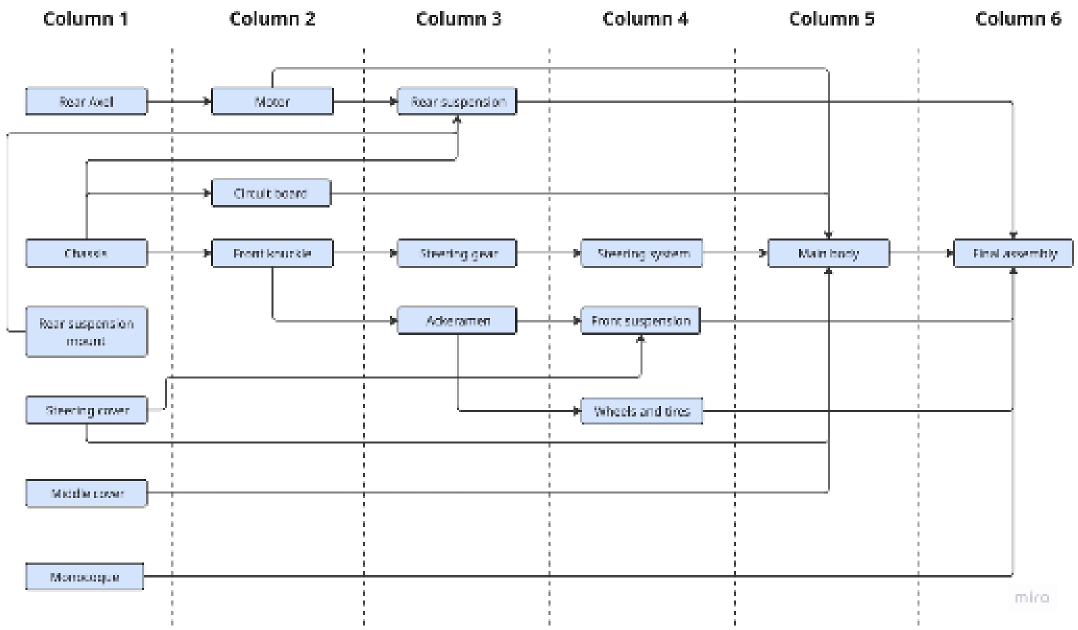


Figure 11 Precedence diagram organized by columns

Table 8 Kilbridge and Wester's results

Kilbridge and Wester's				
Station	**Subassemblies**	**Tek**	**Total time**	**Idle time**
1	Rear axel	15,5	196	4,21
	Chassis	29		
	Rear suspension mount	10,5		
	Steering cover	15		
	Middle cover	26		
	Monocoque	20		
	Motor	51		
	Front knuckle	29		
2	Circuit board	148	197,5	2,71
	Rear suspension	25		
	Steering gear	24,5		
3	Ackerman	42	178,5	21,71
	Steering system	24,5		
	Front suspension	34		
	Wheels and tires	78		
4	Main body	74	87,5	112,71
	Final assembly	13,5		

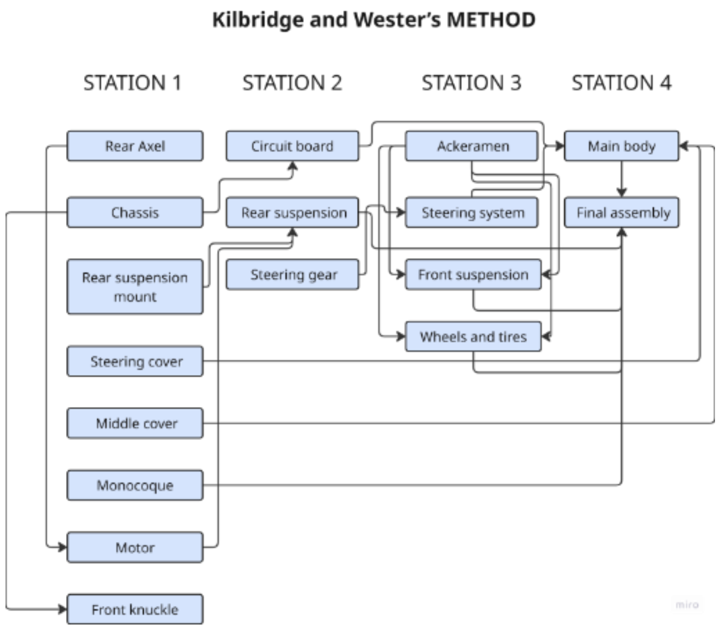


Figure 12 Kilbridge and Wester's results with precedence flow

11.3 RPW method

This method is a hybrid approach since it prioritizes both task times and precedence constraints. Therefore, the subassembly list presented below was made according to the Ranked Positional Weight of each subassembly. This value is given by the total sum of each task's time plus the time of all the succeeding tasks within the precedence diagram, until reaching the end of the assembly line. Therefore, considering k each subassembly, the RPW for that subassembly is given by the following formula,

$$RPW_k = T_{ek} + \sum_{all\ successors\ of\ k} Te$$

Where,

$$T_{ek} = Standard\ time\ for\ subassembly\ k = handling\ time + insertion\ time$$

Table 9 RPW Values

RPW values listed in a descending order			
Subassembly	**Tek (sec)**	**Successors**	**RPW (sec)**
Chassis	29	Rear suspension Circuit board Front knuckle Steering gear Ackerman Steering system Front suspension Wheels Main body Final assembly	521,5
Front knuckle	29	Steering gear Ackerman Steering system Front suspension Wheels Main body Final assembly	319,5
Rear Axel	15,5	Motor Rear suspension Wheels Main body Final assembly	257
Motor	51	Rear suspension Wheels Main body Final assembly	241,5
Ackerman	42	Front suspension Wheels Main body Final assembly	241,5
Circuit board	148	Main body Final assembly	235,5
Steering gear	24,5	Steering system Main body Final assembly	136,5
Steering cover	15	Front suspension Main body Final assembly	136,5
Middle cover	26	Main body Final assembly	113,5
Steering system	24,5	Main body Final assembly	112
Wheels	78	Final assembly	91,5
Main body	74	Final assembly	87,5
Rear suspension mount	10,5	Rear suspension Final assembly	49
Front suspension	34	Final assembly	47,5
Rear suspension	25	Final assembly	38,5
Monocoque	20	Final assembly	33,5
Final assembly	13,5	-	13,5

Based on this formula, we organized in a table all the RPW values, following the same principle as the LCR method, which was to organize it in a descending order, therefore starting with the one with the highest RPW value. This table is demonstrated below.

Table 9 Subassemblies' list organized by descending order regarding the RPW value

Similar to the previous methods, the next step in this method was to divide the subassemblies into stations, always respecting the time limit per station and the precedence constraints. The results are shown in Table 10.

Table 10 RPW results

RPW				
Station	**Subassemblies**	**Tek**	**Total time**	**Idle time**
1	Chassis	29	191	9,21
	Front knuckle	29		
	Rear axle	15,5		
	Motor	51		
	Ackerman	42		
	Steering gear	24,5		
2	Circuit board	148	189	11,21
	Steering cover	15		
	Middle cover	26		
3	Steering system	24,5	187	13,21
	Wheels and tires	78		
	Main body	74		
	Rear suspension mount	10,5		
4	Front suspension	34	92,5	107,71
	Rear suspension	25		
	Monocoque	20		
	Final assembly	13,5		

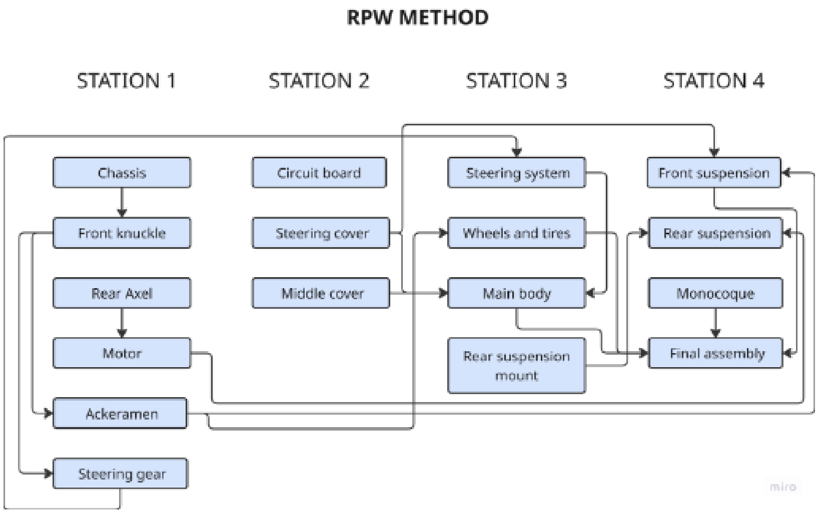


Figure 13 RPW results with precedence flow

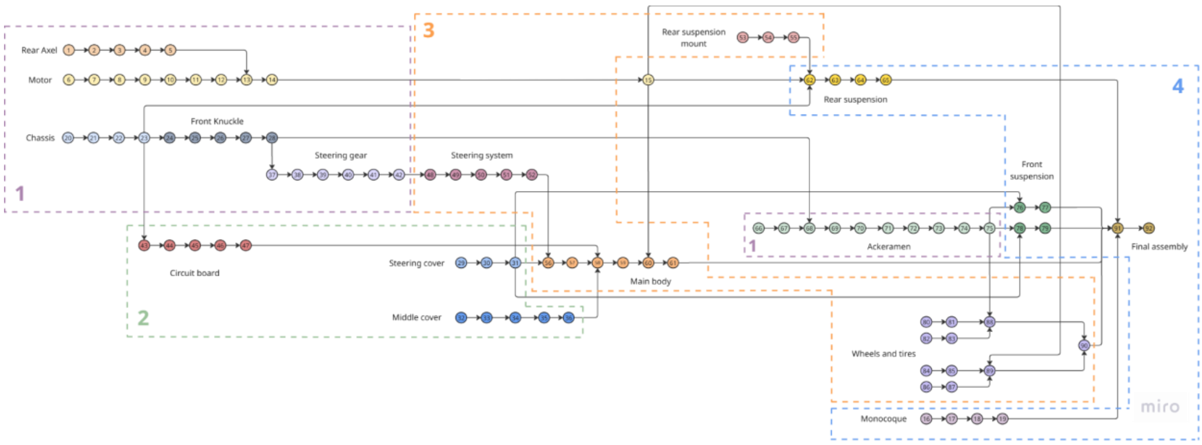


Figure 14 Station representation within the precedence diagram

11.4. Comparison of method's results

In order to choose the best solution for our product we used 4 parameters, including the total idle time, the average idle time, the standard deviation and the number of working stations. It is important to note that the total idle time is the same for all the methods since they all include the 17 subassemblies, although they are distributed in different ways between stations. Besides this, the ideal number of working stations given by all three methods was 4, which makes this parameter irrelevant to perform this evaluation.

Therefore, the parameters used to choose the best solution for the assembly line balancing were the average idle time and the standard deviation. The final decision on choosing the results from the RPW was based on achieving both a low average idle time and standard deviation. The standard deviation represents how evenly distributed is the idle time between stations, where a lower value indicates a smoother process with a smaller difference between each station's assemble time. Therefore, between the ones with the lowest standard deviation (LCR and LCR) we chose the one with the lowest average idle time, which is the RPW.

Table 11 Comprasion of Line Balancing Methods

Method	Total idle time	Average idle time	Standard deviation	Number of working stations
LCR	141,34	24,960	31,48	4
Kilbridge and Wester's	141,34	12,960	45,29	4
RPW	141,34	12,210	41,81	4

This comparison can be observed in the Figures presented below, where the light blue represents the assemble time and the dark blue represents the idle time.

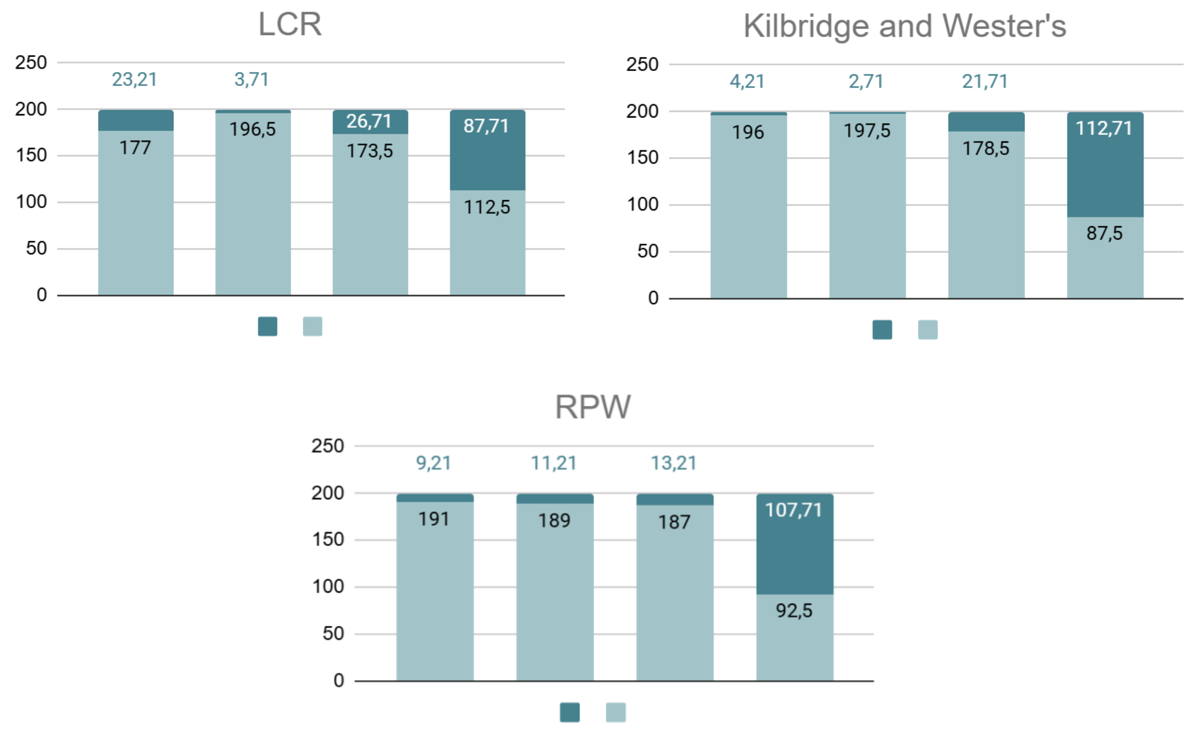


Figure 15 LIne Balancing Methods Charts

Although the results from the RPW method include a high idle time in the last station, we decided to move forward with this method since our goal is to achieve a balance between all the stations by including the packaging operation in the last station. Therefore, the remaining 107,71 seconds will include the time for the operator to move from the workstation 4 to the packaging area and the time to pack the RC-car and the controller.

11.5. Assembly Line Balancing-Controller.

The same method for line balancing, the RPW method, was used to balance the controller's assembly. The calculations are presented in table x.

Table 12 RPW calculations for the controller

Controller line balancing			
Operation	RPW	Tasks along path	Time (sec)
1	276	2,3,13,14,15,17,16,19,20,21,22,23,24	10
2	266	3,13,14,15,17,16,19,20,21,22,23,24	30
3	236	13,14,15,17,16,19,20,21,22,23,24	30
4	302	5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	2
5	294	6,7,8,9,10,11,12,13,14,15,16,17,19,20,21,22,23,24	24
6	270	7,8,9,10,11,12,13,14,15,16,17,19,20,21,22,23,24	12
7	236	8,9,13,14,15,16,17,19,20,21,22,23,24	11
8	225	9,13,14,15,16,17,19,20,21,22,23,24	4
9	216	13,14,15,16,17,19,20,21,22,23,24	10
10	233	11,12,13,14,15,16,17,19,20,21,22,23,24	4
11	229	12,13,14,15,16,17,19,20,21,22,23,24	8
12	221	13,14,15,16,17,19,20,21,22,23,24	15
13	206	14,15,16,17,19,20,21,22,23,24	4
14	202	15,16,17,19,20,21,22,23,24	10
15	192	16,17,19,20,21,22,23,24	40
16	147	19,20,21,22,23,24	8
17	138	20,21,22,23,24	5
18	139	20,21,22,23,24	6
19	139	20,21,22,23,24	6
20	133	21,22,23,24	28
21	105	22,23,24	30
22	75	23,24	60
23	15	24	5
24	10		10

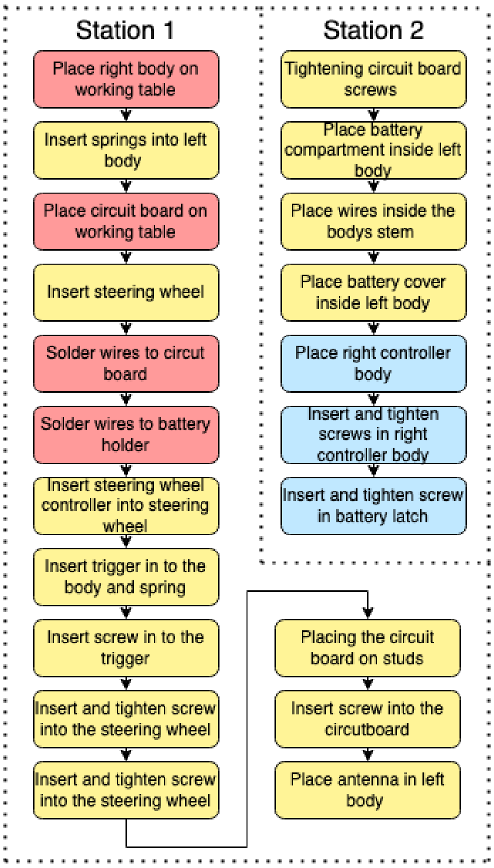


Figure 16 Assembly stations controller

12. Economic Analysis

12.1. Manual Line Economic Analysis

Regarding the economic analysis of our manual assembly line we determined its total cost using the following formula,

$$Total\ cost\ per\ unit\ =\ Total\ variable\ costs\ per\ unit\ +\ Total\ fixed\ costs\ per\ unit$$

Where,

$$Variable\ costs\ per\ unit\ = Labor\ cost\ per\ unit\ +\ Material\ cost\ per\ unit$$

The labor cost per unit was calculated based on parameters such as:

$$Number\ of\ workers\ to\ assemble\ unit\ =\ 6$$
$$Shifts\ per\ day\ =\ 2$$
$$Hours\ per\ shift\ =\ 8$$
$$Labor\ cost\ per\ hour\ (Manufacturing\ wage)\ =\ 217{,}3\ SEK$$

$$Labor\ cost\ per\ day\ =\ 6\ *\ 2\ *\ 8\ *\ 217{,}3\ =\ 20\ 860{,}8\ SEK$$

Since we are working with an annual demand we calculated the Annual labor cost per unit.

$$Working\ weeks\ per\ year\ =\ 48$$
$$Working\ days\ per\ week\ =\ 7$$
$$Working\ days\ per\ year\ =\ 48\ *\ 7\ =\ 336$$

$$Annual\ labor\ cost\ =\ Working\ days\ per\ year\ *\ labor\ cost\ per\ day$$
$$=\ 336\ *\ 20\ 860{,}8\ =\ 7009228{,}8\ SEK$$

Considering that $Annual\ demand\ =\ 90\ 477$,

$$Labor\ cost\ per\ unit\ =\ \frac{Annual\ labor\ cost}{Annual\ demand} = \frac{7\ 009\ 228{,}8}{90\ 477} = 77\ SEK$$

$$Material\ cost\ per\ unit\ =\ 20\%\ *\ Selling\ Price\ =\ 20\%\ *\ 199{,}90\ \approx\ 40\ SEK$$

Therefore,

$$Total\ variable\ cost\ per\ unit\ = Labor\ cost\ per\ unit\ + Material\ cost\ per\ unit$$
$$Total\ variable\ cost\ per\ unit\ = 77\ +\ 40\ =\ 117\ SEK$$

Regarding the Fixed Costs we started by calculating its annual value and then the value per unit.

$$Total\ Annual\ Fixed\ Costs\ =\frac{Working\ stations\ cost}{Investment's\ duration}$$

Where $Working\ stations\ cost$ includes all the manufacturing equipment costs, as presented in Table 13.

Table 13 Manufacturing Equipment Costs

S.No	Item	Qty	Cost (USD)	Cost (SEK)	Total Cost (SEK)
1	Andon 3-colour tower light	6	177	1716,9	10301,4
2	Electronic ergonomic chair + joystick/dashboard	6	6595	63971,5	383829
3	LED task "Tibe-light"	6	100	970	5820
4	Kanban card holder	12	45	436,5	5238
5	7-bin part organiser	42	60	582	24444
6	Heavy-duty assembly table	6	589	5713,3	34279,8
7	Industrial barcode scanner	6	368	3569,6	21417,6
8	Weller WE-1010 solder station	6	115	1115,5	6693
9	Rubber mallet	6	10	97	582
10	Drill-press stand / holder	6	80	776	4656
11	Foot-switch pedal	6	35	339,5	2037
12	ZEISS DuraMax CMM	1	50000	485000	485000
13	EPAL Euro pallet	1	17	164,9	164,9
14	Hand pallet truck	1	464	4500,8	4500,8
15	Mini 6-axis robot arm	1	7500	72750	72750
16	Dual-lane packaging station	1	5000	48500	48500
17	Modular belt-conveyor section (≈3 m)	14	2200	21340	298760
18	Inbound parts organiser rack	1	200	1940	1940
TOTAL COST FOR ALL THE WORKING STATIONS					**1410913,5**

Where,

$$Total\ Cost\ (SEK)\ =\ Qty\ *\ Cost\ (SEK)$$
$$Investment's\ duration\ =\ 5\ years$$

Therefore,

$$Total\ Annual\ Fixed\ Costs=\frac{1\ 410\ 913{,}5}{5}=282\ 182{,}7\ SEK$$

$$Total\ Fixed\ Costs\ per\ unit=\frac{Total\ Annual\ Fixed\ Costs}{Annual\ Demand}=\frac{282\ 182{,}7}{90\ 477}=\ 3{,}2\ SEK$$

These calculations allowed us to conclude that, for our manual assembly line,

$$Total\ Cost\ per\ unit\ =\ 117\ +\ 3{,}2\ =\ 120{,}2\ SEK$$

Of this cost, 64% is associated with labor cost, 33% with material cost and 3% with fixed costs.

$$ROI=\frac{Savings-Investment}{Investment}=\frac{7\ 211\ 017-1\ 410\ 913{,}5}{1\ 410\ 913{,}5}=4{,}11$$

Where,

$$Savings = Annual\ Revenue - Annual\ Cost$$

$$Savings = (199{,}90 * 90477) - (120{,}2 * 90477) = 7\ 211\ 017\ SEK$$

$$Investment = 1\ 410\ 913{,}5\ SEK$$

12.2. Partial Automated Line Economic Analysis

An estimated value for the total cost of having a partially automated assembly line was calculated based on several changes.

Firstly, stations 3 and 4 were converted into fully automated stations. Stations 1 and 2 for both the RC car and the controller were not included in this decision since they integrate some delicate operations, like the wiring of the circuit board. With automation, each station integrates a robot with 2 grippers, a tool changer [4] for the robot to be able to change between grippers, and a linear feeding system. The robot chosen for these two stations was the Universal Robot UR5e [5] since it is widely used for small part assembly, providing good precision and flexibility to support more than 1 gripper. For these stations, the types of grippers considered were force and vacuum grippers, since they are reliable and adaptive for parts with different geometries. The feeding system chosen was a linear one because it is suitable for delicate components, like small plastic parts, and a moderate production volume.

Furthermore, all the screwing operations were considered to be done by an electric screwdriver. Therefore, the electricity cost associated with these operations and the cost of acquiring 6 electric screwdrivers (one for each station) were added to the total cost.

To calculate the electricity cost, some assumptions were made, including

- Screwing power of 10W
- Screwing time of 1 second
- Electricity price (Sweden) of 2,76 SEK / kWh

$$Electricity\ cost\ per\ screwing\ operation = \frac{10}{3600 * 10^3} * 2{,}76 = 0{,}0000077\ SEK$$

According to the information presented in the Parts list, the total number of screws, for the RC car and the controller, is 32. Therefore,

$$Total\ cost\ of\ electricity\ per\ unit\ (by\ using\ an\ electric\ screwdriver) = 32 * 0{,}0000077 = 0{,}00025\ SEK$$

All these costs, plus those associated with the basic manufacturing equipment for an assembly working station, are represented in Table 14.

Table 14. Manufacturing Equipment Cost

S.No	Item	Qty	Unit USD	Unit SEK	Final Price In SEK
1	Andon 3-colour tower light	6	177	1716,9	10301,4
3	LED task “Tibe-light”	6	100	970	5820
4	Kanban card holder	12	45	436,5	5238
5	7-bin part organiser	42	60	582	24444
6	Heavy-duty assembly table	6	589	5713,3	34279,8
7	Industrial barcode scanner	6	368	3569,6	21417,6
8	Weller WE-1010 solder station	6	115	1115,5	6693
9	Rubber mallet	6	10	97	582
10	Drill-press stand / holder	6	80	776	4656
12	ZEISS DuraMax CMM	1	50000	485000	485000
13	EPAL Euro pallet	1	17	164,9	164,9
14	Hand pallet truck	1	464	4500,8	4500,8
15	Mini 6-axis robot arm	1	7500	72750	72750
16	Dual-lane packaging station	1	5000	48500	48500
17	Modular belt-conveyor section (≈3 m)	14	2200	21340	298760
18	Inbound parts organiser rack	1	200	1940	1940
19	Robot Arm Station 3	2	34184,5	331589,94	663179,882
20	Gripper 1	2	5127,68	49738,496	99476,992
21	Gripper 2	2	6267,16	60791,452	121582,904
26	Tool (Gripper) Changer	2	1367,38	13263,586	26527,172
27	Linear Tray Feeders	2	5126,47	49726,759	99453,518
28	Electric screwdriver	6	53,54	519,338	3116,028
29	Electricity of electric screwdriver	32	7,9E-07	0,0000077	0,0002464
TOTAL COST FOR ALL THE ASSEMBLY WORKING STATIONS					**2038383,996**

Moreover, another cost considered in this analysis was the cost of having a fully automated packaging station. The breakdown of this cost is represented in Table 15.

Table 15. Equipment cost for automated packaging

S.No	Item	Qty	Unit cost (SEK)	Final Price In SEK
1	Mini 6-axis robot arm	1	72750	72750
2	Modular belt-conveyor section (~3 m)	4	21340	85360
3	Dual-lane packaging machine	1	48500	48500
4	Heavy-duty packaging table	1	5713	5713
5	Automatic box-sealer / flattener	1	15000	15000
6	Pallet / outbound rack (EPAL-style)	1	1940	1940
7	Label-printer / small barcode station	1	10000	10000
TOTAL COST FOR PACKAGING STATION				**239263**

By integrating all these changes into the assembly line, we achieved a new value for the total number of fixed costs.

$$Total\ fixed\ costs = 2\ 277\ 647\ SEK$$

$$Total\ Annual\ Fixed\ Costs\ = \frac{2\ 277\ 647}{5} = 455\ 529{,}4\ SEK$$

$$Total\ Fixed\ Costs\ per\ unit = \frac{455\ 529{,}4}{90\ 477} = 5{,}03\ SEK$$

Moreover, integrating automation into the assembly line, besides impacting the total amount of fixed costs, also influences the total cost of variable costs, since less labor is required.

Therefore, by converting stations 3 and 4 into fully automated stations, the total number of operators decreased to 3, which makes the labor cost per day, the annual labor cost, and the labor cost per unit half of that for manual assembly.

$$Labor\ cost\ per\ day\ =\ 3\ *\ 2\ *\ 8\ *\ 217{,}3\ =\ 10430{,}4\ SEK$$

$$Annual\ labor\ cost\ = 3\ 504\ 614\ SEK$$

$$Labor\ cost\ per\ unit\ = \frac{Annual\ labor\ cost}{Annual\ labor\ demand} =\ 38{,}73\ SEK$$

Since the material cost remained the same, the new value for the total variable cost is given by the following formula,

$$Total\ variable\ cost\ per\ unit\ = Labor\ cost\ per\ unit\ + Material\ cost\ per\ unit$$

$$Total\ variable\ cost\ per\ unit = 38{,}73 + 40 = 78{,}73\ SEK$$

Therefore, having both types of costs taken into consideration,

$$Total\ Cost\ per\ unit\ =\ 5{,}03 +\ 78{,}73\ =\ 83{,}76\ SEK$$

With this, it is possible to observe that the total cost with automation is less than the total cost of a manual assembly line.

$$ROI = \frac{Savings - Investment}{Investment} = \frac{10\ 507\ 999 - 2\ 277\ 647}{2\ 277\ 647} = 3{,}61$$

Where,

$$Savings = Annual\ Revenue - Annual\ Cost$$

$$Savings = (199{,}90 * 90477) - (83{,}76 * 90477) =\ 10\ 507\ 999\ SEK$$

$$Investment = 2\ 277\ 647\ SEK$$

$$Payback\ period = \frac{Investment}{Annual\ Savings} = \frac{2\ 277\ 647}{10\ 507\ 999} = 0{,}22\ years$$

13. Design for Assembly

13.1 Manual Assembly

The concept of design for assembly is a key factor in determining a successful assembly solution. The result of DFA analysis provides a design of products that are easy to assemble, require fewer parts, improve the quality of the product and most importantly reduce the assembly time. During the DFA analysis for our product we thought of multiple ways to redesign some of the parts, hence reducing the number of parts by improving this overall assembly efficiency.

To achieve a good design for assembly, the number of separated parts should be minimum. So, we asked three questions for each part and answered yes or no and if all the three questions are answered no then that part is not required.

1. Does the part experience relative motion with respect to all other assembled parts during product operation? Only significant movements should be taken into consideration, while small motions that can be absorbed by inherent elastic elements are not relevant for determining a positive response.

2. Does the part require a different material or isolation (such as insulation, electrical isolation, vibration damping) from all other assembled parts due to fundamental reasons associated with material properties?

3. Is it necessary for the part to be separate from all other assembled parts in order to enable the assembly or disassembly of other separate parts? This condition arises when the presence of the part prevents the necessary manipulation or connection of other components.

Below is the table listed the answers of above questions for the parts of RC car which will help in assessing the necessity of the part and hence reducing the part count.

From the table above, the result we got is that we can remove or integrate 5 parts from the 44 parts with the existing parts. As a result of this we got a theoretical number of parts (N_{min}) as 39 parts.

Table 16 DFA Non Essential Components Table

Prt.No	Part Name	Question 1	Question 2	Question 3	Essential ?
1	Monocoque	No	No	Yes	Yes
2	Spoiler	No	No	No	No, Possible to combine with Monocoque design
3	Rubber Bushing	No	Yes	Yes	Yes
4	Spoiler Washer	No	No	No	No, Possible to combine with Monocoque design
5	Bumper	No	No	No	No, Possible to combine with Body
6	Rim	Yes	No	No	Yes
7	Tyre	No	Yes	No	Yes
8	Spring & Damper	Yes	Yes	Yes	Yes
9	Upper A Arm	Yes	Yes	Yes	Yes
10	Lower A Arm	Yes	Yes	No	Yes
11	Cover	No	Yes	Yes	Yes
12	Pinion	Yes	Yes	No	Yes
13	Rack	Yes	Yes	Yes	Yes
14	Ring Gear	Yes	Yes	Yes	Yes
15	RingGear Shaft	Yes	Yes	No	Yes
16	Curved Internal Gear	Yes	Yes	Yes	Yes
17	Rivet	No	Yes	Yes	Yes
18	Tie Rod	Yes	Yes	Yes	Yes
19	Steering Arm	Yes	Yes	No	Yes
20	Wheel Bearing	Yes	Yes	No	Yes
21	Riveted Shaft	No	Yes	Yes	Yes
22	Main Shaft	Yes	Yes	No	Yes
23	Spur Gear	Yes	Yes	No	Yes
24	Spacer	No	Yes	No	Yes
25	Hex ending	No	Yes	Yes	Yes
26	MotorCover Left	Yes	Yes	Yes	Yes
27	Main Motor	No	Yes	No	Yes
28	MotorCover Back	No	Yes	Yes	Yes
29	MotorCover Middle	Yes	Yes	No	Yes
30	Compound Gear	Yes	Yes	No	Yes
31	Compound Gear - shaft	Yes	Yes	No	Yes
32	Body	No	Yes	No	Yes
33	Circuit Board	No	Yes	No	Yes
34	Connecting Wires	No	No	Yes	Yes
35	Steering Motor	No	Yes	No	Yes
36	Steering Cover	No	Yes	Yes	Yes
37	Locator	No	No	No	No,Possible to combine with cover
38	MiddleBody Cover	No	Yes	Yes	Yes
39	BackBody Cover	No	Yes	Yes	Yes
40	Rear Suspension Mount	No	No	No	No,Possible to combine with cover
41	Battery cover	No	Yes	No	Yes
42	On - Off switch	No	Yes	No	Yes
43	Steering Calibrator	No	Yes	No	Yes
44	Battery Terminal	No	Yes	No	Yes

The DFA index

$$E_{ma} = \frac{N_{min} * t_a}{t_{ma}}$$

The DFA index also known as assembly efficiency provides a synthetic measure of how well a product is designed for assembly. The higher DFA index indicates a more efficient design and also means that the product was designed in a simple way. Below is the table which conveys the handling and insertion time for each part based on the boothroyd table from where we will calculate t_{ma}.

Table 17 DFA using Boothroyd Dewhurst Table

Part no.	Part	Handling Time (s)	Insertion TIme(s)
1,2&4	Monocoque with spoiler and spoiler washer	2.7	6
3	Rubber Bushing	10,8	3
6	Rim	6	22
7	Tyre	6	22
8	Spring & Damper	7,2	46
9	Upper A Arm	11,7	11
10	Lower A Arm	11,7	11
11	Under Cover	1,5	6,5
12	Pinion	4,35	5,5
13	Rack	1,95	5,5
14	Ring Gear	3,6	6,5
15	Ring Gear Shaft	4,35	5,5
16	Curved Internal Gear	5,1	10
17	Rivet	4	8
18	Tie Rod	4,75	11,5
19	Steering Arm	5,1	5,5
20	Wheel Bearing	4	6,5
21	Riveted Shaft	4	8
22	Main Shaft	3,6	1,5
23	Spur Gear	4	2,5
24	Spacer	4	1,5
25	Hex Ending	4	3,5
26	Motor Cover Left	1,95	6
27	Main Motor	1,95	2,5
28	Motor Cover Back	1,95	6
29	Motor Cover Middle	1,95	6
30	Compound Gear	4,8	3,5
31	Compound Gear Shaft	3,6	1,5
5&32	Body and Bumper	1,95	1,5
33	Circuit Board	1,95	5,5
34	Connecting Wires	1,13	8
35	Steering Motor	1,95	2,5
36&37	Steering Cover & Locator	1,95	2,5
38	Middle Body Cover	1,95	25
39&40	Back Cover and Rear Suspension Mount	1,95	2,5
41	Battery Cover	1,95	2,5
42	On -Off switch	5,1	6,5
43	Steering Calibrator	5,1	2,5
44	Battery Terminal	7,8	20

t_{ma} we calculated the value from boothroyd dewhurst table both insertion and handling time which totaled to **256,7 sec**.

N_{min} From the above table we determined whether the part is absolutely required or not. So,we require around **39 parts** if we do some modifications to the design.

t_a we use the standard value without any handling or insertion time for a part it will take an average of **3sec**.

$$E_{ma} = \frac{39 * 3}{256,7} = 0,456 = \mathbf{45,6\%}$$

13.2 DFA automated assembly

Design for Automatic Assembly (DFAA) is equally vital if not more than DFA for manual assembly. In automatic assembly cost is not driven by task duration but by the cycle rate of the entire assembly system. DFA for automatic assembly focuses on system wide efficiency, not just individual task optimisation.

Eskilander method

For the analysis of DFAA we used Eskilander method. In this method the assembly index is evaluated two times, one for product and another for part level. Product level evaluates the overall quality of the product and part level evaluates the design suitability of each individual component.

Product Level

Product level index we analyse factors like number of parts, unique parts, base object etc. and give them a score of either 1,3 or 9. Then sum up the score and divide it by maximum point you will get an index.

Table 18 Product Level (Question for Assembly Process)

Product Level							
Reduce number of parts	Unique parts	Base object	Design base object	Assembly directions	Parallel operations	Chain of tolerances	**SUM**
1	1	9	1	1	3	1	**17**

$$Assembly\ Index_{\ product} = \frac{Total\ Sum}{Maximum\ point} = \frac{35}{63} \approx 27\%$$

Part Level

Similar to product level for part level we analyse multiple factors like weight, need to assemble, tolerance etc. and give them a score from 1, 3 or 9. Below is the table that answers 18 factors for all the 44 parts of the RC car. From this we will get the total score and then divide it by maximum possible points and no. of products to get the assembly index in part level.

Table 19 Part Level (Question for Assembly Process)

Parts	Need to Assemble	Level of Defects	Orientation	Fragile parts	Hooking	Centre of Gravity	Shape	Weight	Length	Gripping	Assembly motion	Reachability	Insertion	Tolerances	Holding Down	Fastening method	Joining	Check/Adjust	Sum
Monocoque	9	3	1	3	1	1	1	9	9	1	3	9	3	9	3	3	3	3	74
spoiler	1	3	1	9	1	1	1	9	9	9	1	9	1	9	1	3	3	3	74
spoiler washer	1	3	1	9	9	3	1	9	3	3	1	9	3	3	1	3	3	3	68
Rubber Bushing	9	3	1	9	9	3	9	9	1	1	9	9	1	1	9	9	1	9	102
Rim	9	3	1	9	9	1	3	9	3	9	1	9	3	3	1	3	3	3	82
Tyre	9	3	1	9	9	3	9	9	9	3	3	9	3	3	3	9	3	3	100
Spring & Damper	9	3	1	9	1	1	1	9	3	1	1	3	1	1	3	3	3	3	56
Upper A Arm	9	3	1	9	9	3	1	9	1	1	1	9	1	3	1	3	3	3	70
Lower A Arm	9	3	1	9	9	3	1	9	1	1	1	9	1	3	1	3	3	3	70
Under Cover	9	3	1	9	9	3	3	9	3	3	1	9	1	3	3	3	3	3	78
Pinion	9	3	1	9	9	1	9	9	1	1	1	9	1	3	1	9	9	1	86
Rack	9	3	1	9	1	3	1	9	3	3	1	9	3	3	1	3	3	1	66
Ring Gear	9	3	1	9	1	1	3	9	1	1	1	9	1	3	1	3	9	3	68
Ring Gear Shaft	9	1	1	9	9	9	9	9	1	1	1	9	1	3	9	9	9	1	100
Curved Internal Gear	9	3	1	9	1	1	1	9	3	1	1	9	1	3	1	3	3	3	62
Rivet	9	1	1	9	9	1	3	9	1	1	1	9	3	3	3	9	3	9	84
Tie Rod	9	1	1	9	1	1	1	9	3	1	1	3	1	3	3	9	9	3	68
Steering Arm	9	3	1	9	1	1	1	9	1	1	1	9	1	9	1	3	3	3	66
Wheel Bearing	9	3	1	9	1	1	3	9	1	1	1	9	3	9	1	3	3	3	70
Riveted Shaft	9	1	1	9	9	1	3	9	3	1	1	9	3	9	3	9	3	9	92
Main Shaft	9	1	1	9	9	9	9	9	9	1	1	9	1	1	1	9	9	9	106
Spur Gear	9	3	1	9	1	1	3	9	1	1	1	9	1	9	3	3	9	3	76
Spacer	9	3	1	9	9	1	3	9	3	3	1	9	3	9	3	3	9	3	90
Hex Ending	9	3	1	9	9	3	3	9	3	3	1	9	3	1	9	3	9	9	96
Motor Cover Left	9	9	1	9	1	1	1	9	9	9	1	9	3	3	3	3	3	3	86
Main Motor	9	9	1	9	9	3	1	9	3	9	1	9	1	3	3	9	9	3	100
Motor Cover Back	9	9	1	9	1	1	1	9	3	9	1	9	3	3	3	3	3	3	80
Motor Cover Middle	9	9	1	9	1	1	1	9	9	9	1	9	3	3	3	3	3	3	86
Compound Gear	9	3	1	9	1	1	3	9	1	1	1	9	1	1	1	9	9	3	72
Compound Gear Shaft	9	1	1	9	9	1	9	9	1	1	1	9	1	3	9	9	9	9	100
Body	9	9	1	9	9	1	1	9	9	9	1	9	3	9	9	9	9	3	118
Bumper	1	3	1	9	9	1	1	9	3	9	1	9	1	9	3	3	3	3	78
Circuit Board	9	9	1	9	9	3	1	9	3	3	1	9	1	9	3	3	3	3	88
Connecting Wires	9	1	1	9	1	1	9	9	9	1	1	9	1	9	1	1	1	3	76
Steering Motor	9	9	1	9	9	3	1	9	3	9	1	9	1	9	3	3	9	3	100
Steering Cover	9	3	1	9	1	3	1	9	9	9	1	9	3	9	9	3	3	3	94
Locator	1	3	1	9	9	3	9	9	3	1	1	9	3	9	3	3	3	3	82
Middle Body Cover	9	3	1	9	1	3	1	9	9	9	1	9	3	9	9	3	3	3	94
Back Cover	9	3	1	9	1	3	1	9	9	9	1	9	3	9	9	3	3	3	94
Rear Suspension Mount	1	3	1	9	1	1	1	9	3	9	1	9	1	3	1	3	3	3	62
Battery Cover	9	3	1	9	1	3	1	9	9	3	1	9	3	3	9	9	3	3	88
On -Off switch	9	9	1	9	9	1	1	9	1	1	1	3	1	1	3	3	3	3	68
Steering Calibrator	9	3	1	9	9	1	1	9	1	1	1	9	3	3	1	9	9	3	82
Battery Terminal	9	3	1	9	1	1	1	9	9	3	1	9	1	3	9	9	9	3	90
Total Sum																			3642

$$Assembly\ Index_{Part} = \frac{Total\ Sum}{Maximum\ points * No.of\ parts} = \frac{3642}{162 * 44} = 0{,}511 \approx 51{,}1\%$$

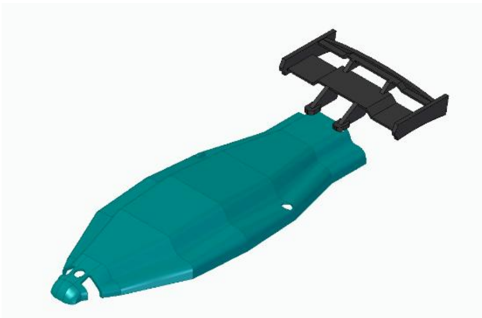
13.3 Design change recommendation.

During the DFA analysis of our product we gave a thought on how the product can be redesigned for achieving a better assembly index. Below we will discuss how it can be designed by comparing it to the existing solution for the 5 parts we removed by asking the questions in the DFA manual section.

Spoiler and Spoiler washer

In the existing product we have four parts to attach the spoiler to the monocoque but that part is not connected to any other part of the assembly so we can manage to design a monocoque and spoiler as a single part, hence we remove the washer and the screws. By doing this we are saving assembly time and cost by not manufacturing two additional parts. In the below figure you can see the conceptual design for the redesigned monocoque. **Parts 1,2 and 4 impacted because of the proposed changes refer to Table 1.**

1



2

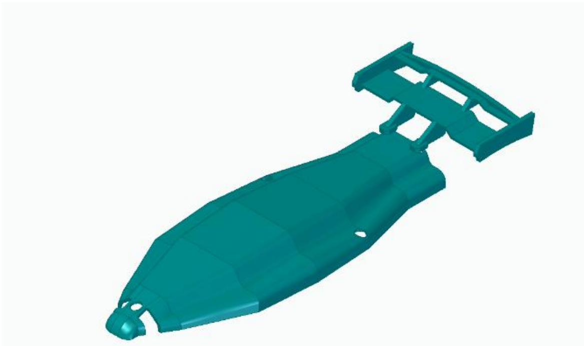
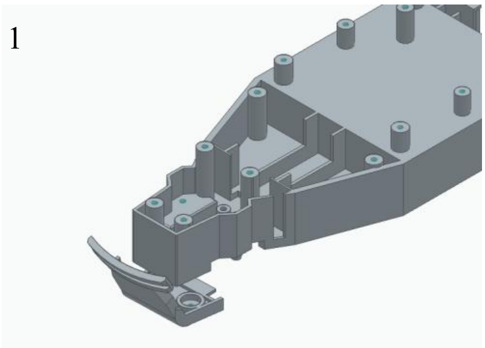


Figure 17 Existing Design vs New Proposed Design with Unibody Construction for Spoiler

Bumper

In the existing product we have separate parts for bumper and body, the function of the bumper will remain the same even if it was manufactured with the body. And it does not stop any part from disassembling. By making this design change we are saving assembly time. Below are the figures you can see the design change. **Parts 5 and 52 are impacted because of this change refer to Table 1.**

1



2

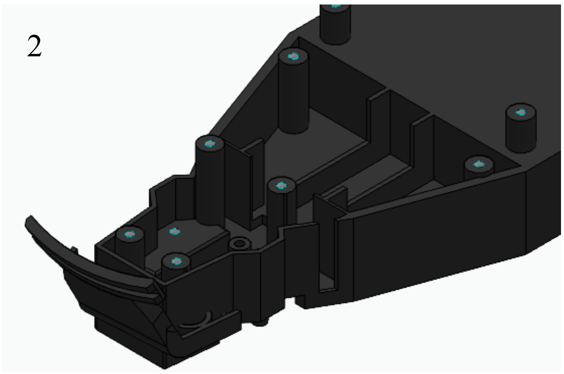


Figure 18 Existing Design vs New Proposed Design with Unibody Construction for Bumper

Locator

In this existing product we have three locators, and it is manufactured as separate parts. But we thought that it didn't have any specific functionality and justification to be a separate part. It is just used to mount the monocoque. So, we have decided to come up with an idea to manufacture it as a single part with the steering cover and middle cover hence reducing time and number of individual parts. **Parts 36,37 and 38 are affected because of these changes refer to Table 1.**

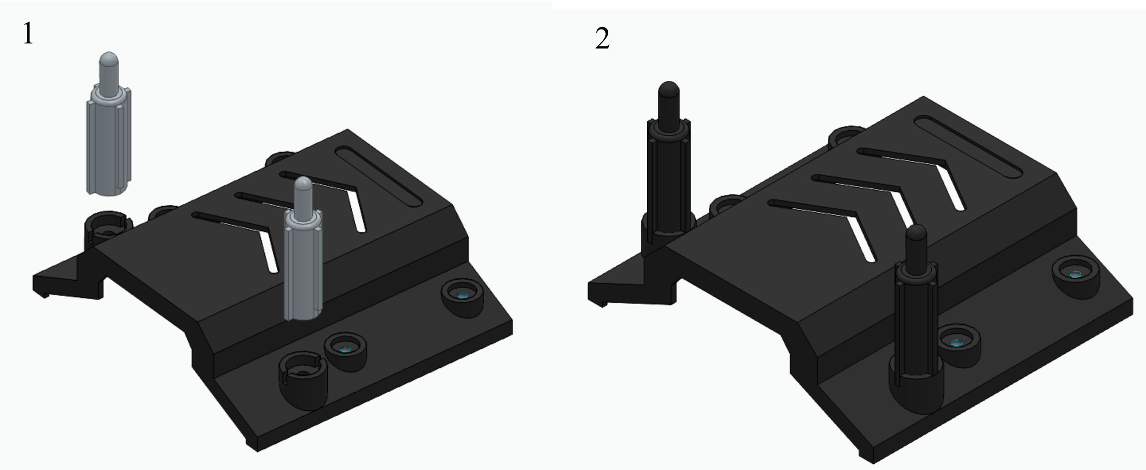


Figure 19 Existing Design vs New Proposed Design with Unibody Construction for Locator

Rear Suspension Mount

In the existing design the mount for placing the rear suspension mount was well designed but it is a separate part from the back cover. But it doesn't have any use case to be a separate part. So, we have designed a new back cover which is manufactured with the rear suspension mount. Below is the picture of the redesigned part. **Parts 39 and 40 are the affected parts because of the changes made refer to Table 1.**

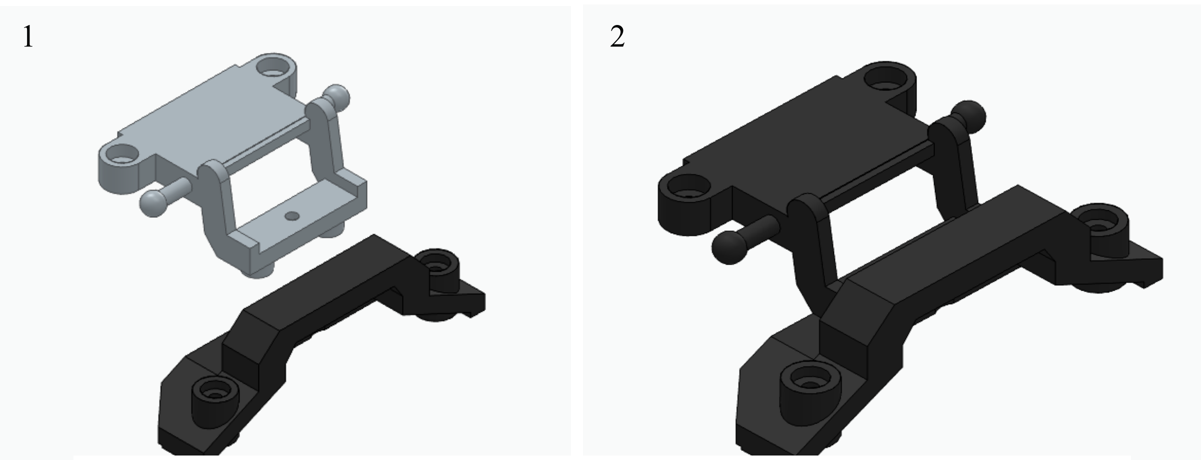


Figure 20 Existing Design vs New Proposed Design with Unibody Construction for Rear Suspension Mount

13.4 Impact on Assembly Efficiency

The proposed redesigned parts will reduce the T_{ma} of the assembly hence directly improving the DFA index of Manual Assembly. The T_{ma} values in Table 17 is after improvement of design changes and reducing the number of parts. Below we have listed out the T_{ma} before design changes and we will compare the differences.

T_{ma} before design changes = 295,35 sec.

No. of Parts before design changes = 44 parts

T_{ma} after design changes = 256,7 sec.

No. of Parts after design changes = 39 parts

Reduced time ΔT_{ma} = 38,65 sec.

$$\text{Assembly Efficiency}_{\text{before design changes}} = E_{ma} = \frac{44*3}{295,35} = 44.6\%$$

$$\text{Assembly Efficiency}_{\text{after design changes}} = E_{ma} = \frac{39*3}{256,7} = 45.6\%$$

From the above comparison you can see that we have had 1% improvement in the overall assembly efficiency because of the design changes. The part reduction can reduce the fasteners required for these parts also saves the material cost. The part reduction improves the inventory management also gives way for future scalability chances of automation implementation with reduction is part count.

13.5 Automation Assessment and Part Handling

The feasibility of automation for our RC car assembly was evaluated Eskilander DFA approach. Our DFAA index is 27% at the product level and 51% at the part level, as presented in Table 18 and Table 19 and they clearly reflect the challenges of automating this product. These values indicate that, given the current product design, a fully automated production line is not practical. Most of the parts are small, require precise handling, and are designed for relative motion. As a result, further part reduction or simplification is highly limited by functional requirements.

From our analysis only some operations can be automated. Components such as the chassis, screwing, monocoque placement can be handled by robotic arms equipped with vacuum or frictional grippers. These grippers work on the principle of providing a stable, controlled grasp for parts with regular geometry frictional gripper using two flat jaws to grip the part, while vacuum grippers use suction for smooth flat surfaces. The screwing operations can be partially automated with power tools, but it should be done with extreme care due to the small size of screws, which can cause feeding errors. The robots, combined with force or torque sensors, can further improve the orientation, alignment and insertion of the screws for operations like wheel assembling.

Operations involving small, flexible, or delicate parts such as wiring, circuit board handling, and precise suspension, compound gear insertions are blocked by the need for careful manual involvement for precise orientation application, and force application. These steps are not only challenging for typical automation equipment to handle the operation but also introduce a higher risk of product damage if not managed by skilled operators.

The primary reason for automation is not possible in this product, because of many factors related to both parts and assembly requirements. Many of the components are extremely small and require high precision and care, which makes it difficult to implement reliable gripping and accurate placement of the part. In addition, several parts such as wires, springs, and printed circuit boards are flexible or delicate, resisting the consistent handling required for automation and increasing the risk of damage if not controlled with care. The assembly process is further complicated by the high orientation complexity of tiny parts. Finally, the functional requirements of the RC car demand that many parts maintain relative motion to one another, limiting opportunities for further part consolidation or simplification and thereby constraining the potential for automated solutions.

Given these constraints and as also reflected in our DFAA analysis above, the design changes implemented in our project were focused on improving manual assembly efficiency and reliability, rather than enabling full automation, which is very difficult for the product of this kind with many parts. While some operations chassis placement, snap-fit insertions, selective screwing operations can be automated using standard industrial equipment, the overall assembly process is best managed through partial automation which helps us automating repetitive tasks while leaving complex and delicate operations to experienced manual operators.

14. Assembly Design

14.1 Fixture Design

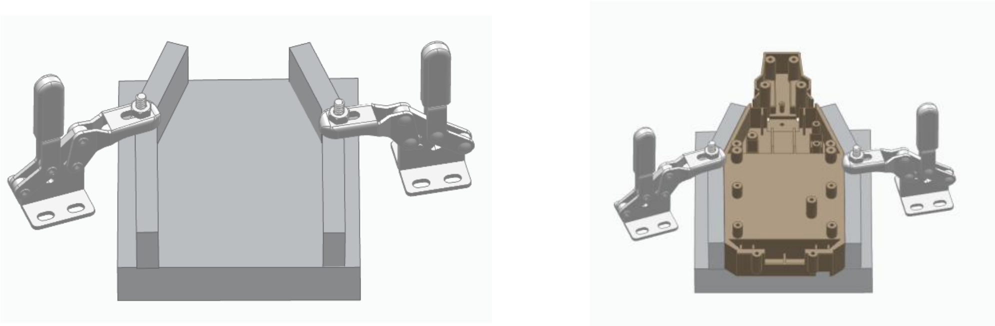


Figure 21 Fixture for Holding the Main Body

The Fixture used in the assembly process is designed to keep the RC body safe during assembly operation. It guarantees stability by limiting the required degree of freedom and supporting accurate, repeatable positioning across the line. This Fixture takes into account accessibility based on the orientation of primary, secondary and tertiary references, allowing for efficient handling and assembly tasks. Since the fixture is modular, but is dedicated to a specific product, it can be used consistently through all workstations without adaptation. Integration into the assembly supports accuracy, reduces handling errors, and maintains quality.

14.2 Workstation Design

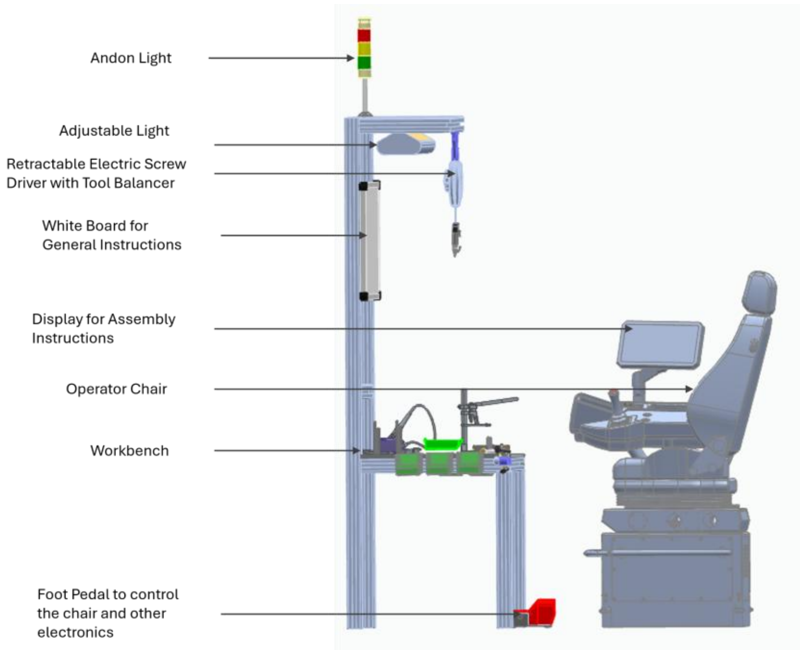


Figure 22 Left View of Workstation

Each workstation on the assembly line is created to ensure consistency of production, ergonomic comfort and operator efficiency. The electronically adjustable chair with a dashboard and joystick is part of the setup and offers flexible operation and accurate task support. The lean material flow is supported by two Kanban card holders, with focused lighting provided by tibial light. Large assembly tables, barcode scanners, solder kits, rubber hammers, drilling holders and foot pedals are conveniently located within the work station range. The organizer with seven bins allows for standardized work and ensures different partial separation. Each station has an Andon Light installed to support a rapid response to line interruptions and receive real-time status signaling. This uniform setup of all stations improves the effectiveness, repeatability and modularity of operator training.

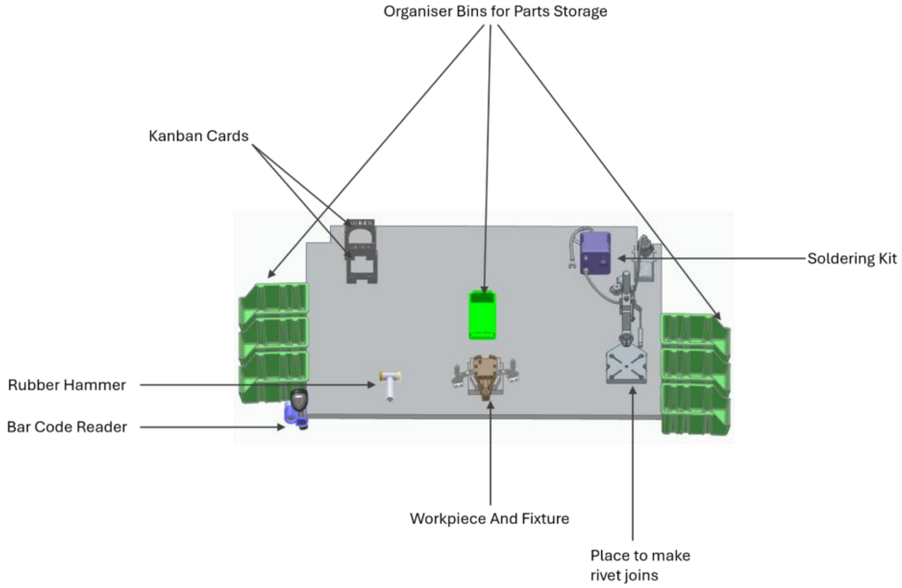


Figure 23 Top View of Worktable

To improve operator performance, many ergonomic designs and engineering concepts were included in the workstation design. Our workstations implement key assembly concepts such as line balancing, standard work layout, and waste reduction through lean design. An overhead clamp driver with a tool balancer reduces the search time for arms and tool searches. Meanwhile, foot movement control and height adjustment options allow for neutral posture and task-specific orientation. Components are arranged according to the frequency-of-use principle, ensuring that high-touch items remain within the optimal ergonomic reach zone. Including visual information about Andon Lights improves responsiveness in real time, and the Kanban system facilitates material flow synchronization with minimal handling. This design contributes to a secure, organized, powerful assembly environment by practicing workstation standardization, accessibility mapping (TAD logic), operator-centric layout.

14.3 Assembly Line Design

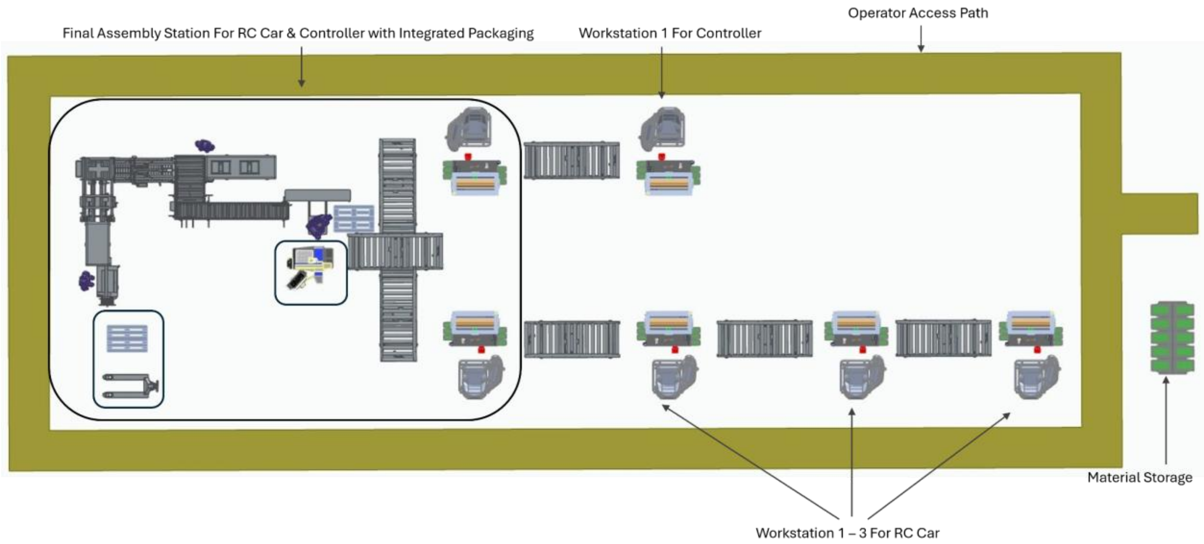


Figure 24 Top View of Assembly Line

The overall factory layout is organised around a closed-loop pallet conveyor that feeds four in-line assembly workstations, a two-station controller branch, and integrated logistics zones. Raw material totes enter at the left-hand inbound dock, pass a kitting rack for just-in-time part presentation, then advance on an asynchronous belt whose speed profile is tuned to the line takt time. A vertical crossover allows empty pallets to return beneath the main flow, eliminating cross-traffic and keeping the work floor clear. Operator stations are positioned on the outside of the loop for direct access to parts organisers, while barcode-scanned pallets provide traceability at each hand-off. After the fourth station, finished RC-car and controller pallets merge and proceed directly to the combined packaging cell at the far right, where boxed units are queued for outbound logistics. This single-piece, pull-driven arrangement minimises work-in-process, maintains clear sightlines for Andon escalation, and provides a compact footprint that can be mirrored for future capacity expansion.

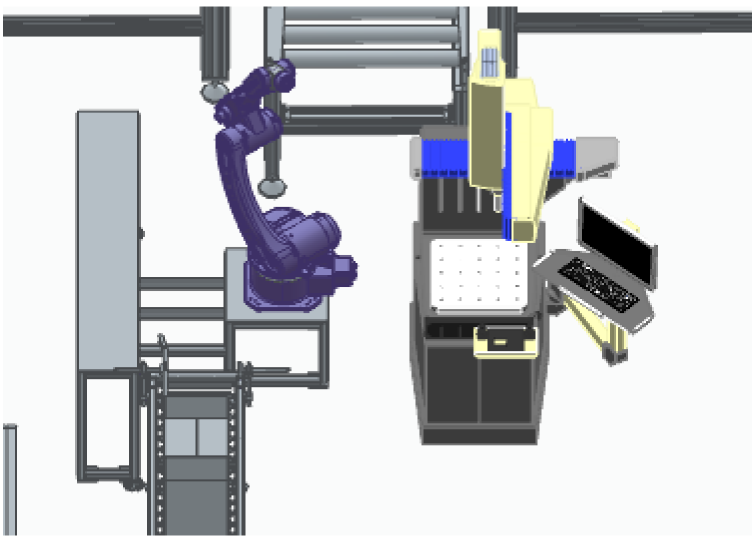


Figure 25 Top View of Quality Station

A ZEISS DuraMax compact CMM is positioned at the head of the line and served by a six-axis pick-and-place robot. The conveyor diverts every hundredth RC-car and controller set onto the CMM pallet, giving a 1 % sampling rate that aligns with the PPAP level-1 requirement for dimensional process capability. DuraMax's integrated rotary table and 3 µm volumetric accuracy allow a full body scan of both assemblies in under three minutes without manual re-fixturing. Measurement results feed directly to the SPC dashboard; any trend beyond the set Cp/Cpk limits triggers an Andon alert upstream. This automated gate maintains quality verification without interrupting the main takt time, ensuring traceable geometry control while the remaining 99 % of units continue single-piece flow to packaging.

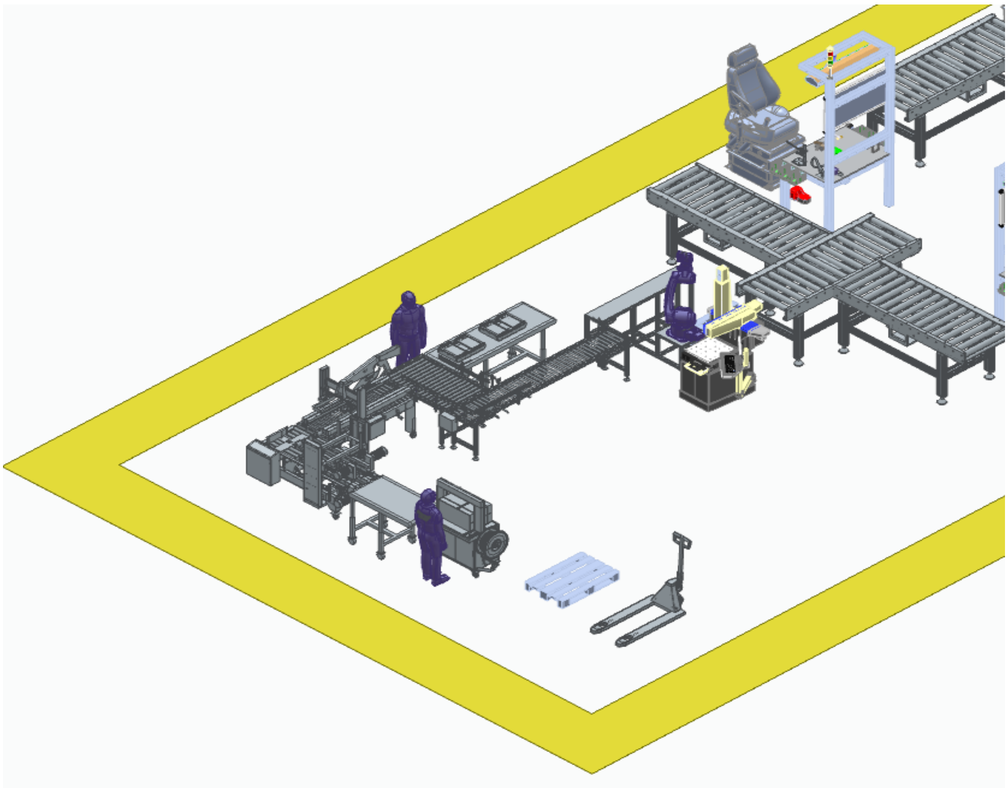


Figure 26 Isometric View of Packaging Station

The manual line is set up using four workstations in a single linear sequence. Workstation 1 takes 191 seconds to perform the task, leaving 9.21 seconds of Idle Time . Workstation 2 lasts 189 seconds and has an idle time of 11.21 seconds. Workstation 3 lasts 187 seconds, leaving 13.21 seconds. Workstation 4 completes the assembly and packs and labels for 92.5 seconds within the station during a 107.71 second remaining window. To absorb the smaller residual gaps that occur between Stations 1-2 and 2-3, successive conveyor segments are set to slightly different speeds: the upstream belt runs marginally slower than the downstream section so the surplus seconds are taken up during transfer, keeping hand-off on takt without adding physical buffers. In parallel, the controller is built on a two-station sideline paced to the same cycle; its pallets converge with the RC-car flow immediately before the shared packaging workstation. This blend of graduated conveyor speeds and branch-line synchronisation preserves one-piece flow, prevents queue formation, and maintains the line balance established by the RPW analysis.

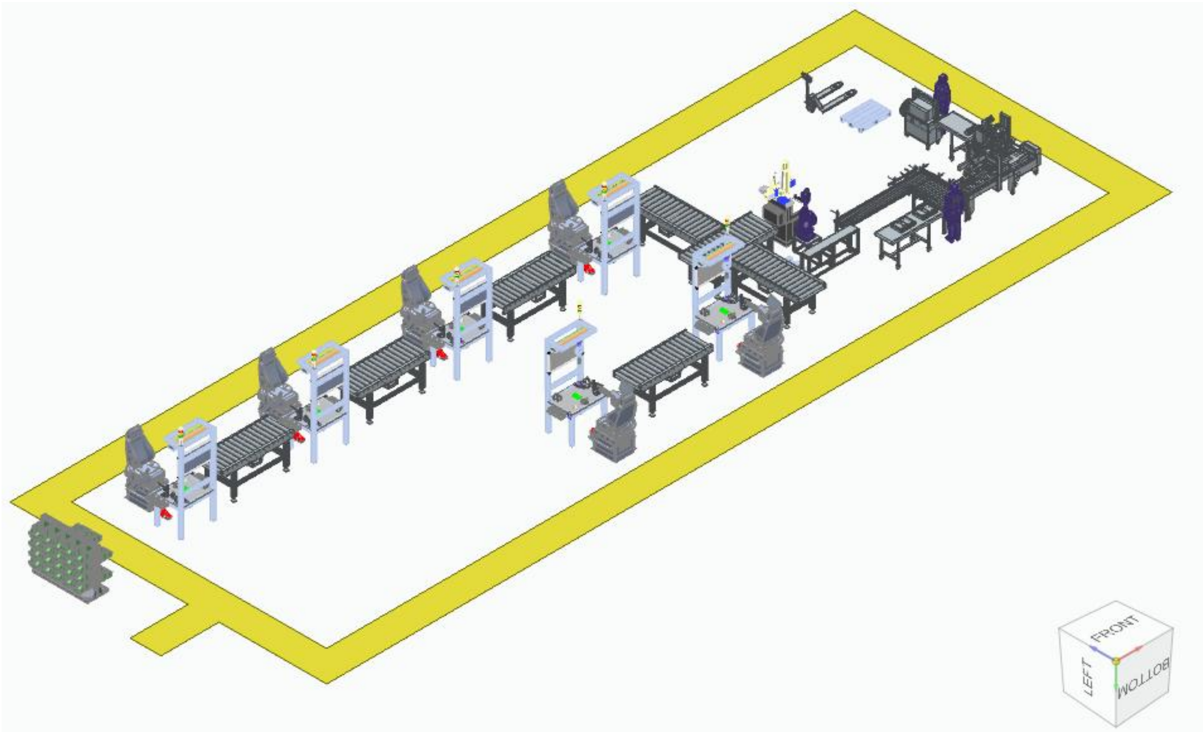


Figure 27 Isometric View of Assembly Line

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