Kungliga Tekniska Högskolan

Assembly Technology
MG2040

Project Report
Assembly of a fishing reel

Group D

Kanishk Hariya
Ferdinand Axel Blase
Riccardo Bronzini
Aiswarya Rajesh
Nabil Khalfi

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1 Introduction

1.1 Objective

The aim of this project is to analyze and document the assembly process of a fishing reel as part of the course ME2040, Assembly Technology, given at KTH.
The product that is going to be assessed in the following is the fishing reel 50RD by Shakespeare. The overall objective of this report is to analyze the product in regard to its manufacturability, propose improvements using design principles learned in class, balance a suggested assembly line, and examine the economic implications of the assembly lines. To achieve and meet these demands, we firstly disassembled the reel, allowing us to identify, categorize and understand the purpose of each part. Based on this detailed disassembly, a comprehensive part list was created, which then formed the foundation for our further analysis.
Following the disassembly, each component was examined with respect to its function, assembly challenges and interaction with other parts. Special emphasis was placed on identifying logical groupings of components into subassemblies such as the clutch assembly, rotor assembly and bail assembly. These groupings facilitated the development of a detailed operation list and a precedence diagram, reflecting the required sequence of actions during assembly.
These steps then led to the creation of an operations list based on one proposed assembly sequence and the operation times were then recorded, which allowed us to start with the line balancing methods.
Next, the economic analysis followed, which encompassed several calculations that allowed us to make a detailed cost plan and formed the base for other Chapters. Lastly, we dealt with proposed design changes and evaluated them to obtain one final solution.

1.2 Market Analysis

In order to understand our product, it's crucial to understand key trends and customer requirements in the underlying market. For this reason, we firstly looked into the market of amateur or leisure fishing reels in general, which in 2024 generated a revenue of about 240 billion SEK [1]. Afterwards we stepped into contact with the manufacturer to find out that Shakespeare EU is only a subsidiary of the Shakespeare Fishing Company, which is based in the US, and that Shakespeare EU is only responsible for the distribution, and the production is carried out elsewhere. However, they told us that the fishing reel that we analyze is only developed and sold for the European market. Therefore, we limited our further research on the European fishing market, which generated a profit of around 30 billion SEK in 2024 [2]. The only available information on the revenue of Shakespeare Fishing Europe that we could find claimed a yearly revenue of 55.672 million SEK [3].
To further understand the market, we also analyzed the position of Shakespeare Fishing in relation to the competitors in the European leisure fishing segment. Notable brands such as Shimano Inc., Daiwa Corporation, GTX Outdoors, The Orvis Company, Inc., Okuma Fishing Tackle Co., Ltd., Pure Fishing, Inc. Accurate Fishing Products are the fishing companies with the highest market share [4]. Most of these operate in a mid to high end market. In contrast, Shakespeare primarily competes in the entry-level to mid-range market, appealing to casual or beginner fishers. Shakespeare is a subsidiary of Pure Fishing but, in comparison to the other companies in its portfolio, plays a rather subordinate role.
Customer requirements in this lower price segment typically emphasize ease of use and value for money over other more expensive features. Given Shakespeare Europe's relatively modest revenue compared to market

leaders, maintaining an efficient and cost-effective production is very important. The product we analyze fits this strategy: it is relatively simple and composed of cost-effective materials, suggesting it was designed with both low manufacturing cost and ease of manual assembly in mind.

2 Product Description and Representation

2.1 Product Description

Fishing reels have been a staple across the globe for generations, facilitating the pursuit of fish in diverse environments. The fishing equipment is a huge market with numerous manufacturers that specialize in rods, reels, and equipment. Shakespeare is a recognized brand within the industry, and the product assigned for this project is the Firebird 50RD spinning reel. This reel is designed to be a reliable and affordable option for those starting their fishing adventures.

The Shakespeare Firebird 50RD is a user-friendly spinning reel, engineered for simplicity and ease of use. It incorporates a rear drag system for quick adjustments during fish fights and a lightweight graphite construction for comfortable extended use. The reel comes pre-spooled with monofilament line, allowing anglers to get fishing immediately.

Consumer products, including fishing reels, are often mass-produced and manufacturers strive to minimize production costs. Even minor improvements can translate to significant savings in time and materials over a year. With increasing customer demand, companies are focusing on optimizing assembly processes to ensure efficiency while maintaining high product quality. Proper assembly design can lead to substantial resource savings, including time, money and labor. Developing an efficient assembly line is a complex and iterative process, with the goal of maximizing productivity.

This description will present an overview of the Firebird 50RD's key features, highlighting its design and intended use. This fishing reel was chosen as it is a popular entry-level product and a good representation of a widely used, budget-friendly fishing reel. The Shakespeare Firebird 50RD is designed to meet the needs of beginner anglers, and this description aims to provide a clear understanding of its features and benefits.

Table 1: Product Specifications [5]

MODEL NUMBER	FIREBIRD 50 RD
SKU	1550362
ANTI-REVERSE FEATURE	Instant Anti-Reverse
BEARING COUNT	1
BRAKING SYSTEM	None
DRAG MATERIAL	Felt
GEAR RATIO	5:2:1
GROSS WEIGHT	0.450g
HEIGHT	4.331in
LENGTH	6.102in
MAX. DRAG LB	6.5kg
MONO CAPACITY M/MM	185/0.35 140/0.40 90/0.50
NET WEIGHT	0.405g
RECOVERY RATE	32.4" | 82cm
REEL SIZE	5000
REEL SPOOL MATERIAL	Graphite
WIDTH	6.299in

2.2 CAD Model

Figure 1: CAD Model of the Firebird 50RD

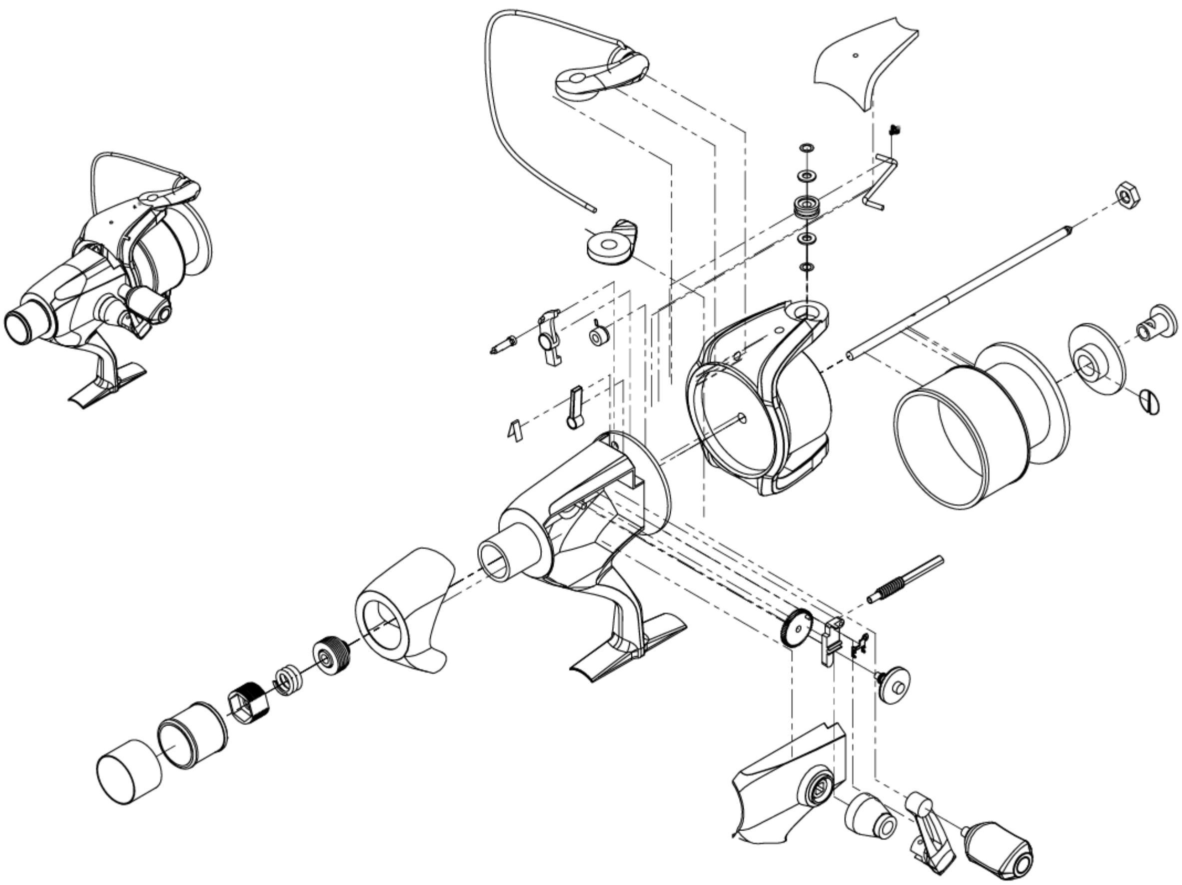


Figure 2: Exploded View

2.3 Part List

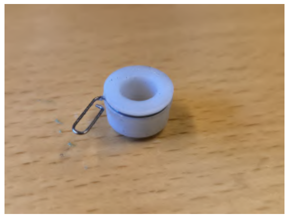
In the following Table, a detailed part list is depicted. To better differentiate the parts, a clear numbering system was used. This numbering system is based on the following guidelines that are established with the help of the Liaison Diagram (see Chapter 2.4):

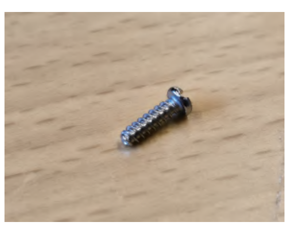
- #**X**000
  - #**0**000 Main assembly
  - #**1**000 Spool assembly
- #0**X**00 Sub-assemblies
- #00**XX** Part number in sub-assembly

Table 2: Part List

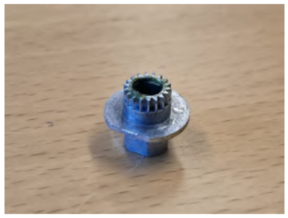
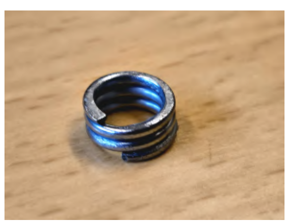
Part No.	Name	Qty.	Image	α	β	Size (mm)	thickness (mm)	Description
#0001	Body	1		360°	360°	125	45	The main structural part of the reel that houses all the internal components.
#0002	Pinion Gear	1		360°	0°	45	5	The pinion gear is an integral part of the spinning wheel; it converts handle rotation into spool motion for smooth line retrieval. Additionally, it ensures precise gear engagement and consistent performance under varying loads.
#0003	Ball Bearing	1		180°	0°	16	8	The single ball bearing reduces friction and improves reel performance, ensuring consistent operation under varying loads.

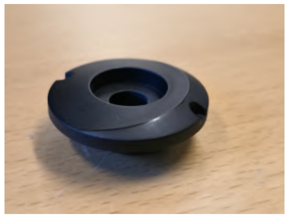
#0004	Pinion Gear Screw (M2)	2		360°	0°	7	3.5	Secures the ball bearing and the pinion gear in place, ensuring stable gear alignment during rotation.
#0005	Switch	1		360°	360°	17	12	The switch prevents backward spool rotation; it maintains line tension for secure hook sets and improves line control. Engaging the switch provides precision, and disengaging allows for a more flexible fishing technique.
#0006	Switch Arm	1		360°	360°	22	9	The switch arm facilitates smooth and effortless control of the anti-reverse mechanism, allowing the reel to adapt to different fishing styles and conditions.
#0007	Grip Spring	1		360°	180°	10	3.5	It is a key part of the anti-reverse mechanism, ensuring that the spool only turns in one direction, preventing backward rotation and maintaining consistent line tension and drag performance during use.
#0008	Lever Screw (M2)	1		360°	0°	5	1.5	Attaches the control lever to the reel body, allowing smooth engagement of the mechanism.
#0009	Resistance Arm	1		360°	360°	29	9	It is activated by the switch and is located within the reel. It engages into the grooves in the rotor to prevent the rotation in one direction.

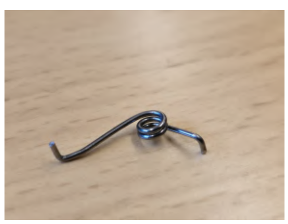
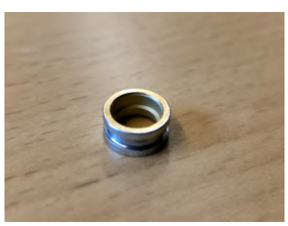
#0010	Resistance Arm Screw (M2.5)	1		180°	0°	13	3.5	Holds the resistance arm firmly, contributing to its function.
#0011	Resistance Arm Guider	1		360°	360°	23	10	It supports and guides the resistance arm's movement, ensuring smooth operation.
#0012	Oscillation Gear	1		360°	0°	24	6	This oval-shaped gear is fixed and features a non-circular pin; it rotates in a circular path and engages with the slider to drive the spools' up and down movement.
#0013	Slider	1		360°	360°	22	11	The slider in a fishing reel is a component that facilitates the oscillation of the spool, ensuring even distribution of fishing line during retrieval.
#0014	Main Shaft	1		180°	360°	140	12	The main shaft serves as the central support structure inside a spinning reel. It holds the spool and guides its oscillation, while the rotor spins around it to wind the line.
#0015	Slider Retainer	1		360°	360°	16	0.5	It secures the slider to the main shaft to allow for the transition of the force inside the reel.

#0016	Slider Retainer Screw (M2.5)	1		360°	0°	6	2.5	Fixes the slider mechanism, ensuring it remains properly aligned during reel operation.
#0017	Drive Gear	1		360°	0°	34	17	The drive gear transfers power from the handle to the pinion gear and oscillation gear, enabling the retrieval of the fishing line. The main gear is important in maintaining the smoothness and efficiency of the reel.
#0018	Drive Gear Washer (plastic)	2		360°	0°	14	7	The washer acts as a barrier between the main gear and other components. Additionally, it prevents wear and distributes the load evenly.
#0019	Side Cover	1		360°	360°	61	18	The side cover provides protection to internal components like gears and screws from dirt, moisture and even damage. Made from plastic, the cover is lightweight and easy to remove, providing easy access for maintenance.
#0020	Body Screw (M3)	4		360°	0°	10	2	Connects the main body sections, maintaining the structural integrity of the reel.
#0021	Rear Cover	1		360°	360°	47	36	A removable cover is located at the rear of the reel body, enclosing the drag mechanism and covering some of the body screws.

#0022	Rear Cover Screw (M2)	1		360°	0°	6	2	Secures the rear cover, protecting internal components from dust and moisture.
#0023	Base Ring	1		180°	0°	26	13	Keeps the Bottom cover in place by sliding ito the grooves
#0024	Bottom Cover	1		360°	0°	22	14	A small circular cap that is used to adjust the clutch, meaning that it can adjust the drag of the spool before it starts to slip.
#0025	Rubber Grip	1		180°	0°	14	14	This part is made out of rubber or a similar material to secure a tight grip with the bottom cover.
#0026	Handle Assembly	1		360°	0°	130	24	The unit that the angler uses to generate the force that allows the reel to function.
#0027	Handle Screw Cap	1		360°	0°	21	8.5	A small cap that screws onto the end of the handle arm to secure the handle assembly in place.

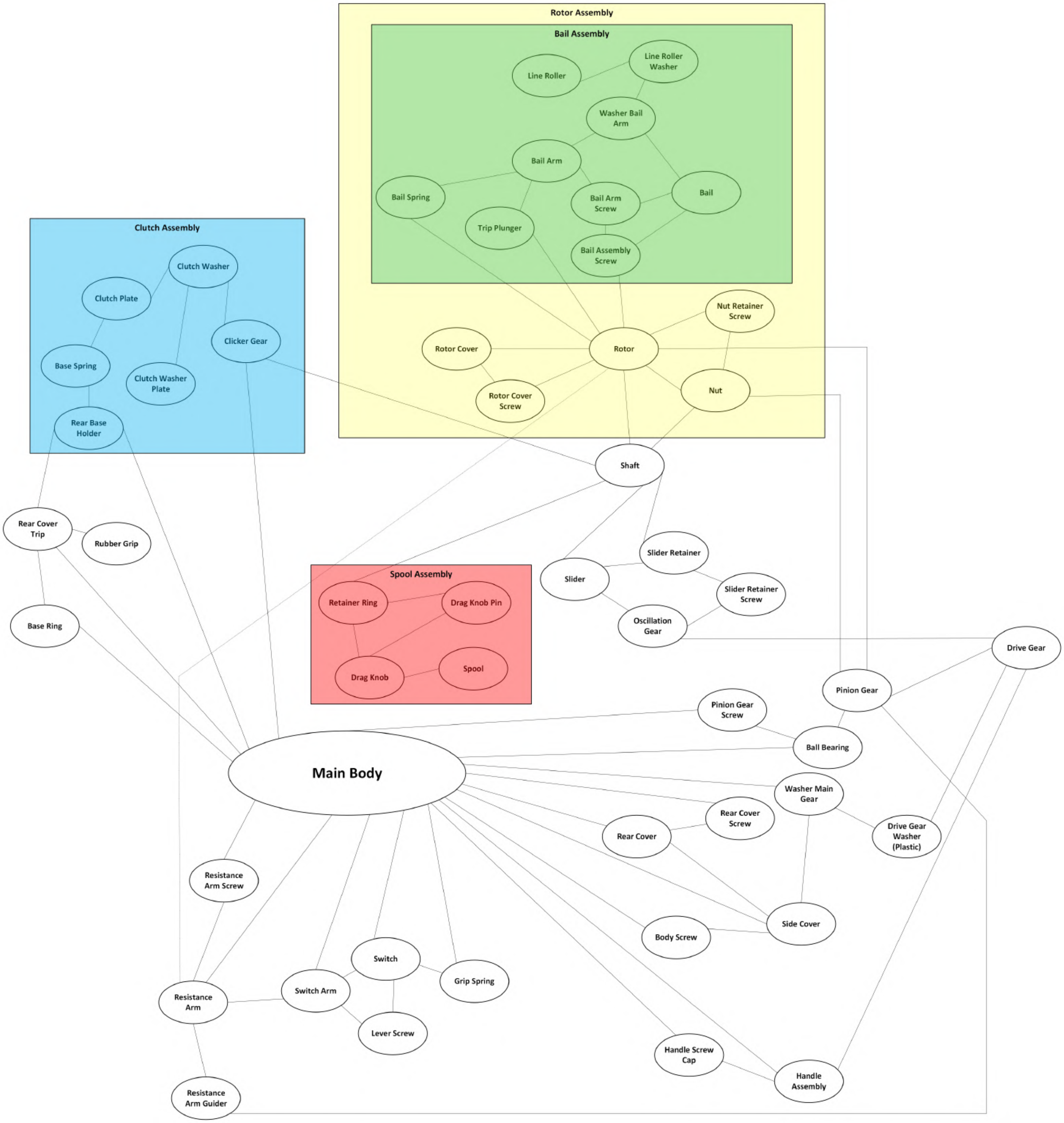
#0101	Clicker Gear	1		360°	360°	14	7	Clicker gears produce a clicking sound when the spool moves to alert the angler of line movement. This part improves bite detection and prevents accidental spool overrun.
#0102	Clutch plate washer	1		180°	180°	14.5	7.3	Reduces friction and ensures smooth engagement/disengagement of the clutch system, preventing wear and tear.
#0103	Clutch Washer	3		360°	180°	14.5	7.3	Acts as a barrier to prevent metal-to-metal contact, allowing smooth drag operation.
#0104	Clutch Plate	2		360°	180°	14.5	7.3	The clutch plate transfers tension to the drag system, controlling spool rotation.
#0105	Base Spring	1		180°	0°	11	5.5	This small spring provides tension near the reel base, helping to secure the internal components and ensuring the function of the clutch.
#0106	Base Holder	1		360°	0°	16	8	This functions as a retaining cap at the end of the reel; it secures the internal components.

#0201	Drag Knob	1		360°	0°	35	17.5	The unit at the top of the reel that houses the drag knob pin.
#0202	Drag Knob Pin	1		360°	0°	16	8	A small pin that allows for the removal of the spool from the rotor with the help of the Retainer ring.
#0203	Retainer Ring	1		180°	180°	14	7	A circular clip or ring that fits into the groove on the drag knob pin and enables the removal of the spool.
#0204	Spool	1		360°	180°	59	27	The spool assembly is the reel spool assembly. It stores the fishing line and allows it to be released or rewound when casting and retrieving. It is usually mounted on a spindle and moves up and down to ensure the line is wound evenly.
#1001	Rotor	1		360°	0°	85	50	It is the rotating part of the reel. As the handle turns, the rotor spins around the spool, guiding the fishing line onto it through the line roller.
#1002	Nut	1		360°	0°	12	35	A threaded fastener is used to secure various components of the reel together. It is placed inside the rotor.

#1003	Nut Retainer Screw (M2)	1		360°	0°	6	3	Locks the nut in place, preventing the central nut from loosening.
#1004	Rotor Cover	1		360°	360°	37	12	A cover that sits on the side of the rotor and has the goal of holding the trip plunger and the bail spring in place during operation.
#1005	Rotor Cover Screw (M2)	1		360°	0°	7	2.5	Fixes the rotor cover, shielding the rotor mechanism from damage and dust.
#1101	Trip Plunger	1		360°	360°	37	2	A small, spring-loaded pin or plunger that is part of the bail arm mechanism. It is involved in the process of automatically tripping the bail closed when you start reeling.
#1102	Bail Spring	1		360°	360°	2.6	10	A spring that provides tension to keep the bail arm securely in either the open or closed position.
#1103	Line Roller	1		360°	0°	11	5	A small roller located on the bail arm that guides the line onto the spool during retrieval, reducing friction and line twist.

#1104	Line Roller Washer	2		180°	0°	4	3	A small washer is positioned around the line roller to reduce friction, provide spacing, or ensure smooth rotation of the line roller.
#1105	Washer	4		180°	0°	5.5	0.5	A flat spacer is used to distribute load or reduce friction between reel components.
#1106	Bail Arm	1		360°	360°	43	13	The semi-circular wire arm that flips open to allow line to be cast and flips closed to engage the line for retrieval.
#1107	Bail Arm Screw (M3)	1		360°	0°	10	3	Fastens the bail arm, allowing it to pivot smoothly during line casting and retrieval.
#1108	Bail	1		360°	360°	97	31	The complete mechanism includes the bail arm, line roller and the parts that allow the bail to open and close.
#1109	Bail Assembly Screw (M3)	2		360°	0°	10	4	Secures the bail assembly components together, ensuring smooth and reliable line guiding during operation.

2.4 Liaison Diagram



3 Assembly Process

3.1 List of Operations

Table 3: List of Operations

Operation	Assembly Group	T_{ek} (in min)	Handling Operation	Inserting Operation	Part Nr.	Precedence
1		0.05	take body and place it		#0001	
2		0.08	take washer and orient it	place it into the cutout in the body	#1105	1
3		0.08	take drive gear washer (plastic) and orient it	place it onto the washer	#0018	2
4		0.10	take pinion gear and orient it	Slide it into the main body	#0002	1
5		0.10	take ball bearing and orient it	slide it onto the pinion gear and into the cutout in the body	#0003	4
6		0.30	take 2 pinion gear screws and orient them	place them into the holes and tighten to secure the ball bearing	#0004	5
7		0.05	take switch and orient it	place it into the cutout in the body	#0005	1
8		0.08	take switch arm and orient it	slide it through the body into the switch	#0006	7
9		0.10	take grip spring and orient it	place it between switch and body	#0007	8
10		0.22	take lever screw and orient it	fasten it to connect switch and switch arm	#0008	8
11		0.08	take resistance arm and orient it	place it onto the body	#0009	8
12		0.20	take resistance arm screw and orient it	fasten it to connect resistance arm and body	#0010	11
13		0.11	take resistance arm guider and orient it	place it onto the pinion gear and connect it with the resistance arm	#0011	6, 12
14		0.09	take oscillation gear and orient it	place it into the body	#0012	1
15		0.08	take slider and orient it	place it onto the oscillation gear	#0013	14
16	clutch assembly	0.07	take clutch plate and orient it		#0104	
17		0.07	take clutch washer and orient it	place it onto the clutch plate	#0103	16
18		0.07	take clutch plate washer and orient it	place it onto the clutch washer	#0102	17
19		0.07	take clutch washer and orient it	place it onto the clutch plate washer	#0103	18
20		0.07	take clutch plate and orient it	place it onto the clutch washer	#0104	19
21		0.07	take clutch washer and orient it	place it onto the clutch plate	#0103	20
22		0.15	take clicker gear and orient it	place it onto the clutch plate and inside the body	#0101	1, 21
23		0.05	take base spring and orient it	place it onto the clutch plate inside the body	#0105	22

24		0.16	take base holder and orient it	place it onto the base spring and tighten it	#0106	23
25	bail assembly	0.05	take bail and orient it		#1108	
26		0.08	take washer and orient it	place it onto the bail	#1105	25
27		0.08	take line roller washer and orient it	place it onto the washer	#1104	26
28		0.08	take line roller and orient it	place it onto the line roller washer	#1103	27
29		0.08	take line roller washer and orient it	place it onto the line roller	#1104	28
30		0.08	take washer and orient it	place it onto the line roller washer	#1105	29
31		0.12	take bail arm and orient it	place it onto the washer	#1106	30
32		0.19	take bail arm screw and orient it	tighten it to connect bail arm to bail	#1107	31
33	rotor assembly	0.05	take rotor and orient it		#1001	
34		0.10	take trip plunger and orient it	place it into the rotor	#1101	33
35		0.10	take bail spring and orient it	place it into the rotor and put the bail arm onto it	#1102	32,34
36		0.09	take rotor cover and orient it	place it onto the rotor	#1004	35
37		0.17	take rotor cover screw and orient it	place it into the rotor cover and tighten it	#1005	36
38		0.45	take two bail assembly screws and orient them	place them into the holes and tighten them to connect the bail and the rotor	#1109	35
39		0.10	take nut and orient it	place it onto the rotor assembly	#1002	33
40		0.25	take main shaft and orient it	slide it through the nut, rotor assembly, pinion gear, slider and clutch assembly	#0014	3, 13, 15, 24, 39
41		0.11	take slider retainer and orient it	place it onto the slider in a way that the main shaft is fixed	#0015	40
42		0.15	take slider retainer screw and orient it	place it onto the slider retainer to connect the slider retainer, main shaft and slider	#0016	41
43		0.10	take drive gear and orient it	place it into the main body onto the drive gear washer (plastic)	#0017	42
44		0.08	take drive gear washer (plastic) and orient it	place it onto the drive gear	#0018	43
45		0.08	take washer and orient it	place it onto the drive gear washer (plastic)	#1105	44
46		0.13	take side cover and orient it	place it onto the body	#0019	9, 10, 45
47		0.42	take four body screws and orient them	tighten them to connect the side cover with the body	#0020	46
48		0.09	take rear cover and orient it	place it onto the side cover and body	#0021	47
49		0.16	take rear cover screw and orient it	place it and tighten it to connect rear cover to body	#0022	48

50		0.29	orient the rotor on the main shaft and slide it all the way down	tighten the nut to fix it in place	#1002	47
51		0.12	take base ring and orient it	place it onto the body	#0023	1
52		0.20	take bottom cover and orient it	place it onto the base ring	#0024	24, 49, 51
53		0.09	take rubber grip and orient it	place it onto the bottom cover	#0025	52
54		0.13	take handle assembly and orient it	slide it through the body	#0026	47
55		0.16	take handle screw cap and orient it	place it into the body and tighten it to fix the handle assembly	#0027	54
56		0.15	take nut retainer screw and orient it	place it onto the rotor and tighten it to prevent the nut from loosening	#1003	50
57	spool assembly	0.07	take the drag knob pin and orient it		#0202	
58		0.11	take the retainer ring and orient it	place it onto the drag knob pin	#0203	57
59		0.12	take the drag knob and orient it	place the drag knob pin with the retainer ring inside	#0201	58
60		0.21	take the spool and orient it	place the drag knob in the spool and tighten it, then place the spool assembly on the shaft	#0204	56, 59

3.2 Precedence Diagram

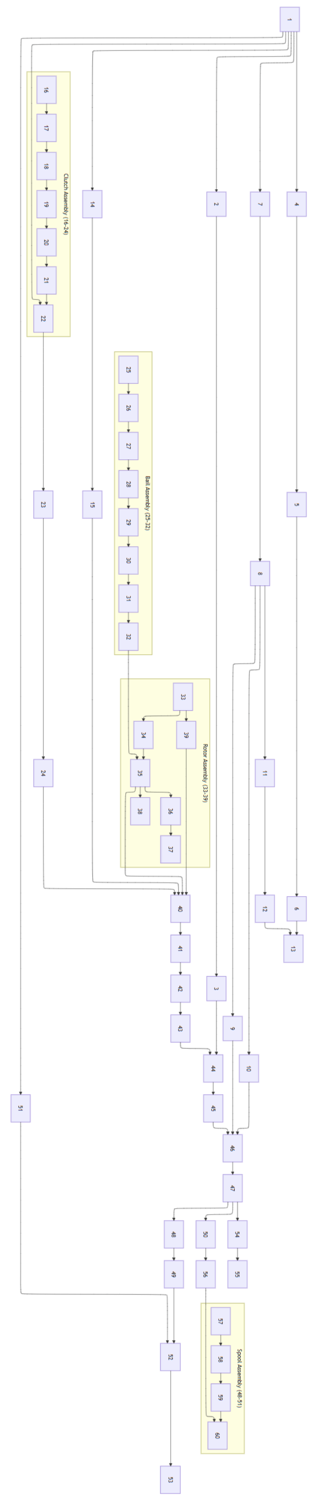


Figure 3: Precedence diagram

3.3 Line balancing

In order to optimize the assembly line, it is crucial to efficiently distribute various tasks across workstations. For this project, we have applied three balancing techniques: the largest candidate rule (LCR), the Kibridge and Wester method (K&W) and the ranked positional weight method (RPW) in an attempt to distribute the assembly workload of the fishing reel evenly across the workstations. These line balancing methods all use a cycle time of $T_c = 2,72$ min (see Chapter 3.3.1), which is based on a yearly demand of 37,520.

3.3.1 Definition of a Production Scenario

In order to achieve an accurate analysis, certain assumptions have to be made to create a production scenario. These assumptions are all based on some sort of statistics, and these will be explained in the following section:

As we were unable to accurately guess the yearly demand by looking at the amount of amateur fishermen in Europe, we have instead decided to calculate the average demand by looking at Shakespeare EU's revenue. To do this, we firstly looked at the amount of items Shakespeare offers in their web store. This accumulated to 133 products consisting of 17 reels, 46 rods, 58 gears and 12 other products [6]. As the reel we have is one of the only items that is sold at XXL, [7] and also most of the other products were not really present in other stores, we have assumed that the reel accounts for a share of 8% the total revenue. With the total revenue from Shakespeare EU being 55,671,000 SEK, the revenue that the reel makes in a year is 4,455,000 SEK. If we now take the price at a regular retail store like XXL for the reel, which is 199 SEK, and assume that their margin is about 40% which is a common margin for sports retail stores, [8, 9] we get a price of 119 SEK. This is the price that Shakespeare EU gets for the reel, and by now dividing the revenue of the reel by the price per reel, we get the annual demand.

$$\frac{4\,455\,000 \text{ SEK}}{119 \text{ SEK}} \approx 37\,500$$

If we now assume that the production is carried out in America, as the parent company is based there (see Chapter 1.2), we have a total of 50 working weeks in a year, with the average working week having about 40 hours. This gets us to a total of 2000 working hours a year, which fits well with the researched number [10, 11]. This would give us a hourly production rate of 18.75.

$$R_p = \frac{D_a}{50 * S_w * H_{sh}} = \frac{37\,500}{50 * 5 * 8} = 18.75$$

With this R_p value we can now determine the necessary cycle time to meet the annual demand. For this calculation we have assumed a line efficiency of 85% based on the example in the lecture slides, which gives us a Cycle Time of 2.72.

$$T_c = \frac{60 * \eta_l}{R_p} = \frac{60 * 0.85}{18.75} = 2.72 \frac{\text{min}}{\text{unit}}$$

This cycle time will also be used in the following for the different line-balancing methods. Additionally, we can now use the cycle time and the total work content time T_{wc} to calculate the theoretical minimum number of workstations w^*.

$$w^* = \text{Minimum Integer} \geq \frac{T_{wc}}{T_c} = \frac{\sum_{k=1}^{n_e} T_{ek}}{T_c} = \frac{7.54 \frac{\text{min}}{\text{unit}}}{2.72 \frac{\text{min}}{\text{unit}}} \approx 2.772$$

The minimum number of workstations required is therefore 3.

Disclaimer: All of these results can change drastically if different assumptions are taken. Additionally it is likely that the production facility is shared with multiple other products and therefore an automatic or robot assembly strategy is more economically viable. For the sake of this course we will further continue with the assumption of a manual assembly line and will not go into more detail for other strategies

3.3.2 Largest Candidate Rule

The Largest Candidate Rule assigns work elements based on task time priority while respecting precedence constraints and the station time limit. To complete this method, the first step is to list the operations in descending order according to their standard time T_{ek}.

Table 4: List of Operations ordered according to highest T_{ek}

Operation	T_{ek} **(min)**	**Precedence**
38	0.45	35
47	0.42	46
6	0.30	5
50	0.29	47
40	0.25	3, 13, 15, 24, 39
10	0.22	8
60	0.21	56, 59
12	0.20	11
52	0.20	24, 49, 51
32	0.19	31
37	0.17	36
24	0.16	23
49	0.16	48
55	0.16	54
22	0.15	1, 21
42	0.15	41
56	0.15	50
46	0.13	9, 10, 45
54	0.13	47
31	0.12	30
51	0.12	1
59	0.12	58
13	0.11	6, 12
41	0.11	40
58	0.11	57
4	0.10	1
5	0.10	4
9	0.10	8
34	0.10	33
35	0.10	32, 34

39	0.10	33
43	0.10	42
14	0.09	1
36	0.09	35
48	0.09	47
53	0.09	52
2	0.08	1
3	0.08	2
8	0.08	7
11	0.08	8
15	0.08	14
26	0.08	25
27	0.08	26
28	0.08	27
29	0.08	28
30	0.08	29
44	0.08	43
45	0.08	44
16	0.07	-
17	0.07	16
18	0.07	17
19	0.07	18
20	0.07	19
21	0.07	20
57	0.07	-
1	0.05	-
7	0.05	1
23	0.05	22
25	0.05	-
33	0.05	-

This Table is now used to assign the different operations to different workstations. This is done by selecting the first element that satisfies all precedence constraints and does not exceed the previously mentioned cycle time of 2.72 min. Applying this method, a total of 3 workstations are needed with the following distribution of tasks:

Table 5: Solution of the Largest Candidate Rule

Station	**Operations in the order of the methods**	$\sum$
1	16, 17, 18, 19, 20, 21, 57, 58, 59, 1, 22, 51, 4, 5, 6, 14, 2, 3, 15, 7, 8, 10, 9, 11, 12, 13	2.71 min
2	23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 38, 39, 40, 41, 42, 43, 36, 37, 44	2.72 min
3	45, 46, 47, 50, 54, 55, 56, 60, 48, 49, 52, 53	2.11 min

3.3.3 Kilbridge Wester Method

The Kilbridge and Wester method is designed to distribute tasks across workstations based on their position in the precedence relationships. In contrast to the Largest Candidate Rule, the Kilbridge Wester Methods prioritizes tasks that appear earlier in the precedence diagram to avoid disturbing the logical assembly flow. The first step in this method is to create a precedence diagram in which work elements with the same precedences are arranged vertically in columns. In our case most of the operations could be associated to multiple columns e.g. work elements 58 and 59 could be in every column up to the 21st.

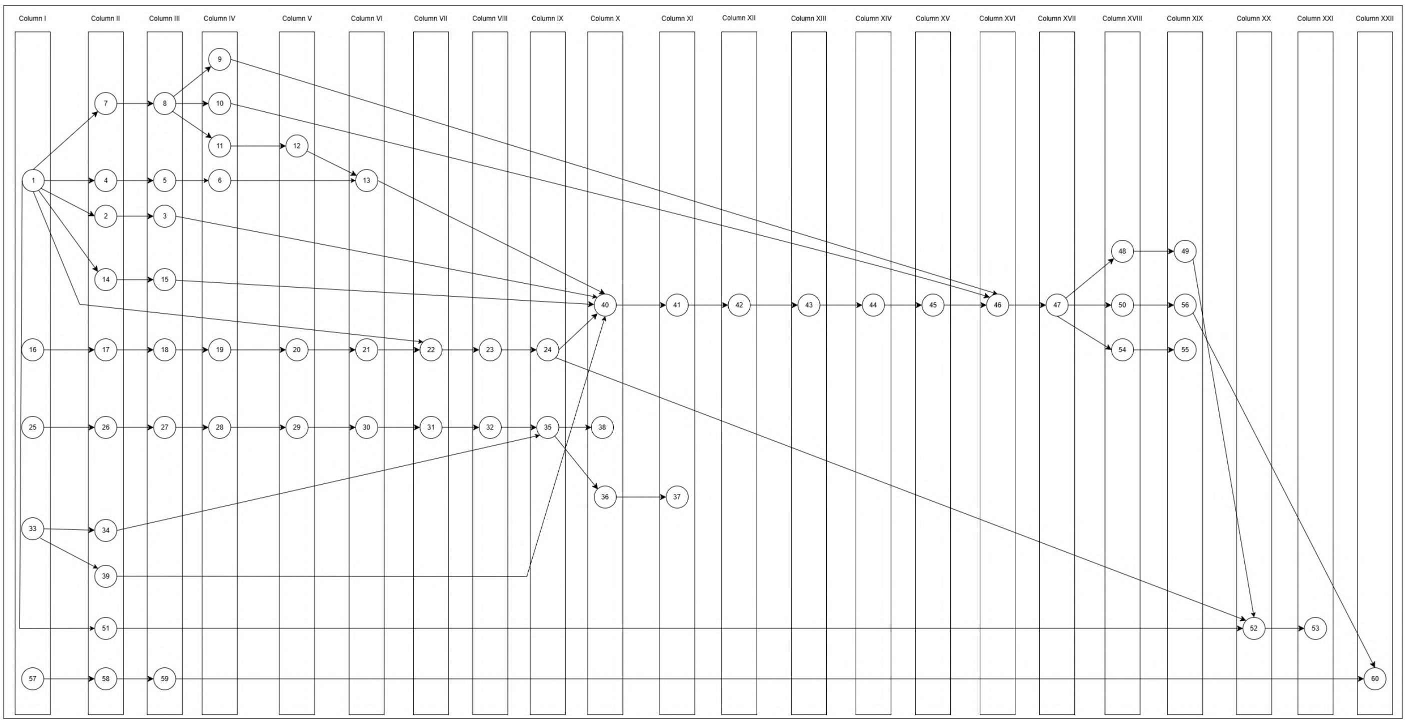


Figure 4: Kilbridge and Wester method diagram

After creating the diagram the following step is to list the elements in a Table according to their column. We have decided to only list every work element once, in the first possible column, to limit the amount of duplicates and the time spent on this method.

Table 6: Kilbridge and Wester method ordered Table

Work Element	**Column**	T_{ek}	**Sum of column** T_{ek}
1		0.05	
16		0.07	
25	I	0.05	0.29
33		0.05	
57		0.07	

Work Element	**Column**	T_{ek}	**Sum of** T_{ek}
2	II	0.08	0.9
4		0.1	
7		0.05	
14		0.09	
17		0.07	
26		0.08	
34		0.1	
39		0.1	
51		0.12	
58		0.11	
3	III	0.08	0.61
5		0.1	
8		0.08	
15		0.08	
18		0.07	
27		0.0.08	
59		0.12	
6	IV	0.3	0.85
9		0.1	
10		0.22	
11		0.08	
19		0.07	
28		0.08	
12	V	0.2	0.35
20		0.07	
29		0.08	
13	VI	0.11	0.26
21		0.07	
30		0.08	
22	VII	0.15	0.27
31		0.12	
23	VIII	0.05	0.24
32		0.19	
24	IX	0.16	0.26
35		0.1	
36	X	0.09	0.79
38		0.45	
40		0.25	
37	XI	0.17	0.28
41		0.11	
42	XII	0.12	0.15

Work Element	Column	T_{ek}	Sum of T_{ek}
43	XIII	0.1	0.1
44	XIV	0.08	0.08
45	XV	0.08	0.08
46	XVI	0.13	0.13
47	XVII	0.42	0.42
48 50 54	XVIII	0.09 0.29 0.13	0.51
49 55 56	XIX	0.16 0.16 0.15	0.47
52	XX	0.2	0.2
53	XXI	0.09	0.09
60	XXII	0.21	0.21

Using the Table above (see Table 6) we are now able to distribute the operations to work stations according to their column. The resulting distribution can be seen below:

Table 7: Kilbridge and Wester method solution

Station	Elements	Sum of T_{ek} at Station
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16, 17, 18, 19, 25, 26, 27, 28 33, 34, 39, 51, 57,58 59	2.65
2	12, 13, 20, 21, 22, 23, 24, 29, 30, 31, 32, 35, 36, 37, 38, 40, 41, 42, 43	2.7
3	44, 45, 46, 47, 48, 49, 50, 52, 53, 54, 55, 56, 60	2.19

From the Table you can see that in total three stations are required with each assigned multiple elements.

3.3.4 Ranked Positional Weight Method

The last method that we will apply here is the Ranked Positional Weight (RPW) Method. This method balances the task time and precedence position into one new metric and uses this to assign the work element to different stations. The metric is called RPW hence the name and is calculated in the following way:

$$RPW_k = T_{ek} + \sum_{\text{all successor of k}} T_e$$

Table 8: RPW ranked list

Element	RPW	T_{ek}
14	4.38	0.09

Element	**RPW**	T_{ek}
15	4.29	0.08
16	4.21	0.07
17	4.14	0.07
25	4.12	0.05
18	4.07	0.07
26	4.07	0.08
33	4.06	0.05
1	4.04	0.05
19	4.00	0.07
27	3.99	0.08
28	3.91	0.08
34	3.91	0.10
29	3.83	0.08
32	3.81	0.19
30	3.75	0.08
35	3.71	0.10
31	3.67	0.12
20	3.30	0.07
21	3.23	0.07
22	3.16	0.15
23	3.01	0.05
24	2.96	0.16
7	2.95	0.05
8	2.90	0.08
39	2.90	0.10
40	2.80	0.25
41	2.55	0.11
42	2.44	0.15
2	2.35	0.08
10	2.33	0.22
43	2.29	0.10
3	2.27	0.08
9	2.21	0.10
44	2.19	0.08
45	2.11	0.08
46	2.03	0.13
47	1.90	0.42
4	0.61	0.10
50	0.56	0.29
48	0.54	0.09

Element	RPW	T_{ek}
5	0.51	0.10
57	0.51	0.07
49	0.45	0.16
38	0.45	0.45
58	0.44	0.11
51	0.41	0.12
6	0.41	0.30
11	0.39	0.08
56	0.36	0.15
59	0.33	0.12
52	0.29	0.20
54	0.29	0.13
36	0.26	0.09
60	0.21	0.21
12	0.20	0.20
37	0.17	0.17
55	0.16	0.16
13	0.11	0.11
53	0.09	0.09

Using this ranked list, a similar logic compared to the Largest Candidate Rule is used to assign the elements to the corresponding work station. The result is displayed in the following Table:

Table 9: Result RPW Method

Station	Elements	Sum of T_{ek} of Station Elements
1	1, 7, 8, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 39, 40, 41	2.60
2	2, 3, 4, 5, 9, 10, 38, 42, 43, 44, 45, 46, 47, 48, 49, 50, 57	2.70
3	6, 11, 12, 13, 36, 37, 51, 52, 53, 54, 55, 56, 58, 59, 60	2.24

3.3.5 Comparison

After applying the three line-balancing methods to our fishing reel, we find that each of the methods produces a valid three-station layout under our cycle-time constraint of 2.72 minutes. They only slightly differ in the order of assigned work elements and the time spent per station.

The largest-candidate rule tends to front-load stations, maximizing early station utilization (2.71, 2.72, 2.11), while the Kilbridge–Wester method better preserves task sequence but results in a similar distribution (2.65, 2.70, 2.19). The Ranked Positional Weight method offers the most balanced workload for each station overall (2.60, 2.70, 2.24), but the overall task distribution only changes marginally.

These very similar results are the result of really codependent work elements with short T_{ek}, which leads to a distribution of work elements that is always alike. The long cycle time does not help with this issue, and with the theoretical minimum number of stations required being 2.772 all of the methods deliver the best possible result. We have come to the conclusion that we will use none of the proposed sequences but come up with our own allocation that has the goal to evenly distribute the work elements in a way that each station has approximately the same amount of time to complete its tasks.

The following Table presents the final station-element allocation based on our customized approach:

Table 10: Custom Station-Element Allocation

Station	**Elements**	**Sum of T_{ek} (min)**
1	1, 2, 3, 4, 5, 6, 7, 16, 17, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34,57, 58, 59	2.54
2	8, 9, 10, 11, 12, 13, 14, 15, 23, 24,35, 36, 37, 38, 39, 40, 41,42	2.59
3	43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 60	2.41

4 Design for Assembly Analysis

In order to measure the efficiency of assembly, a technique called Design for Assembly (DFA) is used. The DFA analysis is conducted for manual and automatic assembly; the steps and results are provided in this section. Manual assembly is evaluated by the Boothroyd Dewhurst method. For the automatic assembly, the Eskilander method is performed. The primary goal of DFA is to reduce the number of parts and simplify the directions of insertion. This approach facilitates an efficient assembly process, which in turn reduces assembly time and associated costs. The DFA analysis encompasses three main components:

- Assembly operations optimization
- Part relevance identification
- Assembly cost estimation

4.1 Manual Assembly DFA (Boothroyd-Dewhurst Method)

Design for Manual Assembly (DFMA) is a method that helps make products easier to put together. For this, the Boothroyd Dewhurst method is implemented. The **Design for Assembly (DFA) index** is represented by E_{ma}, which quantifies the ease of assembly:

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

N_{min} = theoretical minimum number of parts required
t_a = basic assembly time for one part
t_{ma} = estimated time to complete the assembly of the product
Total number of parts = 49
Minimum parts number, three criteria ($Nmin$ evaluation)
A part is considered essential only if one of the following criteria is met.

- **Relative motion:** During normal operation, the part moves relative to all other parts already assembled.
- **Material or isolation requirement:** the part must be made of a different material or isolated from other parts for functional reasons.
- **Assembly/disassembly constraint:** the part must be separate from all others because otherwise necessary assembly or disassembly of other parts would be impossible.

Table 11: Minimum number of parts criteria

Part No.	Name	Question 1	Question 2	Question 3
1	Body	No	No	Yes
2	Pinion Gear	Yes	Yes	No
3	Ball Bearing	Yes	Yes	No
4	Pinion Gear Screw (M2)	No	No	Yes

5	Switch	Yes	No	Yes
6	Switch Arm	Yes	No	Yes
7	Grip Spring	Yes	Yes	No
8	Lever Screw (M2)	No	No	Yes
9	Resistance Arm	Yes	Yes	No
10	Resistance Arm Screw (M2.5)	No	No	Yes
11	Resistance Arm Guider	Yes	No	No
12	Oscillation Gear	Yes	Yes	No
13	Slider	Yes	No	No
14	Rotor	Yes	No	Yes
15	Main Shaft	Yes	Yes	Yes
16	Slider Retainer	No	No	Yes
17	Slider Retainer Screw (M2.5)	No	No	Yes
18	Clicker Gear	Yes	Yes	No
19	Clutch plate washer	Yes	Yes	No
20	Clutch Washer	Yes	Yes	No
21	Clutch Plate	Yes	Yes	No
22	Base Spring	Yes	Yes	No
23	Base Holder	Yes	No	Yes
24	Drive Gear	Yes	Yes	Yes
25	Drive Gear Washer (plastic)	No	Yes	No
26	Side Cover	No	No	Yes
27	Body Screw (M3)	No	No	Yes
28	Rear Cover	No	No	No
29	Rear Cover Screw (M2)	No	No	Yes
30	Base Ring	No	Yes	Yes
31	Bottom Cover	Yes	No	Yes
32	Rubber ring	No	No	No
33	Nut	No	Yes	Yes
34	Nut Retainer Screw (M2)	No	Yes	Yes
35	Trip Plunger	Yes	Yes	Yes
36	Bail Spring	Yes	Yes	Yes
37	Rotor Cover	No	No	Yes
38	Rotor Cover Screw (M2)	No	No	Yes
39	Line Roller	No	Yes	Yes
40	Line Roller Washer	No	Yes	No
41	Washer	No	Yes	No
42	Bail Arm	Yes	No	No
43	Bail Arm Screw (M3)	No	No	Yes
44	Bail	Yes	Yes	Yes
45	Bail Assembly Screw (M3)	No	No	Yes
46	Handle Assembly	Yes	No	Yes
47	Handle Screw Cap	No	No	Yes
48	Drag Knob	Yes	No	Yes
49	Drag Knob Pin	Yes	No	Yes

50	Retainer Ring	No	Yes	Yes
51	Spool	No	Yes	Yes

Upon analysis, it has been determined that 2 out of the initial 51 parts can either be integrated with each other or eliminated entirely. As a result, the theoretical minimum number of parts required for the assembly is reduced to 49.

$$N_{min} = 49.$$

Therefore, the required assembly time for a well-designed product would be:

$$\text{Ideal time} = N_{min} \,.\, t_\alpha = 49 \, * \, 3 = 147 \, s,$$

assuming $t_\alpha = 3\,s$ as suggested in the Boothroyd-Dewhurst Method.

Table 12: Handling and insertion time

Part No.	Name	Handling Time (sec.)	Insertion time (sec.)
1	Body	1.95	2
2	Pinion Gear	1.13	8
3	Ball Bearing	1.13	1.5
4	Pinion Gear Screw (M2)	1.43	8
5	Switch	1.95	5.5
6	Switch Arm	1.95	9
7	Grip Spring	1.8	2
8	Lever Screw (M2)	2.18	8
9	Resistance Arm	1.95	9
10	Resistance Arm Screw (M2.5)	1.43	8
11	Resistance Arm Guider	1.95	5.5
12	Oscillation Gear	1.13	5.5
13	Slider	1.95	9
14	Rotor	1.95	1.5
15	Main Shaft	1.5	1.5
16	Slider Retainer	3.34	9
17	Slider Retainer Screw (M2.5)	1.43	8
18	Clicker Gear	1.95	2
19	Clutch plate washer	1.43	1.5
20	Clutch Washer	1.43	1.5
21	Clutch Plate	1.43	1.5
22	Base Spring	1.13	1.5
23	Base Holder	1.13	1.5
24	Drive Gear	1.13	5.5
25	Drive Gear Washer (plastic)	1.13	1.5
26	Side Cover	1.95	8

27	Body Screw (M3)	1.43	8
28	Rear Cover Screw (M2)	1.43	8
29	Base Ring	1.84	2
30	Bottom Cover	1.13	8
31	Nut	1.13	8
32	Nut Retainer Screw (M2)	1.43	8
33	Trip Plunger	1.95	6.5
34	Bail Spring	2.7	6.5
35	Rotor Cover	1.95	8
36	Rotor Cover Screw (M2)	1.43	8
37	Line Roller	1.43	1.5
38	Line Roller Washer	1.88	1.5
39	Washer	2.18	1.5
40	Bail Arm	1.95	8
41	Bail Arm Screw (M3)	1.43	8
42	Bail	1.95	8
43	Bail Assembly Screw (M3)	1.43	8
44	Handle Assembly	1.13	8
45	Handle Screw Cap	1.13	8
46	Drag Knob	1.13	1.5
47	Drag Knob Pin	1.13	1.5
48	Retainer Ring	1.43	4
49	Spool	1.5	2

$$t_{ma} = \Sigma(\text{Handling Time} + \text{Insertion Time})$$

$$t_{ma} = 199.25$$

$$DFA_{index}\,(E_{ma}) = \frac{(49) * (3)}{199.25} = 0.7377666 \approx 73.78\%$$

4.2 Automatic Assembly DFA (Eskilander Method)

The Eskilander method is utilized for the evaluation of the suitability of a product for automatic assembly based on two indexes. These indexes are categorized as product level, based on the matrix represented in Table 13 and part level, based on the matrix represented in Table 14.

Table 13: Part level matrix of Eskilander method

Product Level								
	Reduce number of parts	**Unique number of parts**	**Base Object**	**Design base object**	**Assembly directions**	**Parallel operations**	**Chain of tolerances**	**SUM**
Firebird 50RD	1	1	9	3	1	3	1	19

The Assembly index based on the product level matrix 13 can be calculated as:

$$\text{Assembly index}_{\text{Product level}} = \frac{\text{Total sum}}{\text{Maximum}} = \frac{19}{63} = 30.15\%$$

Since the spinning reel consists of only unique parts and has multiple directions for assembly, the assembly indexes indicate that it is not ideal for automatic assembly.

Table 14: Part level matrix of Eskilander method

Part level																		
	Need tp assemble part?	**level of defects**	**Orientation**	**fragile parts**	**Hooking**	**Centre of gravity**	**Shape**	**Weight**	**Length**	**Gripping**	**Assembly motions**	**Reachability**	**Insertion**	**Tolerances**	**Holding assembled parts**	**Fastening method**	**Joining**	**Check/Adjust**
Body	9	3	9	9	9	3	1	9	3	9	9	9	9	9	9	9	9	9
Pinion Gear	9	3	3	9	9	3	3	9	9	3	1	3	3	3	3	3	9	3

Ball Bearing	9	3	9	9	9	9	9	9	9	9	3	9	3	9	9	3	9	9
Switch	9	3	1	9	9	9	1	9	9	3	3	9	3	9	3	3	3	3
Switch Arm	9	3	1	9	9	3	1	9	9	9	1	3	3	9	1	3	9	3
Grip Spring	9	1	3	9	9	9	1	9	9	1	9	9	3	9	3	3	9	3
Resistance Arm	9	3	1	9	9	9	1	9	9	3	1	1	3	9	1	3	9	3
Resistance Arm Guider	9	3	1	9	9	3	1	9	9	3	1	1	3	9	1	3	9	3
Oscillation Gear	9	3	3	9	9	3	3	9	9	3	1	3	3	3	1	3	9	3
Slider	9	3	1	9	9	9	1	9	9	3	1	1	3	9	1	3	3	1
Rotor	9	3	9	9	9	9	3	9	3	9	3	9	9	9	3	3	3	9
Main Shaft	9	3	3	9	9	3	1	9	3	3	3	9	9	9	1	3	9	9
Slider Retainer	9	3	1	9	9	3	1	9	9	3	1	3	3	9	1	3	3	1
Clicker Gear	9	3	3	9	9	3	1	9	9	3	1	9	3	3	3	3	9	3
Clutch Plate Assembly	9	3	1	9	9	3	1	9	9	3	1	9	1	9	3	3	9	3
Base Spring	9	3	3	9	9	3	9	9	9	9	9	9	1	9	3	3	9	9
Base Holder	9	3	3	9	9	9	3	9	9	9	3	9	3	9	3	3	3	9
Drive Gear	9	3	3	9	9	1	3	9	9	3	1	3	3	3	1	3	9	1
Drive Gear Washer	9	3	3	9	9	9	3	9	9	1	1	3	1	9	3	3	9	9
Side Cover	9	3	3	9	9	3	1	9	3	3	9	9	3	9	3	3	3	9
Rear Cover	9	3	3	9	9	9	1	9	9	3	9	9	3	9	3	3	3	9
Base Ring	9	3	1	9	1	9	9	9	9	3	9	9	3	9	9	9	9	9
Bottom Cover	9	3	3	9	9	3	3	9	9	3	9	9	9	9	3	3	3	9

Rubber Grip	1	9	1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Nut	9	3	1	9	9	9	3	9	9	9	9	9	3	3	3	3	9	9
Trip Plunger	9	3	1	9	9	9	1	9	9	1	1	9	1	9	1	3	9	1
Bail Spring	9	1	1	9	9	3	1	9	9	1	1	9	1	9	1	3	9	1
Rotor Cover	9	3	3	9	9	3	1	9	9	3	3	9	3	9	3	3	3	9
Line Roller	9	3	1	9	9	9	3	9	9	3	3	9	9	3	3	3	9	3
Line Roller Washer	9	3	1	9	9	9	9	9	9	3	3	9	3	9	3	3	9	9
Bail Arm	9	3	1	9	9	3	1	9	9	1	3	9	3	9	1	3	3	9
Bail	9	3	1	9	9	3	1	9	3	1	3	9	1	9	1	3	3	9
Handle Assembly	9	3	3	9	1	3	3	9	3	3	3	9	3	9	3	3	9	9
Handle Screw Cap	9	3	1	9	9	1	3	9	9	3	3	9	1	3	3	3	9	9
Drag Knob	9	3	3	9	9	3	3	9	9	3	9	9	3	9	3	3	9	9
Drag Knob Pin	9	3	1	9	9	1	3	9	9	3	3	9	3	9	3	3	9	9
Retainer Ring	9	3	1	9	1	9	3	9	9	1	3	9	3	9	9	9	3	9
Spool	9	3	9	9	9	3	1	9	3	3	9	9	3	9	9	9	9	9

The assembly index based on the part-level matrix is calculated as:

$$\text{Assembly index}_{\text{PART}} = \frac{\text{Total sum}}{\text{Maximum points} * \text{Number of parts}} = \frac{4\,033}{162\ *\ 38} = 0.65513 = 65.5\%$$

The DFA indices were calculated from Tables 13 & 14. It can be observed that the indices for both product level and part level are relatively low. This is predictable since all the parts in the product are unique with varying shapes. This requires a variety of robotic grippers and automated machines. Hence, it can be concluded that automating the assembly process is not feasible.

5 Feasibility of Automation

The assembly process of the Shakespeare Firebird 50RD fishing reel is not suitable for full automation due to several design, operational and economic factors, as outlined in this report and further detailed below. These factors are derived from the product's characteristics, the Boothroyd and Dewhurst method's Design for Assembly (DFA) analysis (4.1), the Eskilander method's Design for Assembly (DFA) analysis (4.2), and the production scenario.

5.1 Reasons for Infeseability of Full Automation

- **Complex and Unique Part Design:** The reel consists of a majority of unique parts with varying shapes, sizes and materials (e.g., graphite body, metal screws, plastic washers and V-shaped grip spring). The Eskilander part-level matrix (Table 14) assigns high complexity scores (e.g., 9 for handling and insertion) due to non-standardized geometries. This diversity would require multiple specialized robotic grippers and tools, significantly increasing automation costs and complexity.

- **Multiple Assembly Directions:** Components require insertion from various angles, as indicated by the α and β angles in the part list (e.g., 360° for the body, 180° for the main shaft). This necessitates multi-axis robotic systems, which are expensive and complex to program for precise alignment, making automation less practical for a low-volume product.

- **Low Production Volume:** The annual demand of 37 520 units is far below the threshold for cost-effective automation. Literature suggests high-speed automated lines are viable for volumes exceeding 2.4 million units and robotic lines for several hundred thousand units [12]. The low volume of the Firebird 50RD aligns with manual assembly, as confirmed by the assembly decision graph (see Figure 9).

- **Precision and Tactile Feedback Requirements:** Several operations, such as threading the bail spring (#1102) and trip plunger (#1101) into the rotor (Operation 35), require precise alignment and tactile feedback to manage spring tension. Automated systems would need advanced vision and force-sensing technologies, which are cost-prohibitive for this scale and complexity.

- **Frequent Component Interactions:** The liaison diagram (Figure 2.4) shows extensive inter dependencies (e.g., the main shaft connects to the pinion gear, slider and clutch assembly). This sequential assembly process limits opportunities for parallel automation, increasing cycle times and reducing the efficiency of automated systems.

The Eskilander method's DFA indices quantify the reel's unsuitability for automation:

- **Product-Level Assembly Index:** 30.15% (Table 13), indicating poor suitability due to the high number of unique parts and multiple assembly directions.

- **Part-Level Assembly Index:** 65.5% (Table 14), reflecting challenges in handling and inserting parts with complex geometries. The low indices confirm that the reel's design is better suited for manual assembly, where human dexterity can manage variability and precision tasks.

The Shakespeare Firebird 50RD's assembly process is not suitable for full automation due to its complex and unique part designs, multiple assembly directions, low production volume, precision requirements and extensive component interactions. Challenges such as high initial costs, component handling difficulties, error detection needs, limited system flexibility and maintenance risks further support the preference for manual assembly. The proposed hybrid approach (Section 6.2) automates simpler operations (e.g., Operations 4–6, 16–24), but even this is less cost-effective than manual assembly due to insufficient time savings to reduce labor costs (Section 7.2). The manual assembly line, optimized with redesign proposals (Section 8), remains the most practical and economical solution for this product.

5.2 Feeder and Gripper Infeasibility

Automating the feeding and gripping of components is particularly challenging due to the reel's part characteristics. Table 15 evaluates key components based on factors critical for automation: rotational symmetry, part stiffness, fastener orientation, part delivery and insertion force. These factors determine the suitability of vibratory or linear feeders and the type of gripper required (e.g., friction, parallel-jaw, vacuum).

Table 15: Feeder and Gripper Suitability Analysis for Key Components

Part No.	**Name**	**Rotational Symmetry**	**Part Stiffness**	**Fastener Orientation**	**Part Delivery**	**Insertion Force**	**Feeder Type**	**Gripper Class**	**Automation Feasibility**
#0001	Body	Low (complex shape)	High (graphite)	N/A	Manual tray	N/A	None (Manual)	Custom gripper	Low (complex geometry)
#0007	Grip Spring	Low (V-shaped)	Low (flexible)	N/A	Vibratory (prone to jamming)	Low (tension)	Vibratory (complex)	Friction (specialized)	Very Low (Jamming risk)
#0014	Main Shaft	High (cylindrical)	High (metal)	180°	Linear feeder	Moderate	Linear	Parallel-jaw	Moderate
#0103	Clutch Washer	High (circular)	High (plastic)	180°	Vibratory	Low	Vibratory	Vacuum	High
#0104	Clutch Plate	High (circular)	High (metal)	180°	Vibratory	Low	Vibratory	Vacuum	High
#1101	Trip Plunger	Low (asymmetric)	High (metal)	360°	Vibratory (alignment needed)	Moderate	Vibratory (complex)	Parallel-jaw (custom)	Low (alignment issues)
#1102	Bail Spring	Low (coiled)	Low (flexible)	360°	Vibratory (prone to tangling)	High (tension)	Vibratory (complex)	Friction (specialized)	Very low (tangling risk)
#1106	Bail Arm	Low (semicircular)	High (metal)	360°	Manual tray	Moderate	None (manual)	Custom gripper	Low (complex shape)

Conclusions from Table 15:

- **Feeding Challenges:** The grip spring (#0007) and bail spring (#1102) are flexible and asymmetric, leading to high risks of jamming or tangling in vibratory feeders. The body (#0001) and bail arm (#1106) have complex geometries, requiring manual tray delivery, which is incompatible with automated feeding. Even simple parts like clutch washers (#0103) and plates (#0104) require precise alignment to avoid stacking errors, necessitating additional sensors.

- **Gripping Challenges:** Flexible parts like springs require specialized friction grippers with force control to avoid deformation, while complex parts like the body and bail arm need custom grippers, increasing automation costs. The trip plunger (#1101) and bail spring (#1102) require precise orientation (360°), complicating robotic gripping without advanced vision systems.
- **Fastener Orientation:** Nine distinct screw types (e.g., #0004, #0010) with varying lengths and heads require multiple feeder tracks and grippers, further complicating automation. The bail spring's high insertion force and tension add complexity to robotic insertion.

6 Workstation Design and Factory Layout

6.1 Proposed manual design

To efficiently meet the annual production quota, the assembly process is organized into three workstations arranged in an L- shaped configuration. We chose this over a conventional layout to utilize the factory floor space and to facilitate a better integration of things like the storage areas, office areas, first- aid area etc. The L shaped configuration also improve operator visibility and the operators focus by creating a more structured workspace. We also believe that opting for an L - shaped configuration allow for better and smoother flow of materials, whether it be restocking of parts/ movement of finished assemblies from one station to the next.

The product flow in the configuration is strictly uni-directional. Assembled parts move to the next station using gravity fed conveyors equipped with end stops, with this we aim to reduce the number of powered equipments, additionally this form of transfer reduces unnecessary part handling and relives operators/ workers from fatigue. To support a lean form of part supply, our layout utilizes the 'three-bin kanban system'. This system was opted in an attempt to ensure just-in-time (JIT) delivery of parts thereby minimizing overstocking. In our factory layout, each part required at a workstation is assigned its own set of three kanban bins. The first bin is located at the workstation with enough parts for immediate use, the second bin is stored in the storage area and serves as a buffer for the workstation bin. The third bin remains with the supplier and acts as a part replenishment trigger. Each bin has a removable kanban card contain all necessary product details. When the part gets used up at the workstation, the empty bin along with the kanban card is returned to the storage, the storage then replaces this bin with a bin that is full. The empty bin from the workstation is sent to the supplier for replenishment. Once the supplier refills the bin, it is sent back to the factory store, ensuring a closed loop system.

This system ensures that one spare bin exists for each part at any time to help manage uncertainties. Additionally, we believe that this system reduces the complexities associated with hoppers and centralized feeder systems, which might not be ideal for a product that has a large number of tiny and fragile parts. The clear visual control that labeled bins and cards provides helps in the easy retrieval and identification, further strengthening our decision to avoid automated part-delivery systems. Additionally as we believe that our product is manufactured in a facility that also produces other products, the Kanban system can help to clearly distinguish between the different products. This would simplify the restocking process as less errors should occur.

In the future we would also like to implement a pick-by light system to support a more accurate and efficient part retrieval from the boxes. We believe that this visual support system can help to clearly identify parts that look alike (e.g. screws) and can make the assembly process even faster.

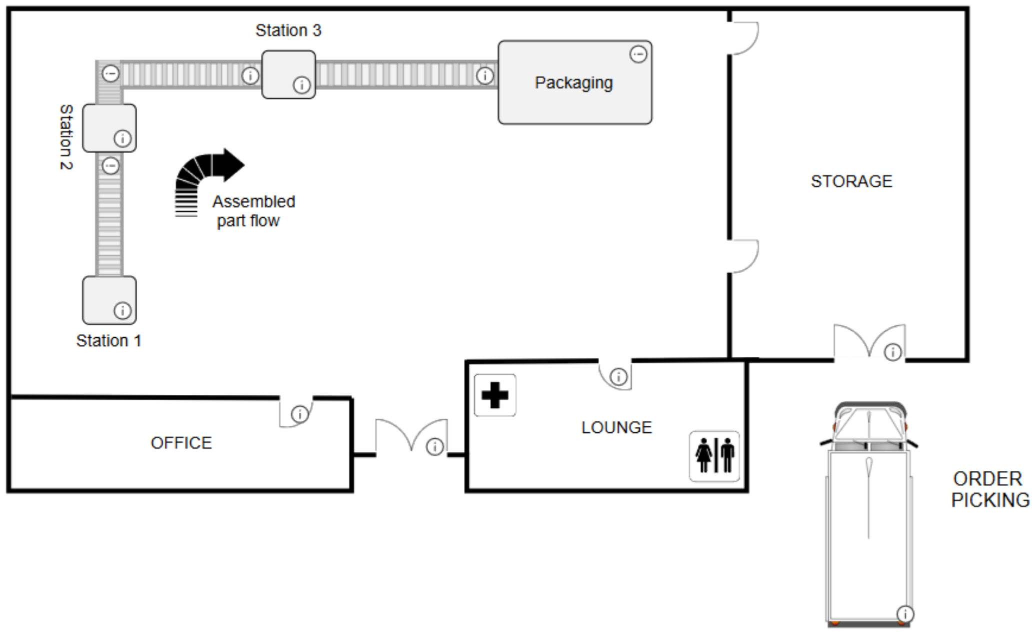


Figure 5: Factory layout

When it comes to our workstation design, we have designed each of them with a strong focus on ergonomics in mind. Tools and containers are placed within reach, the seats for the operators are height adjustable to further improve operators comfort. Torque controlled electric screwdrivers are provided at all the stations to ensure consistent fastening, which is critical for assembling the fishing reel. We decided to utilize the idle time in station 3 by incorporating a final quality inspection. During the idle time the operator will carry out visual checks and functioning of the reel to check if it meets the company standards.

The factory will also consist of a packaging area with a compact plastic shrink wrapping machine, after plastic wrapping each reel will be placed in a box, once 10 reels are placed the box is moved to the storage area.

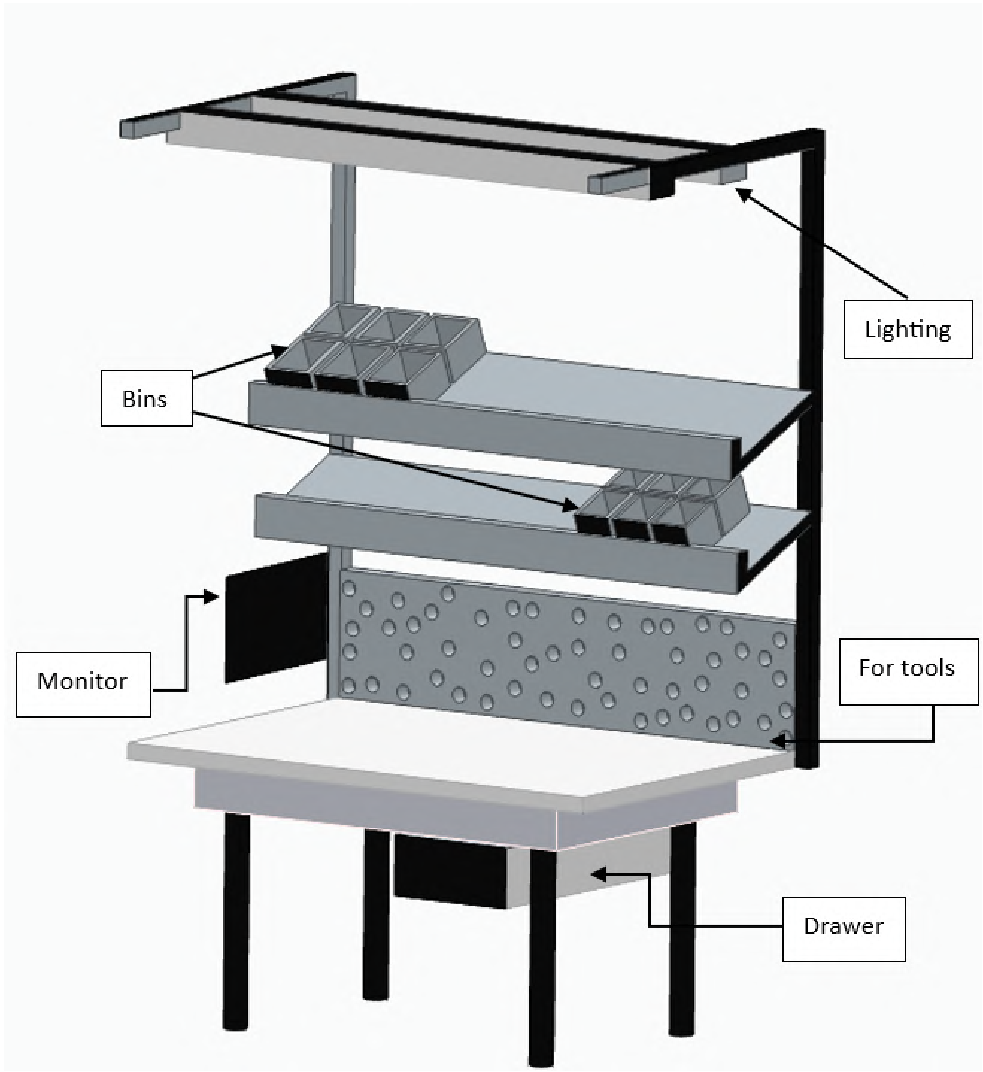


Figure 6: CAD model of Workstation

Overall, the workstation design eliminates unnecessary automation while retaining process discipline and lean flow. With a structured flow of assembled units and a well-balanced task distribution across workstations, the layout supports a reliable and scalable production system tailored to the needs of our product (Figure 6).

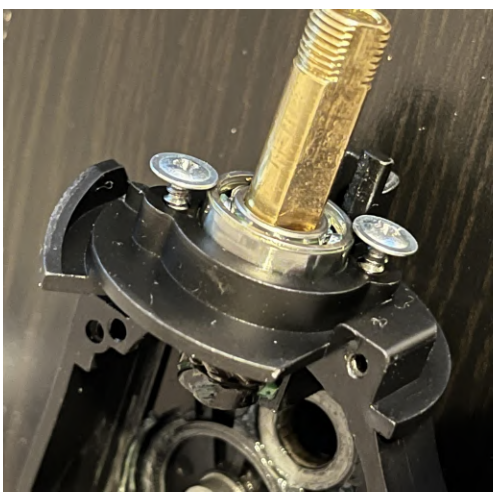
6.2 Alternative hybrid approach

Until now the focus of this project has been laid primarily on manual labor due to the conclusions drawn from the Eskilander method (see Chapter 4.2) and the economic analysis (see Chapter 7).
To show a deeper understanding of relevant course concepts, a partial automation or hybrid approach will be shortly discussed in the following section.

When we wanted to include an automatic assembly section, we came relatively quickly to the conclusion that it is not feasible to automate the whole process due to our production scenario in the first place, but also the tedious steps that require careful alignment that make the automation harder. Lastly, our assembly process is heavily reliant on the main body, as everything is assembled onto it with little to no parts that can be assembled separately.

Instead we came up with a hybrid approach that combines the use of manual labor with the benefits of an automated assembly line.
To get started we looked at the operations that are easy to automate and preferably lay on the same axis to prevent the need for reorientation of the main body. Additionally, we wanted to select operations that end up with all components being fixed to make sure that at the end of the assembly process no parts are loose. With this approach we have identified 12 operations (4-6; 16-24) that take a total time of 1.28 minutes to perform by a human, which in our opinion could be automated with little effort. These operations also include the parts of the clutch that have previously been identified as being feasible for automation (see Table 15).
All of these operations occur at the beginning of the assembly process, which makes the process a bit easier, as no other parts could get in the way and no precedence constraints will be breached. Additionally, all the operations take place along the axis of rotation of the spool, which stops us from needing to rotate the main body.

The idea that we came up with for our use case is a dial-type assembly configuration. All of these operations take a similar amount of time, which suggests the use of a synchronous transfer system. Additionally, the assembly steps that would be performed here are all relatively simple and do not vary. Lastly, all of the parts are small, which further supports the choice of a dial-type assembly system.
For the following part of the Chapter, we split the selected operations into two types of operations, as they will also be performed from different orientations.
The first set of operations includes the operations 4, 5 and 6. During these operations, the pinion gear is placed into the main body with the ball bearing, and then they are fixed in place with the help of two screws (see Figure 7a).
The second set of operations includes the operations 16, 17, 18, 19, 20, 21, 22, 23 and 24. These operations make up the clutch assembly, the clicker gear, the base spring and the base holder (see Figure 7b).



(a) Assembled first set of operations

(b) Parts for second set of operations

Figure 7: Operations for Dial-type assembly configuration

The idea that we had is that an operator places the main body into a horizontal placement device that is connected to the dial-type assembly system. The proposed dial-type setup can be seen in Figure 8.

Then the first operation that is performed is the placement of the pinion gear inside the main body. This can simply be done with the help of a placement device that takes the pinion gear from a feed track and places it into the body.
Afterwards the ball bearing is placed onto the pinion gear at the second station, which would work in a similar way to

the first station. A placement device positions the ball bearing onto the pinion gear and then slides it all the way down. At the third station, the two screws that hold the ball bearing and therefore the pinion gear in place are aligned with the holes and then tightened with a screwdriver. Ideally the screws are magnetic so the screwdriver can pick the individual screws up from a feeding track and then directly screw them into place.
At the fourth station the clicker gear is placed into the body. This is again a simple task where a placement device could be used to pick up the clicker gear and just place it into the body.
Then the clutch parts are all placed onto the clicker gear in one single station. This can be done as the clutch plate, clutch washer and clutch plate washer are all not connected in any way and just need to be aligned, which can easily be done with the holes they all have in the middle. Our idea was that we have three chutes with the three parts. Then they are dropped into one chute in the correct order, starting by the clutch plate, then one clutch washer, then the clutch plate washer, clutch washer, clutch plate and finally one more clutch washer. This prepared assembly in the chute is then dropped onto the clicker gear as a whole in station 5.
In the last station the base spring and the base holder are screwed into place. For this operation, the spring needs to be placed previously into the base holder, which is then aligned with the body and tightened to fix all the parts in place.

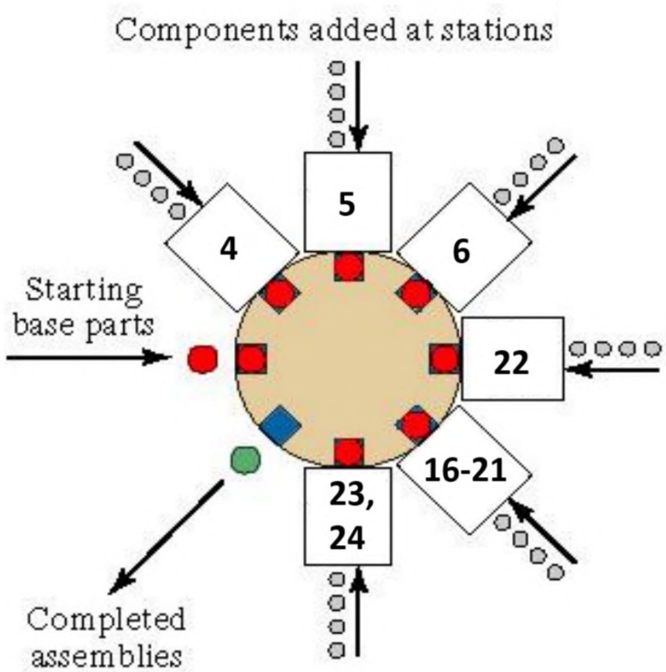


Figure 8: Proposed dial-type assembly system

To ensure this process runs smoothly, it is crucial that there are always enough parts available and no jams occur. This can be checked with the help of sensors that for example measure the amount of parts available in each feeding line and creates a visual or acoustic signal when a minimum threshold is reached.
It is also very important that only one part at a time is released onto the assembly line. This can be controlled with sensors, for example a visual sensor that checks how often a light barrier is passed, that stop the line if a deviation occurs to prevent the occurrence of any damage to the system.

One thing that we have neglected until now is the roll up process of the fishing line onto the spool. For the sake of our project we have assumed that the spool we get already includes the line. In reality it is more likely that we buy the fishing line in bulk which would lead to us rolling it onto the spool. This is also a process where the use of some automation, or at a least machine, is beneficial to ensure consistency and speed throughout the process. This could also be included into some separate assembly line where the spool is placed into a machine that spins the spool and moves it up and down to unwind the fishing line onto the spool.

7 Economic Analysis

After creating a production scenario in Chapter 3.3.1 we wanted to decide on an assembly scenario in particular, which assembly approach we would use. To help us make this decision we have looked at different material. Firstly we have looked at the provided graph (see Figure 9), which suggested the use of a manual assembly strategy as the aimed production volume is relatively low.

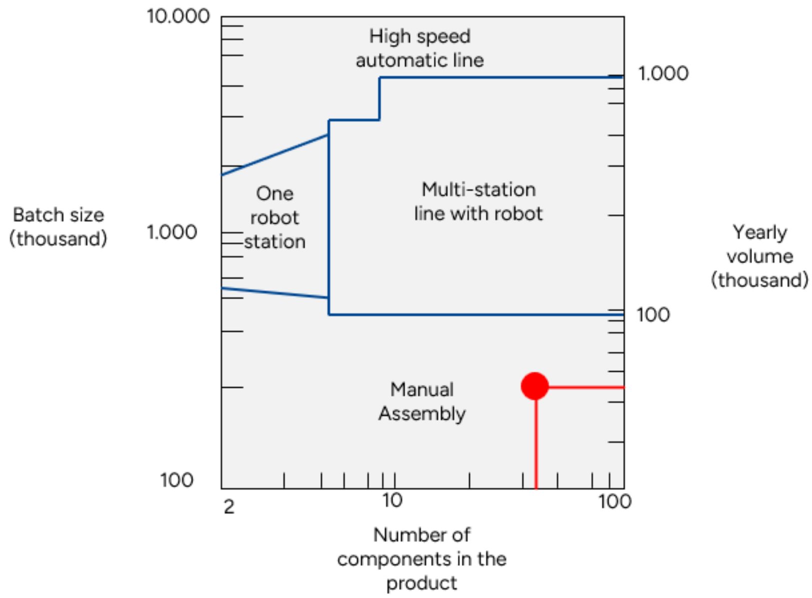


Figure 9: Assembly decision [13]

To validate this result we further looked at literature that suggested a high speed automatic assembly line for a yearly production volume of ≥ 2.4 million parts and a robot assembly line for production volumes that exceed the mid-range of a few hundred thousand [12]. This further confirms the use of a manual assembly line for our proposed production scenario.

For this reason the Chapter 7.1 that deals with the analysis of a manual assembly line is very detailed. For the scope of this project a hybrid line is assessed in Chapter 7.2 but with less attention to detail.

7.1 Manual Assembly Financial Analysis

To assess the economical viability of the manual assembly of reel at 37,500 units/year, we estimate the associated production costs, split into institutional, fixed and variable costs and evaluate the therefore expected ROI.
Fixed costs are expenses that remain constant regardless of the level of production or output, including investments in factories, assembly lines or tool costs for a specific assembly process. Institutional costs on the other hand are costs that are necessary but not directly associated with the production. This mainly includes overhead costs, such as insurances and distribution costs but also organizational costs that can not be clearly associated with one particular product (e.g. Human resources department are responsible for all employees and not only for workers of a certain product). Variable costs on the other hand are all the costs that change in proportion to the production volume. These could be costs like raw materials and direct labor costs. There are certain costs that are harder to clearly associated to one type of cost for example electricity costs as they scale up if production scales up but a certain amount of electricity will also be consumed if the production would stand still [14, pp. 84–85].

Fixed costs:

- **Initial Investment:** The biggest expenses would be the 3 Workstations that need to be acquired in the beginning. The price would include the whole workstations including the station itself, standing seats for the workers, lights and all other tools and fixtures that are necessary for the station. The station would be relatively simple and assuming a price for one is challenging. After some online research we found varying prices ranging from $1 000 - $20 000 per station [15]. We have decided to go for a rather higher price, to ensure the financial feasibility and robustness, of $16 000. This corresponds to 154 825 SEK per station and 464 475 SEK in total.
- **Rental Costs:** Assuming we need an assembly space of 50 sqm and a storage space for our material and the finished products of 150 sqm. The total space required would be 200 sqm, which would correspond to rental costs of 31 235 SEK a month with an underlying price of $1.5 per square foot per month [16].

Institutional costs:

- **Organizational Costs:** Additionally we have decided to include some organizational costs to account for general insurances, administrative costs, office supplies, marketing costs and so on. Here we assumed a total of $20 000 or 193 505 SEK a year.

Variable costs:

- **Labor Costs:** In our current work layout we need to employ 3 workers to fill all work stations. The average yearly wage in the US for Assemblers and Fabricators is about $43 570 [17]. Therefore the expected hourly wage for three workers is:

$$\text{Labor Costs} = 3 * \frac{\text{yearly wage}}{\text{Working hours per year}} = 3 * \frac{43\,750}{2\,000} = 3 * 21.875 = 65.625\ \frac{\$}{\text{hour}} \approx 635.30\ \frac{\text{SEK}}{\text{hour}}$$

- **Raw Material Costs:** As we assume that we buy most of our parts externally and only focus on the assembly steps we have assumed that the material costs accumulate to a total of about 45% of the retail costs [18].

$$\text{Material Costs} = \text{Retail Price} * 45\% = 119\ \text{SEK} * 0.45 = 53.55\ \frac{\text{SEK}}{\text{unit}}$$

- **Electricity Costs:** The electricity consumption will be relatively low as manual labor is general does not consume very large amount of electricity. The electricity consumption of a light with 2000 Lumen as an assembly station should have a LUX value of about 1000 [19]. A light with these parameters consumes about 0.02 kWh [20]. Additionally if we want to use electric screwdrivers the electricity usage would not exceed 0.2 kWh. In total we believe that an electricity consumption of 1 kWh per station is a very conservative assumptions but as it is hard to get an accurate estimation that is the value we will use. The average price per kWh in the US in February 2025 was 8.23 cents [21]. Therefore the price for electricity per hour is the following:

$$\text{Electricity Costs} = 3 * 1\ \text{kWh} * 8.23 = 24.69\ \frac{\text{cents}}{\text{hour}} \approx 2.39\ \frac{\text{SEK}}{\text{hour}}$$

Now we can calculate the amount of Profit we make from each sold unit. To get the profit we need to subtract all expenses per unit from our retail price, which is 119 SEK. To get the profit we exclude the initial investment for now as these costs will be used to determine the Break-Even Point later on. To get the profit per unit we need to calculate the expenses per unit, which we get by distributing the costs to each unit.

$$\frac{\text{Organizational Costs}}{\text{Unit}} = \frac{193\,505\ \text{SEK}}{37\,500} = 5.16\ \frac{\text{SEK}}{\text{unit}}\ ;\ \frac{\text{Rental Costs}}{\text{Unit}} = \frac{31\,235\ \text{SEK}}{\frac{37\,500}{12}} = 10.00\ \frac{\text{SEK}}{\text{unit}}$$

$$\frac{\text{Labor Costs}}{\text{Unit}} = \frac{635.30\ \text{SEK}}{18.75} = 33,88\ \frac{\text{SEK}}{\text{unit}}\ ;\ \frac{\text{Electricity Costs}}{\text{Unit}} = \frac{2.39\ \text{SEK}}{18.75} = 0,127\ \frac{\text{SEK}}{\text{unit}}$$

These brings us to the following profit per sold unit:

$$\textbf{Profit per sold unit} = 119 \text{ SEK} - 5.16 \text{ SEK} - 10 \text{ SEK} - 33.88 \text{ SEK} - 53.55 \text{ SEK} - 0.127 \text{ SEK} = \textbf{16.283 SEK}$$

$$\textbf{Profit margin} = \frac{16.283 \text{ SEK}}{119 \text{ SEK}} = \textbf{13.68 \%}$$

With the profit we can now determine at what time the Break-even point (BEP) occurs, which is the time it takes us to make the money we have spent on the workstations in the beginning. From this moment in time onward all the money we make from each sold unit is profit.
To calculate the BEP we need to solve the following formula:

$$\begin{aligned}\text{BEP (in years)} &= \text{Initial Investment} - \text{Profit per Unit} \times 37\,500 \times x \\ x &= \frac{\text{Initial Investment}}{\text{Profit per Unit} \times 37\,500} \\ x &= \frac{464\,475}{16.283 \times 37\,500} = 0.76\end{aligned}$$

As can be seen above the low initial investments that are necessary for the chosen type of production allow us to gain a profit within the first year.

7.2 Hybrid Assembly Financial Analysis

In the following Chapter we will analyze the financial implications of implementing the proposed partial automation from Chapter 6.2 without changing the other parameters.
This would not affect our minimum numbers of station as the time saved from the automation which accumulates to 1.28 minutes is not enough to replace one whole station.

$$w^* = \text{Minimum Integer} \geq \frac{T_{wc} - T_{saved}}{T_c} = \frac{(\sum_{k=1}^{n_e} T_{ek}) - T_{saved}}{T_c} = \frac{7.54 - 1.28 \frac{\text{min}}{\text{unit}}}{2.72 \frac{\text{min}}{\text{unit}}} \approx 2.3$$

This would mean that despite the reduced manual work time per reel, the saved time is not enough to replace one whole station. This would thereby not reduce the labor cost and instead drive initial investment higher due to the spending on the automated assembly line. If we now calculate the costs for the dial-type configuration, we can add the costs onto the calculations from Chapter 7.1 and calculate the new BEP.

- **Feeder:** According to literature one vibratory feeder costs about \$27 000 which is ≈ 259 000 SEK [22]. If we now need one feeder per station this would accumulate to 1 554 000 SEK
- **Table:** Looking for source for a rotary indexing table is quite hard as most manufactures do not publish their prices. We found one Festo reseller that sold one rotary indexing table for \$3 000 which would be ≈ 29 000 SEK [23]. The tabletop would cost an additional ≈ 2 000 SEK, which brings the total price for the table to 32 000 SEK.
- **Robot arm:** The robot we have selected has a very limited reach of 420mm and is also not able to carry very heavy load. However, this should be enough for our use case. The cost for one robot would be 86 000 SEK which would lead to a total of 516 000 SEK [24].
- **Gripper:** During our search for gripping devices we limited ourselves to grippers that has an opening of 20mm or more to make sure that they can grasp all the components. We found varying prices ranging from 1 700 SEK to 5 500 SEK. We have therefore decided to continue with the average of both (3 600 SEK) and multiplied it with 4, to account for the screwdriver station, to get to a total of 14 400 SEK [25, 26].

- **Screwdriver station:** The Screwdriver we have selected for this costs 81 500 SEK and because we would need two of them the total cost would be 163 000 SEK [27].

$$C_{\text{total}} = C_{\text{Feeders}} + C_{\text{Table}} + C_{\text{Robot}} + C_{\text{Gripper}} + C_{\text{Screwdriver}} = 2\,279\,400 \text{ SEK}$$

With the total cost for the dial-type assembly system being 2 279 400 SEK, we can now calculate the BEP. For the sake of simplicity we will not add additional running costs for the maintenance or the electricity consumption. Instead we will just add the costs for the automatic assembly line on top of the initial investment for the manual assembly line.

$$\text{BEP (in years)} = \text{Initial Investment (manual)} + \text{Initial Investment (automatic)} - \text{Profit per Unit} \times 37\,500 \times x$$

$$x = \frac{\text{Initial Investment (manual)} + \text{Initial Investment (automatic)}}{\text{Profit per Unit} \times 37\,500}$$

$$x = \frac{464\,475 + 2\,279\,400}{16.283 \times 37\,500} = \frac{2\,743\,875}{610\,612.5} \approx 4.494$$

This would mean that the project would reach its break even point after about 4.5 years.

If you were to now just compare the two BEP's of manual assembly (Chapter 7.1) and the hybrid approach (Chapter 7.2), it is clear that the manual assembly is the better option. However, this must be looked at with caution. The implementation of the dial-type assembly line frees up space at all of the workstations. Currently the saved time is not enough to completely remove one station but the additional time could be used to increase the production rate.
All in all it can be said that for our production scenario the partial automation approach does not create any advantages and therefore we would suggest to pursue the manual assembly strategy.

8 Redesign Proposals

When looking at the current design of the fishing reel, there are certain areas where improvements could be made to make the assembly easier. Some parts are unnecessarily complex or just take too much time to assemble, which could have been avoided if the assembly process had been considered more in the early design phase.
Of course, making something easier to assemble can sometimes mean sacrificing durability, aesthetics or even increasing cost, so it always needs to be kept in mind that not everything change is worth it. Still, by analyzing the product with an assembly-first mindset, we can find smarter solutions, which could include removing unnecessary parts, combining parts or just making things easier to handle for the worker. Especially when using automatic assembly the design of parts is increasingly relevant as handling machines increase drastically in price when parts have unique shapes or special assembly mechanisms. The goal in the following sector is not to redesign the whole reel but to identify areas that could be improved that would simplify the assembly steps.

8.1 Removal of Rear Cover

The first proposed redesign changes in the removal of one unnecessary part, the Rear cover, which can be seen in the Figure 10a below.
The reel, as it is, works just fine without the Cover as it does not serve any function. For this reason it also gets discarded in the Minimum parts evaluation (see Table 11). The only purpose that we were able to identify was to hide some of the main body screws and give the reel a more appealing look. The look of the reel without the cover can be seen in Figure 10b. To improve the assembly steps the rear cover could be removed and instead the body and the side cover could be painted to give the whole reel a more appealing look. This would mean that a new design for the main body would be necessary which in return could lead to increased material costs. For this reason it needs to be evaluated if potential cost increases are worth the reduced assembly time, which would be about six seconds.

(a) Rear Cover

(b) Reel without Rear Cover

Figure 10: Redesign proposal 1

8.2 Assembly of the Grip Spring

The second design improvement that we would suggest is the Assembly of the Grip Spring.
This redesign proposal is a result of our own experience, as it might happen that during the disassemble and assemble process the spring jumps out of its socket because there are no measures to keep it in place. The main issue is that during the assemble process the spring is under tension in the socket, as it is encompassed by the main body on the one side and the switch with the switch arm on the other side (see Figure 11b). In addition the spring is a V-shaped spring with

the opening facing out of the socket meaning the applied force is pointing out of the socket, which results in the spring jumping out in some cases. Our solution during the assembly process to this problem was that we inserted the spring as late as possible and then held it in place as soon as we moved the reel. This solution did help to some extent but was not able to completely remove the issue.
Therefore we have proposed a new design which includes a small ridge at the top of body where the spring can 'snap' in place and prevent it from jumping out. The ridge needs to be carefully placed and dimensioned to ensure that it does not interfere with the mechanism and it is still possible to place the spring in the socket. The proposed solution can be seen in Figure 11c. With this solution the insertion of the grip spring is not harder than beforehand but it is secured in place. We do not expect a direct time save as a result from this measure but instead we hope to reduce the overall amount of errors that the spring previously created.

(a) Grip Spring

(b) Socket for the Grip Spring in Main body

(c) Redesigned solution

Figure 11: Redesign proposal 2

8.3 Change of Screw type

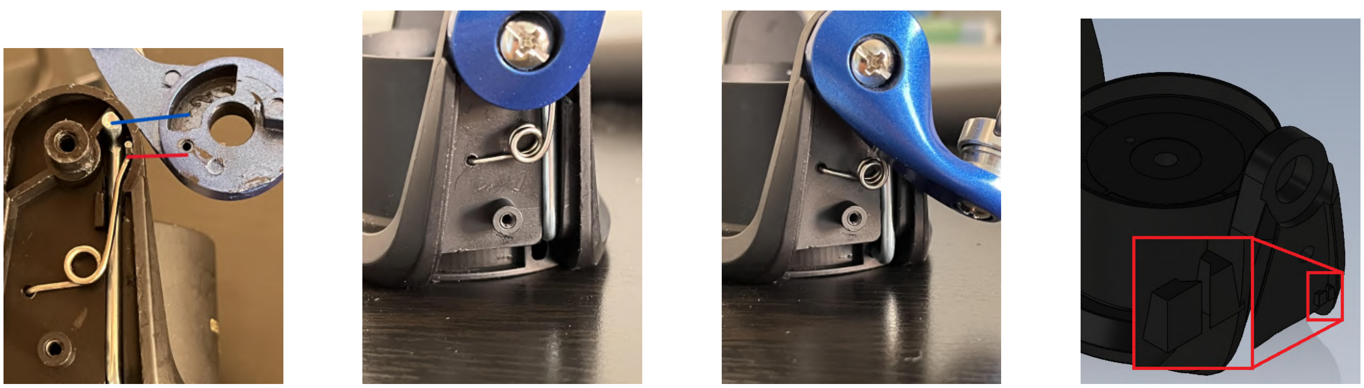
During the project, we also identified that a very high number of different screws are used, namely nine distinct types. The main issue here is that all of the screws have different lengths, diameters and screw heads which makes the assembly process a lot more time consuming and increases the difficulties. From our perspective this is done to make sure that the correct screw is inserted in the right hole and no mix up occurs. However as previously mentioned this leads to various types of screwdrivers being needed.
A possible solution for this issue would be to keep the current different lengths and sizes of screws to save on redesign changes, and instead just change the screw head so one standard head. This on its own might make the problem even worse but by using a visual guidance for the workers, for example a pick-by-light mechanism (as seen in Chapter 6.1), on each container the worker is guided to the correct type of screw and therefore will not need to search for the correct screw. This would shorten handling times resulting from picking the right screw drastically and also makes the assembly job easier for the worker.

8.4 Assembly of Bail Tension mechanism

Another section that we have identified as improvable is the current bail assembly. This assembly realizes the snapping motion of the bail relative to the rotor. The position of the bail determines whether the fishing line is able to unspool or

if the line is guided over the Line Roller onto the spool. Additionally, the position of the bail arm changes the position of the trip plunger (see Figure 12b and 12c) which in return prevents the rotors rotation during the release of the fishing line.
With the current solution you place the bail spring and the trip plunger into the rotor in the correct position and then thread them both into the bail arm as can be seen with the help of the markings in Figure 12a. However when this is done the bail arm and the rotor cover both still need to be screwed in place before the spring and the trip plunger are fully fixed. From our experience these steps can sometimes take a lot of time as the spring is under tension while the trip plunger is very loose and moves a lot. This is another extremely tedious process which currently takes around 50 seconds which does not even account for the time lost when the spring or the trip plunger jump out of the housing. This would usually lead to the removal of screws and parts to replace the spring or trip plunger into the correct position and then restart the process again.

The main issue that we faced during the redesign process is that we are not able to place anything inside the rotor side, which would make the assembly process easier, because the spring needs to move freely inside the side to realize the bail arms movement.
In addition, we were unable to think of any other feasible design for the bail arm, as the slots must remain in the same position and have the same dimensions as they currently do. Both of these requirements limited the possibilities that we had for the redesign.
Instead of fixing both parts at the same time, we have now decided to focused on making the assembly process of the trip plunger easier at first. Our idea here is that we add a small elastic plastic part into the rotor where the trip plunger can 'snap' in place and wont move during the next assembly steps. However it is important that this does not block the movement of the trip plunger up and down, which is why we have decided to make the insertion gap quite small but keep the space behind it relatively big. Our proposed new design can be seen in Figure 12d.



(a) Threading of Spring and Lever

(b) Bail Arm reel-in Position without the rotor cover

(c) Bail Arm Release Position without the rotor cover

(d) Redesign Solution

Figure 12: Redesign proposal 4

8.5 Thread the Resistance arm guider on Resistance arm

The last redesign improvement that we suggest here regards the resistance arm guider. During the assembly the resistance arm guider needs to be placed on the pinion gear and the little retaining metal clip needs to be aligned with the resistance arm and slid in place. This final assembly of the two parts can be seen in Figure 13b. This step needs to be carried out before the rotor is inserted with main shaft because the rotor limits the accessibility of the section otherwise. Therefore the threading of the resistance arm guider needs to happen before. While this step is relatively easy to perform and

does not pose any major issues the fact that the rotor is insert later does. This leads to a lot of other assembly steps happening before the resistance arm guider is fixed in place, which leads to the resistance arm guider sometimes sliding off the metal pin on the resistance arm. This issue is though to fix as it requires filigree work in a very small space (see Figure 13c) and most of the times it is easier to just demount the last parts and then fix the issue. This looses a lot of time and therefore increases the production time.
To solve the issue we have thought about adding a small magnet on the Resistance Arm to ensure the fit with the Resistance Arm Guider. Adding the magnet could secure the connection even when the reel is tilted and the Resistance Arm guider would otherwise slide off. If a magnet would simply be glued on top of the Resistance Arm there would not be any impact on the functionality of the reel whilst still improving the assemblability. This improvement could however lead to increased overall costs and the saved time would likely be less than the time spent to attaching a magnet to the Resistance Arm. Therefore a more feasible solution for the practices could be a fixture that keeps the reel in an upright position during the next assembly steps.

(a) Resistance Arm Guider (b) Threading without Rotor (c) Resistance Arm assembly steps

Figure 13: Redesign proposal 5

9 Conclusion

This project provided a detailed examination of the assembly process specific to the Shakespeare Firebird 50RD fishing reel in terms of manufacturability, assembly efficiency and cost savings. Through detailed disassembly, we identified and categorized the reel's components, creating a structured part list and operation sequence that informed the development of a precedence diagram and line balancing strategies. The market research emphasized the positioning of the reel in the entry to mid-range segment of the European fishing market, with an emphasis on cost-efficient production to address consumer needs for affordability and ease of use.

The economic study performed compared manual, automatic and hybrid assembly operations, ultimately determining that the manual assembly line is a financially viable option for the estimated production of 37 500 units annually with a break-even period of approximately 0.76 years versus 4.5 years for the hybrid operation. Although the suggested dial-type assembly system is appropriate to be automated for some of the operations, it did not pay for its higher upfront cost because the time saved from employing it was not sufficient to warrant the removal of a workstation.

Design improvement proposals were directed towards addressing weak areas to enable assemblability to be enhanced; for example, the removal of the redundant rear cover, the addition of a ridge to hold the grip spring, standardizing screw heads, the bail tension mechanism enhancement, and the addition of a magnet for the guider resistance arm stabilization. These improvements are aimed at reducing assembly time, minimizing errors and making the process altogether more efficient without interfering with the performance of the reel or incurring significant costs.

Lastly, the Shakespeare Firebird 50RD is a suitably designed product for its target segment, yet focused design improvement and manual assembly strategy can increase the efficiency and cost-effectiveness of production. This project highlights the necessity of balancing design and assembly processes towards operational excellence while maintaining low prices for customers.

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