Automated Fist Assembly Line Design

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AUTOMATED FIST ASSEMBLY LINE DESIGN

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ABSTRACT

In many industries, assembly lines are automated to reduce production cost. Utilizing industrial robots which are superior to humans in repetitive and dangerous operations. This paper presents an automated and flexible FIST assembly line concept which consists of layout of plant, timing and options for each action. 'L' shaped connected stations states in which sequence the closure products are being assembled. It is through line balancing that optimal number of stations, cycle time and efficiencies are approved. Besides, financial analysis, to which ROI, TBO and TCO are critically correlated, are elaborated accordingly as well.

Keywords

Automated line, flexible assembly line, financial analysis, TBO, TCO.

1 INTRODUCTION

Commscope is a telecom manufacturing company whose main products include: FIST, FOSC and antenna, etc. Currently, FIST is manually assembled on 4 identical parallel production lines. The goal is to design an automated line to replace the current manual line. The automated line should be flexible to handle different closure products with 3 years ROI. Automation options such as flex feeders and bowl feeders are selected after comparison. A financial analysis is also included for the argumentation of the advantage from automation.

1.1 Objective

The objective is to design a batch build automated assembly line which is flexible and modular automated. Flexibility indicates the line can assemble variant types of products and SMED¹ is less than 9 minutes. In case the whole assembly line is too difficult to automate, the line could be automated at different segment which is modular automation. The ROI is three years or less with cycle time less than one minute. If the cycle time could be reduced from 4,2 minutes to less than 1 minute, then the reduction rate could increase tremendously. At the same time, no safety issues and perfect output quality is our objective as well.

2 PRODUCTION

2.1 Product introduction

The product introduced is called FIST which stands for Fiber infrastructure system technology. It is the environmentally sealed, fully mechanical enclosure for the fiber management system that provides the functions of splicing and passive integration in the external network. Trays and organizers are designed to store the fiber and splices for single-element, single-circuit, and single and multiple-ribbon fiber management. The closure is single-end design made of thermoplastic material. [1] It is mainly composed of following elements: UMS² profile, base, dome and clamping system. The UMS profile contains the fibers, on which the trays are mounted. Gel is used to seal the cables so that the closure can be used underwater, up in the air or underground.

There are 232 different kinds of FISTs in total, 129 out of 232 are active. Including three level of runners: 29 high runners (1000-10000), 54 medium runners (100-999), 46 special runners (1-99). Output per year for all the FISTs is 122834

¹Single Minute Exchange of Die

²Universal Mounting System

pieces. We are mainly discussing two FISTs: FIST-GCOG2-HK-8SC-DE19 (figure 1) and FIST-GCO2-BE6-NN (figure 2).

Figure 1: FIST-GCOG2-HK-8SC-DE19

Figure 2: FIST-GCO2-BE6-NN

2.2 Differences and required flexibility

As can be seen from Fig. 1 and Fig. 2, there exists 4 differences between product 1 and 2. The first one is the top metal plate. Product 1 has two pieces of top metal plates while product 2 has only one piece. Secondly, product 2 has no black top connection while product 1 has two. For the base metal plate, product 1 has a 6-edge metal plates and product 2 has two smaller metal plates. Moreover, the shape of button metal supporter is different for the two products.

The difference between product 1 and 2 is also shown from the layout (figure 7). The yellow boxes represent the optional components for product 2 at station 1, 2 and 3. Therefore, corresponding changes are required at each station. Including: different components to the flex feeders, gripper changes and PLC programs. As a result of using flex feeders, those changes could be easily made by feeding different components. Flex feeders contribute a lot to the flexibility of the plant. Because product 2 doesn't have top black part, so the third flex feeder at station 3 will standby when product 2 is produced. As a matter of fact there exists over 100 types of FISTs, time is so limited to investigate all of them. Around 6 of them were compared and we found the differences between them could be handled. So it is actually interesting to introduce automated flexible line here for our products. Especially, it doesn't require too much change to the construction of the line.

2.3 Assembly line

Currently products are assembled at 4 similarly designed manual lines. The size of 4 assembly lines are 27.7 meters long and 13.3 meters wide which is 368 square meters large. 5 operators on each line are sharing a 2 shift system. 2 shift system means that a whole calendar day³ is divided into 2 different segments with set periods of time during which different groups of operators perform their duties. With the plant that we've investigated, one shift is from 6:00 till 14:00, another one is from 14:00 till 22:00.

Each assembly line is composed of 5 different stations and 3 stacks. Stacks are used to store different components that were transferred from the warehouse. The 5 stations are correspondingly: Riveting station, Base Station, Faselock station (figure 3), clamping station and packaging station (figure 4). They are arranged in an 'L' shape (figure 5): riveting station in parallel with base station while base and other stations are in series. Every two lines are sharing one roller conveyor so there

³ 24 hours

Figure 3: Station 1 & 2 & 3

Figure 4: Station 4 & 5

are two conveyors in total. Sub-assemblies are transferred through the conveyors to the next station. As different products are assembled on different workdays, different operation manuals as well as different components are provided at each workstation every workday. There are both numberings and nicknames for the components. For instance, ‘Playboy’ represents long metal bars, etc. Whenever a person enters the plant, he always has to wear safety glasses and shoes. We will split up the assembly process into different stations and take a closer look at each station. (Figure 6)

Figure 5: Current ‘L’ shaped plant layout

Figure 6: Flow chart of current assembly process

Station 1, the riveting station, is used to assemble the UMS (universal mounting system) profile. Station time is 50 seconds. Components needed include: top metal plate, bottom metal plate, metal bars and rivets. A jig who can turn and has rectangular shape with grooves is where operator places the metal plates and metal bars. There is a pneumatic controlled riveting gun as well, operator uses it to do the riveting once metal bars and metal plates are aligned to each other. Each side requires 8 times riveting to make sure that the UMS profile will not bend or tilt. After finishing the front side, operator pushes a button that turns the jig around for riveting the other side. The finished sub-assemblies are hung in a rack until a dozen that will be transferred to the next station.

Station 2 is the base station where base are assembled as well as the UMS profile. Station time is 60 seconds. This station different types of pneumatic screwing guns with different forces and torques. Bases were well positioned in a big package and UMS profiles were hung in a rack. Components include: bolts and washers, 6 – edge metal plate, O – ring, reinforcement, top black part and screws. First of all, operator picks up the base and places it on the table, inserting the 6-edge metal plate, 6 washers and bolts separately and sequentially and screws them in. Sequentially, place the o – ring. At the same time, if the operator of station 1 has done enough buffers, he shall come to station 2 helping with assembling the UMS profile. Reinforcements are inserted at the middle of the UMS and then two top black parts inserted. Afterwards, operator picks up the UMS and inserts it into the 6-edge metal plate and screws it. The finished sub-assembly will be placed on the conveyor and transferred to the next station. There are buffers appearing on the conveyors.

Station 3 is the Fasblock station. At this station, some small parts are added to the sub-assembly. Station time is around 60 seconds. Components including: Velcro, Fasblock, plastic plates, chemical material, plastic trays. In the first place, operator picks up two sub-assemblies from the conveyor and places them on the work table. Inserting Fasblock into the 3rd hole of the UMS profile and inserting the plastic trays as well. Then inserts the Velcro and clamps it to fix the trays. Afterwards, turning the two sub-assemblies and do the same actions at the other side. The finished sub-assemblies were then transferred to the clamping station.

Station 4 is the clamping station where domes are added and being clamped. Components including: dome and clamps and stickers. Station is mainly composed of a pneumatic clamping device. Pushing the button will force the clamps to close. First, operator puts the stickers onto the dome, then pick and place the sub-assembly from the previous station into the pneumatic clamping device. Sequentially, puts the dome on and clamps it. Station time is around 60 seconds.

Station 5 is the last station – packaging station. FIST is put into a box with added pre-packs, gels, handbooks, etc. When 6 packages are ready, operator will move them to the warehouse

3 REASONING

3.1 Compare manual linewith automated line

	Current	Future	Saving
Total man hour(hours)	24529	11269	13260
Focusing man hour(hours)	866	536	330
Size of line(m ²)	368	105	263
Cycle time of line(s)	252	36	216

Table 1: comparison between current and future

As can be seen from table 1, the automated assembly line saves a lot in total production hours which means saves a lot of money. As well as the size of the plant reduces a lot. Savings includes not only operator savings, but also soft savings. There are soft savings in different aspects: quality, operator safety, etc.

3.2 Advantages of automation

1. Increased availability of line. Availability is the ratio of the total time a production line is capable of being used during a certain period to the length of the period. With an automated assembly line, the robots can work continuously without stopping which reduces the downtime and increase the availability.
2. Improve customer delivery.
3. Reduce production cost – ROI is 3 years or less. After automation, less operators will be needed and reduce the cost as well. A small ROI means the company can cover the investment cost very fast.
4. Reduce cycle time and reduce cost.
5. Save local jobs. It means company doesn't have to relocate to another place with lower operator costs.

4 METHOD

4.1 Theory

4.1.1 Automated assembly line

Automated assembly line is a manufacturing process that assembles products station by station automatically. Each station adds components to the sub-assembly and transfers the sub-assembly to the next station through conveyors or motorized vehicles. Each robot or machine performs specific task at each station. Automated assembly lines are mostly used at automobile industries. There are various types of automated assembly lines, for example: continuous transfer system, synchronous transfer system, etc. The current assembly line is batch assembly lines and we want to replace them with robotic assembly lines. In a normal assembly line, because of repetitive work, workers may have physical or mental fatigue that requires breaks during a day. While the robots can work continuously without breaking.

4.1.2 Flexible automation

Automation is the use of various control systems for operating equipment such as Machines, equipment with minimal or reduced human intervention. When we say automation, we mainly mean production automation. There are different types of production automation: fixed (hard) automation and flexible (soft) automation. Fixed (Hard) automation is automation application customized to a single product or a specific task. While flexible (soft) automation is the ability for a robot or system to manufacture different products or different tasks. Flexible automation allows rapid reconfigurability of the production system in order to manufacture several different products, achieving high degree of machine utilization, reduction of in-process inventory, as well as decrease in response times to meet the changing customer preferences [2]. It is typically composed of 6-axis robots to perform actions, sensors to inspect and detect, PLCs to provide the logics. Because it is flexible so the robot equips different grippers, sensors have a wide range and the PLCs should be applicable to different product operations. Flexible automation can evolve with your process and demand, reduce and fix production costs, improve quality and eliminate health and safety issues. When changing from one product to another one, all we need is just a change in the command to the PLC and change the components in the flex feeders.

4.1.3 Modular automation

Modular automation means breaks down a whole assembly line into standard modules. Modularization provides significant benefit both during engineering and project phase. Suppose we can't automate a whole assembly line at once, but we can automate one part at a time. Or the purpose is we only automate one module of the assembly line while keeping all the other parts the same, in this way there will be better profit as well.

4.1.4 Line balancing

Assembly line balancing studies how to assign production tasks to the different stations of an assembly line while optimizing different objectives like the number of stations, the cycle time or the cost of the line [3]. Based on the order of project tasks, line balancing aims to divide or combine the different tasks to make all the work station have uniform load. So, the production equipment will be full use and the idle time will be reduced as much as possible. The line efficiency will increase at the same time. Line balancing is an important method in production process design. By line balancing, the efficiency of operator and equipment both increase; the cost and man-hour per piece both decrease.

Line balancing is to analysis all the tasks in production line. We can make the stations time as close as possible by adjusting the tasks distribution. The purpose is to reduce the waste and improve the line efficiency. After line balancing, the less number of people and machine can be used to produce the same amount of products.

4.1.5 ROI (return on investment)

Return on investment (ROI) is the earning power of assets measured as the ratio of the net income (profit less depreciation) to the average capital employed (or equity capital) in a company or project. ROI is concerned about the profit return through the investment on some business. It covers the profit aim of investor and it is usually expressed as ratio or percentage. ROI is a simple method to evaluate the profitability of investment. But it is not suitable for comparing the investments which have different construction periods and different revenue cycle. Besides, it cannot show the absolute value of return profit of an investment because it is a ratio. It's typically between 0 and 1. The bigger the number the better profitability it will be.

4.1.6 Cycle time

It is the time duration between two same products produced or the time from the parts input to one product output. It means how long to produce one unit and the time is constant for all products. Usually, it can be determined by the desired product quantity and required time to produce. It can also be the longest workstation time in a line.

4.1.7 Idle time

It means the time when operator or machine does not do an effective work during the work hour. When the workstation time is not equal, there will be the idle time. Then we need to do the line balance. Idle time equals to cycle time minus workstation time. The less total idle time means a better line balancing.

4.2 Plant analysis

After automation, the future automated assembly line is flexible to variants types of FISTs with a ROI less than 2 years. Cycle time reduced from around 4 minutes to 36 seconds which means productivity increased to 100 pieces per hour. There is no safety issues and Condition based maintenance has been chosen as the maintenance method.

The area of the plant will reduce from 368 square meters to 105 square meters as well as the number of operators will reduce from 4 to 2. 6 Yaskawa robots will take the place of operators and distributed in 5 different stations. At station 1 there are two robots as a result of line balancing to reduce the cycle time. All workstations will be connected by roller conveyors, so we will have 4 conveyors in total. Two of them will be 5 meters long; one will be 11, 5 meters long and another one 10 meters long. Future layout will also be 'L' shaped which means the first 4 stations are in series and the last packaging station is in parallel with station 4. All the conveyors are connected from the previous station to the next station except for the conveyor from station 1 which is directly connected to station 3. The reason is station 1 and 2 are doing the

Figure 7: Future layout in 2D: 'L' shaped

Figure 8 : Future layout in 3D (from left to right: station 1, 2, 3, 4, and 5): 'L' shaped

assembly at the same time. Station 3 needs parts from station 1 and 2 to do the assembly work. Based on the number of components needed at each station, we determine the number of flex feeders: 4 for station one, 2 for station two and 3 for station 3. These flex feeders will be responsible for feeding different components to the robots that does the pick and place. And the flex feeders are feed manually by operators. Except for the flex feeders, there will be 1 bowl feeder at station 1 and 1 bowl feeder at station 3 as well. The purpose of those bowl feeders is feeding the screws or rivets.

Not only industrial robots, but also two more assemble machines will be added to our production line: one O – ring machine and one Packaging machine. Base and dome will be separately perfect positioned at station 2 and station 4. Each station is equipped with a light which will light up when the flex feeder is nearly empty. Then the operator could recognize it and fill it up. All the flex feeders will be at the same side in order to make it easier for the operator to fill up. One operator is responsible for filling up all the flex feeders and does the stickers while the other operator is responsible for the pre-packs. Pre-packs are the small plastic or metal parts that are put in plastic bags and will be installed by the customer themselves. All the components and pre-packs can be taken from the stacks. Stacks are big shelves containing all the parts taken from the warehouse by operators. The 4 stacks will be at the same side as the flex feeders for the convenience of taking.

Because we have installed inspection sensors at each station for quality inspection, so the detected parts will be marked and extracted. At station 4, there will be an extraction section to remove all those detect parts. At last, in case of variations in the production process, like changes in the supply of materials or different speed of production at each station, we introduce buffers at each end of the conveyors. Buffers are inventories of those sub-assemblies to compensate for unequal and stabilize the production process and make it run smoothly. Buffer plays an important role in our assembly line. It can balance our assembly line, helps different stations complete their tasks at the same time and can transfer the sub-assemblies to the next station at the same time. It helps diminish the problem of stopping or breakdown.

While these four stations have different components to assemble, the working table will not be the same and will have their own special fixtures to perform specific functions. At station 1, a jig is added to the surface of the turntable. A jig is a rectangular frame with grooves where robots can place the metal bars and metal plates. Each time after riveting the front side, the jig will turn automatically and the robot can assemble the other side. At station 2 where the base is assembled, a special shape function is added to balance the counter torque. When we are screwing the bolts, the screwing force will generate a counter torque which will make the base to rotate as well. We have to balance this generated counter torque. So we designed a cylinder shaped rectangle with a groove inside. Because the base is symmetric around a rib, so we can fix the rib into the inside groove then the base will not turn any more.

At station 3, another special function is added: a hollow shelf and a nut runner. First, we locate the base into the hole of the shelf then insert the UMS profile. The hole in the shelf is used to let the nut runner in and do the screwing. We fix this function onto the table and a bowl feeder will be connected to the nut runner. The difficulty at station 4 is the clamp, it's

difficult to automate the clamping motion. We got the idea from what we have now. There will be three cylinders, first cylinder pushes the clamp into a circular groove, then the other two cylinders will push the two sides of the clamp against each other and the clamp will be fixed into the dome. The sensor mounted on the robot will detect all the correct trigger moments.

4.3 Comparing different automation options

4.3.1 Flex feeders.

Definition: A flex feeder is a feeding system that can transfer different components into an assembly system. Normally it is composed of following parts: A big box to contain the components, a shake table, a vision system to detect the components and a robot to do pick and place.

Advantage: Flex feeders can increase productivity, reduce cost and add product variety. The traditional feeding method requires multiple workstations to handle while the flex feeder can accommodate wide range of part sizes and shapes. [4] And because there is a vision system, the work piece doesn't have to have fixtures and can have different orientations. Then the robots can find and handle the parts easily. There is no extra time consuming for part-changing and no costly set-up. Besides, the flex feeder provides attractive prices compared to other feeding methods. That's why we suppose flex feeders to be our best option for automation.

Disadvantage: Flex feeder can be slower than bowl feeder.

4.3.2 Bin picking

Definition: With the help of a 3D vision system, the robots detect, pick and place the randomly place objects. The process is usually seen in an automotive industry.

Advantage: Bin picking can handle components with different sizes and shapes with a low cycle time. Bin picking also reduces the cost and improve safety issues. For example, with bin picking, we can handle different components with only one work cell which gives a quick ROI. And with bin picking we can handle heavy objects which can reduce the number of accidents happened to the operators. With programming bin picking can reduce the part sorting cost and improve total productivity. [5] There are different kinds of grippers like vacuum, mechanical or magnetic gripper which means flexibility.

Disadvantage: Compared to flex feeder, bin picking is more expensive. And Bin picking only works on simple big parts.

4.3.3 Perfect positioning

Definition: Different components are placed regularly in predefined-positions. The component can be big or small, all the same components have the same orientations and the positions were already programmed, so the robots know where the components are and can pick and place them without detection. So there is no Vision system.

Advantage: Because there is no vision system, it is simple and compact so it is cheap and fast. We suppose using it when the component is big or has regular shapes. It is supposed to be a very good option for our automation as well.

Disadvantage: Manual interference could cause problems.

4.3.4 Bowl feeder

Definition: It's composed of a bowl and a spiral track on top of the bowl. There are components (only single type) inside the bowl while the bowl is vibrating the components were positioned properly into the tracks and transferred upwards. It is usually used to feed components one by one into an assembly line. And we use robots to pick and place the components.

Advantage: Without a vision system, the robot can pick and place the components at a fixed position so it's cheap. It's cost-effective, fast and reliable.

Disadvantage: it can only handle one kind of component because of the limited shape of the tracks.

4.4 Robot actions and automation options

Figure 9: Flow chart of automated assembly line

Figure 9 presents a flow chart of the automated assembly line. Now, let's take a closer look at situations at each station.

Station 1 is where the UMS Profile being assembled. Totally 5 different types of components included in this station (figure 10). Different components have different options and timing for automation. Actions taken by the robots will be somehow the same. First robot with sensor detects the component, then picks it up and moves it. Orientate the component to the right position and release it in the end. The shape and size of the components differs while the gripper will change according to the differences automatically. The mounting sequence will be: top metal plate – bottom metal plate – metal bars – riveting – repeat for the other side – reinforcements. Timing for each step is different, ranges from 4 seconds to 14 seconds. Summing up to 32 seconds in total, that's our station time as well. We got the timings from our mock-up which is we pretended ourselves to be robots and simulate the actions while counting the time. We did it twice and take the average value for the final result. As can be seen from our layout, we place two robots for this station. One is responsible for placing the different parts on the jig; the other one will do the riveting for it. When the jig turns for the other side, the second robot will place and insert the reinforcements. In this way, we can save a lot of time and keep our cycle time very low. We arranged this step here after line balancing. There are different automation options for each step as well. For the first 4 components we provide 2 automation options: flex feeder + 2D vision + robot and perfect positioning + robot. For the last component – reinforcement, the options we provide are: Flex feeder + 2D vision + robot and bowl feeder + robot. The reasons why we choose those options will be discussed later.

Figure 10: Components at station 1

At station 2, we will assemble the base which is composed of a 6-edge metal plate, 6 bolts and washers and 1 O-ring (Figure 11). Station time will be 21 seconds. First we consider picking up the base; we only provide one option for this step: perfect positioning + robot. The timing will be 3 seconds. Then is the O-ring who requires an O-ring machine and timing is 3 seconds as well. We insert the 6-edge metal plate after the O-ring. Options includes: flex feeder + 2D vision + robot and perfect positioning + robot. Timing is 3 seconds. The last components will be the bolts and washers whose timing is 12 seconds. We suggest making the washers and 6-edge metal plates to be one piece then we can save a lot of time. Another option is to use flex feeder with 2D vision.

Figure 11: Components at station 2

At station 3, we assemble some small parts including Faseblock and plastic trays (Figure 12). Station time is 33 seconds. But first of all, robots will pick up the UMS and base from previous two conveyors and assemble them together which takes 10 seconds. Subsequently, assemble the Faseblock and plastic trays. Options will be the same: perfect positioning + robot + 2D vision. Timing is 13 seconds and 10 seconds. Similar robot actions: detect – pick – position – insert – release – repeat 2 times. The special situation of this station is we will have three pre-packs. The previous manually assembled Velcro, plastic part and chemical material will be put into pre-packs because of their complex handling process. We found it very difficult to assemble those small components by robots; it's a waste of time and work.

Figure 12: Components at station 3

Robot from station 4 picks the semi-finished product out from conveyor and places it in a part-hollow table and put the two top black parts on (Figure 13). Timing will be 13 seconds. Options includes: flex feeder and bowl feeder. Then, it picks a dome up and put it on the base. Both of domes and clampers are perfectly position on the pallet, so we have no flex feeder here. Subsequently, an open clamber is placed on the table with suitable position. And a cylinder from back side will come out and push the clamber to suck at the dome. Then, two cylinders from left and right sides come out to lock the clamber, which is the same as current manual line. Lastly, the robot picks the finished product up and put it in a box with pre-pack. The box moves on a 10m conveyor and through a taping machine to the packaging station. Then the box can be sealed by the taping machine. The station time is 36 seconds and it is also the cycle time of our whole assembly line.

Station 4:

Figure 13: Components at station 4

The last station is the packaging station. Every 6 boxes will be sealed together and transferred to the warehouse. The operating time is 4, 6 minutes.

4.5 Productivity

Different FISTs have different output quantities. The output quantity ranges from 3 to 12684. At the same time, different FISTs have different production rates as well, ranging from 5 PCs/hour to 80 PCs/hour. The production rates of the FISTs that we are focusing on are: 14.7 PCs/hour for FIST – GCOG2 – HK – 8SC and 28, 6 PCs/hour for FIST – GCO2 – BE6 – NN. The output quantity for the former one is 12386 pieces and production hour is 842 hours. The output quantity for the later one is 369 pieces and production hour is 12, 9 hours. Different FISTs have different production rates and different man hours. Here are some calculations:

The working efficiency can be calculated by

$$\eta = \frac{T_1}{T_2} \times 100\% = 103.4\% \quad (1)$$

Where

T_1 Is planned man hours.

T_2 Is real man hours.

For FIST – GCOG2 – HK – 8SC

The production rate

$$R = \frac{Q}{T} \eta = 14.7 \text{ pieces/hour} \quad (2)$$

Where,

Q is the production quantity,

T is the production time and η is work efficiency

$$\text{Cycle time is } C = \frac{1}{R} \times 3600 = 245 \text{ sec/piece}$$

4.6 Line balancing

In the automated FIST line design, we did the functional decomposition first. We analyzed how the robots move and listed each action of robots. This can make the production process more specific. In addition, we simulated the actions and measured the time. Then, we could get an estimate time of each action and calculated the task time. (Table 2)

No.tasks	Work element description	Task time(s)	Must be preceded by
1	Assembly the UMS profile	18	
2	Assembly the base with metal star	18	
3	Place the reinforcement in UMS	14	1
4	Assembly the UMS profile and base	10	1,2,7
5	Place the fasblock in UMS	13	1
6	Place the top connction part in UMS	13	1
7	Place the O-ring in base	3	2
8	Assembly the dome	10	3,4,5,6
9	Clamp dome and base	12	8
10	Place product on conveyor for packaging	3	9

Table 2: Task times

The required cycle time $C = 36s$

Then the number of work stations N can be got:

$$N = \frac{\sum_{i=1}^n t_i}{C} = 3.2 \approx 4 \quad (3)$$

Where,

t_i Is the time of task I

n is number of tasks.

Then, we need to distribute the tasks to 4 work stations.

Figure 14: Line balancing

Balancing the line, four stations are needed, and each station time cannot exceed 36s. The workstation time has to be as close to cycle time as possible. The figure above shows an optimal solution to our case. Based on the tasks procedure, task 2 and 7 must be done in one station; task 1 and 3 should be completed in one station and so on. Based on this, we can calculate the line efficiency and some other data.

Work station	Task	Task time(s)	Workstation time
1	1	18	32
	3	14	
2	2	18	21
	7	3	
3	4	10	36
	5	13	
	6	13	
4	8	10	25
	9	12	
	10	3	

Table 3: Stations with task times

Evaluate the efficiency of the line:

Line efficiency

$$E = \frac{\sum_{i=1}^n t_i}{NC} \times 100\% = 80\% \quad (4)$$

Total idle time:

$$IT = NC - \sum_{i=1}^n t_i = 30s \quad (5)$$

Line smoothness index:

$$SI = \sqrt{\sum_{j=1}^N (C - S_j)^2} = 19 \quad (6)$$

Where,

If $SI = 0$ means perfect balancing

S_j Is time of station j

Balance delay factor:

$$\frac{IT}{NC} \times 100\% = 20\% \quad (7)$$

All the parameters above give a direct evaluation of the line. The most important one is line efficiency. From the calculation, we can see that 80% is good, which can be accept in the line design.

4.7 Mock up

In order to estimate the timing of feeding to different stations, we did a mock up (figure 15). Tables represent

Figure 15: Mock up layout

stations and chairs represent flex feeders. There are 5 stations in total and the last one is the packaging station. The distances between different tables are very close to the real distance between the robot stations. We pretended ourselves to be the real operators and measured the timing to fill up everything at start up and the timing to fill up during operation. Suppose the stations could continuously run for half an hour that's 50 FISTs output. Then we have the quantities for different components which times different constants we get the real quantities and the real time they will last. Because we think it's convenient for the operator to fill one station at once. So the numbers we estimated was based on this principle. And we did the simulation twice by different people, after taking the average value we think it's more close to the real number. So in the end the number we got was 6, 3 minutes which means if we want the assembly line continuously run for half an hour, every 6, 3 minutes the operator has to go for a round and fill up.

4.8 TCO & TBO

4.8.1 TCO

Total cost of ownership (TCO) is a financial estimate intended to help buyers and owners determine the direct and indirect costs of a product or system.

TCO is an important tool to manage the real cost of investments or projects. Companies not only consider the purchase price, but also the cost relevant to procurement, using and storing the products. Besides the prices, TCO also includes the cost from ordering, finding and choosing the suppliers. Based on TCO, it is easier for the company to analyze a business deal and realize the potential costs. Table 4, 5&6 illustrates line components cost, commission & standby cost and wages for engineers accordingly.

Line Component Cost			
Name	Unit price (K€/Unit)	Units	Total price (K€)
Robot	35000	6	210000
Station	25000	5	125000
All Conveyors	170000	1	170000
Assemble Machine	50000	2	100000
Extraction	10000	1	10000
Nut runner	20000	1	20000
PLC + maintenance	50000	1	50000
Vision system	10000	4	40000
TOTAL			€ 725.000

Table 4: Line component cost

Commission & standby			
Cost per person per week		2500	
Time	Worker	Total	Cost
1st week	4 mechanical, 2 electrical	6	15000
2nd week	2 mechanical, 2 electrical	4	10000
3rd week	2 Robots, 1 PLC, 1 electrical	4	10000
4th week	1 Robot, 1 PLC	2	5000
TOTAL			€ 40.000

Table 5: Commission & Standby

Project manager + Engineer		
Cost per person per week		5000
Engineer	Time (m)	Cost
Project manager: 20%	6	6000
Mechanical design: @ 100%	3	15000
Elec. Design & PLC prog.: @ 100%	2	10000
TOTAL		€ 31.000

Table 6: Wages for Manager & engineer

4.8.2 TBO

Total benefit of ownership (TBO) is used to analyze the positive influence of the investment. It helps people maximize the value of business plan and estimate the indirect benefits. A TBO analysis often shows there can be a large difference between the short term benefit to the business and its long term benefit. TBO is where the soft savings will be considered. In our project, there is soft savings on productivity because we use the flex feeder. We also have supervisor savings because of the fewer operators. The quality savings is estimated to be 10%. The training savings is also from the fewer operators. Furthermore, there will be savings on safety of operators as well. (Table 7)

Soft Savings	
productivity	10%
supervisor savings	yes
quality	yes
trainer savings	yes
safety of operator	yes
selling of scrap materials	10000

Table 7: Soft savings

4.9 ROI & Payback

4.9.1 ROI (return on investment)

The formula is:

$$ROI = \frac{\text{Net income}}{\text{Investment}} \quad (8)$$

Where,

Net income = profit of investment – cost of investment

For our project, the automatic line is designed to replace the manual line. The net income is the savings of operator salary.

Current situation:

Total operator cost (TOC):

$$TOC = \text{Total man hour} * \text{salary per hour} = 785K€ \quad (9)$$

Where,

Total man hour = 24529 hours

Salary per hour = 32 euro.

After automation:

Total man hour (TMH):

$$\text{Total man hour} = \text{Cycle time} * \text{quantity} = 1228 \quad (10)$$

Where,

Cycle time = 36 seconds.

Quantity = 122834 pieces.

So, ROI = 71%

Because our production time reduced a lot, the saved time can be used to produce extra amount of products. We will have extra benefits.

4.9.2 Payback

Payback period in capital budgeting refers to the period of time required to recoup the funds expended in an investment, or to reach the break-even point. [12] It is used to evaluate the speed to recover the cost on investment. But it does not concern about the time value of money thus the payback year may not be the exact time to get the investment back. To calculate a more exact payback period [13]:

$$\text{Pay back} = \frac{\text{Amount to be Invested}}{\text{Estimated Annual Net Cash Flow}} = 1,5 \quad (11)$$

Where:

Amount to be invested = 1063.250k€

Estimated annual net cash flow = 706.4k€

4.10 Maintenance

4.10.1 CBM (condition based maintenance)

Definition: CBM is maintenance when needed. When one or more indicators show that the equipment is going to fail or the performance is deteriorating. It is applicable to mission-critical and non-mission critical system.

Advantage: CBM can downtime of a machine by planned maintenance. Thus reduce cost and human error influence. CBM can reduce the cost of asset failures. Minimize spare part costs. Minimize system downtime.

Disadvantage: its initial cost is high – the equipment can be expensive. Some failures are not easily detected with CBM measurements. Unpredictable maintenance periods. Increased number of parts that need maintenance and check.

4.10.2 PM (preventive maintenance)

Definition: PM is the maintenance that is regularly performed on the specific device to see the possibility of failing. It includes: inspection, detection, correction and prevention of failures.

Advantage: reduce equipment downtime and the number of major repairs. Extends the lifecycle of assets and decrease the need for capital replacements. Preventing equipment failure and save money. Improve the safety of equipment and operator as well.

Disadvantage: Could be costly due to replacement of components that are still good.

4.10.3 CM (corrective maintenance)

Definition: is the maintenance task performed to identify, isolate and rectify a fault so that the failed equipment, machine can be repaired to an operational condition within tolerance.

4.10.4 Our maintenance

In our project, we use two types of maintenance. The first one is the basic maintenance (BM). This is done by 2 workers in factory. The BM tasks include keeping the line clean, checking if everything runs normally. This happens once a week and takes 2 hours each time. The time is Friday evening because people will take off work in advance on that day. Besides, inspectors also do the conveyor lubrication, oil change, axis test, minor adjustment and so on (60min). But these tasks are only done once 3 months. In addition, the air leakage (30min) also needs to be checked by them once a month.

The robots are maintained by the supplier, and they will come once a year. And the time they come is Easter holiday, so it will not influence the normal production.

The other maintenance type is condition-based maintenance (CBM). In this way, we can know the right time to fix or replace the worn parts. And we only focus on important parts, which can minimize the spare parts cost and the time spent on maintenance. The chosen parts are bearings, motors and circuit cabinets.

In our maintenance schedule, we use the thermal detector to check bearing (TB) once 3 months, thermal checking for motor(TM) once a year and thermal checking for circuit cabinets (TC) once a year. Each of them will take 60 minutes to be finished. The specific maintenance time table has already been shown in the chart. If the inspectors find something badly worn, they will take the spare parts to replace in time. So, the production can continue after a short time.

Normally, the CBM is combined with BM together to be finished. But, the total time to maintain is always 2 hours. Thus, if CBM need to be completed, the time of BM will be reduced. And we always keep full time in the second week of each month to do the basic maintenance.

Because we take the condition-based maintenance, the initial investment will be high. The cost includes buying the spare parts, storing motors and training people to use the inspection equipment and replace the spare parts.

Based on the CBM, system reliability will increase maintenance costs and number of maintenance operations will both decrease. Then, the influence of inspector mistake can also be reduced.

Maintenance Work	Period	Duration	Technicians
Basic Maintenance	Every week	2 hours	2
Thermo checking for bearing	Once 3 months	1 hour	2
Thermo checking for motor	Once a year	1 hour	2
Thermo checking for circuit cabinets	Once a year	1 hour	2
Air leakage checking	Once a month	0.5 hour	2
Conveyor lubrication	Once 3 months	1 hour	2
Robot maintenance	Once a year	10 hours	2

Table 8: Maintenance

	JAN				FEB				MAR				APR				MAY				JUN				JUL				AUG				SEP				OCT				NOV				DEC			
Type	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4								
<u>Basic maintenance</u>	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√						
<u>Thermo checking for bearing</u>																																																
<u>Thermo checking for motor</u>																																																
<u>Thermo checking for circuit cabinets</u>																																																
<u>Air leakage checking</u>																																																
<u>Conveyor lubrication</u>																																																
<u>Robot maintenance</u>																																																

Table 9: Maintenance Schedule

4.11 Quality inspection

Quality inspection is a way to detect and measure the product characteristic and compare the test results with the standard production requirements. It only aims to check if the quality is good and stop the bad quality products flow in market. This means the production process is not influenced and just failure products are returned to improve. Thus, quality inspection cannot improve the production system compared to the quality control. But it is still an important part in production line.

For manual assembly line, operators could judge the material by eye. But in an automated assembly line where operators are replaced by robots. The robots can't tell. So the quality of incoming material is the first thing to inspect. When the robot picks up a part from the flex feeder, a sensor will take a picture of the part and send it to computer. Computer will compare the picture with a standard component and tell if it is good. There requires a better quality sensor with an extra software which could cost around 10,000 euro

Although robots are reliable, Problems still may occur when riveting and screwing in case of misalignment Therefore, with the help of inspection sensor, the accuracy of alignment could increase a lot. Every part coming from previous station has a sticker on it. Because the sub-assembly and base are transferred from station 1, 2 to station 3 by conveyors. Actually, we could install inspection sensors at the end of each conveyor. And with the help of the sticker, the worn part will be extracted at an extraction section at station 4.

4.12 OEE (overall equipment effective)

OEE is used to evaluate how effectively a manufacturing operation is utilized. Availability represents the percentage of scheduled time that the operation is available to operate. Often referred to as Uptime. Performance represents the speed at which the Work Center runs as a percentage of its designed speed. Quality represents the Good Units produced as a percentage of the Total Units Started. Commonly referred to as First Pass Yield (FPY).

$$OEE = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (12)$$

$$\text{Availability} = \frac{\text{operating time}}{\text{Scheduled time}} \quad (13)$$

In our case, the production line is scheduled to run for 8 hours a day with 1 shifts and total 40 hours for a week. We assume that the maintenance time and solving technical problem time (if there are some technical problems happen) totally are 2.4 hours per week. Then the availability is 94%.

$$\text{Performance} = \frac{\text{Parts produced} * \text{Ideal cycle time}}{\text{Operation time}} \quad (14)$$

Because our line is automation production line, even if there is some unscheduled time for the operator, the machine can still run with enough feeding parts. We assume the performance of our line is 100%.

$$\text{Quality} = \frac{\text{Units produced} - \text{defective units}}{\text{units produced}} \quad (15)$$

Therefore, OEE = 91.2%

4.13 Simulation

Two main simulations we have done in our project are the Robotic Studio and Enterprise Dynamics. With the help of Robot studio, we simulated the actions taken at each station and the assembling sequence as well. The actions including such as pick and place the parts, screw the bolts and rivet. Besides, we did a 3D layout drawing. Like the positions of stations, conveyors and feed mechanism are indicated. Some details of the fixture and position of operators are also given. The first operator walks back and forth between the parts rack and flex feeder to fill the parts. The second one just stands at station 4 to do pre-pack. Every 36 seconds, he needs to put a box on conveyor.

Enterprise Dynamics is an object-oriented simulation software. It can be used in modeling, simulation, visualization and controlling the dynamic system. Users can choose the basic elements from standard library. Each element can represent a machine, a counter or product. Here we use it to simulate the production process. Based on the cycle time, we can analyze if the process will get a jam after a long time production.

5 DISCUSSION

Only two types of FISTs are being investigated while there are over hundreds different types of them. Is our automated assembly line really flexible to all of them? It's not yet completely covered in the text and our research. If so, there must be some further changes required, for instance: number of stations, PLC programming, etc. We have only given a concept of the assembly line. If we are going to implement the project, there is too much work left to be finished. First of all, we need to contact the suppliers of assembling machines, the flex feeders and Yaskawa robots to discuss about the prices, functions, training, etc. Then external workforce like professional programming engineers, mechanical engineers will be called to join the project. The possibility to implement our project is based on the decision of the top managers. Later on, we will hand in the whole turn-key project to our top managers to decide whether invest or not.

During the designing phase, we found out if making some changes to our components for example: combine the washers and 6-edge metal plate to be one piece; it would save a lot of production time. Therefore if it's possible for the R&D department to figure out those changes and design new components will be future steps as well.

6 CONCLUSION

A concept of an automated FIST assembly line whose cycle time is 36 seconds to replace the manual we have now has been generated. Through line we proved our future layout which consists of number of stations, number of robots, number of flex feeders, etc. The productivity of our future layout will increase to 100 pieces/hour which is much higher than the current situation. After comparing different options, flex feeder and perfect positioning have been chosen to be our best automation options. The payback of the whole project will be 1, 5 years. TCO and TBO are analyzed as well to estimate the cost of our project and decide if to invest.

7 AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

8 AUTHORS' CONTRIBUTIONS

Zhang Xiao analyzed this assembly line design and finished the report.

9 DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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