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Fast changeovers using AIV and a tool platform.

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ABSTRACT

Fast changeover is changing from one process or machine to another line, process, or machine to produce different products or services. Lean aims at reducing waste, improving productivity, and eliminating non-value-added activities to the customer. Whilst achieving sustained continual improvement in certain activities and process of an organization. This project focuses on implementing the methodologies used in lean to improve a manufacturing process that has a changeover, and integrate an AIV (Automated Intelligent Vehicle) with a tool platform or top module into the same process. After careful literature review and research, I was able to set up a process in the machining laboratory of 'UiT Universitet i Norge, Narvik,' that is of value to a customer. I identified the step with the need of a fast tool change and optimized the entire process using a software called Simul8. After running the simulation for a period of two weeks and doing some analysis for the processes, I achieved an optimal solution that ensures that all bottlenecks and buffers were eliminated. I also conducted a smooth flow of the process, improving productivity, efficiency, and reduction in changeover time.

Keywords: Fast changeover, Lean Manufacturing, AIV (Automated Intelligent Vehicle), MiR100, Simul8

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1 INTRODUCTION

Fast changeover is the process of converting a line or machine from running one product to another. Changeover times can last from a couple of minutes to several weeks, depending on the task at hand. For example, automobile manufacturers retooling for brand new models. Toyota, Japan, initially developed Lean Manufacturing (LM), which is now widely practiced by many manufacturers worldwide. Lean manufacturing is simply a way of pointing and minimizing waste (non-value-added activities) through continuous improvement by flowing the merchandise at the pull of the customer in pursuit of perfection. LM is crucial, primarily due to waste reduction and reduction in a time interval. Lean production is originated from the thought of kaizen or continual improvement. This philosophy infers that tiny incremental changes duly applied and sustained over an extended period resulted in significant improvements. Continuous improvement is completed dramatically while using lean.

Additionally, to the present, lean production involves, motivates, and develops employee skills through education and a multi-skilling program. Lean ensures and assures the most straightforward utilization of labour. Also, to extend productivity, the organizations should use the 5s system completely or a minimum of a neighbourhood, ultimately making sure the organizations realize a far better performance of their system. Lean assures the most uncomplicated labour and knowledge management utilization, which might be simpler and more accurate [1]. The market challenges, like shorter product life cycles, more significant product variants, and growing economic volatility, require that companies be ready to quickly adapt their production methods to changing market conditions to sustain their competitiveness. Therefore, companies must be capable of continuously improving their production processes and developing them further. This suggests that the extent to which the actors in a corporation are ready to implement the required changes is becoming an increasingly important question. This makes all employees' power contribute to improvements, a critical success factor for the operative excellence of production processes [2].

Implementing a shop floor management system is a crucial step for lean leadership. A standard management style in companies is often described as "management by remote control." This approach is predicated on reports, ERP systems, and so on. The result of that is the managements specializes in a so-called "supposed reality." The question arises if managers know their processes and the effective way they lead [3].

As many companies begin to manoeuvre towards Industry 4.0 and implement Smart Manufacturing techniques, flexible manufacturing comes to the fore and sees the necessity for intelligent strategies. This enables a facility to adapt to changing needs and demands, with less impact on production than rigid production lines. Typically, introducing the latest equipment into an assembly line is somewhat straightforward because the equipment is usually static. In recent times, however, Autonomous Intelligent Vehicles (AIVs) became a key component of intelligent production lines.

1.1 Industrial Engineering Laboratory at UiT

The lecturing is research-based, and there is availability for studying the bachelor online. In education, the department's primary goal is to educate technologists for the private business sector, public administration, research, and teaching. By achieving this goal, the department would be contributing to the sustainable development of the Nordic region.

The industrial department's Research and Development (R&D) activity is categorized into two main groups:

i. Intelligent production and logistics.
ii. Arctic technology.

Students and researchers gain access to advanced and fully automated production equipment through the department's laboratory facilities, such as robots, 3D printers, and CNC-controlled machines.

The department works closely with local and regional businesses through subject-based projects and student projects, research projects, and development projects.

Internationally, the department has contacts in several educational institutions in Sweden, China, Russia, England, the USA, Japan, Hungary, and Spain [25].

Figure 1: Industrial Engineering laboratory at UiT

Figure 2: Industrial Engineering Laboratory at UiT

1.2 Project Description

The principles and methods of Lean Production are generally accepted worldwide because of the standard for its highly efficient and competitive production. Despite that, most companies still do not realize the unlimited potential of Lean. The outcomes of a Lean transformation often lag the management's expectations. However, experts suggest that Lean initiatives enlarge their limited focus from production and logistics to implementing an integrated comprehensible Lean Management System for sustainable bottom-line effects. As an essential part of management systems, the traditional standard absorption costing is recognized as a barrier to a sustainable Lean transformation.

Managers and controllers got to remember traditional accounting issues in Lean environments as accounting alternatives to support Lean [3].

1.2.1 Problem Analysis

The AIV was introduced in the laboratory to eliminate conveyor belts and save some floor space. Even though driverless cars (AIVs) are fast becoming a reality, with engineers at top technology and auto companies racing to supply a secure and affordable autonomous vehicle, there are other unintended consequences related to the arrival of AIV. If cars, trucks, and buses start driving themselves, people that earn their living from driving these vehicles will suddenly find themselves out of employment. Consistent with the U.S. Bureau of Labour Statistics, in 2018, quite 1.9 million people were employed as tractor-trailer truck drivers [4]. Taxi and delivery drivers account for 370,400 jobs, and 680,000 Americans are employed as bus drivers [5,6]. Taken together, that represents a possible loss of quite 2.9 million jobs, which is quite the number of jobs lost during 2008 thanks to the excellent recession [7].

1.2.2 Project Limitation

- Most productions done in the laboratory are one-off or standalone projects.
- There is only one tool platform available in the laboratory, which limits the use of the AIV.

1.2.3 Project Formulation/Objectives

1.2.3.1 Formulation

This project aims to implement the various methodologies in lean as one process in designing a method to do fast "changeovers" using a robot that can transport production tools installed on portable tables in the industrial laboratory at UiT Norges Arktiske Universitet.

1.2.3.2 Objectives

The main objectives of this project are as follows:

i. Setting up a process with several activities in our machining lab, identifying customer value for the suggested product.
ii. Identify process step with the need for fast tool changes.
iii. Suggest a Kanban system for communication with the AIV for collecting materials and changing tools.
iv. Suggest a plan for optimal utilization of process resources.

v. Simulation of the process in the software Simul8

1.3 Thesis Structure and Layout

This project is structured as follows: In chapter one, an introduction is made to the research topic and an overview of the industrial engineering laboratory. Chapter two introduces the reader to some common terminologies such as the lean aspect of layout planning, fast changeover, value stream mapping, etc. Chapter three explains how the MiR works, how to use the Simul8 software and the process steps with several activities. Chapter four discusses the results and analysis of my work in chapter three. Chapter five is the final chapter of this project, presenting the conclusions. In this chapter, I reflected on the work done and future research possibilities.

Figure 3: the thesis structure and layout

1.4 Resources

1.4.1 Software

Simul8 software will be used to design and analyse the process steps in this project.

2 LITERATURE REVIEW

The history of intelligent vehicles has developed over the last 20 years. Although the primary ideas were born within the 1960s, the extent of maturity of the technology at that point did not allow pursuit of the first goal of implementing fully autonomous all-terrain all-weather vehicles. A couple of groups fielded the primary documented prototypes of automated vehicles within the military arena within the mid-1980s [14]. The initial stimulus that geared these innovative ideas was provided by the military sector, which was to provide a complete automation to its fleet of ground vehicles. Not before the 1980s, this interest was transferred to the civil sector: governments worldwide launched the primary projects, which supported an outsized number of researchers in these topics. The interest of the automotive industry in developing real products was only triggered after feasibility studies were successfully completed and therefore, the first prototypes were demonstrated. Testing autonomous vehicles on real roads during a real environment was among the foremost important milestones within the history of intelligent vehicles. This happened within the mid to late 1990s. Figure 1 shows the recent automotive intelligent vehicles that pioneered the event of intelligent vehicles. Within the summer of 1995, the Carnegie Mellon Navlab group ran their No Hands Across America experiment [15]. They exhibited automated steering, based solemnly on computer vision over 98% of the time on a 2800-mile trip across the United States. The vehicle was ready to drive autonomously for 95% of the trip. The car suggested and executed manoeuvres to pass other vehicles; unlike the other robot cars, this car located itself on this road and followed it until otherwise instructed. It did not localize itself in global coordinates and will drive without Global Positioning System (GPS) and road maps found during a modern automotive navigation system. The car's trunk was filled with transputers and unplanned hardware. VisLab followed a unique approach at the University of Parma within the Argo project: the designed and developed coach was a supported low-cost approach.

Figure 4: Recent pioneering autonomous intelligent vehicle [26]

An off-the-shelf Pentium 200 MHz pc (PC) was mounted to process stereo images obtained from low-cost cameras installed within the driving cabin. The vehicle was ready to follow the lane, locate obstacles, and change lanes, and overtake slower vehicles when instructed. The most milestone of this project was the successful test of the Argo vehicle during a tour of Italy of quite 2000 km called 'Millemiglia in Automatico,' during which the vehicle drove itself for 94% of the entire distance. Current research initiatives are oriented towards intelligent vehicles in realistic scenarios. However, due mainly to legal issues, full autonomy has not yet been set because of the ultimate goal. The automotive industry has set its primary goal to equip vehicles with supervised systems and, more generally, advanced driving assistance systems (ADAS) rather than automatic pilots. In other words, the driving force remains responsible for running the vehicle. Still, the drive is monitored by an electronic system that detects possibly dangerous situations and reacts by either warning the driving force in due time or taking control of the vehicle to mitigate the results of the driver's inattention. Given the legal issues, the last word goal has shifted towards driving assistance systems since complete vehicle automation was not considered a primary strategic investment area for automotive industries. Concurrently, Departments of Transportation worldwide are primarily curious about social, economic, or environmental objectives to enhance fuel-efficiency, road network usage, and improve quality of life in terms of mobility. The outstanding results obtained by ADAS within the automotive arena in recent years have induced the military sector to offer a vigorous replacement push to the first ideas of automating its fleet of ground vehicles. The Defence Advanced Research Projects Agency (DARPA) launched the Grand Challenge in 2003, a race for autonomous vehicles that had to travel for quite 200 km in a disorderly environment. This unprecedented challenge attracted an outsized number of top-level research institutes, who worked with the million-dollar prize in mind and helped the scientific community take a substantial breakthrough [17].

2.1 Benefits of Intelligent Vehicles

Having intelligent vehicles running on our road network would bring a variety of social, environmental, and economic benefits. An intelligent vehicle ready to assess the driving scenario and react just in case of danger would allow up to 90% of traffic accidents caused by human errors to be eliminated, saving human lives [18]. Consistent with the planet Health Organization an estimated 1.2 million people worldwide are killed annually. About forty times this number injured, thanks to traffic accidents. At an equivalent time, vehicles ready to drive at high speeds and really on the brink of one another would decrease fuel consumption and polluting emissions; furthermore, they might also increase road network capacity. Vehicles communicating with a ground station could share their routes and be instructed to reroute so as to take care of a smooth traffic flow. Vehicles that will sense and obey speed limits or traffic rules would scale back the likelihood of misinterpretation and antisocial driving behaviour. Fully automatic vehicles would also offer a better degree and quality of mobility to an enormous population, including young, old, or infirm individuals, reducing the necessity even for a driver's license. Finally, the supply of vehicles that would drive themselves would increase the standard of mobility for everybody, turning personal vehicles into taxis ready to devour people and take them to their final destination in total safety and luxury, dedicating the driving time to their preferred activities. However, this complete application of intelligent vehicles is far from being complete since unmanned vehicle technology remains underdeveloped for several other applications [19]. The automation of road vehicles is probably the foremost common everyday task that draws the best interest from the industry. However, other sectors such as agricultural, mining, construction, search and rescue, and other dangerous applications generally are looking out to autonomous vehicles as a possible solution to the difficulty of the ever-increasing cost of personnel. If a vehicle could move autonomously on a field to seed, enter a mined field, or perform dangerous missions, the number of people put in danger would drastically decrease. At an equivalent time, the efficiency of the vehicle itself would be increased because of a 24/7 operational schedule. The key challenge for intelligent vehicles is safety; accidents must not occur thanks to automation errors, and there is intolerance to human injury and death. This chapter focuses on road and traffic applications of intelligent vehicles, speeding up the automotive industry's interest, car makers, and providers of automotive technologies.

2.2 Lean aspect in layout planning

The automotive assembly industry utilizes the essential assembling operations within the world. In MIT's study, quite ninety plants were visited and investigated, representing almost half the assembly capacity of the whole world at that point [20].

Plants are vast, and thousands are employed. Massive conveyers are needed to manoeuvre vehicles through the assembly, and quite 10,000 parts are involved within the assembly of the typical car. Therefore, any reduction in space, inventory, or cycle times, even the minor ones, will provide returns with significant savings. One of the determinants in lean is the standard. The standards at work, methods, and parts are the idea for any improvement. Indeed, the finished car itself is even largely typical, since although body designs will vary around the world, the fabrication techniques are remarkably similar. Therefore, the most standard method in manufacturing may be line production. Identical or equivalent parts are utilized in different models [20]. Because of outsourcing alongside collaboration, even other manufacturers may use a matching feature to realize the advantages of economies of scale. However, the planning of a vehicle may be a very complex task and requires technical know-how from many areas. Facilities and equipment are expected to be utilized for an extended time. In this way, design is highly much associated with fabrication. It is also an essential introduction to car manufacture since any failures in design will simply recur later in production. A drag may go undetected in a worst-case scenario, maybe even ignored, and ultimately suffered by the customer, e.g., consider Toyota in 2009, when 4,3 million cars had to be recalled for a malfunctioning accelerator, even suspected to be a cause of some fatal accidents. Toyota's factory was stopped at a price of over a billion dollars per month [21].

2.3 Fast Changeover

In manufacturing industries, Fast changeover is the process of converting a line or machine from running one product to another. Changeover times can last from a couple of minutes to the maximum amount as several weeks within the case of automobile manufacturers retooling for brand spanking new models.

SMED, or Single Minute Exchange of Dies, is the technique of reducing the quantity of your time to vary a process from running one specific sort of product to a different one. The aim of reducing changeover time is not for increasing production capacity but for allowing more frequent changeovers to extend production flexibility. Fast changeovers leave smaller batch sizes.

2.3.1 The benefits of fast changeover include:

I. Reduce defect rates - Fast Changeover reduces adjustments as part of the set-up and promotes quality on the first piece.

II. Reduce inventory costs - Elimination of or reducing batches' numbers and sizes allow for recovery of operating cash and manufacturing space.

III. Increase production flexibility - Increase output and improve customer orders' timeliness.

IV. Improve on-time delivery - Quick Changeover supports the ability to meet customer demands.

The words set-up and fast changeover are sometimes used interchangeably, however, this usage is incorrect. Set-up is only one component of the changeover. Changeover can be segmented into the 3 Ups:

1. Clean-up: the removal of the previous product, materials, and components from the line.
2. Set-up: the process of converting the equipment.
3. Start-up: the time spent fine-tuning the equipment after it has been restarted.

The following are the keys to fast changeover:

I. Rethink the idea that machines can be idle, but workers cannot be idle.

II. The ideal setup change is no setup at all or within seconds.

III. Ensure that all tools are always ready and in perfect condition.

IV. Blow a whistle and have a team of workers respond to each changeover.

V. Establish goals to reduce changeover times, record all changeover times and display them near the machine.

VI. Distinguish between internal and external setup activities and convert internal to external setup [39].

To identify and separate the fast changeover process into key operations, the external setup that involves the operations needs to be done while the machine is running. Before the changeover process begins, Internal Setup is people who must happen when the equipment is stopped. Apart from that, there can also be non-essential operations. Use the subsequent steps to attack the fast changeover:

2.3.1.1 Eliminate non-essential operations

This involves adjusting only one side of guard rails instead of both and replacing only the necessary parts and making all others as universal as possible.

2.3.1.2 Perform External Set-up

This involves gathering parts and tools, pre-heat dies, and having the correct new product material at the line because there is nothing worse than completing a changeover only to find out that a key product component is missing.

2.3.1.3 Simplify Internal Set-up

This setup involves using pins, cams, and jigs to reduce adjustments, replacing nuts and bolts with hand knobs, levers, and toggle clamps. Remember that no matter how long the screw or bolt is used, only the last turn tightens it [38].

2.3.1.4 Measure

The only way to realize if changeover time and startup waste is reduced is to measure it!

2.4 Kanban

Kanban system is one among the tools under lean manufacturing system which will achieve minimum inventory at one time. Kanban system provides many necessary advantages in managing operations and business in a corporation. Using the Kanban system may be a strategic, operational decision to be utilized in the assembly lines. It helps to market the company's productivity and reduces waste in production within the same vein. However, the Kanban system requires production only when the demand for products is out there. Manufacturing companies, especially in Japan, have successfully used the Kanban system as this technique emerges from the country. However, it had been found that not all companies in Malaysia, particularly among the tiny and medium enterprises (SME) in the manufacturing sector, are deploying the Kanban system [37]. Although small medium enterprises (SMEs) use the Kanban system, they face problems in making the system effective. Thus, understanding the Kanban system is vital in lean manufacturing. Kanban (Kahn-Bahn) is a Japanese word; when translated and literally, it means "visible record" or "visible part" [21]. Generally, it refers to a sign of some kind; thus, it refers to Kanban cards in manufacturing. The

Kanban system is predicated on a customer of a neighbourhood pulling the part from the supplier of that part. The customer is often an actual consumer of a finished product (external) or the assembly personnel at the next station during a manufacturing facility (internal). Likewise, the supplier might be the preceding station during a manufacturing facility. The premise of Kanban is that material will not be produced or moved until a customer sends the signal to try to do so [21]. Nowadays, to realize manufacturing excellence, most organizations developed various techniques and methods to form their production operations productive and effective. Most Japanese companies use the Kanban system because it helps to save costs by drastically eliminating overproduction, developing flexible workstations, reducing waste and scrap, minimizing the waiting times and logistics costs; thus, reducing the inventory stock levels and overhead costs [22].

2.5 Process Mapping System

Business process mapping (BPM) may be a common industry practice that illustrates the processes within companies that require improvement or process reengineering. As stated by Hammer and Champy, 'business process reengineering' is defined as "the fundamental rethinking and radical redesign of business processes to realize dramatic progress in critical, contemporary measures such as cost, quality, service, and speed." Many organizations have turned to business process reengineering to enhance their competitive position by simplifying, eliminating, and redesigning business processes for increased efficiency and price reduction, resulting in a rise in the number of reengineering projects undertaken [23]. As described by [13], "Process mapping proffers a 'visual aid' to initiate improvement and provides a way for analysing the process. It may be a framework that shows relationships between the activities, people, data and objectives". Process mapping has been applied in various industries, including manufacturing, construction services, and healthcare. The business process modelling view yields a well-documented value, including providing a holistic perspective on how the business operates. Providing a way of documenting processes, providing a vehicle for development and communication, aiding in eliminating non-value-added activities, reducing process complexity, helping in knowledge capitalization, and assisting in managing company rate facts [24]. Many tools exist for representing and analysing business processes, but little information is out there on how these tools are utilized in practice. From the attitude of Human Factor (HF), a Business Process Mapping (BPM) of the assembly system design process could help trigger dialogues around how HF could be embedded into the planning process.

2.6 Value Stream Mapping

Value stream mapping (VSM) is defined as a lean tool that brings into play a flowchart, documenting every step within the process. Many lean specialists see VSM as a foundational tool to spot waste, minimize the time of the process cycle, and implement process development.

VSM is a workplace efficiency tool designed to mix material processing steps with information flow alongside other important related data. VSM is an important lean tool for a corporation eager to plan, implement, and improve its lean journey. VSM helps users create a solid implementation plan that will maximize their available resources and help make sure that materials and time are used profitably. The original VSM template was designed by Toyota Motor Company and implemented through material and process flowcharts. This VSM exhibited the required process steps from order entry to final product delivery and was useful for gaining a wide-reaching view of the company's activities. It allowed Toyota to eliminate non-essential activities that created waste while maintaining the manufacturing process. The "value stream" portion of the VSM system centres on how value is often added to a product or service by changing the market form or function to satisfy the customer's needs. This includes adding functionality and features to a product or service that benefit the customer with no increase in the wasted time and materials (also called muda, the Japanese term for waste) on the company's side. [27]

Value stream mapping became a well-liked practice with Lean's rise within the last half of the 20th century. It had been one among the foundations that made the Toyota Production System a producing sensation, although, by that point, the term

VSM was not present. However, it is a standard misconception that Toyota invented the practice of visually mapping a workflow. This can be proved via diagrams showing the flow of materials and knowledge during a 1918 book called Installing Efficiency Methods by Charles E. Knoeppel. By the 1990s, the worth stream mapping process became a part of the lives of many wester managers. Its popularity began to outgrow manufacturing and eventually spread into knowledge work industries like software development, IT operations, marketing, and many others. Value stream mapping is gaining popularity in knowledge work as it encourages system thinking, improves collaboration, and increases productivity. Even individual contributors can clearly oversee how the team's work is progressing. Consequently, teams can increase work handoffs' efficiency, which may be a significant culprit for accumulating wait time in your system. Waiting is one of the seven wastes of Lean, and thus it should be everyone's priority to attenuate it.

Mapping your process can assist you to visualize where handoffs occur, so you will also discover where the bottlenecks (queues) of your process are and are available up with how to attenuate their damage to your team's productivity. [28]

3 METHODOLOGY

Simple automated guided vehicles (AGV) are used in industrial environments to fulfil simple transportation tasks. With the ongoing progress of new technologies in this area and probabilistic robotics, these approaches for more flexible mobile robots are possible. Autonomous mobile robots (AMR) get more industrial environments for logistical and manipulating tasks. Until now, a standard for mobile robots does not exist. Nearly all state-of-the-art mobile robots are designed to work beside humans in industrial factories using probabilistic algorithms. Examples therefor are the "Mobile Industrial Robots (MiR). These mobile robots mostly use a safety Light Detection and Ranging (LiDAR) system. The problem with this probabilistic method is that there are currently no standards for mobile robots in an industrial environment. The mobile robot MiR100 will be used for transportation and manipulation applications. Furthermore, it uses two SICK Laser scanners for SLAM and obstacle avoidance. It does not identify all-hazard situations [30].

Succeeding a cultural and people-oriented transformation, Lean Producers adopts the philosophy of doing more with less by eliminating non-value-added activities from production processes to maintain effectiveness, flexibility, and profitability. With the context of Industry 4.0, new solutions are available for combining automation technology with Lean Production. Moreover, when effective resource (finance, labour, material, machine/equipment) usage is concerned, it is evident that Industry 4.0 should be applied to lean processes [29][36].

A study was carried in France in 2016 to find an appropriate way to combine and implement lean and green tools and methodologies to identify how to cope with the difficulties of dealing with customers and regulatory requirements; while fostering the economic, environmental, and social pillars of sustainability. Different technologies are emerging because of the fourth industrial revolution, mainly referred to as Industry 4.0. Although it is impossible to stop waste generation completely, it can be minimized using proper methodologies to execute industrial processes. JIT (Just in Time) is a principle introduced to minimize waiting times in the manufacturing process. However, it is widely used throughout the supply chains starting from suppliers' suppliers and extending to customers' customers in the current context. With this principle being appropriately implemented, no one will wait for something to happen, and no machine or human will be idle, which verifies the optimal use of resources. This concept is implemented using a Kanban system method that will provide alerts in advance to notify when certain things are due [31].

3.1 MiR100 (Mobile Industrial Robot)

We human beings are constantly looking for ways to optimize our productivity and efficiency. The use of mobile robots enables us to implement these optimizations to improve efficiency, productivity, and safety. MiR's can autonomously transport material and empty containers between warehouse and assembly. The MiR will be equipped with the MiR tool platform or table for this task. It can be used as a conveyor belt to transport semi-finished materials and finished goods from production-to-production cell. If one has more than one MiR for transport, they can have an adaptable link between the production lines. Using the MiR is a new way to produce, enabling companies to upscale without any production downtime. Its usability is not limited to transport alone, and it can also be equipped with different top modules or tool platforms, such as a hook, conveyor belt, e.t.c. They can detect obstacles, and we not only always track their location but also their tasks. From doing just manual assemble line stuff, which is the elementary format. One can also upgrade the base to have a conveyor system on them, they can now go down to the warehouse and collect raw materials, and they can deliver that to the production line [40]. By putting the conveyer on the MiR, one can gain the flexibility to move anything where one wants around the factory [41]. The MiR has an open interface to connect third-party equipment to the robots. We chose MiR as our mobile robot because it was a flexible solution to see many potentials. Its senior brother MiR500 can handle a payload of up to 500 kg, which is also easy to setup and can start operating as fast as possible.

It is proven that the MiR's can learn their routes by themselves and are perfectly able to collaborate with employees and forklift trucks in complete safety. It is easy to use the robot itself and its application. Mobile robots create an entirely new opportunity to deliver components or elements without human involvement and significantly increase our safety. It avoids any potential collisions between assembly-line employees and devices such as a forklift truck or a tugger. MiR fleet allows us to manage deliveries to prioritize orders and supervise the battery charge, which enables us to work continuously. It ensures safety, improvement of productivity, low automation costs, and flexibility in layout changes because it is fast and easy to integrate into any factory layout.

3.2 How it works

When an employee is ready to send an item that he or she just finished working on to the next production line, a MiR robot can be summoned with a pressable button. Once the button has been pressed, a signal is sent to the MiR fleet management software; the fleet management software runs behind the scenes and manages all the MiR robots. The system automatically instructs the appropriate robot to navigate to the source point. The item is placed or attached to the robot, and it is ready for transit to its destination. The robot drives 100% autonomously and can easily navigate around obstacles on its way. The fleet management software automatically adjusts traffic in real-time, ensuring that everything runs smoothly and efficiently. When the robot has delivered the item to its destination, the robot can be set up to automatically park itself at the pre-set parking spot and recharge if there is nothing else in the queue. The robots can also be summoned via tablet, automatic communication from production lines, or the ERP (Enterprise Resource Planning) system. One can even have the possibility to create rush orders placed in front of the order queue. Because the robots drive autonomously, they can perform complex manoeuvres such as navigating multiple floors. If a robot encounters an obstacle that it cannot navigate around, a notification is automatically sent to the user that an action is required. When the item has reached its destination, the robot automatically sends a notification to the user. The top modules can be easily changed, so the robot can be redeployed for different tasks, whether transporting small, medium, or oversized items. Programming the MiR robot is simple; the user-friendly and intuitive interface allows for fast and hassle-free implementation. It comes with customizable dashboards that make it easy to tailor the interface to individual needs. Because factory layouts change quickly, the MiR has been designed to reprogram routes easily. One is ready to go with a few clicks, and it is that simple.

Figure 5: MiR100 with two different top modules

3.3 Safety Ring for mobile robots

To guarantee a safe mobile robot for the industry, which works in the same area as humans without many restrictions or fences, a safety ring for mobile robots is in development. The safety ring must guarantee to detect any obstacle in the maximum braking distance of a mobile robot. If any obstacle is in danger distance of the safety ring, a safety controller applies an emergency stop and turns off the motors of the mobile robot. Various new approaches for state-of-the-art probabilistic robotics could find permission to get used in industrial environments due to a safety ring. Thus, a broad spectrum for self-navigation of a mobile robot is possible.

Furthermore, non-tactile sensors like LiDAR makes it possible for probabilistic approaches. The MiR100 has two SICK S300 Professional laser scanners, an Intel RealSense 3D camera, and four Ultrasonic safety sensors to detect obstacles. However, the sensors are designed for the height of the robot of 995mm. If a framework is added to upgrade the MiR100, additional safety sensors are needed to detect obstacles, which would crash into the framework higher than 995mm. The safety of the mobile robot is also not guaranteed at fall-down areas like stairs or steep ramps, so additional ground sensors to detect dangerous fall-down areas are needed. If a human is not detected, a barrier is implemented to counter any harm for humans or robots. Therefore, some safety bumpers will be the last opportunity to counter a hazard situation for humans around the mobile robot. Important sensing for mobile robots is its perception, so it knows its environment. Therefore, obstacle avoidance sensors are, especially for human safety-relevant subjects. The MiR100 has two LiDAR sensors diagonally implemented on the robot. An advantage is that it uses electronics, which can resolve the information in picoseconds, which makes this obstacle avoidance very fast. It has two SICK laser sensors for the safety of people because these sensors are the only ones that are certificated with a performance level and guarantee a functional safety function on the mobile robot [30].

Safe Navigation for mobile Robots

However, it is essential to differentiate between an autonomous mobile robot (AMR) and an automated guided vehicle (AGV). AMRs do not need a defined track because they navigate dynamically in the environment. A map can be built automatically (SLAM) or saved in the robot, which allows it to plan its path in the factory. Further, it is easy to expand or change the work area because the MiR's map can be updated to work perfectly with the new changes in the work area. In contrast to the AMR, an AGV requires "tracks" in the form of lines or figures on the floor. Therefore, it is not as easy and time-consuming to expand or change the work area. Thus, AGV is restricted to fixed routes and stops at any obstacle without the possibility to change the route [30]. The available MIR100 uses this already in V- and VL-Marker to detect positions like the docking station in the factory.

3.4 PROCESS SETUP

According to my objective in 1.2.3.2 above, I identified a product of value to the customer, and I will describe the process in this section. I will be working on the process steps for making Rexolite glasses. It is a military-grade polymer lens made of plastic which should be resistant to almost anything, especially harsh environments. Initially, before my optimization, this process was done using only the 5-axis machine. The production of the Rexolite glass was not done on a large scale. But to improve the fast changeover and the process flow, I suggested the use of a milling machine, so that one would not have to wait for one process is done before you move to the next.

In any production company, there is always a step that consumes most of the time, and that step is the process planning. In this case, the process planning includes programming and setup of the 5-axis machine, mainly the dmu40 and the milling machine. Other parts of the process planning include tool library or preparation of tools, programming of the Hexagon Tigo SF, and physical setup.

3.4.1 SIPOC Process Mapping

A high-level process map is a simple depiction of the four to eight critical steps within a process. Using this tool illustrates the importance of customer needs and process outputs being the same. The output of a process creates a product or service that meets or exceeds some expressed or implied customer needs. Developing a process map aims to identify customers and the team's orientation to the process that will need improvement to achieve project goals [33].

SIPOC diagram is a tool used by a process improvement team to identify all relevant elements of a process improvement project before work begins and helps to define a complex task that may not be well-scoped. A SIPOC Map is a high-level summary of the process. It provides a big picture view of the crucial elements of the process to understand how the process occurs. SIPOC is an acronym that stands for Suppliers, Inputs, Processes, Outputs, and Customers [35].

SIPOC analysis is widely used in process design and improvement initiatives (such as Six Sigma) to identify essential elements of a process and define the scope of a project when it is too early for a detailed process mapping. The most common areas at which the SIPOC analysis is used are at the beginning process improvement initiatives during the Define phase of DMAIC, and during the planning phase of Kaizen events [34].

To create a SIPOC map, one must specify the main activities of the process and identify the potential suppliers, inputs, outputs, and customers:

1. A Supplier is a person or company that supplies inputs to the process.
2. Inputs are the materials, energy, information, customer requirement, customer feedback, and financial and other resources needed to execute the process.
3. A Process is the collection of activities that together transform inputs into outputs of value to the customer.
4. An Output is a tangible product or service that results from the process.
5. A Customer is a person or company that receives the outputs of the process.

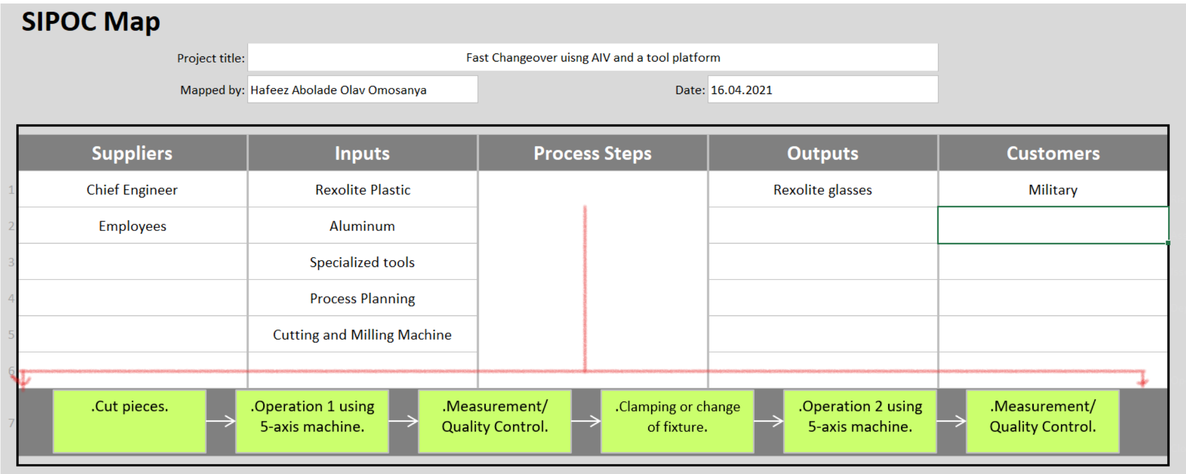

Figure 6: the SIPOC map of my process

3.4.2 Process steps

1. Process planning as described in the section above (process setup).
2. Stock material, i.e., getting material from the warehouse.

Figure 7: Rexolite from stock

3. Cut piece using the cutting machine.

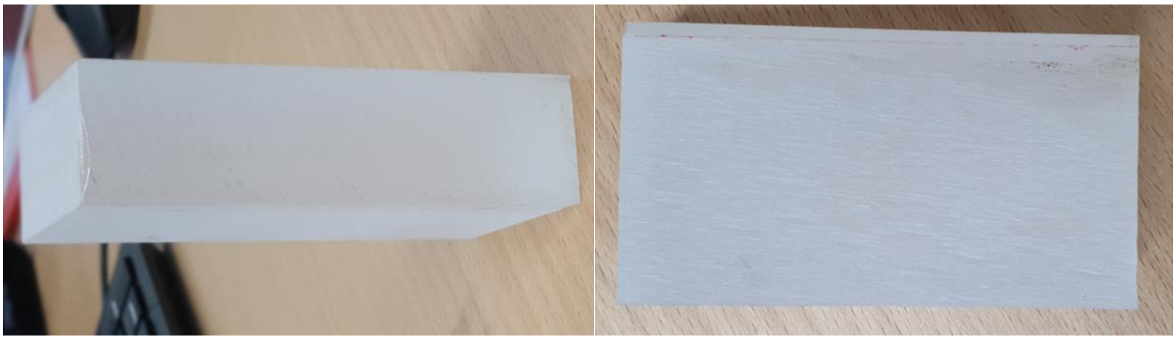

Figure 8: Pieces after cut

4. Manufacturing of operation 1 using the 5-axis machine (dmu40).

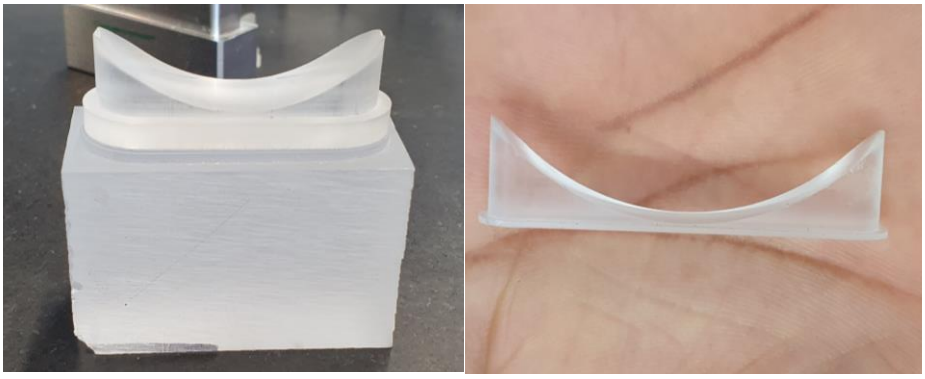

Figure 9: finished product after operation 1

5. Quality Control is done using the Hexagon Tigo SF or the Hex 8515 CMM (coordinate measuring machine).
6. Production of fixture for operation 2. The process is only executed once, and we can continue to mass produce without repeating the process.

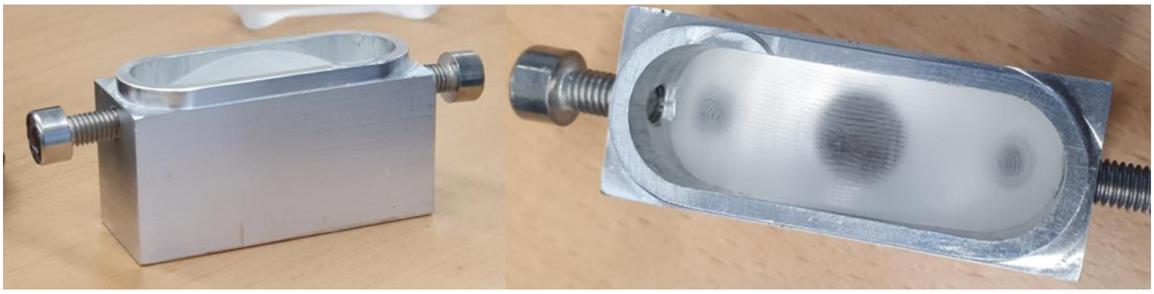

Figure 10: Samples of Fixture

7. Clamping procedure: in the process, there is changeover done. And in accordance with my objective in 1.2.3.2 above, the MiR100 can be used to do the changeover and transport finished goods in batches of 5 from Operation 1 to Operation 2. The fixture produced in 6 above is used in Operation 2 as a reference point to complete Operation 2. The finished product from Operation 1 is clamped in this fixture, then the milling in Operation 2 is carried. The fixture also assists in avoiding movement is misalignment while Operation 2 is being carried out.

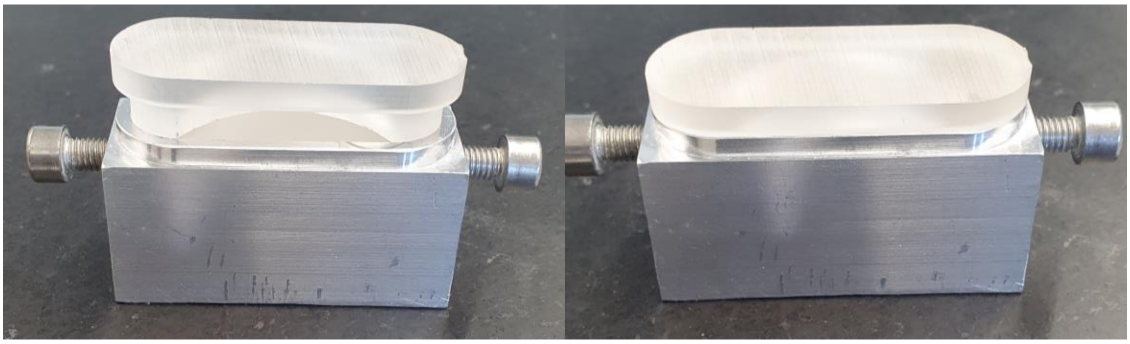

Figure 11: Clamping ready for Operation 2.

8. Manufacturing of operation 2 using specialized tools and the milling machine. In this process, the concave part is milled at the surface facing you in Figure 11 above. There is meant to be a distance of 0.5mm top to bottom, in the middle point after this operation is done. Unfortunately, there is no finished products to be shown. As this project is a confidential one, there is a limit to what I can share.
9. Quality Control is done using the Hexagon Tigo SF or the Hex 8515 CMM (coordinate measuring machine). Either of the Hex machine is used to measure every part of the Rexolite glasses to ensure it meets the required measurement. This machine(s) is developed for the shop floor; the TIGO SF is a fully protected and versatile coordinate measuring machine (CMM) that combines robust construction, innovative technology, and setup to ensure high-accuracy measurement in the harshest of environments. TIGO SF is an accurate and compact CMM designed explicitly for use on the shop

floor. With a measurement volume of 500 x 580 x 500 mm (X/Y/Z), it is the ideal measurement solution for a wide range of small and medium-size parts from all industrial sectors. The solid and robust TIGO SF features air-free movement to ensure performance in harsh shop-floor environments. The machine structure is fully protected by the covers and bellows to prevent contamination of the moving parts. Electronic equipment is housed in the machine stand, and an IP54-rated version of the stand is available as an option for extra protection in the harshest environments. Passive dampeners mitigate the effects of vibration, and an active dampening system is available as an option for workshop setups where vibrations may have a more significant impact. Thanks to its cantilever structure, TIGO SF is open on three sides and therefore offers optimal accessibility for manual and automatic part loading and unloading for seamless integration into various production processes. The thick granite worktable also incorporates a dense grid of fixturing holes to make part placement easy and quick. TIGO SF is the all-in-one measuring solution for production areas; in the standard configuration, both the controller and the PC are housed inside the machine stand. The monitor and keyboard are positioned on a swivelling arm to ensure maximum efficiency ergonomics with the minimum footprint. This standalone compact configuration can be easily relocated to suit changing production needs [32].

10. Packaging, shipping, and delivery to the customer are done.

3.5 Factory Layout or Floorplan

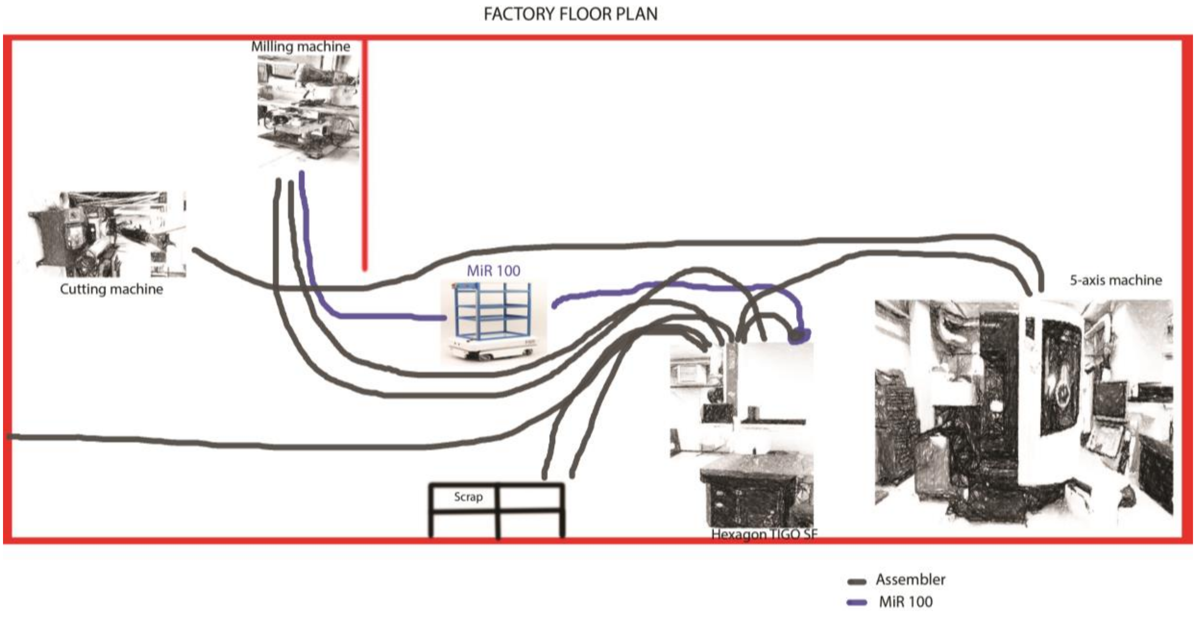

Figure 12: The spaghetti diagram

This shows the movement of the resources on the floor plan. This floor has about 315 m^2 in space, housing several different machines and robots apart from the identified machining types of equipment in Figure 12. The above figure is simplified to show the relevant machines needed and the movement related to those machines. As such, space utilization is nearly impossible.

3.6 Process flow chart

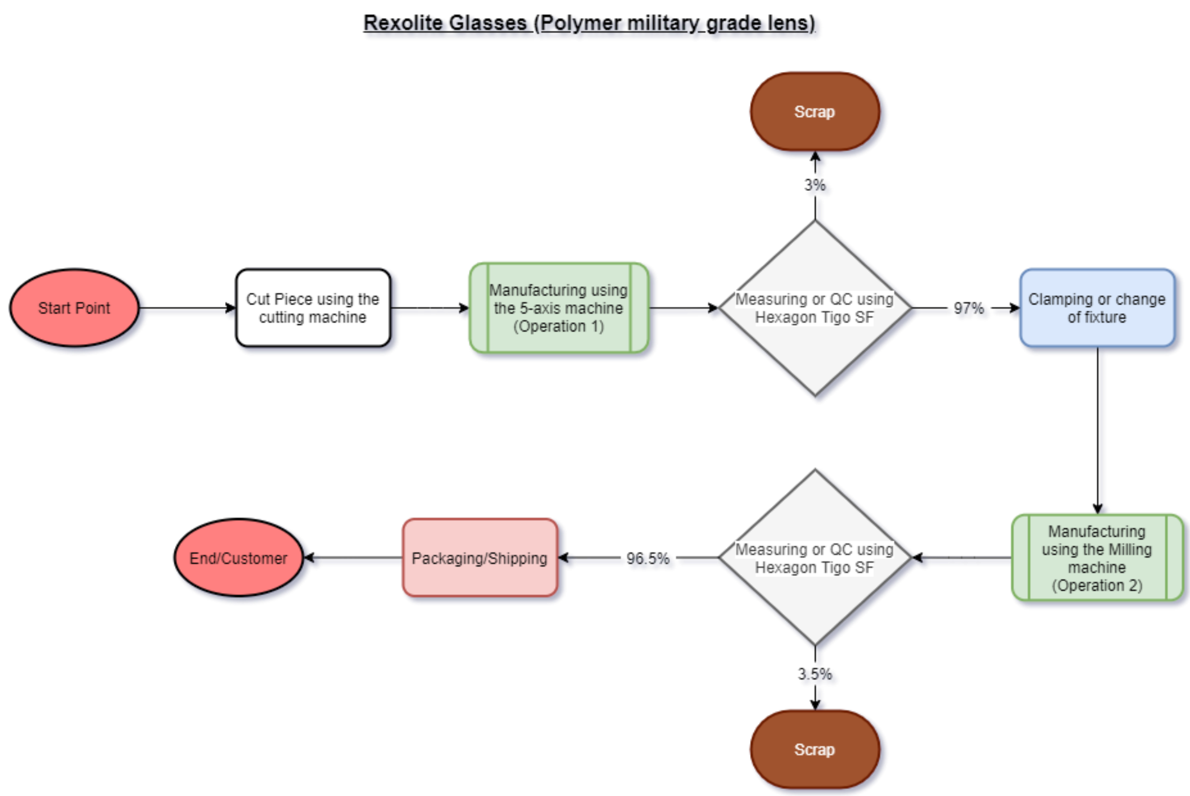

Figure 13: Process flow chart

The diagram in Figure 13 above describe the flow of the entire process in the laboratory with an arrow indicating the start point to the end point. This chart only shows how the process should run daily or weekly, as the case may be, without considering the one-time processes discussed in 3.4.2 above.

3.7 Simul8

Before a simulation can be made, I had to set my period and clock for my entire simulation, i.e., how long I want to run the whole process. So, I set my time unit to 'Minutes' and my time format to 'Time and Day.' My simulation will run for 8 hours a day and five days a week (Monday to Friday), and my result collection period will be two weeks as shown in

Figure 14. 30 minutes of lunch time was incorporated in the daily task, so basically, 7.5 hours of work is done in a day.

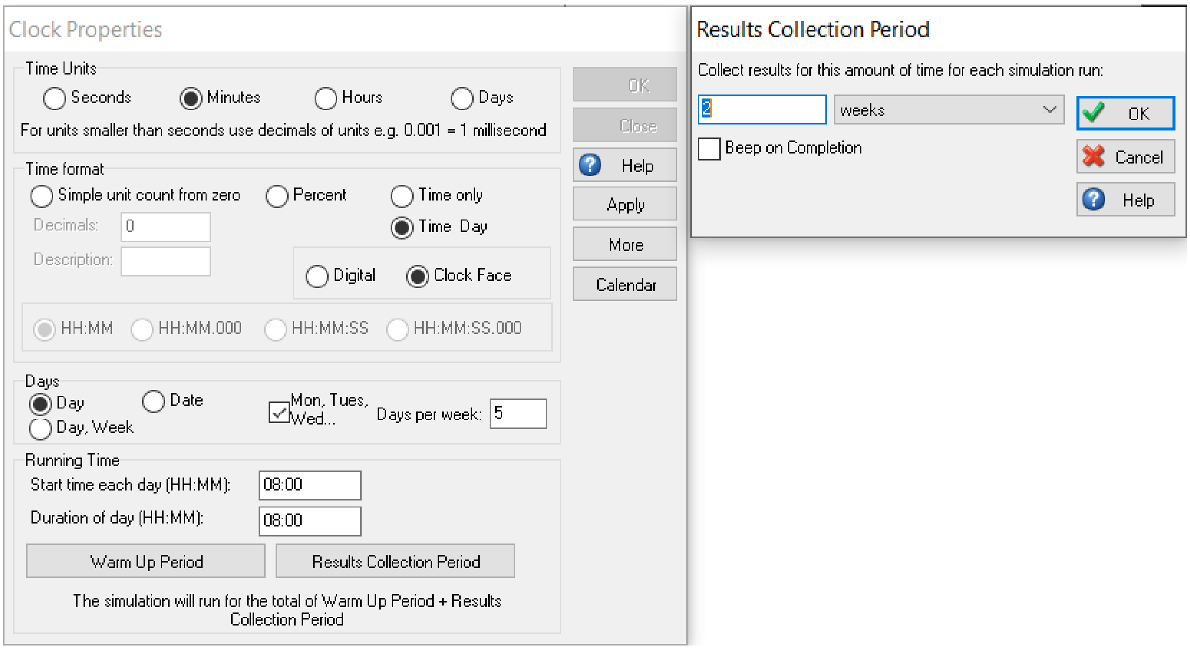

Figure 14: the clock properties of the entire simulation

To implement the lunch break in the simulation, one has to open the first activity's properties, click on efficiency, select the detailed option, and click on the 'More' button. Then I named it 'Lunch Break.' select the blue highlight to confirm that it is created. Then to create the break time, you click on 'Time between Breakdowns,' fixed distribution, and do some calculation. Because my start time is from 8 am, and I want the break to be at noon, that is a difference of 4 hours, so four multiplied by 60 minutes equal 240 minutes. So, my fixed distribution is 240 minutes, as shown in Figure 15 below. MTBF and MCBF mean 'mean time between period of failures' and 'mean cycles between period of failures' respectively.

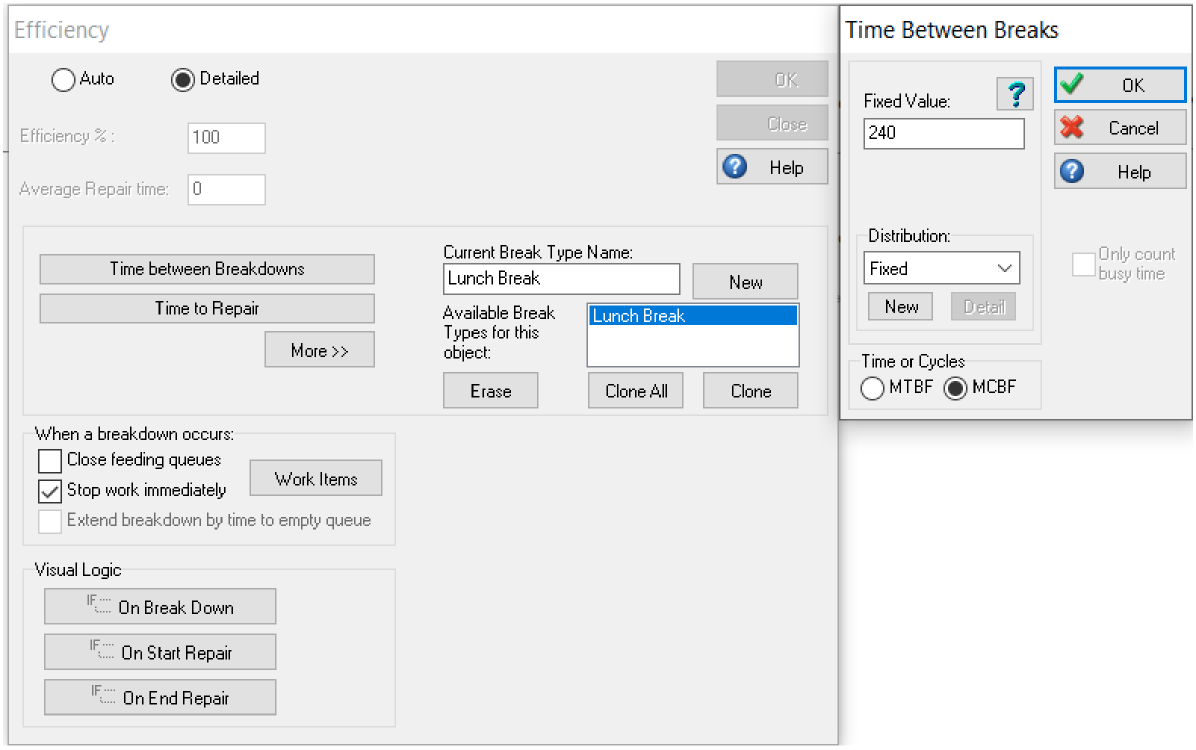

Figure 15: how to set lunch break.

To set the break length, click on 'Time of Repair.' I used a fixed value of 30 minutes and selected ok, as shown in Figure 16 below.

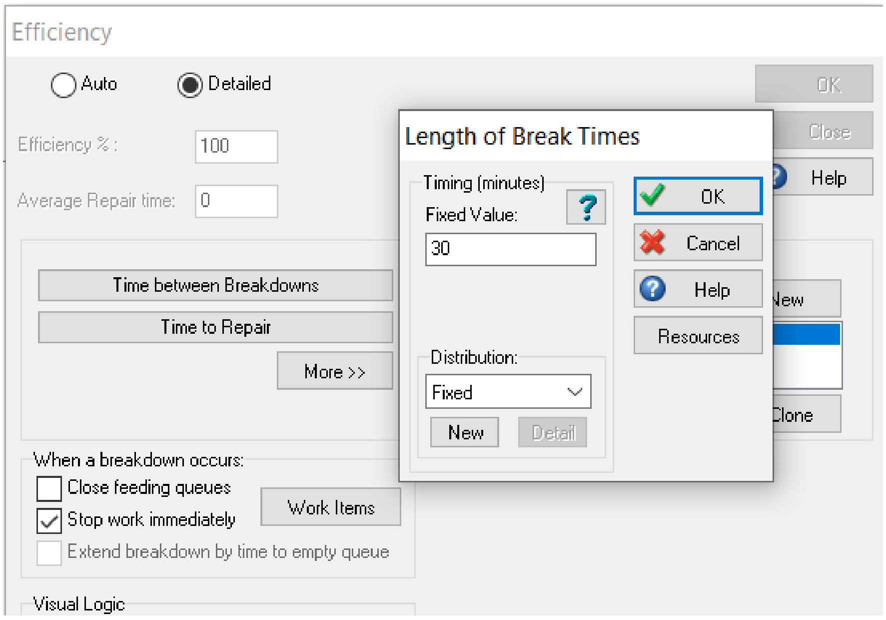

Figure 16: Length of the break

To create process steps in the Simul8 software, you have to use the building blocks located at the top left corner of the software by clicking and dragging the desired block to the workspace in the software. These building blocks are shown in Figure 17

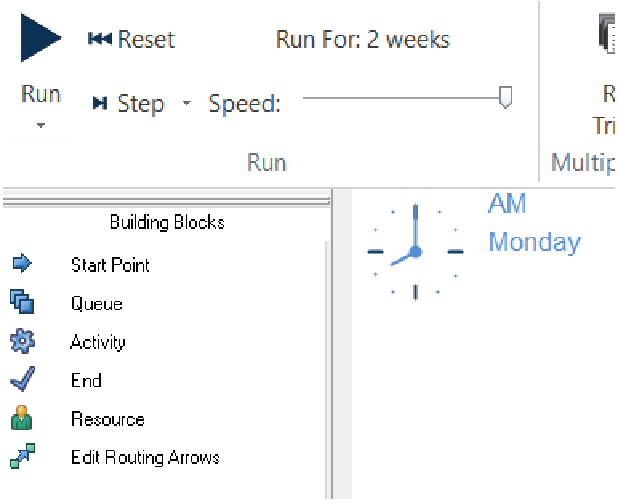

Figure 17: building blocks in Simul8.

i. The 'Start Point' is an active object because it pushes work into the process.

ii. The ‘Activity’ is also an active object because it pulls work or pushes work into the system.

iii. The ‘Queue’ is a passive object because it waits for work to be pushed or pulled to or from it.

iv. A 'Resource' is something that is in a limited supply. For example, Assemblers, MiR.

It is of great importance to separate active objects from passive objects.

3.7.1 Process steps in Simul8

3.7.1.1 Start Point

In this Activity, products are pushed into the system with an average distribution of 15 minutes, as shown in Figure 18

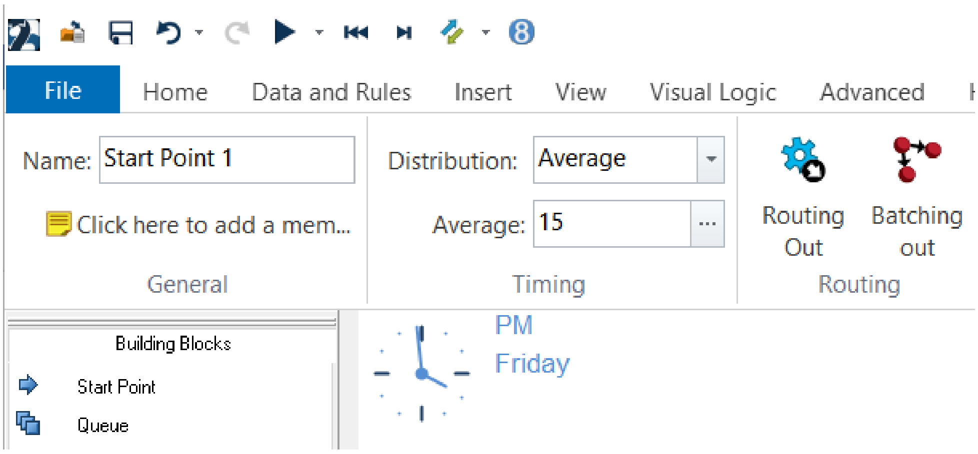

Figure 18: Start point in Simul8.

3.7.1.2 Cut Piece

This process has a uniform distribution of lower bound 8 minutes and upper bound of 10 minutes as shown in Figure 19 below, i.e., it takes between 8 to 10 minutes to complete this Activity.

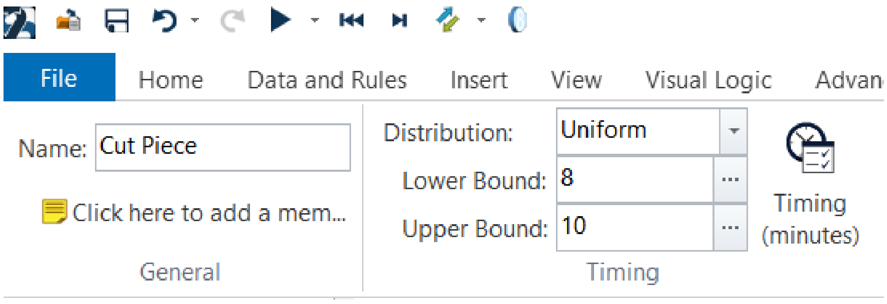

Figure 19: cut piece distribution

3.7.1.3 Operation 1: Manufacturing using 5-axis machine.

This process step involves using a 5-axis machine to produce the concave side of the Rexolite glass. It has an average distribution of 18 minutes. This means it takes roughly about 18 minutes to complete this process, as shown in Figure 20 below.

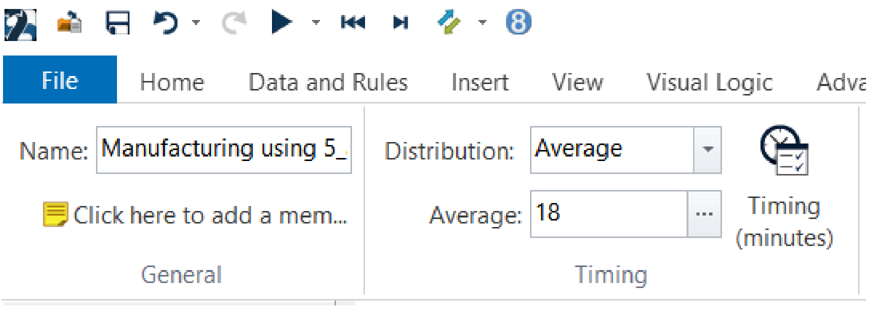

Figure 20: Operation 1_Manufacturing using a 5-axis machine.

3.7.1.4 Measuring or Quality Control 1

In this process, measurements are done to ensure that the product's dimensions meet the requirement for the following process. Quality control is done using the Hexagon Tigo SF machine, which takes about 10 minutes to measure after programming.

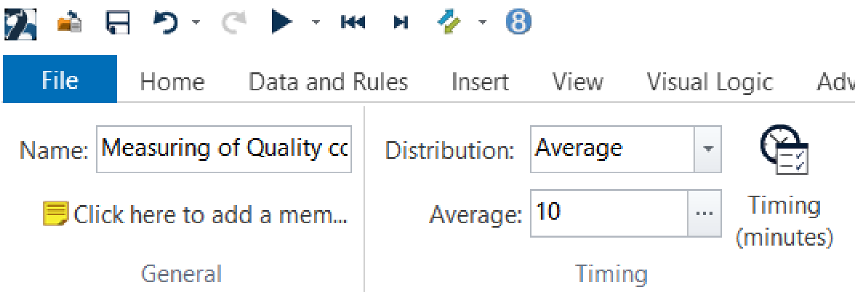

Figure 21: Measuring or QC 1

After measurement, about 3% of the products go to scrap due to wearing out of the tools, affecting the dimensions. The scrap procedure is done in the routing out tab, select 'Percent,' allocate 3% to scrap and 97% to the next process step, as shown in Figure 22 below.

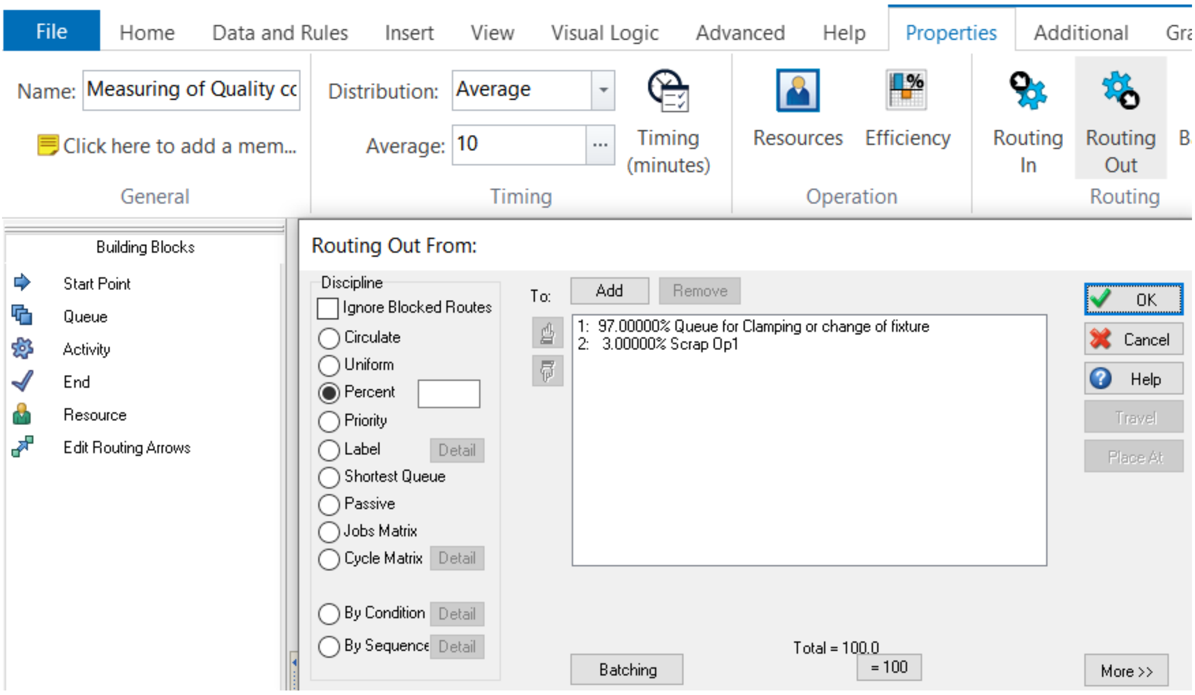

Figure 22: routing out from QC 1.

3.7.1.5 Clamping or Change of Fixture

In this process, there is a change over from operation 1 to operation 2 using the MiR100 to transport finished products from operation 1 to operation 2. And to save time, a batch of 5 finished products is collected and transported in this process. This batching method is shown below by routing in the discipline of the queue to collect five pieces.

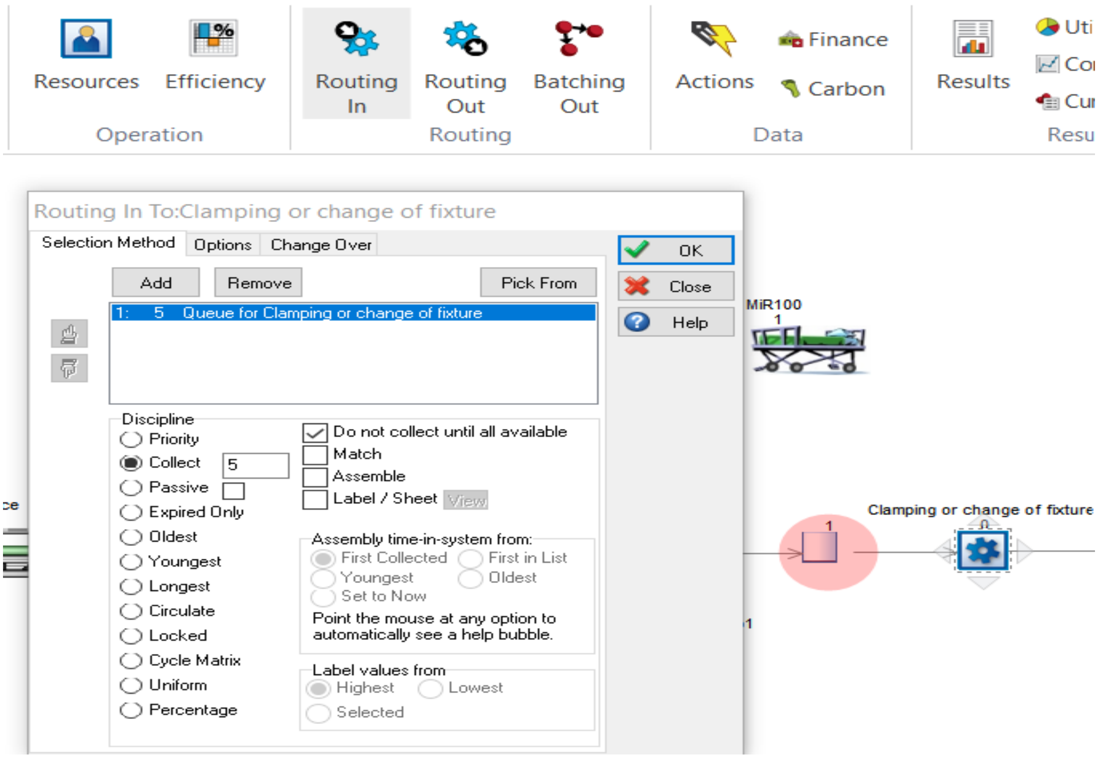

Figure 23: routing in to Clamping.

Also, in the same 'Routing In' box, there is a tab for 'Change Over' to allocate the amount of time it takes to change over in the process. It is set that a changeover is done for every 5 work items. And it takes between 0.5 to 3.5 minutes for the robot to complete its transportation by considering some time for obstacle avoidance. This configuration is shown in Figure 24 below.

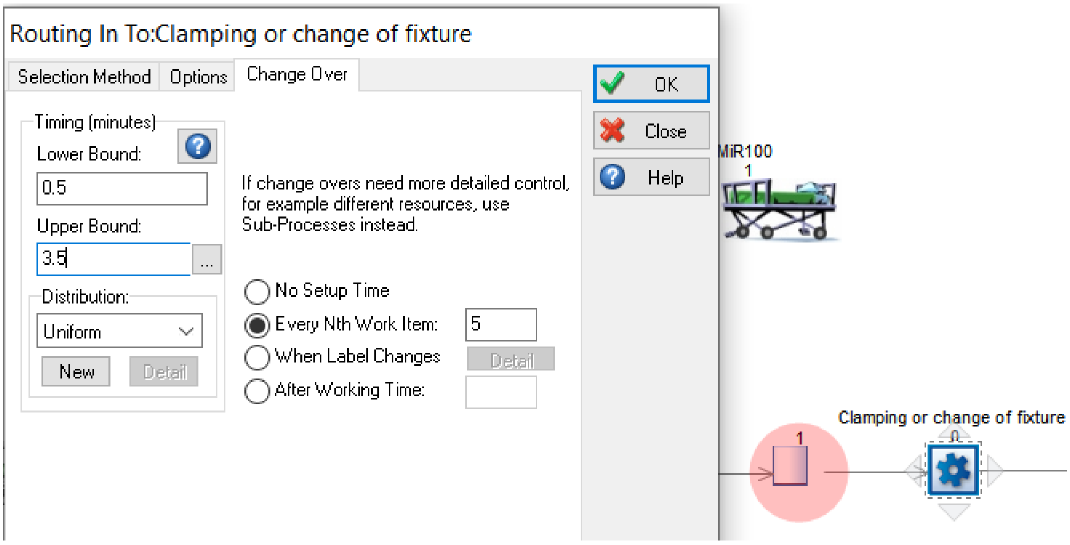

Figure 24: change over configuration

The entire clamping process takes about 3 minutes to complete, as shown in the distribution settings below.

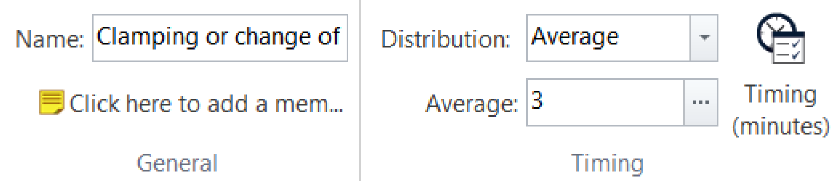

Figure 25: Clamping distribution

3.7.1.6 Operation 2: Manufacturing using Milling Machine.

This process involves using a milling machine and specialized tools to cave the convex part of the Rexolite glass. This step has a uniform distribution of about 15 to 20 minutes, i.e., and it takes roughly 15 to 20 minutes to complete.

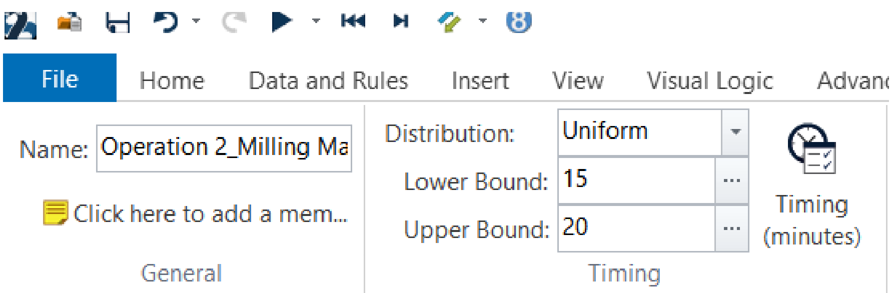

Figure 26: Operation 2_Manufacturing using a Milling machine.

3.7.1.7 Measuring or Quality Control 2

The assembler does another quality control to ensure that the measurement suites the customer's specifications and need. This quality control is also completed using the Hexagon Tigo SF machine, and after programming, it takes on an average of 10 minutes to complete. The distribution time can be seen in Figure 27 below.

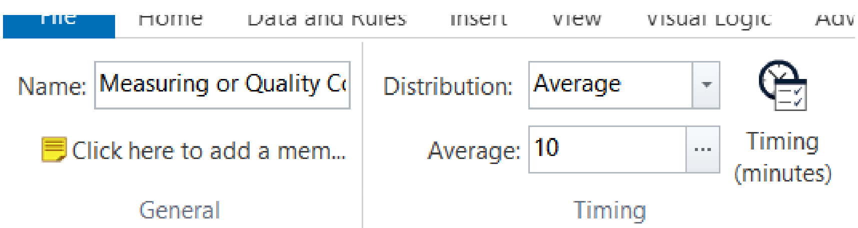

Figure 27: measuring or QC 2.

And due to wear in tools after a long period of use, about 3.5% of the products goes to scrap using the 'Routing Out' configuration as shown below.

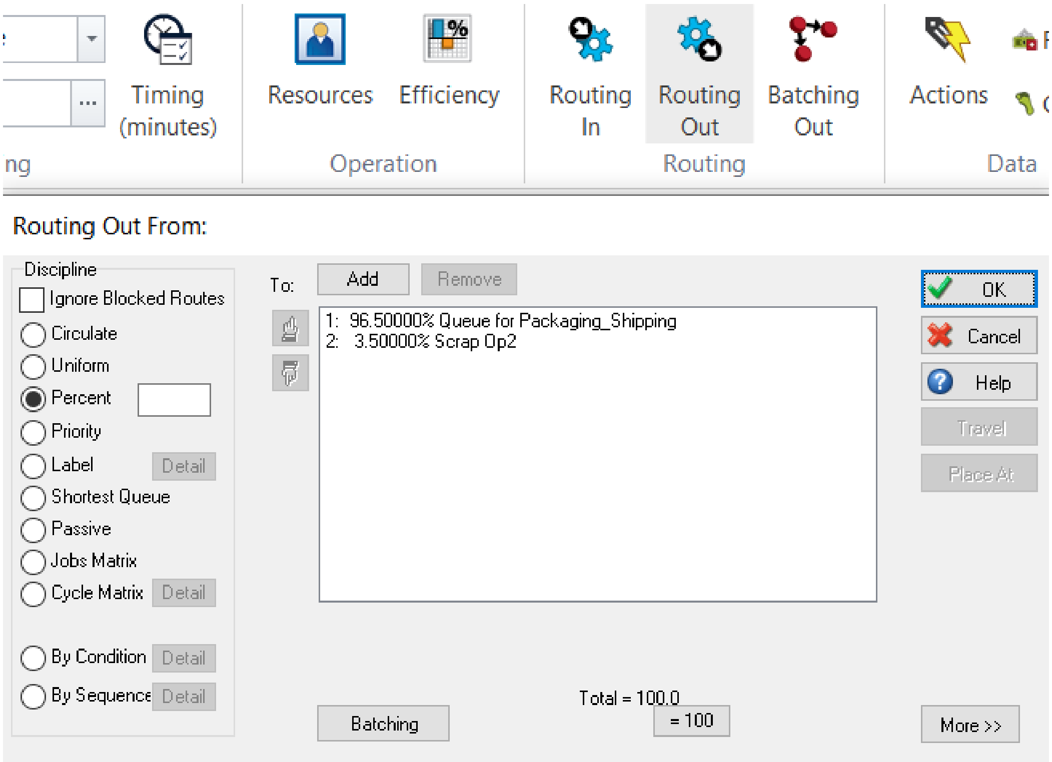

Figure 28: routing out QC 2

3.7.1.8 Packaging and Shipping

Packaging and shipping take about 2 to 5 minutes to complete, as seen in the figure below.

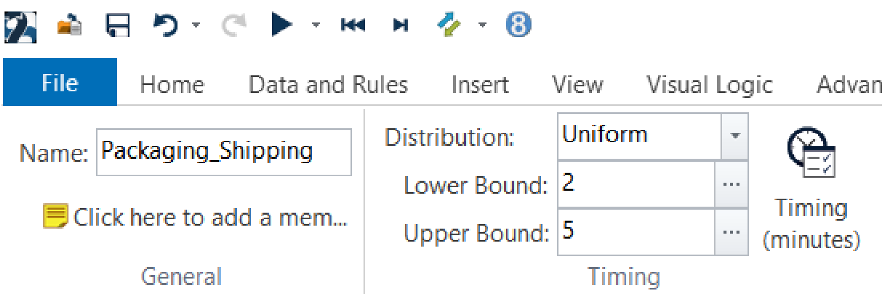

Figure 29: Packaging and shipping

3.7.1.9 Pool Resource

The assemblers are assigned to the pool resource, as shown in Figure 30 below. To differentiate between a normal and a pool resource, the 'Pool Resource' box must be checked in the properties, or if you have an older version of the Simul8 software, you will find the box in the 'Additional' tab.

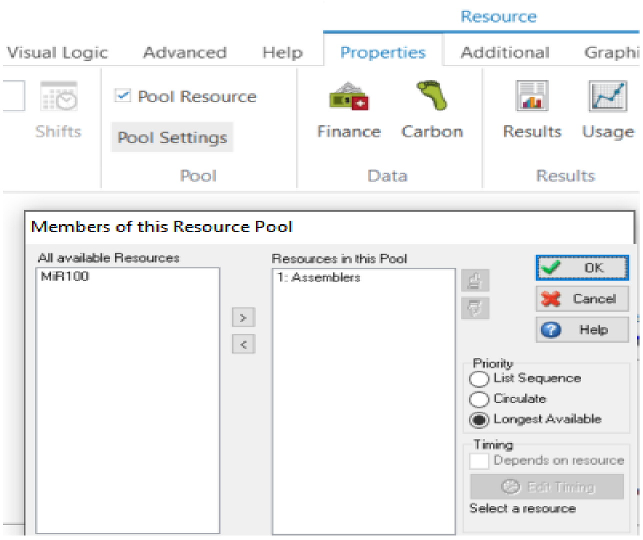

Figure 30: pool resource

3.7.2 Complete Simulation in Simul8

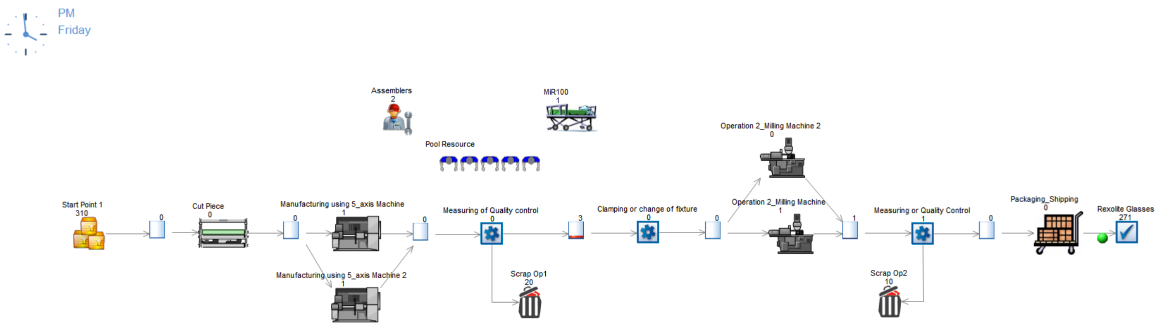

Figure 31: Final/Concluded Simulation

The picture shown in Figure 31 above is my final and optimal solution using the Simul8 software. I must admit, though, it will cost a lot to implement. Still, suppose this product is to be produced massively for clients in the military, satellite or aerospace industries, Electronics industries, etc. In that case, the return of investment will be a matter of few years. This final simulation eliminates all bottlenecks, neutralizes the utilization of resources, i.e., ensures that the resources are not overused. And it provides a smooth flow in the process. Detailed analysis of the results and the attempted simulations or alternative simulations will the discussed in section 4 below.

4 Results and Analysis

In this section, I will discuss the various attempts and optimizations suggested before coming to a final decision in the simulation. Put in mind various vital modifications and results, like the number of resources used, the bottle necks, the number of machines added, the throughput, and so on. Also, the simulation runs for two weeks, five days a week, and 7.5 hours a day.

Firstly, I started with just one human resource (Assembler). After the end of the simulation, I realized that there is a massive bottleneck in the 'cut piece' process. About 137 items waiting to be processed after 310 items were put in the system, as shown in Figure 33, and a throughput of 144 Rexolite glasses as shown in Figure 34. The content in Figure 33 also proves that the bottleneck will never depreciate, as the graph of the work with respect to time is linearly inclined. In Figure 32 below, the assembler is 100% utilized, which is not healthy for any human being to last long in this kind of work environment. And from the utilization pie chart, a large percentage of items are starved.

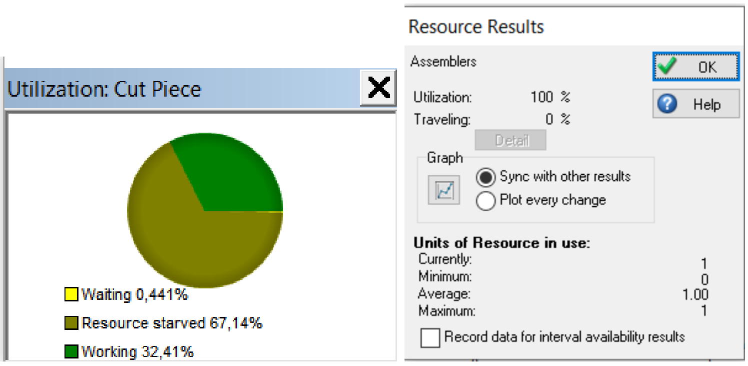

Figure 32: utilization and resource result of 1 assembler

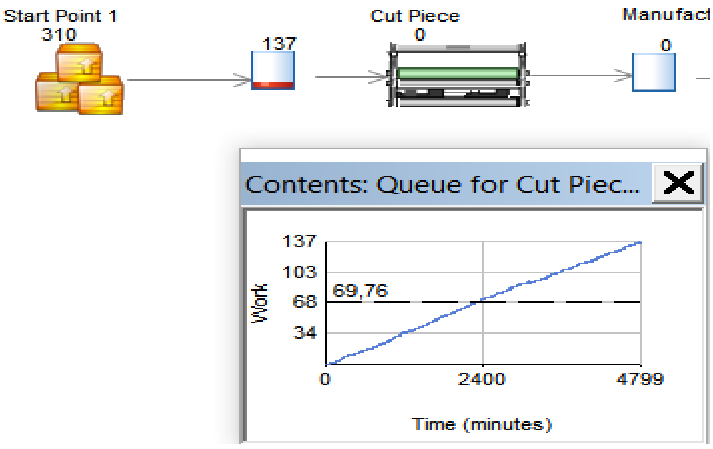

Figure 33: bottleneck and content at the cutting process

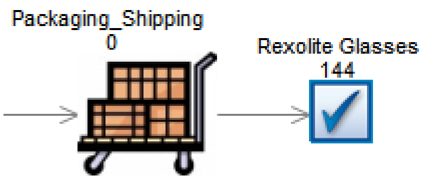

Figure 34: throughput or final result at the first simulation without optimization

There are several ways these challenges can be solved; I added another cut-piece process since that is where the bottle neck is. But this does not seem to solve the problem as the bottle neck before the 'cut piece' still exists, though slightly reduced. And it is observed that a new bottle neck is developed before the first measuring process (about 128 items waiting to be attended to), as shown in Figure 35 below. Also, my throughput has reduced drastically to 106 items, as shown in Figure 36 below. This idea does not look like it is the best solution so far.

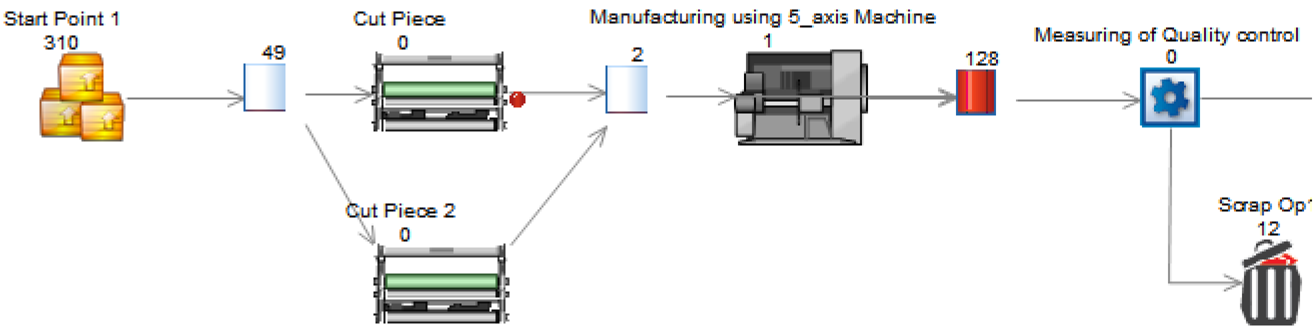

Figure 35: bottleneck at Hexagon Tigo machine after adding extra cutting process.

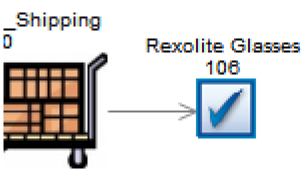

Figure 36: throughput after adding second 'cutting' process.

Another alternative is to hire a new assembler, to increase the number of assemblers to two. So, the tasks can be shared amongst the two employees. This improved the process flow slightly, and there is a significant improvement in the throughput, with 229 items delivered. Some bottlenecks were cleared, but I have a new bottleneck in Operation 1 (manufacturing using a 5-axis machine), as shown in Figure 37 below.

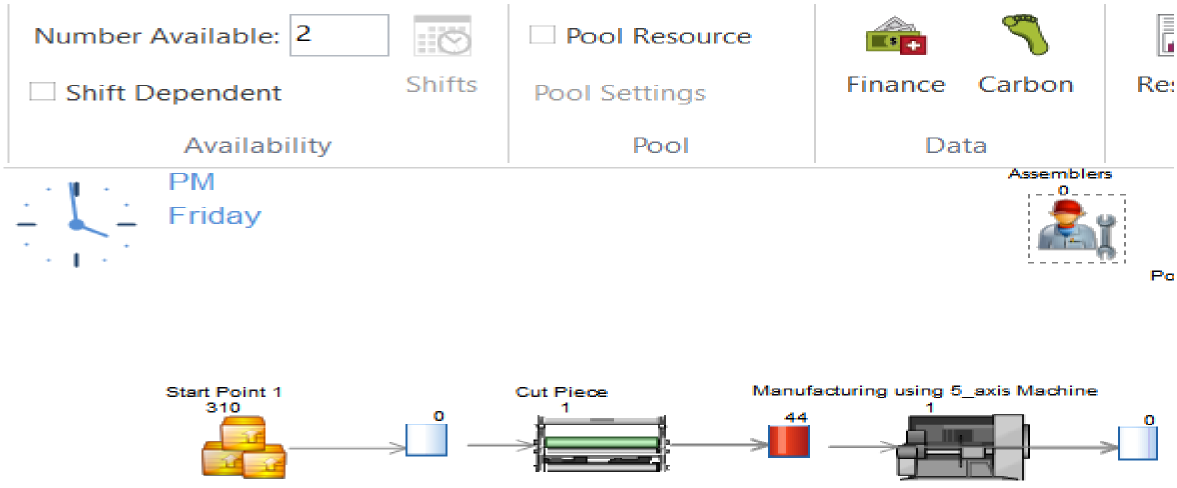

Figure 37: bottleneck at Operation 1 after hiring a second employee.

Figure 38: throughput after hiring a second employee.

The graph from the bottleneck shows that the content will continue to increase with time. There is no sign that the bottleneck will ever be cleared out as the graph is linearly inclining. This is shown in Figure 39 below.

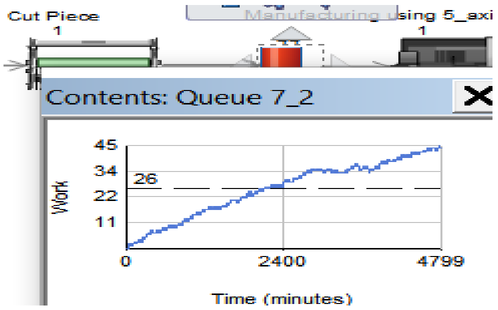

Figure 39: bottleneck contents in the queue before Operation 1

It is also noticed that the utilization of the assemblers has dropped to 91%, since a new employee's employment. This is shown in Figure 40 below.

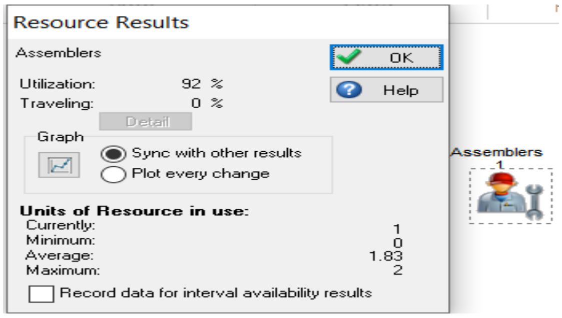

Figure 40: Utilization result of 2 Assemblers

This is a sure improvement in the process flow but, unfortunately, not the optimal solution. So, I tried to increase the number of employees from 2 up to 10, and this does not seem to improve the process flow, as I still got the same results as I got in Figure 37 and Figure 38 above. This is shown in Figure 41 and Figure 42 below. Take note of the number of employees, the bottleneck before the 5-axis machine, and the throughput.

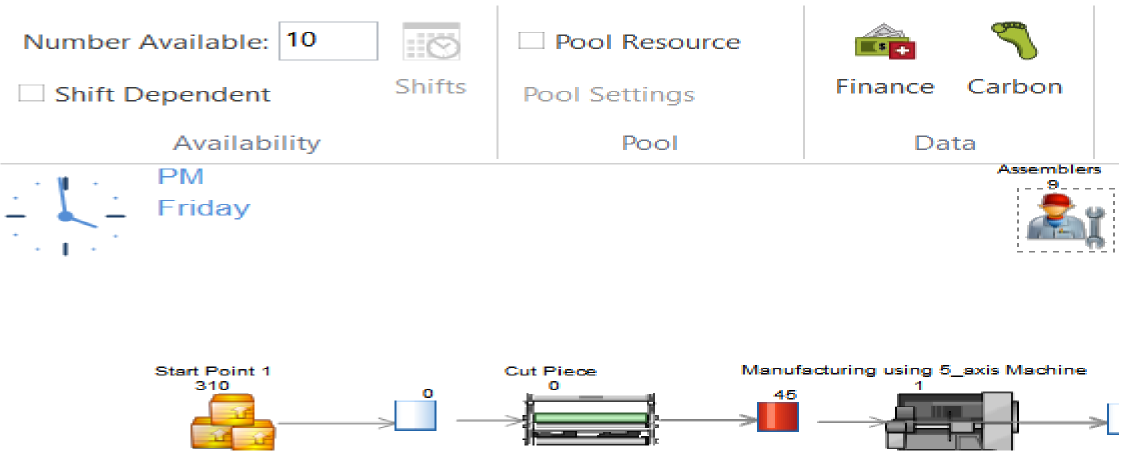

Figure 41: bottleneck at Operation 1 after hiring up to 10 employees.

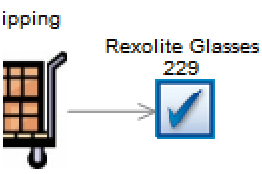

Figure 42: throughput after employing ten resources.

The following solution is to add a new 5-axis machine to the process, as shown in Figure 43, and retain the two employees. This will cost a lot of money, but it is my best option at the moment. After a successful simulation, the throughput improved to 257 items at the end of the two weeks, as shown in Figure 44, and most bottlenecks were eliminated. But a slight bottleneck is developed in Operation 2. In my opinion, this can be ignored. Because at some point, if the manufacturer decides to stop work on the shop floor, this slight bottleneck can be cleared out after work has been halted in the preceding process steps.

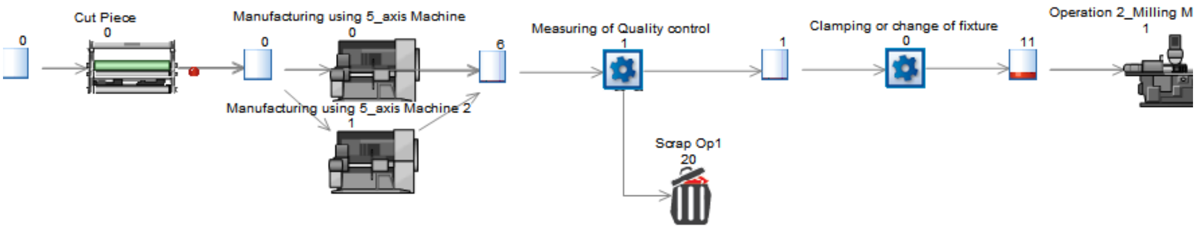

Figure 43: additional manufacturing process in Operation 1

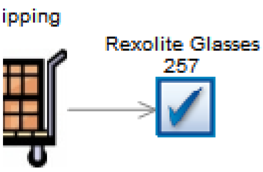

Figure 44: throughput after added process in Operation 1.

The reason for suggesting that the bottleneck can be ignored is because, according to the graph shown in Figure 45**,** the work done with respect to time is sinusoidal, i.e., it goes up and down, although slightly increasing. Still, there is proof that sometimes it goes up and sometimes comes down.

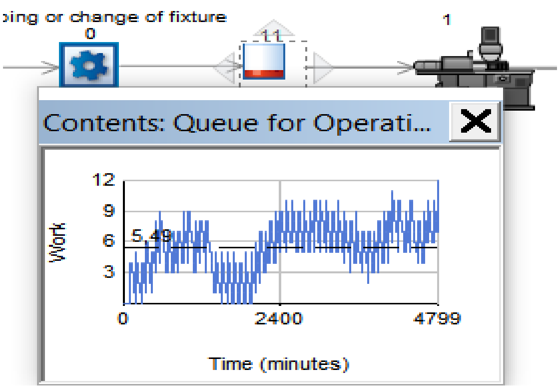

Figure 45: Bottleneck at Operation 2

The final adjustment to the simulation is to add another milling process. This will eliminate all forms of bottleneck and ensure a smooth flow in the entire process for as long as possible. Also, it is suggested that an extra employee should be hired, making it a total of 3 assemblers on the shop floor. Because as seen in Figure 40 above, the two operators are utilized up to about 92%, which is not suitable for human beings, health, and safety-wise.

Figure 46 and Figure 47 below show that the process flow is smooth, and a reasonable throughput is achieved.

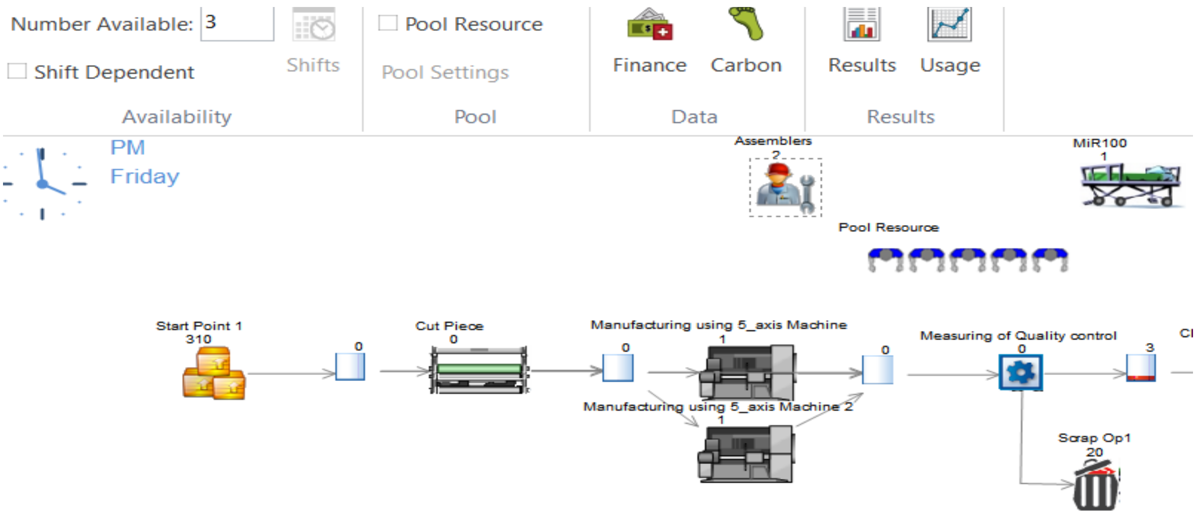

Figure 46: first part of optimal solution

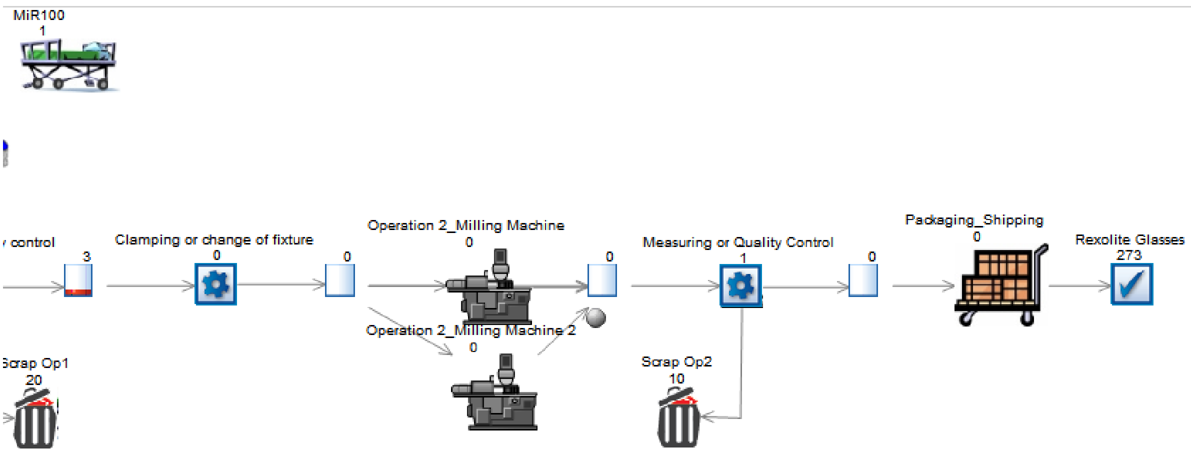

Figure 47: the second part of the optimal solution

From Figure 48 below, we can see that the utilization of the employees has reduced to 61%. This is good for the system, as there would not be any fatigue affecting the performance of the assemblers.

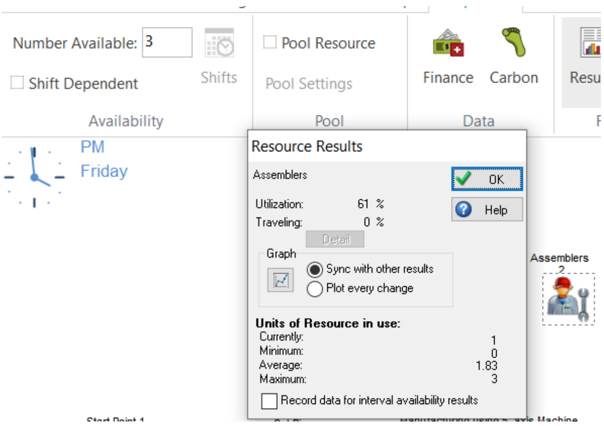

Figure 48: Utilization result of 3 assemblers

After my optimal solution has been decided, I did multiple runs of 100 trials to get the Key Performance Index (KPI) for the entire two weeks. From the results shown in Figure 49 below, in two weeks, 288.3 finished products are achieved on a slow day, an average of 289.5 products can be completed, and 290.7 outcomes on a good day. This variation in the result is due to some of the processes with the lower and upper bound distribution.

SIMUL8 Results Manager

SIMUL8 CORPORATION Results Manager

KPIs | KPI History | Scenarios | All Object Results | Custom Reports

100 Trials		Low 95% Range	Average Result	High 95% Range
Start Point 1	Number Entered	317.67	318.52	319.37
Cut Piece	Number Completed Jobs	317.05	317.91	318.77
	Current Contents	0.50	0.60	0.70
Manufacturing using 5_axis Machine	Current Contents	0.44	0.54	0.64
	Number Completed Jobs	158.14	158.65	159.16
Manufacturing using 5_axis Machine 2	Current Contents	0.51	0.61	0.71
	Number Completed Jobs	157.59	158.06	158.53
Measuring or Quality Control 1	Current Contents	0.46	0.56	0.66
	Number Completed Jobs	315.10	315.93	316.76
Scrap Op1	Number Completed	9.29	9.90	10.51
Clamping or change of fixture	Current Contents	0.04	0.25	0.46
	Number Completed Jobs	60.52	60.75	60.98

Operation 2_Milling Machine	Current Contents	0.45	0.55	0.65
	Number Completed Jobs	150.37	151.30	152.23
Operation 2_Milling Machine 2	Current Contents	0.45	0.55	0.65
	Number Completed Jobs	149.39	150.33	151.27
Measuring or Quality Control 2	Current Contents	0.53	0.63	0.73
	Number Completed Jobs	299.46	300.54	301.62
Scrap Op2	Number Completed	10.04	10.62	11.20
Packaging_Shipping	Current Contents	0.17	0.26	0.35
	Number Completed Jobs	288.30	289.54	290.78
Rexolite Glasses	Number Completed	288.28	289.52	290.76
	Maximum Time in System	182.96	184.74	186.52

Figure 49: Key Performance Index (KPI) after 100 trial runs

Some terms to be familiar with:

1. Minimum Queue Time (QT): the shortest time anything spent waiting in the queue.
2. Minimum (Non-Zero) QT: the shortest time anything spent waiting in the queue (excluding items that did not have to queue).
3. Average QT: the average time anything spent waiting in the queue (excluding items that did not have to queue).
4. Average (Non-Zero) QT: the average time anything spent waiting in the queue (not counting any zero queuing times).
5. Maximum QT: the longest time anything spent waiting in the queue.
6. Number of non-zero queuing times: number of items that had to spend some time in the queue.

SIMUL8 Results Manager

SIMUL8 CORPORATION **Results Manager**

KPIs | KPI History | Scenarios | All Object Results | Custom Reports

100 Trials

		Low 95% Range	Average Result	High 95% Range
Start Point 1	Number Entered	317.67	318.52	319.37
Queue for Cut Piece	Average Queue Size	0.04	0.04	0.04
	Maximum Queue Size	2.09	2.18	2.27
	Items Entered	317.67	318.52	319.37
	Average Queuing Time	0.57	0.59	0.62
	Average (Non-zero) Queuing Time	2.62	2.71	2.79
	Maximum Queuing Time	23.38	24.17	24.97
	Number of Non-zero Queuing Times	68.02	69.67	71.32
Queue for 5_axis machine	Average Queue Size	0.01	0.01	0.01
	Maximum Queue Size	1.03	1.08	1.13
	Items Entered	317.03	317.88	318.73
	Average Queuing Time	0.11	0.12	0.13
	Minimum (Non-zero) Queuing Time	0.18	0.23	0.27
	Average (Non-zero) Queuing Time	2.53	2.68	2.82
	Maximum Queuing Time	6.98	7.42	7.85
	Number of Non-zero Queuing Times	13.65	14.43	15.21
Queue for Measuring of Quality control	Average Queue Size	0.13	0.13	0.14
	Maximum Queue Size	1.99	2.05	2.11
	Items Entered	315.79	316.64	317.49
	Average Queuing Time	1.94	1.99	2.05
	Minimum (Non-zero) Queuing Time	0.04	0.05	0.06
	Maximum Queuing Time	17.11	17.83	18.55
	Average (Non-zero) Queuing Time	4.53	4.61	4.70

	Number of Non-zero Queuing Times	134.21	136.61	139.01
Queue for Clamping or change of fixture	Average Queue Size	1.98	1.99	1.99
	Maximum Queue Size	5.00	5.00	5.00
	Items Entered	304.84	305.92	307.00
	Average Queuing Time	31.07	31.24	31.41
	Maximum Queuing Time	93.63	95.49	97.36
	Minimum (Non-zero) Queuing Time	5.16	5.40	5.64
	Average (Non-zero) Queuing Time	38.83	39.05	39.26
	Number of Non-zero Queuing Times	242.27	243.20	244.13
Queue for Operation 2_Milling Machine	Average Queue Size	0.87	0.87	0.87
	Maximum Queue Size	3.47	3.57	3.67
	Items Entered	302.58	303.75	304.92
	Average Queuing Time	13.73	13.75	13.77
	Maximum Queuing Time	37.57	37.71	37.85
	Minimum (Non-zero) Queuing Time	7.02	8.24	9.47
	Average (Non-zero) Queuing Time	22.83	22.86	22.89
	Number of Non-zero Queuing Times	181.34	182.03	182.72
Queue for Measuring or Quality Control	Average Queue Size	0.36	0.37	0.37
	Maximum Queue Size	2.09	2.16	2.23
	Items Entered	300.52	301.59	302.66
	Average Queuing Time	5.80	5.87	5.94
	Maximum Queuing Time	21.17	21.65	22.13

	Minimum (Non-zero) Queuing Time	0.08	0.09	0.11
	Average (Non-zero) Queuing Time	7.69	7.77	7.85
	Number of Non-zero Queuing Times	226.32	227.63	228.94
Queue for Packaging_Shipping	Average Queue Size	0.06	0.07	0.07
	Maximum Queue Size	1.00	1.00	1.00
	Items Entered	288.66	289.89	291.12
	Average Queuing Time	1.06	1.09	1.11
	Maximum Queuing Time	8.67	8.85	9.02
	Minimum (Non-zero) Queuing Time	0.04	0.05	0.06
	Average (Non-zero) Queuing Time	3.04	3.08	3.11
	Number of Non-zero Queuing Times	100.48	102.29	104.10
Rexolite Glasses	Minimum Time in System	101.98	102.68	103.38
	Average Time in System	133.23	133.43	133.63
	Maximum Time in System	182.92	184.70	186.48
	Number Completed	288.29	289.53	290.77

Figure 50: The Queuing time for each activity

Some terminologies you should be familiar with:

1. Queue Time: The time work in progress (WIP) is idle in queues, buffers, or storage. Queue time is also known as wait time and delay time.
2. Processing time: this is when activities are being performed on WIP. It may consist of Value-Added Time (VAT) and Non-Value-Added Time (NVAT) activities. Processing time is also known as activity time, In Process time (IPT), and Touch time (TT). Figure 51 shows how to get the processing time.

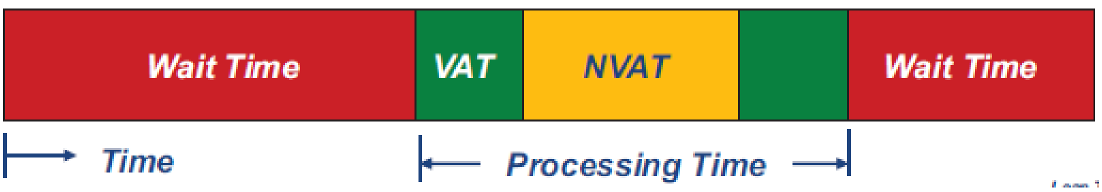

Figure 51: the processing time simplified.

3. Cycle time: this is the time required to execute activities in a process. Cycle time can be measured for a single task or activity, a group of tasks or activities, a single process, or a group of processes. Figure 52 shows how to calculate the cycle time.

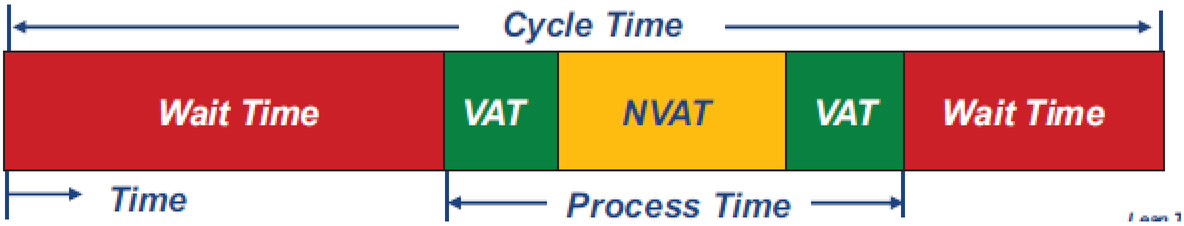

Figure 52: the cycle time simplified.

Some slight calculations are made in Table 1 below. Because I have two 5-axis machines in operation, in column 4, row 3, I collated the results from the two machining equipment. One machine completed 158.06 items on average, while the second machine completed 158.65 items on average, and the time it took to complete the process is reduced to half in column 5, row 3. I used the same procedure in the milling process. In column 4, row 5, one of the machines completed 150.33 items on average, while the other machine completed 151,3 items. The time to process was also reduced in half since I am running two machines simultaneously. To get the processing time after two weeks for each process, I multiplied the average individual process by the number of items produced at the end of the two weeks.

Table 1: Average and maximum Cycle time for each process

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8
Processes	Average Queuing Time	Maximum Queuing Time	Number of items completed	Average Individual Processing Time	Processing Time in 2 weeks	Average Cycle Time (Minutes)	Maximum Cycle Time (Minutes)
Cut piece	0,59	24,17	317,91	9	2861,19	2861,9	2892,78
5-axis machine	0,12	7,42	316,71	9	2850,39	2852,5	2875,64
Quality Control 1	1,99	17,83	300,54	10	3005,4	3038,63	3118,72
Clamping/fixture change	31,24	95,49	303,75	3,5	1063,125	1108,115	1196,325
Milling machine	13,75	37,71	301,63	8,75	2639,2625	2658,8825	2698,6225
Quality Control 2	5,87	21,65	300,44	10	3004,4	3011,36	3034,9
Packaging_Shippin	1,09	8,85	289,54	3,5	1013,39	1014,48	1022,24

5 Conclusion

At the start of this project, several objectives were set, and I would consider them achieved. I was able to identify a manufacturing process that is of value to the customer, identify the process step with the need for fast tool changes, suggest a Kanban for communication with the AIV, and simulate the whole process in Simul8.

Lean methods and principles have been utilized in this project. A SIPOC process map was made, process steps were discussed in detail, a factory layout or floorplan was made, Value streams were identified, and the lean aspect in layout planning was greatly considered. A continuous flow system, especially single-piece flow, is the most desirable feature in lean production and the so-called pull system is the most useful. However, a batch process was done in the changeover step to reduce time spent in changeover.

The current technology, which is the MiR, facilitates fast changeovers in the process of transportation and its ability to use any form of top module. The MiR's easy adaptability to its environment and capability to interact with employees and forklift without having a pre-programmed path has made the MiR a robot best suited for this situation.

Although, the initial manufacturing process involved using only one 5-axis machine, which means once operation 1 is done, you must take out the product, put the fixture in the same machine and clamp the Rexolite to begin operation 2. While this is being done, you must wait for operation 2 to finish before making another product. I optimised the process flow and did a fast tool change by suggesting that operation 2 be done with a milling machine and specialized tools, using the MiR as a transport system for products from operation 1 to operation 2. This solution means you do not have to wait for operation 1 to be finished before starting operation 2. Manufacturing can be done simultaneously.

After careful optimization and results analysis from the Simul8 software, I achieved a continuous flow in the system, with little or no bottlenecks. I was able to increase productivity and efficiency and reduce amount of time spent during changeover. The power of teamwork and collaboration is explored to improve the overall productivity, efficiency, and quality.

5.1 Future Suggestions/Research

The process flow has a framework for future and continuous improvement. However, I have a few suggestions that can be examined for future enhancements and analysis. First, I would suggest a redesign factory layout or the floor plan to reduce steps taken from one machine to another.

Also, I would like to suggest the purchase or fabrication of different top modules for the MiR. This can create a lot of flexibility and use for the MiR. Although, this would also mean the purchase of more MiR.

Lastly, I would recommend that the MiR be programmed in such a way that if can also interact with other departments or sections in the university. So, work or material can quickly be delivered or received from the Electrical department, Design department, Computer Science laboratory, Service Torget, etc.

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