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Program: Mechanical Engineering/Industrial Engineering

Simplicite Toaster Assembly

Work-Time Study

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IND 303: Case Study

Executive Summary

Manufacturing has been a process that has been utilized since the beginning of the industrial revolution. As time moves on and as processes become more complex, the need for better efficiency is needed. As future industrial engineers, it is vital to be able to see a manufacturing facility and have the ability to understand where possible improvements may arise. As companies continue to grow, more are attempting to find ways to increase efficiency and reduce their own costs, and time. This in turn will allow for a similar or better-quality product to be produced, more quickly to be provided to the consumer base.

The case study provided to the students was the manufacturing process of the Simplicite Toaster. This toaster is a very simple build, and very economical, which is why it provided a great starting point for the group to understand the fundamentals of manufacturing. A simple toaster is a great method to understand how larger scale operations function in the day to day lives of manufacturers everywhere. The group was provided a multitude of data which included videos of two workers working, images of the work area, and various theories studied in class to analyze the work being done in the factory, and to come up with ways to better improve the overall efficiency of the facility. Using the knowledge gathered, numerous charts and methods such as tree diagrams, flow process charts, time analysis and many other techniques were created. The aforementioned tools assisted in determining exactly how efficient the current process was. Taking the information gathered into account, the students then developed possible improvements to increase time efficiency, such as preplaced screws, a work stopper, and inclined conveyor belts.

The significance of this project is the ability to be able to notice these inefficiencies and develop reasonable solutions to resolve them. This is precisely why industrial engineers are hired, as they are trained with the ability to improve overall performance, which allows for the company to improve their efficiency, removing any wasted time, and increasing profits. As prospective industrial engineers, it is very beneficial to be able to familiarize ourselves with these tools, on a much smaller scale. Understanding these fundamental methodologies will be vital as our careers progress, and the manufacturing process expands, becoming more complex, with more money and time to be saved.

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Methodology Overview

This case study was developed so that we are able to apply what we have learned throughout the semester in a practical manner. We were provided with both quantitative and qualitative data for the *Simplicite Toaster* in order to properly understand the fundamentals of manufacturing and how they can be applied within the industry.

We were able to use several techniques which go through the entire operation process in order to successfully redesign the manufacturing process to increase efficiency and decrease cost. This case study began by taking the toaster apart and creating a bill of materials (BOM) for every part of the toaster. The bill of materials consisted of an inventory of every part used and other specifications such as material and quantity. A tree diagram was then created showcasing the hierarchy of each of these parts with respect to each of the subassemblies.

The team was then able to create an operations process chart by viewing the videos of both the workers. This chart is used to provide a compact overview of all the systems of operations involved in the production of the toaster. This chart only contained the main activities/ main assemblies but they were further broken down into smaller subassemblies in the flow process chart. Our team was able to divide the entire assembly into 5 separate assemblies and indicated the process from the point of view of the worker. A sequence of flow of the assembly for the toaster is being shown with the appropriate symbols. These include symbols of operation, transportation, inspection and delay. The flow diagram was created to provide an overview of the workstation so the team can visually see the new improvements that can be made. Moving forward the team conducted a MTM analysis of all of the subassemblies to determine the time it should take for the workers to complete their part. This analysis played a large role in the redesign of the operation. We were able to look at the various different analyses conducted and determine possible causes and areas for improvement. Our redesign proposes an efficient solution in order to expedite the operation process and ensure that all aspects are being used in the most efficient manner.

Figure 1 : Simplicite Toaster

Current Situation

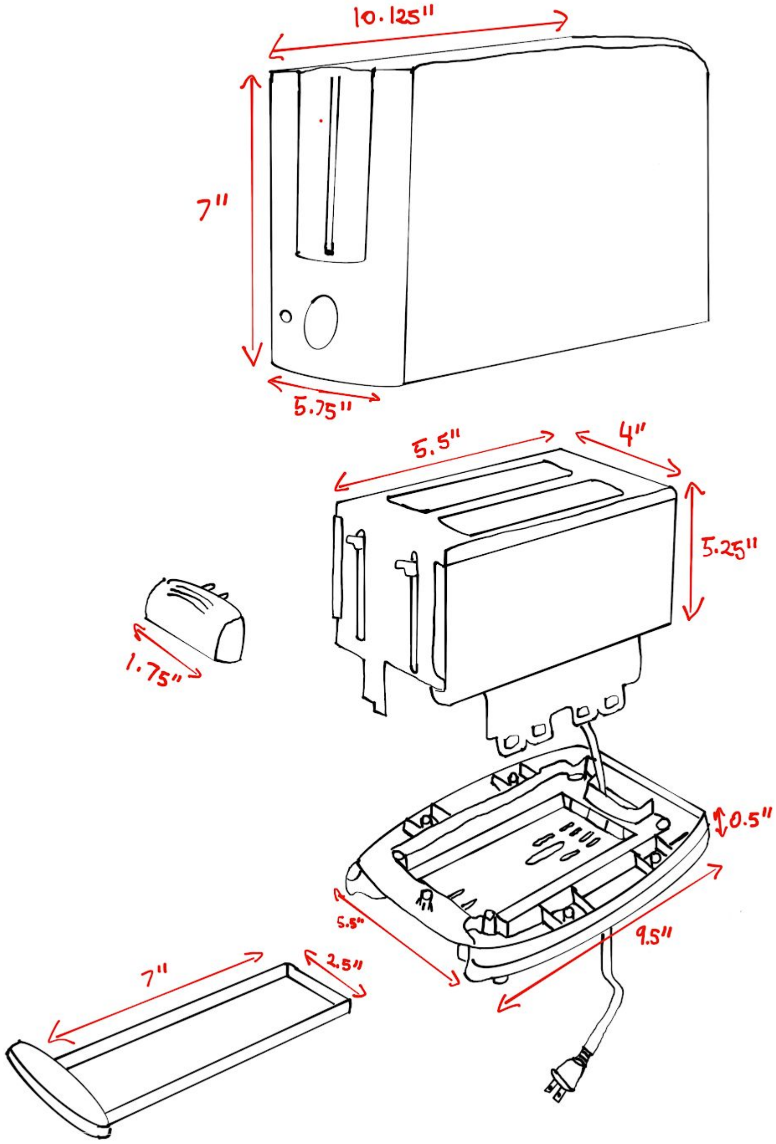

Figure 2 : Current Toaster Design with Significant Parts

In order to successfully complete this case study we were required to analyze the *Simplicite Toaster* and go through the design process to understand the operations associated with assembling the toaster. We were able to take a look at the various components required to build the toaster and brainstorm different ways in which we can improve quality, safety and decrease unit cost.

Bill Of Materials

The bill of material was separated into 7 categories: the item name, the part number, the quantity, the description of the item, the material it is made of and finally a picture of the item. The bill of material really helps us visually see the disassembly of the toaster since each part is shown individually. The bill of material was also helpful for calculating the cost analysis since it showcased the part and how many times it is found in the toaster (for example : there were 5 7/16” screws) .
Please refer to the table 1 in the appendix for further information about the bill of materials).

Tree Diagram

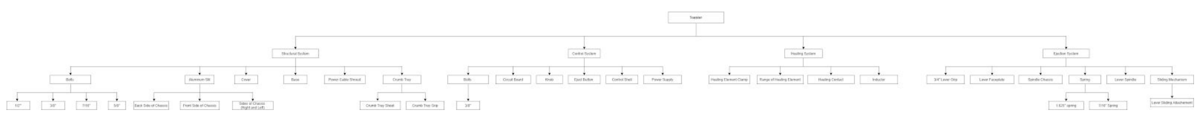

Figure 3: Tree diagram for the toaster

Observing the *Simplicite toaster*, various subassemblies were identified. The first being the Structural System, which forms the structure of the toaster. The second one being the Control System, which is the interface the user interacts with. Followed by the Heating System, which provides the functionality of the toaster. Finally the Ejection System, which interacts with the food being toasted.

These subsystems were branched from the toaster as a way to identify them being the main bodies that make up the whole toaster. Branching from each of these subsystems are components that make up each of the systems. In special cases these components are made of other components which are identified by branching off and labeling. (please refer to the appendix for the full version of the tree diagram, pg 73)

Assembly

The assembly of the toaster was broken into several subassemblies. Subassemblies are defined by multiple components that serve various functions. Structural system is what provides the structural integrity of the toaster. It is the system that deals with forces and retains the shape of the toaster. Control system is the system that the user interacts with. This system identifies the various functions the toaster must serve and make it accessible for the user. Heating system serves to toast the food item. This system produces heat using a heating element. Ejection system allows the food item inserted within the system to be ejected. Without this system the user would have to manually remove the food item, which will make it dangerous for the user. The group believes that splitting the toaster into these specific subassemblies is the optimal way to better analyze the steps when constructing the toaster.

Process

Making an operations process chart and flow process chart is essential in order to fully understand the entire manufacturing process. Specifically the operations process chart represents the sequence of the operations that need to take place. Two symbols are used in constructing the operation process chart: a small circle denotes an operation, and a small square denotes an inspection. ((Freivalds & Niebel, 2014) It allows us to recognize various operations, inspections and storage for all the components that are a part of that assembly process in a glance. Flow process charts go into detail for each assembly process, dividing them into smaller subassemblies. This type of chart shows the reader the sequence of flow of a product by recording all of the events/process through descriptions and symbols. The flow process chart was created from the workers point of view, so the activities that the worker did were recorded and the appropriate symbol was given. The flow process chart is very helpful because it allows the inspector to easily point out changes that can be made to increase the efficiency of the worker. (Minakshi, J. 2016)

Operations Process Chart

Operation process charts (refer to appendix, pg 74) showcase the process by which worker 1 and worker 2 conduct their roles in the facility. The first diagram for worker 1, and second diagram for worker 2 have the times for their processes, materials used and any inspection steps taken during the job. The diagram was constructed by carefully analyzing the workers' tasks and taking note of all the steps, and the duration. The operation process chart is very beneficial in analyzing the overall building process, and determining the sequence of events to better schedule activities when seeking to make improvements. (please refer to the appendix for the full version of our operations process chart, pg 74)

Flow Process Chart

Flow process charts (please refer to tables 3.1-3.5 in the appendix) identify the process for assembling each subassemblies. These were created so that it would be easier to identify the layout of the workspace and what factors could be causing potential problems. For each event that occurred our team was able to create a brief description of it and note down the correct symbol that would go along with it. (Freivalds & Niebel, 2014) It is also important to add the times that it took for the operator to complete the event and any notes that can improve the event. This tool allowed our team to recognize and eliminate any muda or hidden costs of certain components.

Workstation

Flow Diagram

Video: Toaster assembly V1

<u>Top view :</u>

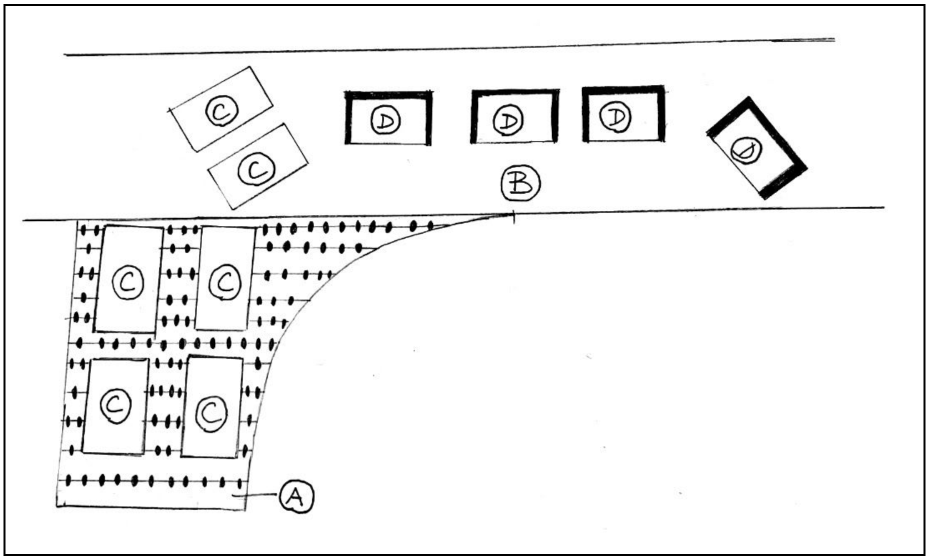

Figure 4: Top view for the workstation for the original design

<u>Front view :</u>

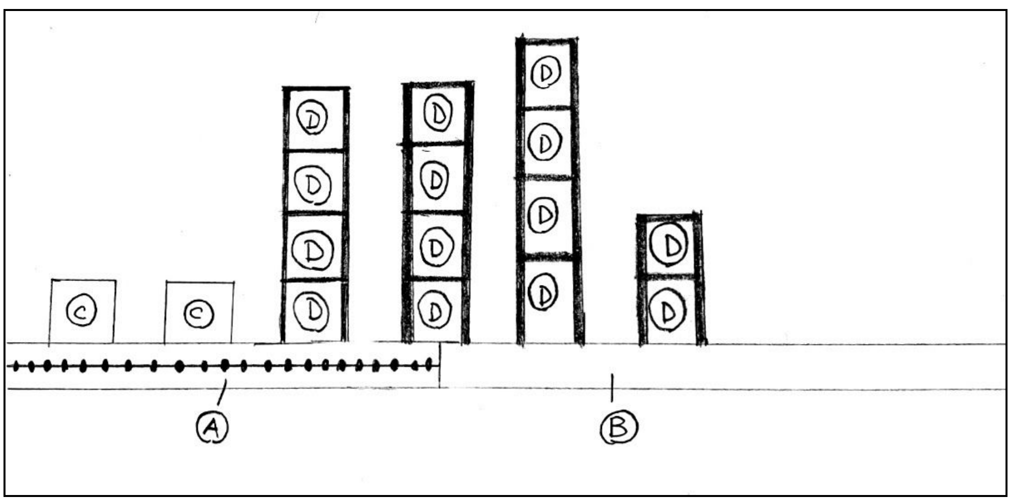

Figure 5: Front view for the workstation of the original design

Legend :

A - Gravity Skate Wheel Conveyor

B - Workbench

C - Storage basket

D - Storage shelves

Video : Toaster cage assembly V1

Top view:

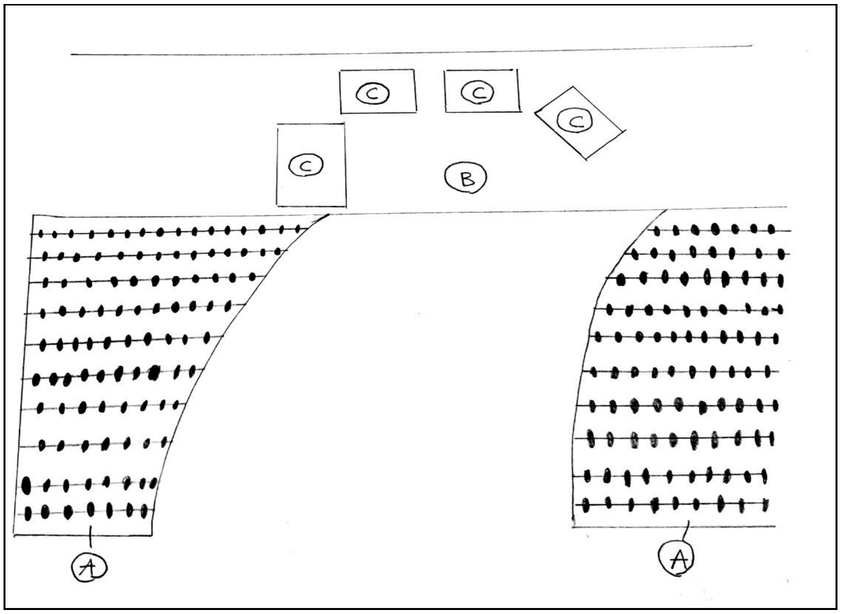

Figure 6: Top view for the workstation for the original design (cage assembly)

Front View:

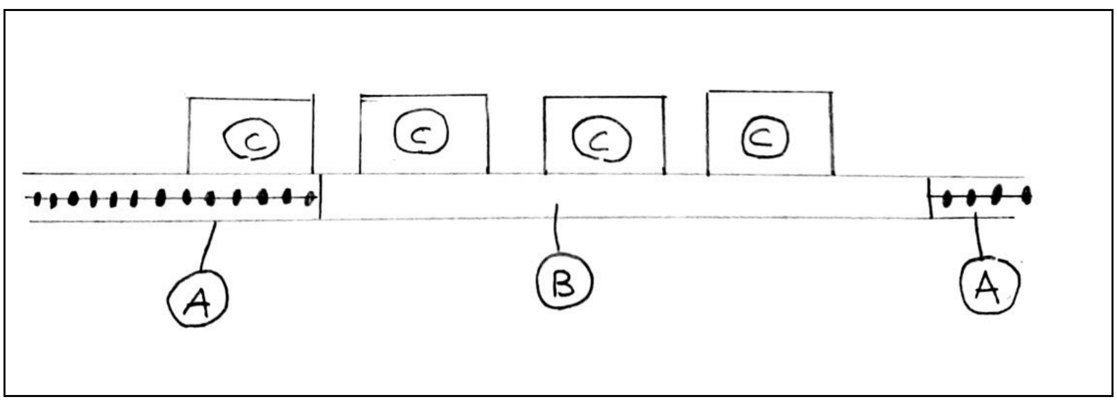

Figure 7: Front view for the workstation for the original design (cage assembly)

Legend :
A - Gravity Skate Wheel Conveyor
B - Workbench
C - Storage basket
D - Storage shelves

From the two videos given , the previous 4 drawings were made. These two workstations both have a Gravity skate conveyor belt, a workbench, storage baskets as well as storage shelves. These designs are not ideal as they cause safety issues and slow down the assembly process. Accessibility is limited within this workplace setup also slowing down the assembly process. These issues will be further discussed in the report and improved for the redesign.

Human redesign

When designing a workstation it is a key element to accommodate most individuals' needs. We need to design for extremes, adjustability and average. After analyzing the two pictures, some good and bad features were found.

Good features:

- The worker has enough space to place all of his equipment
- Everything is in front of the worker so he will not have to travel distances which will not cause fatigue
- All the workers tools are placed in front of him which will decrease the assembly time
- Material placed in different color bins so easy to identity the different type of material

Bad features:

Injuries:

- The toaster could fall on the workers feet
- No eye protection: the worker has no glasses
- The worker is not wearing gloves for safety measures
- Sharp edge near the workers hip

The position of the workstation versus the user :

- The worker is standing and is facing downwards to the workstation
- The worker's elbow should be 90° to the work station. It is evident that in the picture it is at an angle much higher than 90°
- This causes tension in the workers neck
- May lead to pain and discomfort
- Causes bad posture for the worker

Recommendations:

- The worker could use power tools instead of manual tools which will decrease fatigue and be more efficient
- The worker should have more protection
- Make the workstation higher to improve the workers posture , adjust it so the workers elbow is at 90°.
- For postural flexibility we could add a sit/stand option
- However the seat needs to be comfortable, adjustable and have arm and foot rests
- If it is not possible to sit, we can add an anti fatigue mat

Time Standards

In order to determine the time needed to carry out a job or task, many methods can be applicable. For this case study we used a Predetermined Motion Time Systems (PMTS). This system consists of a set of time data and a systematic procedure which subdivides any manual or human task into motions, body movements or other elements of human performance and then analyzes it by assigning each an appropriate time value. [2]

Predetermined Motion Time Systems have different classifications:

- Methods Time Management (MTM)
- Maynard Operation Sequence Technique (MOST)
- Meyers Technique

For this specific case study we conducted Methods Time Management system to help us determine the normal time for each worker when working on their specific subassemblies. The way this time analysis was conducted was by analyzing every step performed by worker 1, and worker 2, and assigning an alphanumeric code to every motion performed by the worker whilst constructing each subassembly. This code is completely dependent on the type of motion performed and the type of object the motion is applied upon, and results in a very thorough chain of steps performed by the individual worker. This data is very useful when seeing how repetitive certain motions are, and allows the facility to see if any changes are necessary, and where exactly to implement them. All the data gathered was then used to generate a specific code provided by table 4.1-4.5 in appendix. Which would then provide the appropriate TMU value for the given tasks.

After the MTM system analysis was completed we were able to determine the normal time by adding up all of the TMU from each subassembly for each worker and then converting from TMU to minutes by using a conversion factor. From this we were able to determine:

Ejection System (operator 2): 306.3 TMU
Circuitry System (operator 2): 488.3 TMU
Structural System 1 (operator 2): 18621.9 TMU
Structural System 2 (operator 2): 545.3 TMU

Total: : 19961.8 TMU

Converting from TMU to Normal time (min):

$$19961.8\ TMU \times \frac{0.0006\ min}{1\ TMU} = 11.98\ min$$

(operator 2)

Heat System (operator 1): 11758 TMU

Total: : 11758 TMU

Converting from TMU to Normal time (min):

$$11758\ TMU \times \frac{0.0006\ min}{1\ TMU} = 7.05\ min$$

(operator 1)

After calculating the normal time for each of the operators we were able to determine the standard time it takes for each operator to complete their tasks. Within the case study we were able to assume that the allowance would be 12%. This was done using the formula:

$$Standard\ Time = Normal\ Time \times (1 + allowance)$$

Operator 1:

$$Standard\ Time = 11.98 \times (1 + 0.12) = 13.4176\ min$$

Operator 2:

$$Standard\ Time = 7.05 \times (1 + 0.12) = 7.896\ min$$

Cost analysis

Hourly rate = $ 16.50
Cycle time = Minutes it takes the slowest worker to do their job = 13 minutes and 04 seconds (taken from the video)
Number of workers = 2

From our bill of material the cost of material in one toaster is :

$$Cost\ of\ material\ of\ one\ toaster : (0.02 \times 5) + (0.02 \times 10) + (0.02 \times 4) + (0.02 \times 2) + (0 \times 1) + (0.03 \times 1) + (0.04 \times 1) + (0.01 \times 1) + (0.05 \times 1) + (0 \times 1) + (0.1 \times 1) + (0.06 \times 1) + (0.01 \times 1) + (0.02 \times 1) + (0.06 \times 1) + (0.02 \times 2) + (0.15 \times 1) + (0.15 \times 1) + (1 \times 3) + (0.01 \times 2) + (0.02 \times 8) + (0.01 \times 1) + (0.01 \times 1) + (0.03 \times 1) + (0.01 \times 1) + (0.01 \times 1) + (0.01 \times 1) + (0.01 \times 1) + (1 \times 0.05) + (2 \times 0.07) + (1 \times 0.05) + (1 \times 0.05) = \$4.7$$

$$Unit\ cost = cost\ of\ materials\ in\ one\ toaster + cycle\ time \times minute\ rate\ of\ a\ worker \times number\ of\ workers$$

$$Unit\ cost = \$\,4.74 + 13.4\ minutes \times \left(\tfrac{16.5}{60}\right) \times 2 = \$12.11$$

Cost to run the company per day = Daily total cost = how many toasters are made X unit cost + overhead

Assuming that 1 toaster is made :

$$Daily\ total\ cost = (1)(\$12.11) + 0 = \$12.11$$

$$Overhead = 43\%\ of\ Daily\ cost = 0.43 \times \$12.11 = \$5.2073$$

Now calculating the daily total cost with the overhead:

$$Daily\ total\ cost = (1)(\$12.11) + \$5.2073 = \$\,17.3173$$

Overhead per unit = 43% of total unit cost after overhead = 0.43 × $17.3173 = $ 7.4467

Total unit cost after overhead = unit cost + overhead per unit = $12.11 + $7.446 = $19.56

Line Balancing

Table 1: Operator 1 and operator 2 standard times

	Standard minutes to perform operation(min)	Wait time based on slowest operator (min)	Standard time (min)
Operator 1 (heating)	7.02	5.95	7.05
Operator 2	12.97	0	11.97

$$E = \frac{\sum_{1}^{2} SM}{\sum_{1}^{2} AM} \times 100 = \frac{7.02 + 12.97}{7.05 + 11.97} \times 100 = 105.10\ \%$$

where :

$E = efficiency$

$SM = standard\ minutes\ per\ operation$

$AM = allowed\ standard\ minutes\ per\ operation$

$\%\ Idle = |100 - E| = |100 - 105.10| = 5.1\ \%$

$Production = number\ of\ toasters\ made\ in\ a\ day = \frac{60\ min/hour \times 8\ hours/day}{11.97\ min/unit} = 40.1 = 40\ toasters\ in\ a\ day$

$R = desired\ rate\ of\ production = \frac{40.1\ toasters}{480\ \ min} = 0.084\ toasters/min$

$N = R \times \Sigma AM = R \times (\frac{\Sigma SM}{E}) = 0.084 \times (7.02 + 12.97)/1.0510 = 1.598\ number\ of\ operators\ needed$

where:

$N = number\ of\ operators\ needed\ in\ the\ line$

$R = desired\ rate\ of\ production$

$Worker\ \#1\ Utilization = \frac{Worker\ \#1\ time}{Cycle\ time} \times 100\%$

$Worker\ \#1\ Utilization = \frac{7.02\ min}{12.97\ min} \times 100\%$

$Worker\ \#1\ Utilization = 54.1249036\% \approxeq 54\%$

$Worker\ \#2\ Utilization = 100\%$

Worker 2 is utilized 100% as worker 2 is the slowest

Worker 2 is being 100% utilized as (s)he is the slowest worker for the assembly process. The other worker cannot be utilized until worker 2 completes their task.

Worker 1 finishes their task before the slowest worker. The time that is spent not being able to work is considered the idle time.

Root Cause Analysis

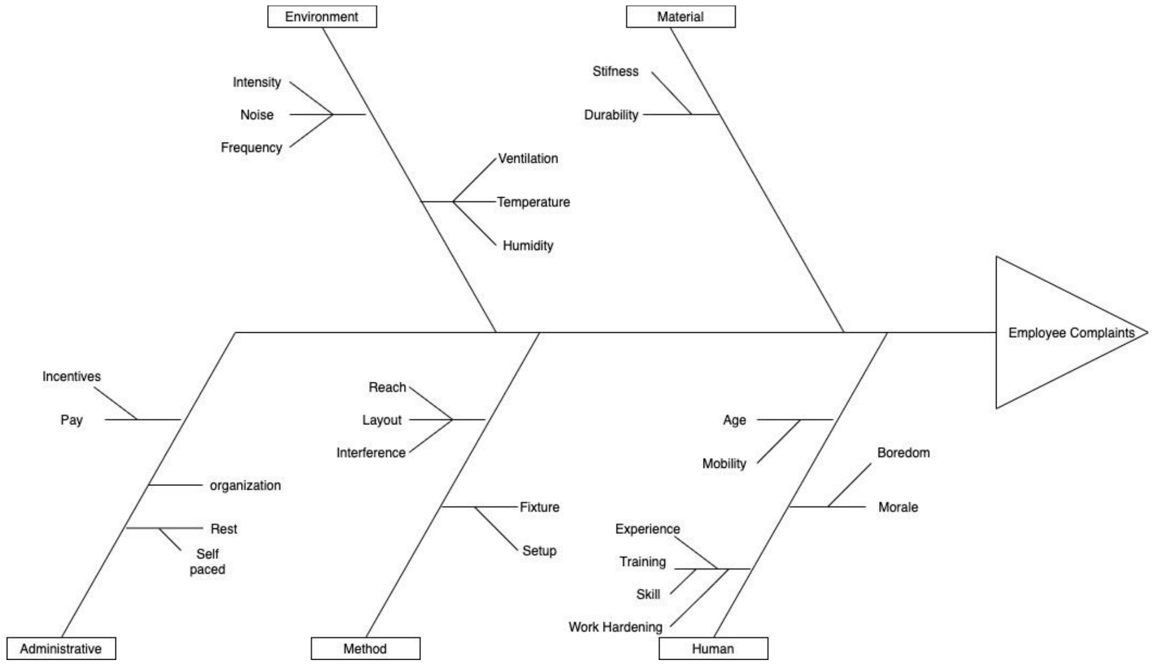

Figure 8: Root Cause Analysis

The fish diagram is just a small sample of the issues that may result in employee complaints. Throughout both videos provided, there are numerous factors that may prove to be an inconvenience for the workers. The first thing to take into consideration is that both workers work in a completely isolated work environment. This is a huge hazard as it may pose a security issue if something may happen to the worker, another possible side effect is the decrease of worker morale. It is proven that workers perform better, and are more willing to work when in collaboration with each other. Another issue is that both workers are working in a depressed work area. This causes the worker to look down, and may result in strains in the muscles of the workers, posing a threat to the longevity of the crewman. In addition the work area is littered with sharp objects and tools, which may cause cuts, and scrapes and there does not seem to be any first aid equipment nearby which may cause a sanitation hazard. These are just a few of the many issues noted, a more through list of issues is seen below:

Environment

- The workers' environment is a large room with not much activity.
- The large room may cause echos to occur more prominently.
- Every movement will cause noticeable noise as there are no other sources of sound.
- Only two sources of ventilation are shown on the roof, this may cause regions in the room to be different temperatures when the ventilation is active.

Material

- The material the workers usually work with are thin sheets of aluminum and durable plastic.
- Thin sheets of aluminum are sharp and may cut worker
- Worker can only grip using pinch grip for the thinner sheets
- Aluminum may retain coldness in colder temperatures

Administrative

- Workers may not have enough incentive to get the required work completed within the desired time frame
- The nature of the current process makes it difficult to accommodate larger demands, or decreased employees(absence, resignation, etc)

Method

- Setup requires worker to work close to the edge of the table as storage bins are on the outskirts of the desk
- Worker is required to stand up and work
- Table height is fixed
- Various vibrant colours are stacked upon each other or beside each other, could be distracting
- Worker bends over when using the desk as support
- Gravity Skate Wheel Conveyor comes within the workers leg space

Human

- There are no other worker, worker may get bored
- Workers muscle may tense up from standing in the same position for the whole assembly
- Worker requires to reach and grab parts, this repetitive motion may affect the worker
- There is no external source of motivation to work as best as the worker can
- Worker is required to know and execute all the steps to the assembly which is a considerable amount

Redesign

This case study identifies a scenario regarding the work process of assembling a toaster. Investigating into the work process of assembling the simplicite toaster, analysis in the forms of time standard, cost analysis, line balancing, and crossover analysis are to be used to quantify the assembly process. Further analysis into workspace redesign analyzes how the worker is affected on a physical and psychological level.

Time Standard

The time standard proposed to analyze the redesign of the assembly process is MTM-1. MTM-1 takes into consideration intricate motions that may affect time. This is helpful in assessing redesign to take out wasted time from excess and/or not essential movement.
MTM analysis for the proposed redesign of the assembly was calculated. The objective of this redesign was to shorten the assembly process. Lower TMU's were expected.
The proposed method of shortening assembly time is to shorten how far the worker is required to reach to grab components by approximately 30%. Another method used to shorten assembly time is to pre-assemble screws onto its corresponding components. This would remove excess time reaching and fitting the screw into place.

After implementing the stated changes, the following TMU's were calculated:

Table 1.1: Operator 1 TMU

Operator 1	
Heat System (operator 1):	9840.6 TMU
Total: 9840.6 TMU	

The redesign states the total TMU for operator 1 decreases from 11758 TMU to 9480.6 TMU. The 2277.4 TMU difference yields a 19.4% decrease.

Table 1.3: Operator 2 TMU

Operator 2	
Ejection System (operator 2):	277.4 TMU
Circuitry System (operator 2):	259.6 TMU
Structural System 1 (operator 2):	12790.7 TMU
Structural System 2 (operator 2):	374.3 TMU
Total: 13702 TMU	

The redesign states the total TMU for operator 2 decreases from 19961.8 TMU to 13702 TMU. The 6259.8 TMU difference yields a 31.4% decrease.

Operator 1	Operator 2
Converting from TMU to Normal time (min): $9840.6\ \ TMU\ \times \frac{0.0006\ min}{1\ TMU}\ =\ 5.90\ min$ (operator 1)	Converting from TMU to Normal time (min): $13702\ \ TMU\ \times \frac{0.0006\ min}{1\ TMU}\ =\ 8.22\ min$ (operator 2)
For the redesign, Operator 1's normal time for assembly decreased from 7.05 minutes to 5.90 minutes yielding a 16% decrease in time. Operator 2's normal time for assembly decreased from 11.98minutes to 8.22 minutes yeuilding a 31% decrease in time.	

After calculating the normal time for each of the operators we were able to determine the standard time it takes for each operator to complete their tasks. Within the case study we were able to assume that the allowance would be 12%. This was done using the formula:

$Standard\ Time\ =\ Normal\ Time\ \times(1+allowance)$	
Operator 1:	$Standard\ Time\ =\ 5.90\ \times(1+0.12)\ =\ 6.61\ min$
Operator 2:	$Standard\ Time\ =\ 8.22\ \times(1+0.12)\ =\ 9.21\ min$
For the redesign, Operator 1's standard time for assembly decreased from 7.90 minutes to 6.61 minutes yielding a 16% decrease in time. Operator 2's standard time for assembly decreased from 13.4 minutes to 9.21 minutes yeuilding a 31% decrease in time.	

Line Balancing

Table 2: Operator 1 and operator 2 standard times

	Standard minutes to perform operation (min)	Wait time based on slowest operator (min)	Standard time (min)
Operator 1 (heating)	7.02	5.95	6.61
Operator 2	12.97	0	9.21

$E = efficiency$
$SM = standard\ minutes\ per\ operation$
$AM = allowed\ standard\ minutes\ per\ operation$

$E = \frac{\sum_1^2 SM}{\sum_1^2 AM} \times 100 = \frac{7.02 + 12.97}{6.61 + 9.21} \times 100 = 126.36\ \%$
$\%\ Idle = \lvert 100 - E \rvert = \lvert 100 - 126.36 \rvert = 26.36\ \%$

$N = number\ of\ operators\ needed\ in\ the\ line$
$R = desired\ rate\ of\ production$

$Production = number\ of\ toasters\ made\ in\ a\ day = \frac{60\ min/hour \times 8\ hours/day}{9.21\ min/unit} = 52.1 = 52\ toasters\ in\ a\ day$
$R = desired\ rate\ of\ production = \frac{52.1\ toasters}{480\ min} = 0.11\ toasters/min$
$N = R \times \Sigma AM = R \times (\frac{\Sigma SM}{E}) = 0.11 \times (7.02 + 12.97)/1.2636 = 1.74\ number\ of\ operators\ needed$

$Worker\ \#1\ Utilization = \frac{Worker\ \#1\ time}{Cycle\ time} \times 100\% = \frac{6.61\ min}{9.21\ min} \times 100\% = 71.7698154\% \approxeq 72\%$
$Worker\ \#2\ Utilization = \frac{Worker\ \#2\ time}{Cycle\ time} \times 100\% = \frac{9.21\ min}{9.21\ min} \times 100\% = 100\%$
Worker 2 is being 100% utilized as (s)he is the slowest worker for the assembly process. The other worker cannot be utilized until worker 2 completes their task. Worker 1 finishes their task before the slowest worker. The time that is spent not being able to work is considered the idle time.

For the proposed redesign, 52 toasters are produced per day compared to the original assembly that produces 40 toasters. The redesign yields a 12 toaster increase per day.

Problem: In the toaster assembly video, the worker had a hard time finding the pieces which wasted time

- **Solution:**
    - Colour code the bins respectively to different types of parts.
    - Labelling them can make it easier for the worker to specifically know where everything is placed.

Problem : The worker had a hard time placing and screwing the screws in place

- **Solution:**
    - The worker could use power tools instead of manual tools which will decrease fatigue and be more efficient
    - The worker could use a magnetic tool to prevent the screw coming off its set path

Problem: The edges of the workstation are sharp which may cause injuries

- **Solution:**
    - Round out the edges so they are not sharp and dangerous.
        - If that is too expensive to change, silicon or a soft material can be added to the edges.

Problem: Workers has to interact with sharp objects

- **Solution:**
    - Workers should be provided with protective equipment i.e. gloves and glasses.
    - The gloves need to be tight and provide a good grip in order for the worker to pick up and manipulate small objects

Problem: The worker has to lean over to work on the assembly

- **Solution:**
    - Make the workstation higher to improve the workers posture , adjust it so the workers elbow is at 90 °.
    - For postural flexibility we could add an ergonomic sit/stand option
    - If it is not possible to sit, we can add an anti fatigue mat

Problem: The toaster is not illuminated well enough which makes it harder for the worker to see and assemble part inside the toaster

- **Solution:**
    - Provide the worker with a head light which will illuminate the inside of toaster

Problem: The worker had a hard time assembling the cage of the toaster, since other parts were interfering

- **Solution:**
    - Use a clamp to hold the other parts in place

Problem: Worker has to reach over the conveyor belt to access the baskets in the back.

- **Solution:**
    - Extend the work station on both sides rather than one.

The first few issues the group started to address is the overall safety of the work area. The space in which the workers work is covered in sharp objects, such as the edge of the table, the bins, and the tools themselves. In addition a light is suggested to improve visibility when dealing with darker parts of the assembly. These solutions aimed specifically to ensure the worker is comfortable with the process, and keeping the worker safe will improve the overall efficiency. The next set of solutions such as the conveyor belt, clamp, color coded bins, elevated workstation and the magnetic tools aim at improving the workers assembly process. Throughout the provided videos, the worker was over extending and reaching to grab different components, overtime this increases the length of time it takes the worker to grab parts, and may cause injury as well. Similarly the colour coded bins and magnetic tools also help speed up the assembly. In the videos it was clear that the worker spent a great deal of time finding the correct screw, then fumbling the screw onto the screwdriver to tighten the components together. The colour coded bins should allow for a faster time grabbing screws, and the magnetic tool/clamps should allow the worker to not worry about holding the screw, the screwdriver, and the toaster simultaneously. The last solution the group suggests is using automated tools. The workers spend a lot of time using pliers, and screwdrivers, making each task longer than necessary and using quite a bit of force. Combine this with an 8 hour workday, and this will become a large problem in terms of production. The assistance of automated tools such as drills, would greatly increase the workers rate of work, and apply less stress on them as well, allowing for a more efficient workday.

Workstation Redesign

Workstation Redesign: Worker 1 (**Video : Toaster cage assembly V1)**

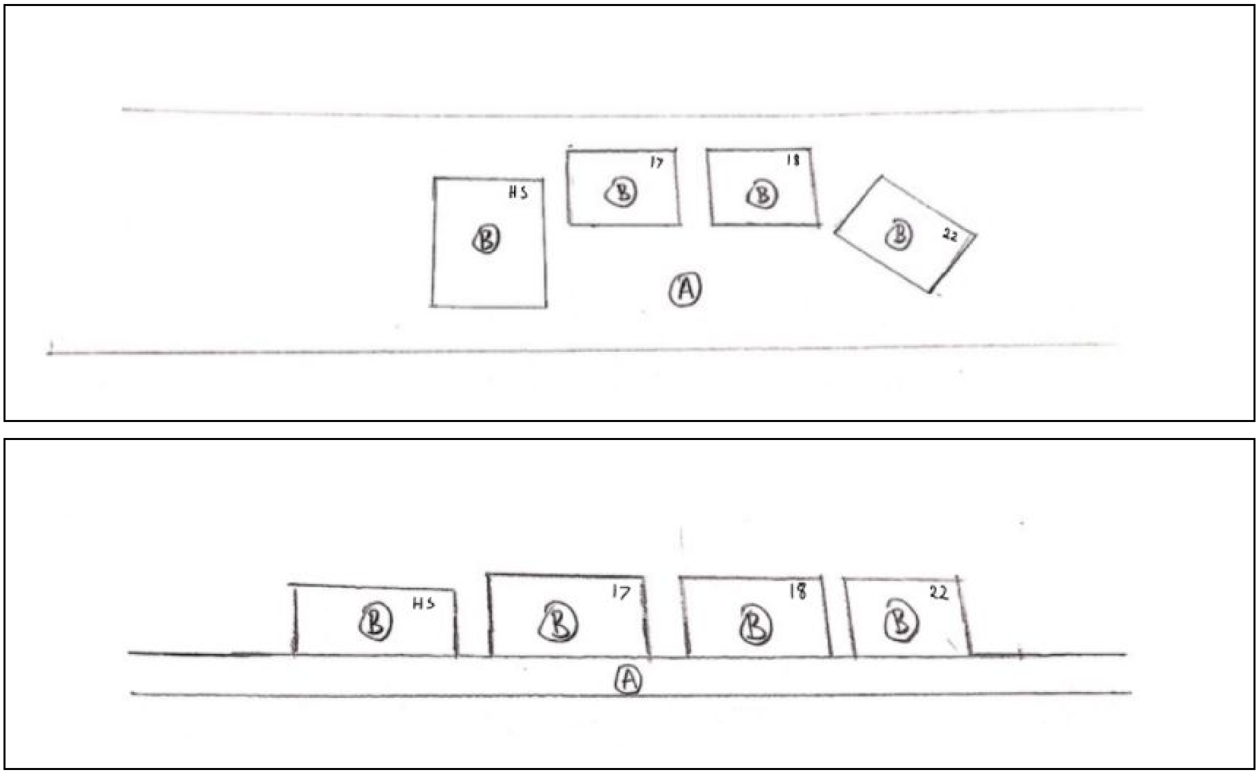

Figure 9 : Top and front view for the workstation redesign (video : toaster cage assembly v1)

<u>Legend :</u>
A - Workbench
B - Storage basket
HS - Preassembled Heating System consisting of parts 19, 20, 21, 23, 24 from the BOM
- Part numbers in reference to the BOM

Workstation Redesign: Worker 2 (**Video: Toaster assembly V1)**

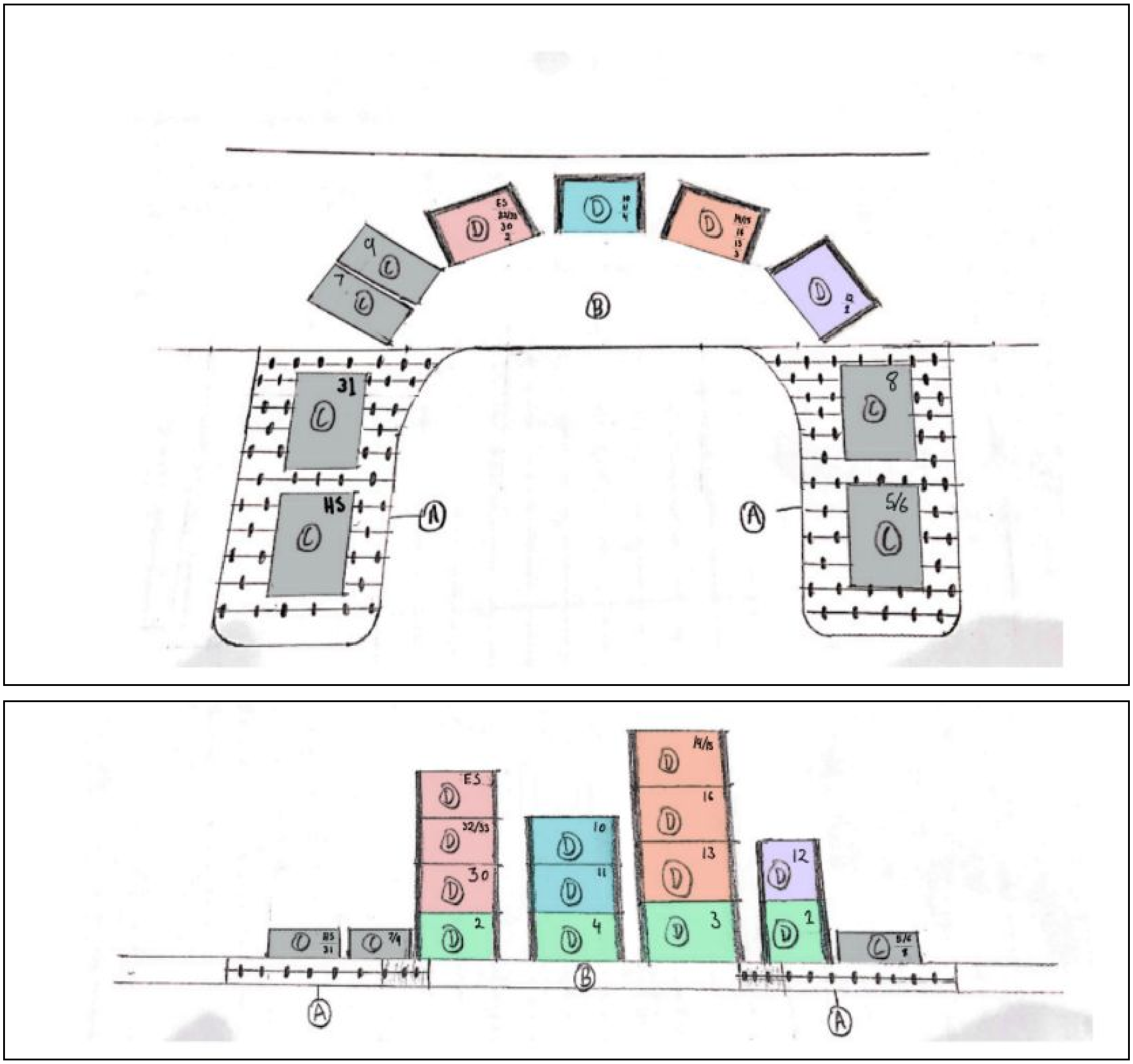

Figure 10 : Top and front view for the workstation redesign (video : toaster assembly v1)

<u>Legend :</u>
A- Gravity Skate Wheel Conveyor
B- Workbench
C-Storage basket
D-Storage shelves
HS - Preassembled Heating System from worker 1's assembly
ES - Preassembled Ejection System consisting of parts 25, 26, 27, 28 from the BOM
- Part numbers in reference to the BOM

Jigs and Fixtures Redesign

Workstation Redesign with Jigs and Fixture: Worker 1 (**Video : Toaster cage assembly V1)**

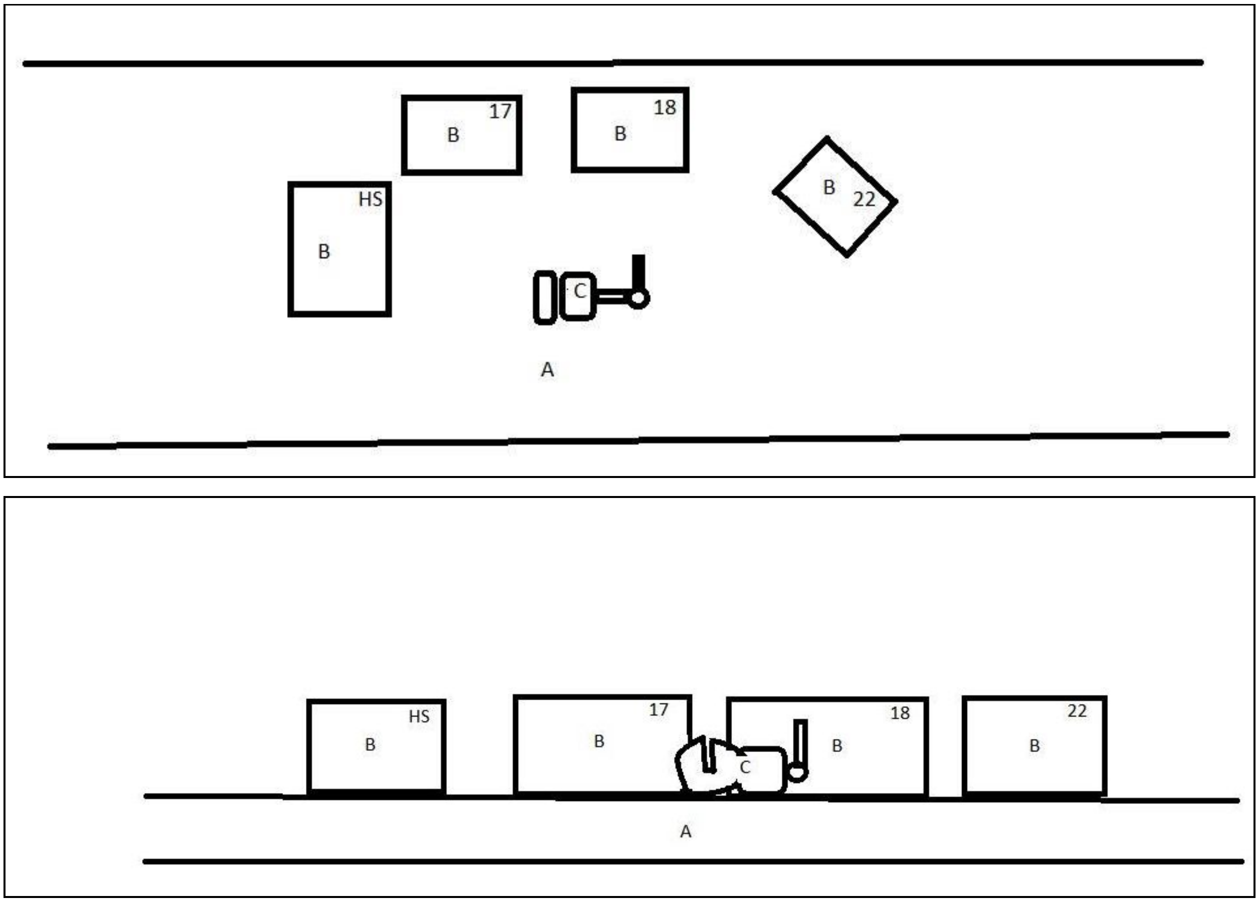

Figure 11 : Top and front view for the workstation redesign with jigs and fixtures (video : toaster cage assembly v1

<u>Legend :</u>
A - Workbench
B - Storage basket
HS - Preassembled Heating System consisting of parts 19, 20, 21, 23, 24 from the BOM
- Part numbers in reference to the BOM

The proposed fixture that was deemed appropriate for worker 1 is a vice. Worker 1 is in charge of constructing the toaster cage, which involves handling a series of thin plates that must be fastened together. At first glance of the worker, it is clear that they spend a lot of time and effort holding all the plates together to be able to attach all components securely. The use of a vice here allows for a fortified hold on the plates to allow for a free hand of the worker. This would ideally speed up the process and allow for the fastenings to be attached quicker.

Workstation Redesign with Jigs and Fixture: Worker 2 (**Video: Toaster assembly V1)**

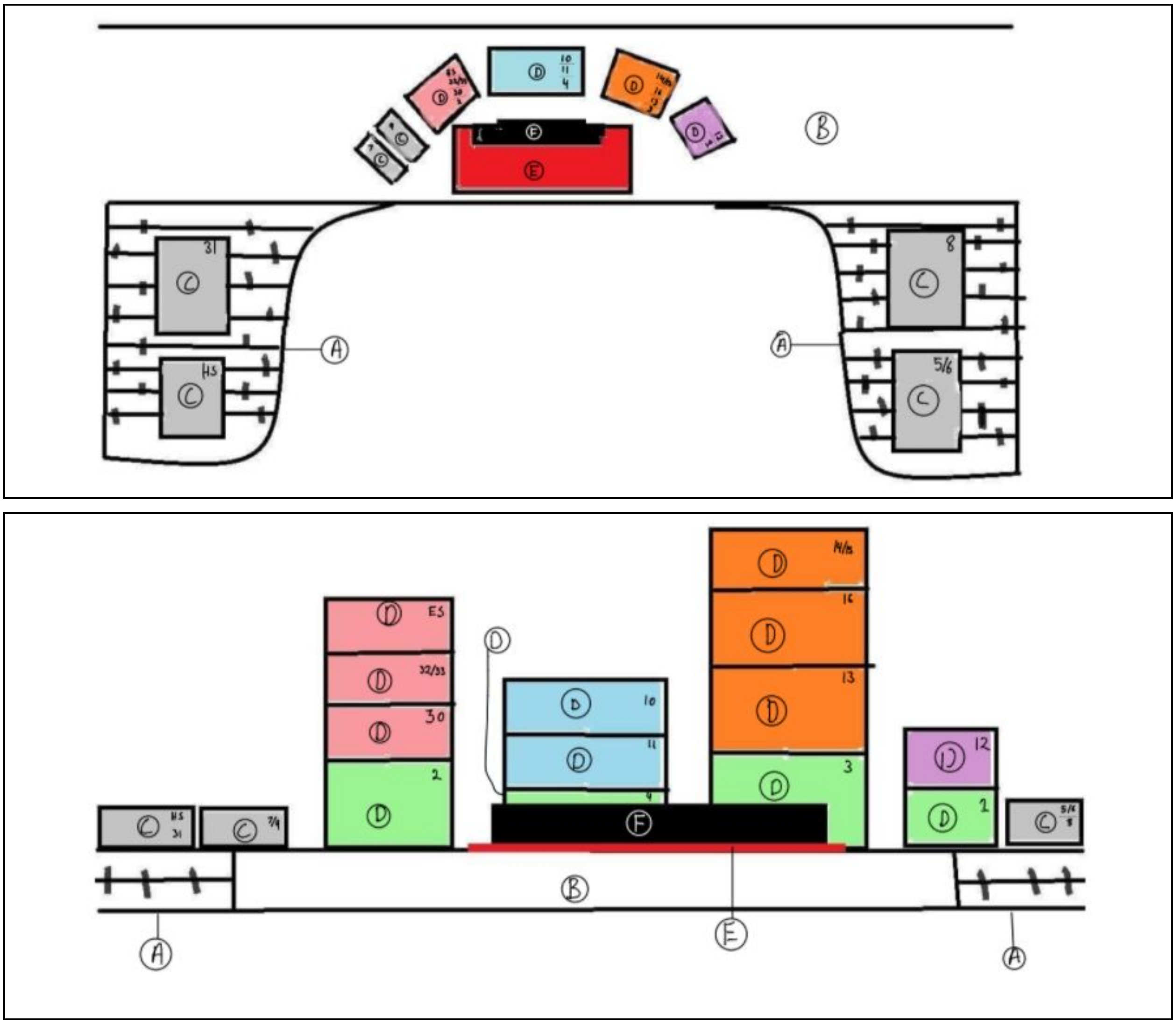

Figure 12 : Top and front view for the workstation redesign with jigs and fixtures (video : toaster assembly V1)

<u>Legend :</u>
A- Gravity Skate Wheel Conveyor
B- Workbench
C-Storage basket
D-Storage shelves
E-Rubber mat
F- Stopper
HS - Preassembled Heating System from worker 1's assembly
ES - Preassembled Ejection System consisting of parts 25, 26, 27, 28 from the BOM
- Part numbers in reference to the BOM

For Worker two the fixtures chosen were a rubber mat, and a stopper. In regards to worker 2 a common issue the worker had was the work area being very slippery and having to often reposition the toaster. To mitigate this the rubber mat will aid in the workers ability to control the toaster, and keep it from sliding. This will reduce travel time whilst the worker is reaching for components and decreases the variation of how far the worker must reach. In addition, a stopper is used to assist in keeping the toaster secured as well. This allows the worker to apply pressure to the taster without it repositioning itself. Similar to the rubber mat, it aids in travel times and decreases the variability in the location of the toaster whilst working.

Discussion

Video : Toaster cage assembly V1

This redesign proposes that by taking out the conveyor belt, there would be less objects getting in the workers' way. The conveyor belt provides no benefits deeming it useless. The bins are organized so items that are used in the assembly follow a sequential order from left to right. Baskets are used to store items as items are rather large in size and not many are needed in this assembly. As well, safety equipment is placed on the workbench to ensure the workers safety.

A change not so apparent in the redesign is that the table the worker assembles the cage upon is height adjustable. Analysing the cage assembly video, the worker is seen bending over the workstation at times to assemble the toaster. Assuming the worker bends over to be in a more comfortable position, it can be concluded that the workstation height is not desirable for that worker. Accounting for the workers comfort at the workstation can improve the workers productivity. For the same reason, the worker should have access to an ergonomic chair. Standing and assembling for a long period can cause the worker to fatigue, resulting in lower quality of work and productivity.

Video: Toaster assembly V1

From the video, a few changes were made for the redesign. First of all, the edges of the conveyor belt have been rounded to ensure the workers safety. In the old design the conveyor belt had sharp edges which can cause injuries when the worker is moving from one corner to the next. As well, safety equipment (glove , head light etc) are placed on the workbench so when the worker arrives at the workstation they know it is their first step to equip themselves for full safety. Another major change is that another conveyor belt is placed on the right side of the worker. Originally, there was only one on the left that had a total of 4 boxes, in order to access two of those boxes the worker had to reach to take the parts which is impractical. To fix that issue another conveyor belt is placed on the right of the worker so he/she will not have to reach to grab the toaster parts. It is important to note that there is enough space for the worker to move freely between both conveyor belts and that they are also not placed too far apart so the walking distance is small.

In the video, the worker seems hesitant to find components for the assembly. Addressing this issue, labels are placed to clearly state which part is placed in which bin. This will save time when assembling the toaster.As well the bins are color coded by different categories which are the following :

The baskets, labeled (C) , consist of larger components in the assembly of the toaster. Items are placed in accordance to what is required from left to right. By organizing in this manner, the worker can save time from searching for the next component, optimizing the workers time.

The bins, labeled (D), are organized so the worker can sequentially follow the procedure to assemble the toaster. The first column of bins consist of all the ejection mechanisms. The Second column consists of all the power cable and accessories. The following column consists of components for the control system. The final column consists of studs as it is the last step in assembling the toaster. Every column of the bin has screws corresponding to the task on the bottom most bin for easy access as it is one of the most common and smallest components the worker has to interact with.

In order to make it easier to assemble the toaster and identify the parts the bins have been colour coded respectively:

- Gray: The gray bins hold the larger components.
- Green: Contains the screws, since they are harder to interact with they are placed at the bottom so it is easier for the worker. Each column has one shelf in the bottom dedicated to screws.
- Pink: This column contains the parts of the ejection system since it is the first component the worker uses to assemble the toaster
- Blue:This column contains the parts for the power cable as it is the next step in the assembly process
- Orange: this column contains the parts for the control system as it is the third step for the assembly process
- Purple: The purple bins contains of the parts that finalize the assembly : the studs

Finally, the worker will have access to either an ergonomic chair or an anti fatigue mat so they will not experience fatigue which will result in better outcomes and faster production.

Project Recommendations

The videos of the workers assembling shows a limited field of view. The first person view helps analyze the various motions that the worker does during the assembly process. Many times within the video, the workers' actions are out of perspective. When considering the redesign, the workers position has to be inferred from the limited view that is being analyzed. By introducing another angle showing the assembly process these issues can be addressed. Similarly the pictures provided don't completely show the workspace. Items are seen blocking other items leaving what is behind them to be inferred. Adding additional pictures from different angles can assist in drawing a clear idea of how the workstation is. Another addition that would have assisted the project's accuracy was a cost sheet that was closer to the model being worked on. The cost data provided was for a different product entirely, and resulted in a much more estimated cost, than what is preferred. Tools detailing guidelines to analyse the toaster such as textbook and lecture notes, can be better explained or incorporated for the project criteria. Textbook had a lot of information that was out of the scope for this project. This easily caused confusion and impeded the project workflow. Lecture notes lacked detail and required further research to comprehend how to execute analysis of the project. This was shown in the line balancing portion of this project. The textbook detailed how to solve for the number of workers needed in a line followed by various charts and graphs whereas the lecture notes had one slide showing a table line balanced with no in-text context. Improvement on delivering details relevant to the project can assist in the quality of the work.

Conclusion

The objective of redesigning the workspace is to better optimize the efficiency of the workers. Accounting for workers comfort as well as hindrances in the workflow, workspace changes can be identified. These changes would not only make the quality of production better but also be more time efficient.

Starting with the bill of materials, parts within the assembly were identified and labeled with description. This was used throughout the analysis as reference. Following this tree diagram identified the subassemblies to manufacture the product. The process was then analyzed. The operations process chart identified the general assembly process for each worker. The flow process chart identified the assembly process for each subassembly. A flow diagram was identified to depict how the current workplace is. Moving onto analyzing the production of the product, numerical calculations were conducted. First time standard in the form of MTM 1 was analyzed to determine the exact motions performed by the individual workers whilst constructing the subassemblies. Next, cost analysis was conducted in order to find the daily total cost. Finally line balancing was used to determine the efficiency of the system and how the work is optimized for each worker. Moving towards the redesign stage, root cause analysis was conducted. This was used to identify the various complaints the workers may have. Based on the analysis, problems and solutions were identified. Using that as a basis, redesign for the workplace was suggested. A redesigned flow diagram depicting the solutions was identified. Next step was to identify jigs and fixtures that may assist in workflow. The reimagined jigs and fixture were implemented once more into the flow diagram. A discussion was then made to further explain our redesign. Overall, this project gave us a better understanding of the scope of the course and helped us learn how to do the charts and tables.

References

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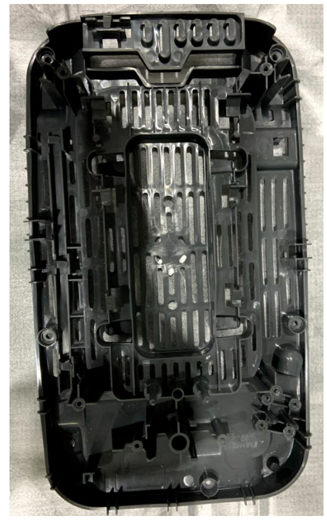
Appendix

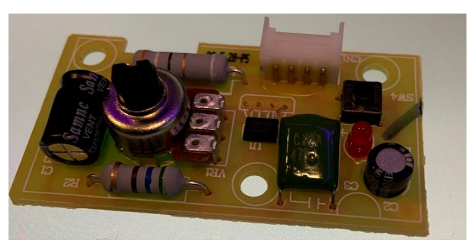
Table 2. Bill of Materials

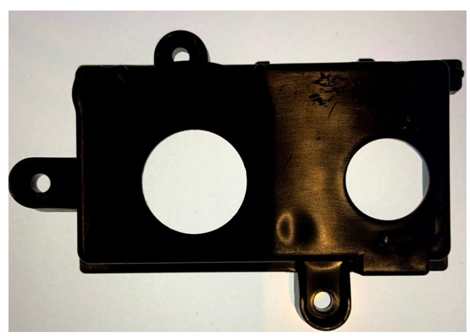
Item	Part Number	Quantity	Description	Material	Figure	Material Cost($)
Category: [Bolts]						
7/16” screw	1	5	-Used to secure the plastic base to the inner components	Steel		$0.02
⅜” screw	2	10	-Used to secure the chassis and the circuity/input	Steel		$0.02

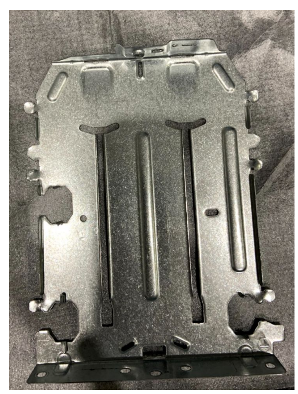
½" screw	3	4	-Used to secure power cable shroud	Steel		$0.02
⅝" screw	4	2	-Used to secure the inductor	Steel		$0.02
Category: [Crumb Tray (Structural System)]						

Crumb tray sheet	5	1	-Removable part of the toaster thats purpose is to remove any excess crumbs from bread -6” x 2.5”	Aluminum		$0.00
Crumb tray grip	6	1	-Comfortable grip that allows the user to comfortably slide the tray out -2.75” x 2.75”	Plastic		$0.03
Category: [Toaster Shell (Structural System)]						

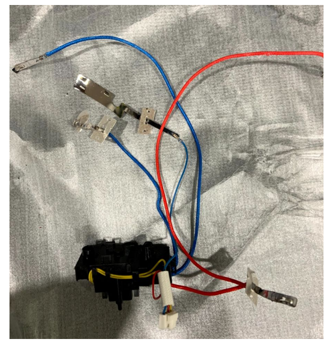
Base	7	1	-Base of the toaster to support the components -9.5” x 5.5”	Plastic		$0.04
Cover	8	1	-Surrounds the toaster to ensure all inner components do not endanger the user, also provides the aesthetics -9.25” x 5.5”	Plastic		$0.01
Aluminum slit	9	1	-Used to avoid injuring and guide the user when placing toast -6.5”x4”	Aluminum		$0.05

Power cable shroud	10	1	-Used to secure the power supply cable from moving around in the inside	Plastic		$0
Power supply cable	11	1	-Supplies power to the toaster circuitry -Length: 36”	Plastic Coating/ Copper Wires		$0.10
Studs	12	4	- Stances the toaster up and off the surface.	Rubber		$0.02
Category: [Timing mechanism /Browning control (Control System)]						
Circuit board	13	1		Plastic/ Copper		$0.06

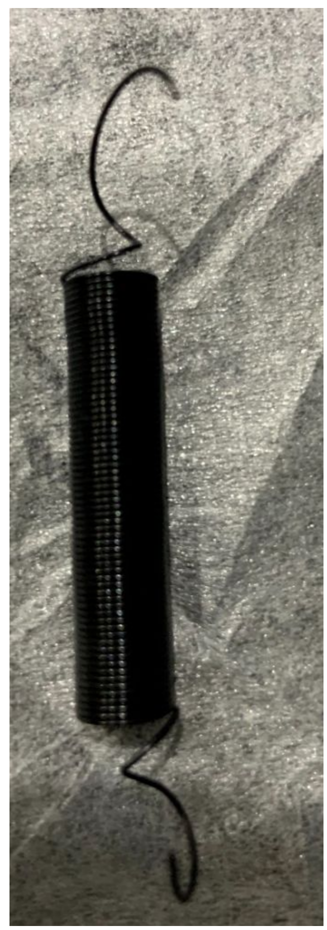
Knob	14	1		Plastic		$0.01
Eject Button	15	1		Plastic		$0.02
Control Shell	16	1		Plastic		$0.06
Category: [Aluminum Shell (Structural/Heating System)]						

Sides of chassis	17	2	-Provides a rigid side to the chassis. Also holds heating elements. -5.5”x5.5”	Aluminum		$0.02
Front side of chassis	18	1	-Provides a rigid back to chassis, connects to the side chassis and heating element -5.25”x3.75”	Aluminum		$0.15
Back side of chassis	19	1	-Provides a rigid front to chassis connects to the side chassis and and all the lever mechanism -5.25”x3.75”	Aluminum		$0.15

Heating Element	20	3	-Wires heat the plate -5"x5"	Nichrome/ Mica		$1.00
Heating element clamp	21	2	-Clamps middle heating element secureley -5"x1/2"	Aluminum		$0.01
Range on heating element	22	8	-Help distribute heat to the bread through the toaster -5" x 1 ⅛"	Aluminum		$0.02

Heating contact	23	1	-Connects heating elements on either side -3”x1.75”	Aluminum		$0.01
Inductor	24	1	-Transfers power into the heating elements of the toaster	Plastic/ Copper wires		$0.01
Category: [Lever Components (Ejection System)]						
Spindle chassis	25	1	-The component in which the beam is attached and allows for user input -2”x2”	Aluminum		$0.03
2/4 lever sliding mechanis m	26	1	-The component that slides along the beam as the user utilizes the lever	Aluminum		$0.01

¾ lever grip	27	1	-Attached to the lever mechanism and helps secure the sliding chassis to the lever	Plastic		\$0.01
Lever faceplate	28	1	-Attached to the lever mechanism to ensure proper contact among the components	Aluminum		\$0.01
Lever cover	29	1	-Covers the end of the lever to ensure user comfort when in use -¾”x5/8”x 1.75”	Plastic		\$0.01
Lever Spindle	30	1	The shaft in which the lever slides on	Steel		\$ 0.05

Sliding mechanism for lever attachment	31	2	-Is used to raise/lower the bread -A part of lever mechanism -7/16” x 5.75”	Aluminum		$0.07
1.625” spring	32	1	-Unstretched -Attached to lever to maintain tension when in use	Steel		$0.05

7/16” spring	33	1	-Uncompressed -used to prevent damage to the lever mechanism when releasing from the lock position	Steel		$0.05

Table 3.1 Flow Process Chart - Heating System

Event Description	Symbol	Time	Distance	Method Recommendation
Secure the ranges of the heating elements within the wall of the shell	○	84 seconds	0	
Inspect fit of the range on the one side of the toaster	□	2 seconds	0	
Secure control shell onto the front side of the chassis	○	96 seconds	0	
Connect the right side of the chassis to the heating elements and range	○	140 seconds	0	Framework can be provided with metal unibody
Inspect fit of the range on the one side of the toaster	□	2 seconds	0	
Connect the left side of the chassis to the heating elements and range	○	96 seconds	0	Framework can be provided with metal unibody
Inspect all elements and ensure that the heating component is properly secure	□	2 seconds	0	

Table 3.2 Flow Process Chart - Structure System 1

Event Description	Symbol	Time	Distance	Method Recommendation
Grab base of toaster	○	3 seconds	0	
Place toaster shell on base	○	11 seconds	0	
Screw toaster shell onto base with ⅜ " screws	○	85 seconds	0	Can use an electric screwdriver to expedite the process
Place inductor onto base	○	7 seconds	0	
Screw inductor onto base using ⅝ " screws	○	50 seconds	0	
Ensure all parts secure	□	2 seconds	0	
Grab power cable	○	4 seconds	0	
Insert power cable through base	○	12 seconds	0	
Grab power cable shroud	○	7 seconds	0	
Place power cable shroud onto base	○	3 seconds	0	
Screw power cable shroud onto base with ½ " screws	○	75 seconds	0	Can use an electric screwdriver to expedite the process
Insert power cable into inductor	○	12 seconds	0	
Ensure all parts secure	□	2 seconds	0	
Grab aluminum slit	○	4 seconds	0	
Place aluminum slit onto aluminum shell	○	15 seconds	0	Framework can be provided with metal unibody
Ensure materials are secure	□	3 seconds	0	

Table 3.3 Flow Process Chart - Structure System 2

Event Description	**Symbol**	**Time**	**Distance**	**Method Recommendation**
Grab cover of toaster shell	○	3 seconds	0	
Place control interface into control shell	○	6 seconds	0	
Screw the control interface onto cover using ⅜" screws	○	80 seconds	0	
Attach inductor to control interface	○	24 seconds	0	
Secure cover of toaster shell onto base	○	20 seconds	0	
Screw cover of toaster shell into place with 7/16" screw	○	100 seconds	0	Can use an electric screwdriver to expedite the process
Make sure all parts are connected	□	2 seconds	0	
Grab lever cover	○	3 seconds	0	
Placelever cover onto lever sliding mechanism	○	6 seconds	0	
Grab crumb tray grip	○	2 seconds	0	
Grab crumb tray sheet	○	2 seconds	0	
Insert crumb tray sheet into crumb tray grip	○	13 seconds	0	
Place crumb tray into toaster shell	○	11 seconds	0	
Place studs onto base	○	17 seconds	0	
Ensure all parts are secure	□	2 seconds	0	

Table 3.4 Flow Process Chart - Control System

Event Description	Symbol	Time	Distance	Method Recommendation
Get control shell from compartment	◯	3 seconds		
Get ejection button from compartment	◯	3 seconds		
Attach control shell and ejection button	◯	6 seconds		
Get circuit board	◯	3 seconds		
Attach circuit board to control shell	◯	6 seconds		
Screw circuit board to control shell using ⅜’’ screws	◯	74 seconds		Can use an electric screwdriver to expedite the process
Grab knob from bin	◯	3 seconds		
Fit knob onto circuit board	◯	8 seconds		
Get cover from compartment	◯	5 seconds		

Table 3.5 Flow Process Chart - Ejection System

Event Description	Symbol	Time	Distance	Method Recommendation
Insert sliding mechanism into toaster slits	◯	20 seconds		
Insert lever spindle into shaft and through 7/16’’ spring	◯	10 seconds		Can use a different type of spring
Connect spindle to lever sliding mechanism	◯	12 seconds		
Secure top clasp	◯	10 seconds		
Make sure all parts are secured properly	▢	2 seconds		
Attach 1.625’’ spring to onto front of chassis	◯	10 seconds		
Connect bottom part of 1.625’’ spring to lever sliding mechanism	◯	15 seconds		
Make sure all parts are secured properly	▢	2 seconds		

Table 4.1 MTM Ejection System

Ejection system				
Left hand description	LH	TMU	RH	Right hand description
		17.5	R30A	Reach to bin
		2	G1A	Grab item from bin
Reach for object	R14B	14.4		
Grasp object	G1A	2		
		16.9	M14C	Move to toaster
		16.2	P2	Position the item
		2	RL1	Release the item
		10.5	R14A	Reach to bins in front
		2	G1A	Grab spindle
		14.4	M14A	Move arm back to work area
Grabs item	G1A	2		
		10.5	R14A	Reaches back to bin
		2	G1A	Grabs spring
		14.6	M14B	Moves arm back to work area

		2	G1A	Grabs item
		2	RL1	Releases item on spindle
Grabs the spindle	G1A	2		
		10.5	R14A	Reaches to bins
		2	G1A	Grabs lever attachment
		14.4	M14A	Moves back lever attachment
		2	RL1	Releases lever attachment on spindle
Moves spindle through the lever components	M4C	8		
Releases spindle	RL1	2		
Moves hand to top	R4B	6.4		
Grabs the top for support	G1A	2/6.4	R4B	reaches hand to to top
		2	G1A	Grabs tab
		3.4	M1C	Moves tab
		16.2	P2	Locks tab In place with force
		10.5	R14A	Reaches to bins
		2	G1A	Grabs spring

		14.6	M14B	Moves spring to location
		43	P3	Attaches one end of spring to toaster
		5.5	T45	Repositions toaster
		2.5	R1B	Reaches to other end of spring
		2	G1A	grabs other end of spring
		4.9	M3A	Moves other end of spring to lever
Moves hand to lever mechanism	R3B	5.3		
Grabs lever mech	G1A	2		
Moves lever down to check	M3B	5.7		
Releases the toaster lever	RL1	2		

Table 4.2 MTM Circuitry System

Circuitry				
Left hand description	LH	TMU	RH	Right hand description
Reach for circuit shell	R14A	10.5		
Grab circuit shell	G1A	2		
Move circuit shell	M14B	14.6		
		10.5	R14A	Reach for bin
		2	G1A	Grab button
		14.6	M14B	Move hand to circuit shell
		10.6	AP	Press button into shell
		10.5	R14A	Reach to bin
		2	G1A	Grab circuit
		14.6	M14B	Move circuit to shell
		5.6	P	Position in shell
Move shell to table	M5A	7.3		
Place on table	RL1	2		
Reach to bin	R14A	10.5		

Grab screw	G1A	2		
		11.5	R10B	Reach for screwdriver
		2	G1A	Grab screwdriver
		12.2	M10B	Move screwdriver back to work area
Move screw to screwdriver	M8B	10.6		
Move screw with screwdriver to circuit shell	M6B	8.9/10.6	M8B	Move screw with screwdriver to circuit shell
Position screw in hole	P1	5.6		
Release screw	RL1	2		
			T	Turn screwdriver until fastened
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole	M14B	14.6		
Position screw in hole	P1	5.6		
Release screw	RL1	2		
			T	Turn screwdriver until fastened

Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole	M14B	14.6		
Position screw in hole	P1	5.6		
Release screw	RL1	2		
			T	Turn screwdriver until fastened
		2	RL1	Release screwdriver
		10.5	R14A	Reach to bin
		2	G1A	Grab knob
		14.6	M14B	Move button to work area
Grab circuit board	G1A	2		
Life circuit board up	M8B	10.6		
		10.6	AP	Press the knob to front of circuit board
Lower shell to work area surface	M5A	7.3		
Release circuit shell	RL1	2		Release circuit shell

Reach for toaster shell	R30A	17.5		
Grab toaster shell	G1A	2		
			R8B	Reach for circuit shell
		2	G1A	Grab circuit shell
		10.6	M8B	Move circuit shell to toaster shells cut-out
		5.6	P	Position the circuit shell accordingly
		11.5	R10B	Reach for screwdriver
		2	G1A	Grab screwdriver
		12.2	M10B	Move screwdriver back to work area
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole	M14B	14.6		
Position screw in hole	P	5.6		
Release screw	RL1	2		

			T	Turn screwdriver until fastened
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole	M14B	14.6		
Position screw in hole	P1	5.6		
Release screw	RL1	2		
			T	Turn screwdriver until fastened
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole	M14B	14.6		
Position screw in hole	P1	5.6		
Release screw	RL1	2		
			T	Turn screwdriver until fastened
		2	RL1	Release screwdriver

Table 4.3 MTM Structural System 1

Structural System 1				
Left hand description	LH	TMU	RH	Right hand description
Reach to bin	R14A	10.5		
Grab base	G1A	2		
Move base to work area	M14B	14.6		
Reach toaster	R2B	4/14.4	R14B	Reach toaster
Grab toaster	G1A	2/2	G1A	Grabtoaster
Move toaster to base	M3A	4.9/4.9	M3A	Move toaster on to base
		5.6	P1	reposition
		10.1	R8B	Reach screwdriver
		2	G1A	Grab screwdriver
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole

		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		

Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
		2	RL1	Release screwdriver
Reach to inductor	R2B	4/10.1	R8B	Reach to inductor
Grab inductor	G1A	2/2	G1A	Grab inductor
Move into slot on base	M1C	3.4/3.4	M1C	Move into slot on base
		10.6	APA	Press into place
		10.1	R8B	Reach screwdriver
		2	G1A	Grab screwdriver
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole

		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
		2	RL1	Release screwdriver
		10.5	R14A	Reach for bin
		2	G1A	Grab cord
		14.6	M14B	Move cord to work area
Reach for base of toaster	R2B	4		
Grab toaster	G1A	2		
Lift toaster up	M2B	4.6		
		5.7	M3B	Move cord through hole of base

Reach for end of cord	R1A	2.5/2	RL1	release
Grab end of cord	G1A	2		
Lead end of cord to the inductor	M1B	2.9		
		10.5	R14A	Reach for plastic holder
		2	G1A	Grab plastic holder
		14.6	M14B	Move plastic holder to designated divet on base
		10.1	R8B	Reach screwdriver
		2	G1A	Grab screwdriver
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		

Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole
		9.4	T180	Twist screwdriver until screw is secured
Reach for bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to work area, and into hole	M14A	14.4		
		10.6	M8B	Move screwdriver to hole

		9.4	T180	Twist screwdriver until screw is secured
Reach for base	R8B	10.1		Release screwdriver
Grab base	G1A	2		
		10.1	R8B	Reach for end of cord
		2	G1A	Grab end of cord
		3.4	M1C	Move ends of cord into the inductor
Release	RL1	2		
Reach for aluminum slit	R30A	17.5		
Grab aluminum slit	G1A	2		
Move aluminum slit to top of toaster shell	M30B	24.3		
		10.1	R8B	Reach for aluminum slit
		2	G1A	Grab aluminum slit
Press onto shell	APA	10.6/10.6	APA	Press onto shell

Table 4.4 MTM Structural System 2

Structural System 2				
Left-handed description	LH	TMU	RH	Right Hand description
		14.4	R14B	Reach toaster shell
		2	G1A	Grab toaster shell
		10.6	M8B	Move toaster shell on top of metal toaster
Reach toaster	R14B	14.4		
Grab toaster	G1A	2		
Turn toaster	T45	5.5		
Release	RL1	2		
Reach toaster shell	R1B	2.5		
Held toaster shell	G1A	2		
Move toaster shell onto toaster	M2A	3.6/3.6	M2A	Move toaster shell onto toaster
		2	RL1	Release toaster shell
		2.5	R1B	Reach for inductor wire

		2	G1A	Grab inductor wire
		2.5	M1A	Move inductor wire into the slot on inner wall of shell
		2	RL1	Release
		4	R2B	Reach to toaster shell
Reach to toaster shell	R2B	4		
Hold all components together	G4C	12.9	G4C	Hold all components
Turn toaster onto back	T180	14.8	T180	Turn toaster onto back
		10.1	R8B	Reach to screwdriver
		2	G1A	Grab screwdriver
		10.6	M8B	Move screwdriver to work area
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole on toaster	M14C	16.9		
		14.8	T180	Twist screw into place until secured

Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole on toaster	M14C	16.9		
		14.8	T180	Twist screw into place until secured
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole on toaster	M14C	16.9		
		14.8	T180	Twist screw into place until secured
Reach to bin	R14A	10.5		
Grab screw	G1A	2		
Move screw to hole on toaster	M14C	16.9		
		14.8	T180	Twist screw into place until secured
Reach to bin	R14A	10.5		
Grab screw	G1A	2		

Move screw to hole on toaster	M14C	16.9		
		14.8	T180	Twist screw into place until secured
Reach toaster	R1B	2.5		
Grab toaster	G1A	2		
Flip toaster onto base	T180	14.8		
		2	RL1	Release screwdriver
		10.5	R14A	Reach bin
		2	G1A	Grab lever cover
		14.6	M14B	Move lever cover to lever slit
		2	RL1	Release
		10.5	R14A	Reach bin
		2	G1A	Grab crumb tray cover
Reach bin	R14A	10.5		
Grab crumb tray	G1A	2		
Move tray to grip	M22A	20.8/20.8	M22A	Move grip to tray

		10.6	APA	Apply force until both pieces are connected
release	RL1	2		
Reach for toaster	R2B	4		
Grab toaster	G1A	2		
Lift toaster onto back	T90	8.5		
		11.8	M8C	Move crumb tray into the slot on back of toaster
		2	RL1	Release
		10.5	R14A	Reach bin
		2	G1A	Grab rubber stop
		16.9	M14C	Move rubber stop into holes on bottom of toaster
		10.5	R14A	Reach bin
		2	G1A	Grab rubber stop
		16.9	M14C	Move rubber stop into holes on bottom of toaster

Table 4.5 MTM Heating System

Heating System				
Left hand description	LH	TMU	RH	Right hand description
		17.5	R30A	Reach to bin
		2	G1A	Grab range
			M14B	Move range to work surface
Reach to aluminum shell	R14B	14.4		
Grab the shell	G1A	2		
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		3.4	M1C	Move clasp
		2	RL1	Release
		10.5	R14A	Reach to bin
		2	G1A	Grab range
		14.6	M14B	Move range to work surface
Reach to aluminum shell	R14B	14.4		

Grab the shell	G1A	2		
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		6.7	M1C	Move clasp
		2	RL1	Release
Reposition shell	T180	9.4/9.4	T180	Reposition shell
		10.5	R14A	Reach to bin
		2	G1A	Grab range
		14.6	M14B	Move range to work surface
Reach to aluminum shell	R14B	14.4		
Grab the shell	G1A	2		
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		6.7	M1C	Move clasp
		2	RL1	Release
		10.5	R14A	Reach to bin

		2	G1A	Grab plate
Reach to shell	R14B	14.4/14.6	M14B	Move plate to the shell, and insert to slits
Grab shell	G1A	2		
		2.9	R1B	Reach to wire
		2	G1A	Grab wire
		2.5	M1A	Move wire to slit
Reach top of shell	R6B	8.6		
Hold components together	G4A	7.3		
		10.1	R8B	Reach to plier
		2	G1A	Grab plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier

		2	RL1	Release plier
Reach to wire	R1B	2.5		
Grab wire	G1A	2		
Move wire to slit	M1A	2.5		
Reach to wire	R1B	2.5		
Grab wire	G1A	2		Reach to wire
Move wire to slit	M1A	2.5/2	G1A	Grab wire
			M1A	Move wire to slit
		2	G1A	Grab plate
Reach to bin	R14A	10.5		
Grab plate	G1A	2		
Move plate to work area	M14B	14.6		
		6.4	R4B	Reach plate
		2	G1A	Grab plate
		2.9	M1B	Reposition plate
Reach to shell	R14B	14.4		
Grip shell	G1A	2		

		10.6	APA	Press the heating element into plate
		6.4	R4B	Reach to top of plate
		2	G1A	Grab clasp
		3.4	M1C	Move clasp
		2	RL1	release
		10.1	R8B	Reach to plier
		2	G1A	Grab plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier

		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		2	RL1	release
		10.5	R14A	Reach to bin
		2	G1A	Grab range
		14.6	M14B	Move range to work area
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		3.4	M1C	Move clasp
		2	RL1	Release
		10.5	R14A	Reach to bin

		2	G1A	Grab range
		14.6	M14B	Move range to work area
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		3.4	M1C	Move clasp
		2	RL1	Release
Reposition toaster	T90	5.4		
		8.6	R6B	Reach plate
		2	G1A	Grab plate
		5.4	T90	Reposition plate
Reach to shell	R14B	14.4		
Grip shell	G1A	2		
		10.6	APA	Press the heating element into plate
		6.4	R4B	Reach to top of plate
		2	G1A	Grab clasp
		3.4	M1C	Move clasp

		2	RL1	release
		10.1	R8B	Reach to plier
		2	G1A	Grab plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier

		5.4	T90	Twist plier
		6.9	M4B	Move plier to slits
		10.6	APA	Squeeze plier
		2	RL1	release
		10.5	R14A	Reach to bin
		2	G1A	Grab range
		14.6	M14B	Move range to work area
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		3.4	M1C	Move clasp
		2	RL1	Release
		10.5	R14A	Reach to bin
		2	G1A	Grab range
		14.6	M14B	Move range to work area
		16.2	P2	Attach the range to shell
		8.6	R6B	Reach to clasp
		3.4	M1C	Move clasp

		2	RL1	Release
		5.3	R3B	Reach for toaster
		2	G1A	Grip toaster shell
		27.1	M30A	Move toaster shell to assembly on right