WISCOOTER

FINAL DESIGN PROPOSAL

ISYE 350: JUNIOR DESIGN LAB

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1 Executive Summary

Our client, WiScooter, is experiencing rapid growth in demand for their 3 current scooter stock-keeping-units (SKUs) and expects high demand for their 2 new commercial SKUs as well (Original SKUs: 1, 2, and 3; New SKUs: 4 and 5.). WiScooter does not currently have the capacity to meet that demand over the next 10 years, and plans to increase capacity at the current manufacturing facility in Madison WI, and move finished goods inventory to a nearby warehouse in Middleton. We were tasked with creating a factory layout and expansion plan that meets demand and also satisfies COVID-19 regulations.

Before we could start on the expansion plan, we had to outline WiScooter's priorities and the evaluation criteria for the project. We did this in the form of an Activity Network Diagram, which predicted the project to take 98 days to complete. We also had meetings with the client, which helped us determine the important metrics of the company: product quality, facility safety and keeping up with demand.

We came up with multiple designs focusing around a single core concept. With the help of the Pugh Matrix we were able to narrow it down to one alternative. Once we had the Design Option, we could move forward to conduct the Capacity, Inventory and MOST Analysis to deduce the production schedule, production process and order schedule. Next, we were able to draft layouts to find the most efficient way to organize the machines as well as comply with COVID – 19 guidelines. Finally, we conducted a FMEA Analysis to find which areas could be improved further. We found 4 aspects with high RPN. We recommended steps WiScooter could take to improve their throughput as well as meet with the growing demand for the next 10 years.

2 Project Definition

WiScooter – a manufacturing company that sells and ships e-scooters throughout the United States has recently started experiencing rapid growth. WiScooter offers five types of scooters, each serving a purpose different from the other. Due to this rapid growth, our team – The ISYEcles – was tasked with Design Option 1. This option encouraged our team to come up with an expansion plan for the WiScooters current manufacturing facility that will increase capacity and move finished goods inventory to a warehouse nearby in Wisconsin.

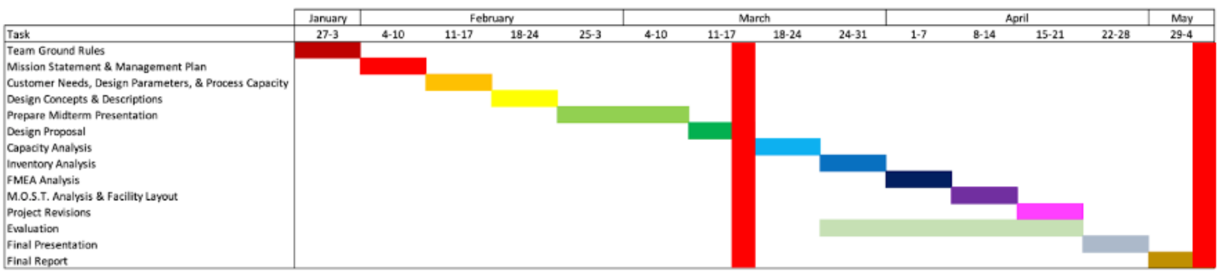
2.1 Project Charter

The purpose of our project was to outline a plan that explains steps that WiScooter can implement in order to keep up with the demand via means of outsourcing to an additional, leased warehouse. To allow WiScooter to keep up with the demand, we conducted Capacity Analysis, Inventory Analysis and MOST Analysis. These analyses helped us determine the production schedule, production process and ordering schedule. Additionally, we came up with Assembly Layouts, Workstation Layouts and Facility Layouts to find ways to free up space and reorganize machines to increase throughput and produce goods in the most efficient manner.

For the scope of our project we deduced that the current facility is roughly 120,000 square feet, the new renovation will free – up 40,000 square feet of the previously noted facility as all finished goods will be moved to another warehousing and distribution facility nearby in Wisconsin. The extra space can now be allocated towards additional manufacturing and assembly areas.

Furthermore, we also came up with some budgetary considerations. The cost per square foot per year to lease the new space (a 72,000 square feet footprint in nearby Middleton; dimensions of 360ft x 200ft x 20ft) is $1.00. The current SKU could be optimized to now manufacture 5 SKU's to account for the increased demand and new space; additional costs will appear when said machinery is added/replaced, workflow is modified/reconfigured and additional work cells are added.

2.2 Project Schedule



Key Dates	
10-Feb	Client Meeting 1
10-Mar	Midterm Presentation
17-Mar	Design Proposal & Client Meeting 2
28-Apr	Final Presentation
4-May	Final Report

Figure 2.1 Gantt Chart

Our project schedule is depicted as the Gantt Chart in Fig 2.2. The Gantt Chart shows the general timeline of activities completed during the project, the tasks that are completed since the project proposal until now are highlighted by the red columns, including various analyses of existing and proposed facilities, the creation of a final design plan, and evaluations of the project.

2.3 Activity Network Diagram

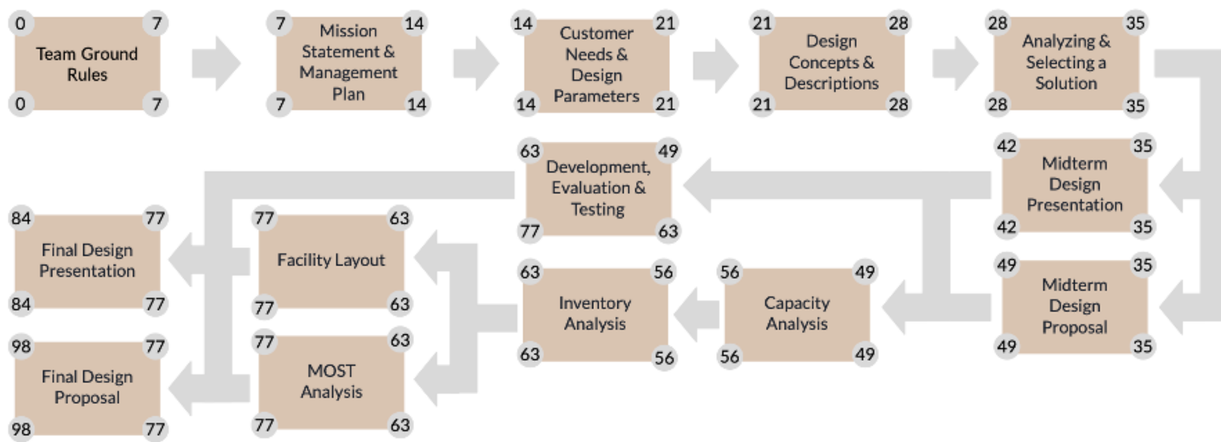


Figure 2.2 Activity Network Diagram (AND)

A tool that we used to map out the design process was an Activity Network Diagram. This helped the team to ensure that each task is being completed in the correct order and within the desired timeframe. We projected that the whole project would take 98 days to complete.

2.4 Resources

The resources that were considered during the project were divided into three groups: People, Equipment and Supplies and Time. The people that were closely related to the project were the ISYEcles members, the client (Prof. Radwin), the Engineering Manager (Laura Younan) and the WiScooter Employees. The equipment and supplies that were required are the old facility, the newly leased facility, new equipment for manufacturing and assembly; replaced/added/modified etc, new equipment for the newly leased warehouse distribution center (finished products) and the products produced. Lastly, we allocated time for the project from February 3rd, 2021 to May 4th, 2021.

We have visualized our plan for the distribution of resources in the Aggregate Resource Table below:

Assignments	Lab Time	Meeting Time	Personal Time	Resources		
Team Ground Rules	45	0	0	Lab Notebook		
Design Project Mission Statement and Management Plan	60	0	0	Google Drive	Lab Notebook	Draw.io, Excel
Customer Needs, Design Parameters, and Process Capability	30	45	0	Google Drive	Lab Notebook	Messages (Group Chat)
Design Concepts and Descriptions	45	30	30	Google Drive	Lab Notebook	Draw.io, Visio
Tools for Analysing and Selecting a Solution	60	0	25	Google Drive	Lab Notebook	Messages (Group Chat)
Design Proposal and Mid-Term Design Presentation	60	30	30	Google Drive	Lab Notebook	Messages (Group Chat)
Capacity Analysis of current facility	45	30	0	Google Drive	Lab Notebook	Messages (Group Chat)
Inventory Analysis	30	30	0	Google Drive	Lab Notebook	Excel
FMEA Analysis	50	20	0	Google Drive	Lab Notebook	
MOST Analysis and Facility Layout	45	0	0	Google Drive	Lab Notebook	Excel
Complete Final presentation	60	30	30	Google Drive	Lab Notebook	Messages (Group Chat)
Complete Final Design Report	60	30	45	Google Drive	Lab Notebook	Messages (Group Chat)
Available Time	750	500	240			
Allocated Time	590	245	160			
Capacity Utilization	79%	49%	67%			

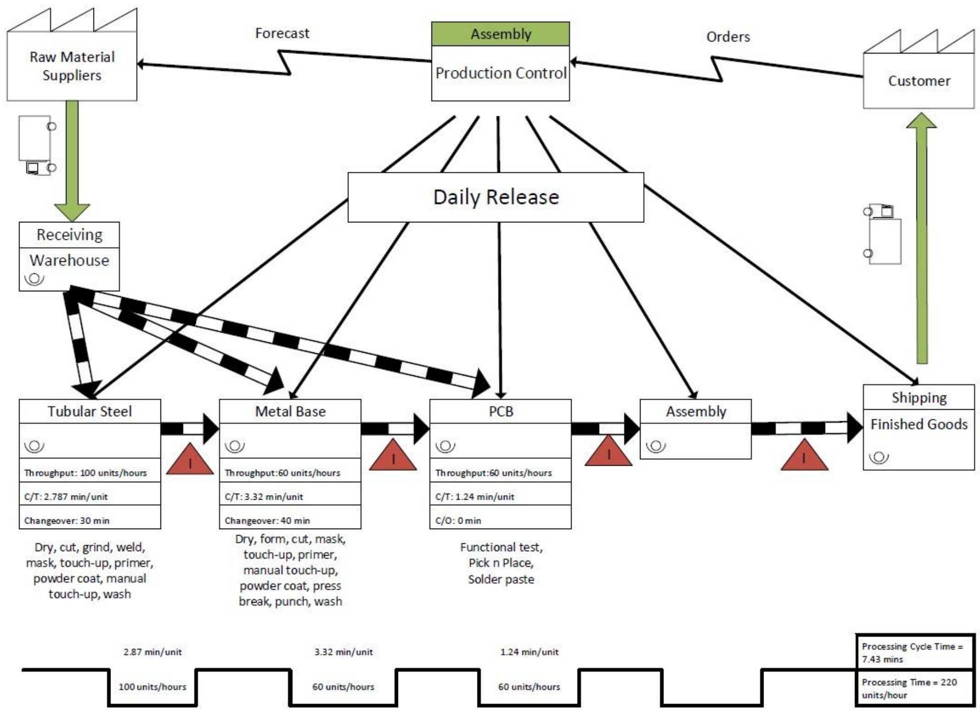
Table 2.4 Aggregate Resource Table

3 Project Goals and Objectives

3.1 Customer Needs and Design Parameters

WiScooter is currently experiencing rapid growth, and there are two new product stock keeping units (SKUs) that need to be included into the production line. The planned five SKUs are three lightweight scooters for personal use and two heavy duty scooters for commercial use. However, the current production process contains manufacturing and inventory in the same facility, which is shown in Figure 3. Since the current Wisconsin facility is designed only for three SKUs, the production capacity would not be able to support the anticipated customer demand for all SKUs, so the client's general need is a design alternative to meet the increasing demand and ensure quality of the products, workplace safety and efficiency of responding to demand.

Figure 3.1: Value Stream Map

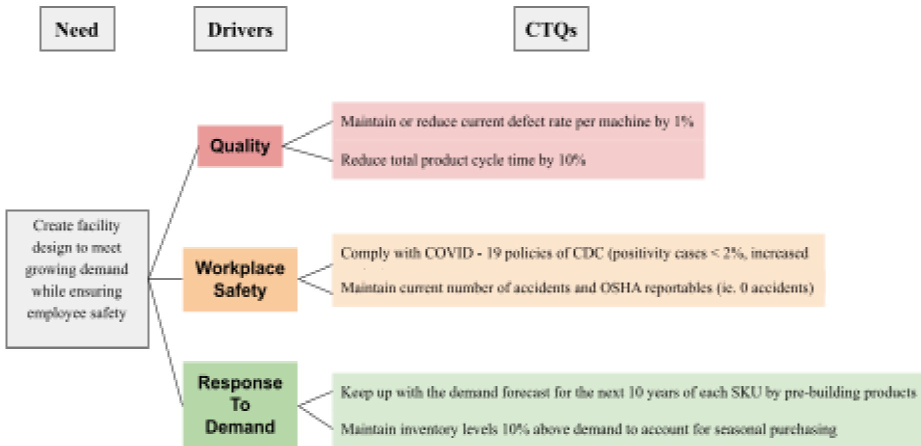


The VSM of the current Madison facility indicates that there is insufficient material flow for the production of five SKUs.

The potential alternative our team is assigned is Option 1, renovating from the dual-purpose manufacturing and distribution center into an exclusive manufacturing facility. In order to accomplish the renovation, all finished goods inventory will be moved to a new warehousing and distribution facility in Middleton, WI. The exclusive manufacturing facility is 120,000 square foot which is the same as the current facility, and the new warehouse is 72,000 square feet. The primary needs of the client is increasing production capacity to meet customer's demand and meeting workplace safety standards including Covid-19 requirements. The cost of renovation and manufacturing change are beyond the scope of the project.

To develop and evaluate the project based on the customer's needs, our team used Critical-to-Quality Tree (see Figure 4) to specify the general need of the client into three drivers and construct two critical features of each driver. Quality of the products is the first consideration, and our team would examine the defects in the products regularly and collect verified data chronologically. The detailed requirements of product quality would be maintaining or reducing the current defect rate per machine by 1% and reducing total product cycle time by 10%. Workplace safety is the second critical driver which can be measured by COVID-19 policies from the CDC Department, and the design alternative would be able to maintain or reduce the number of accidents. According to the meeting with the client, Prof. Randwin, there are no accidents occured in the current facility, therefore, our team would study the current layout and safety procedures in order to perform a high standard of safety. In order to meet customer’s demand on time and adapt to unexpected changes in the market, efficient operation is important. The related factors are keeping up with the demand forecast for the next 10 years and maintaining inventory levels 10% above demand to account for seasonal purchasing, such as summer seasons.

Figure 3.2: Critical-to-Quality Tree



A visual to see the drivers of an efficient design and the measurables CTQ's associated with each driver.

3.2 Design Evaluation Criteria and Relative Weighting

3.2.1 Design Evaluation Criteria

1. Workplace safety:
   a. Employee safety is always the primary consideration in manufacturing, since the working station is equipped with machines.
2. Lead Time:
   a. The design alternative would decrease the lead time for shipping and manufacturing. Since the facility needs to produce five SKUs in the future, the lead time needs to be limited to adapt the expansion. The lead time of shipping products from the manufacturing facility to the warehouse should be minimized, so products can be shipped to customers quickly.
3. WIP Inventory:

   a. Inventory levels of the raw materials and WIP in manufacturing facilities need to be controlled and monitored, so the amount of raw materials can support the production and no overstock WIP in the production process.

4. Product Quality:
   a. Product quality should also be maintained based on the standards set by the client, so the business would keep a healthy manufacturing and working environment.
5. Capacity:
   a. The capacity of the warehouse should support the inventory of all the finished goods, so the manufacturing purpose of the new facility can be maximized. The capacity of the manufacturing facility is measured based on the production of all five SKUs. Therefore, additional machines and equipment are needed.
6. Layout Flexibility:
   a. The flexible layout would improve the efficiency of production, easy for future expansion and minimize waste of the process.
7. Material Handling:
   a. The layout of the fabrication and assembly sections is designed to reduce waste and improve efficiency in material handling.
8. COVID-19 Safety:
   a. Due to the pandemic, social distancing is very important. The design alternative will strictly follow the policies of CDC Department and adapt for regular testing.
9. Sustainability:

a. Equipment which supports good sustainability could be considered in the process, such as solar panels. The improvement can decrease the cost of production to some extent.

10. Utilization:

    a. The design of the fabrication and assembly stations should be realistic based on transportation and material flow inside each station. Purchased machines and equipment should be utilized in the process, so there is minimum or no unnecessary cost or process.

3.2.2 Relative Weighting

After deciding the ten design criterias, our team used pairwise ranking method to compare each criteria with the rest of criterias. Then, we recorded the number of wins each criteria got in the process. Each criteria is weighted on a scale from 1 to 10. After analyzing the weight of each criteria, from the table, the most weighted criteria would be workplace safety and the least weighted would be sustainability. The top weighted criterias are workplace safety, capacity, COVID-19 safety, lead time, and product quality.

Figure 3.3: Pairwise Ranking

Index		A	B	C	D	E	F	G	H	I	J
	Criteria	Workplace Safety	Lead Time	Low WIP Inventory	Product Quality	Sustainability	Capacity (Demand)	Layout Flexibility	Material Handling	COVID-19 Safety	Utilization
A	Workplace Safety		A	A	A	A	A	A	A	A	A
B	Lead Time			B	B	B	F	B	B	I	B
C	Low WIP Inventory				D	C	F	G	C	I	C
D	Product Quality					D	F	D	D	I	D
E	Sustainability						F	G	H	I	J
F	Capacity (Demand)							F	F	F	F
G	Layout Flexibility								G	I	G
H	Material Handling									I	H
I	COVID-19 Safety										I
J	Utilization										

Index	Criteria	Wins	Weight
A	Workplace Safety	9	10
B	Lead Time	6	7
C	WIP Inventory	3	4
D	Product Quality	5	6
E	Sustainability	0	1
F	Capacity (Fulfilling Dema	8	9
G	Layout Flexibility	4	5
H	Material Handling	2	3
I	COVID-19 Safety	7	8
J	Utilization	1	2

4 Design Concepts and Problem Analysis

4.1 Brainstorming, Affinity Diagram and Process for Weighing Criterias

To start the brainstorming process, the following prompt was proposed: “What are the most important design considerations to incorporate into the manufacturing facility and distribution center to ensure the needs of the client are met?” Each member of the group contributed 10 possible design ideas, features, and or solution-based approaches to address the specified question. No ideas were excluded to promote creativity and a diversity in thought.

Once these ideas were finalized, they were grouped by likeness via affinity diagramming into the following ten categories: ‘Factory Flexibility’, ‘Factory Layout’, ‘Covid-19 Safety’, ‘Worker Safety’, ‘Inventory Systems’, ‘Shipping/Receiving’, ‘Service Level/Meeting Demand’, ‘Sustainability’, ‘Product Quality’, and ‘Material Handling’. These conceptual groupings were then converted into actionable design alternatives and or approaches that satisfied the design challenge at hand. These eight design alternatives included: ‘Flexible Manufacturing Facility’, ‘Job Shop’, ‘Split Production (1, 2 / 3, 4, 5)’, ‘Hybrid Inventory’, ‘Single Line’, ‘Higher Cost Sustainability’, ‘Split Production (1, 2, 3 / 4, 5)’, and ‘Flexible Quality’.

Figure 4.1: Affinity Diagramming

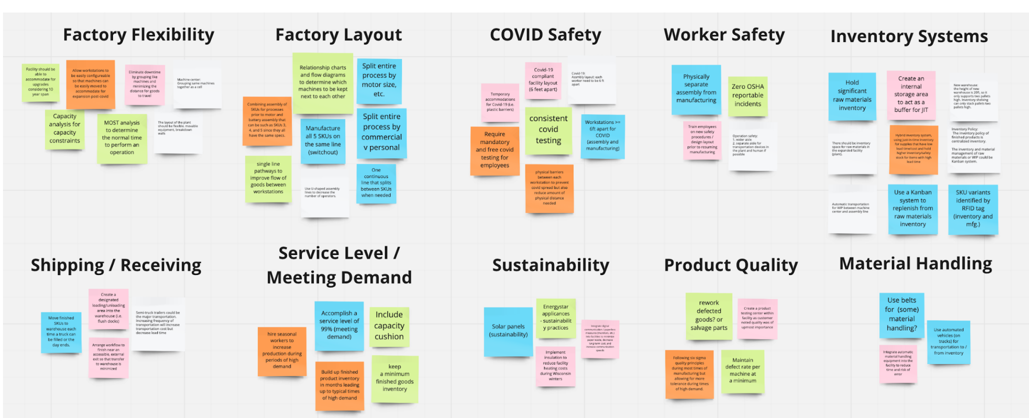


Figure 4.2: Actionable Design Alternatives

There were an amplitude of different considerations when deciphering what design alternatives were preferable over the others; one of the main considerations was prompted via the initial client meeting when our client noted that layout flexibility was of utmost important to account for fluctuations in demand and growth in the upcoming years as well as satisfy the need for alterations due to the impacts of Covid-19 (i.e. facility alterations to incorporate social distancing, flexibility for less demand due to a decrease in disposable income during the pandemic, etc.). Our client also noted that safety- both in regards to that of Covid-19 and general workplace standards- were to be top considerations within our given design. Other considerations included lead time, WIP inventory, product quality, sustainability, capacity, material handling, Covid-19 safety, and utilization. The designated weights for the listed criteria can be found below.

Table 4.1: Weighted Value per Consideration

	Weight
Workplace Safety	10
Lead Time	7
WIP Inventory	4
Product Quality	6
Sustainability	1
Capacity (Fulfilling Demand)	9
Layout Flexibility	5
Material Handling	3
COVID-19 Safety	8
Utilization	2

The weight given to these specified attributes was in part related to the previously noted areas of emphasis given by the client themselves (most notably that of safety and flexibility). Other areas in which our team gave ample weight to were considerations that enabled the facility to meet demand as this was the main, driving factor for the project in the first place; the design needed to satisfy additional considerations- such as safety, compliance, sustainability, etc.- but the main objective was to meet the demand that prompted this expansion. Thus, the weight allocated to each of these considerations reflected their ability to meet this primary objective.

Then, after anonymously undergoing a multi-voting process, these eight conceptual design alternatives were decisively narrowed down into four viable, actionable solutions: ‘Flexible Manufacturing Facility’, ‘Split Production (1, 2 / 3, 4, 5)’, ‘Hybrid Inventory’, and ‘Flexible Quality’.

4.2 Design Alternatives

The first design alternative our group proposed was coined as ‘Flexible Manufacturing’; the main focus of this design was to enable the layout to scale in accordance to demand. This design accounts for general alterations in job shop layout as the manufacturing facility operates under a Just-in-Time (JIT) inventory system allowing for no excess products to be held in case there are fluctuations in demand. The material handling system follows suit and is seemingly ‘temporary’; movable safety measures will be put into place and physical distancing will be implemented where possible to prevent the spread of Covid-19 in a flexible manner.

The second design alternative our group proposed was a ‘Split Production Line’. This design suggests that all 5 SKUs are manufactured on a continuous production line; this production line is then split into 2 sections: one for SKUs 1 and 2, and the other for SKUs 3, 4 and 5. This alternative would use just in time concepts to minimize lead times via work-in-process inventory. Thus, material handling will require efficiency for small quantities and raw material inventory will be stored close to the production line to decrease travel distance and duration. Safety solutions for Covid-19 will mimic the same as in Alternative One accounting for safety through flexibility.

The third alternative our group proposed was a ‘Hybrid Inventory’ design alternative. The main objective of this design alternative is to keep the work-in-progress inventory to a minimum. Additionally, this alternative would follow a job shop layout. Implementing a job shop layout will increase workflow, throughput and allow for more safety and maneuverability. The Hybrid Inventory alternative would follow Covid - 19 guidelines by introducing plexiglass, mask mandate and social distancing.

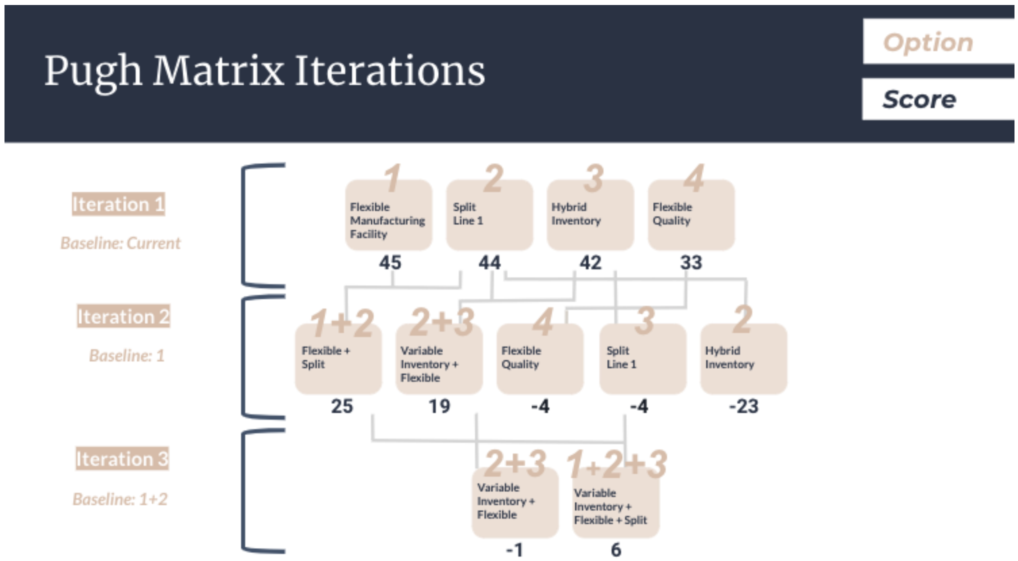
The fourth alternative our group decided was a ‘Flexible Quality’ design alternative. In this design concept, we would not focus as much on product quality and in turn, we would be able to make better use of our resources and make any changes in production volume to meet with the fluctuating demand. Additionally, this alternative would follow a just-in-time production model and a job shop layout to increase flexibility and allow for rearranging the shop floor if required. Finally, this design alternative would mimic the COVID - 19 guidelines as the rest of the alternatives.

4.3 Pugh Matrix

Our Pugh Matrix consisted of 4 options and 10 criterias. We compared each criterion with our baseline by putting positive, negative and 'same' symbols. At the end of our first iteration we discovered that option 1 scored the highest and that became our baseline for the next iteration. Additionally, we merged options 1 and 2 to get a hybrid option that consisted of flexible manufacturing from option 1 and increased throughput from option 2. Following the same thought process, we merged options 2 and options 3 to get another hybrid option consisting of minimized lead times and a lower work-in-progress inventory.

Next, we conducted the second iteration, where we got the highest score for the combined option 1 and option 2. This resulted in the combined option being the baseline for our third iteration. We repeated the same process and merged options 1, 2 and 3 and options 2 and 3. Finally, we got the highest score for the combined options 1, 2 and 3 and hence, proposed that as our final design alternative.

Figure 4.3: Pugh Matrix



Pugh Matrix containing 4 options and 3 iterations

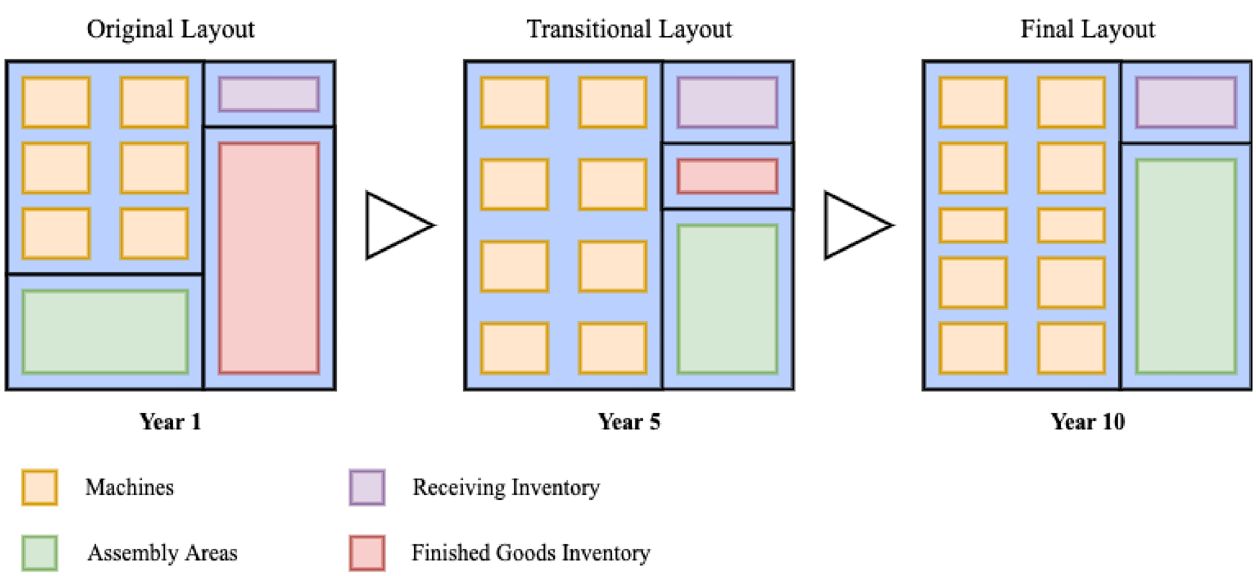
4.4 Selected Design Alternative

Moving forward, we recommend that WiScooter implements our final design alternative. Given its performance in the selection process against the other alternatives, it is the most optimal solution of the options we generated. With WiScooter's approval, we can draft a facility layout and a plan to meet demand and COVID-19 regulations over the next 10 years.

The final design alternative is a combination of the previously described alternatives 1, 2, and 3. That is, it combines ideas focused on factory configurability, agile inventory management, and that splits production paths between SKUs 1, 2 and 3, 4, 5. To put this all together, we'll use a job shop layout and prioritize flow for both SKU production paths, since they share multiple parts and processes.

Each machine and fixture in the factory will be movable in the short term between different areas in the factory to be able to dynamically shift paths when new capacity or regulations are added. For example, to comply with COVID-19 regulations, you could move all machines so that they're 6 ft apart and attach plexiglass screens to workstations to ensure employee safety. Configurability will also help to efficiently meet demand. WiScooter will be adding capacity to meet demand over the next 10 years, and adding it gradually will save money and leave more space for material handling and COVID-19 safety features as WiScooter adds capacity over time. Below is an example of a shifting, configurable layout.

Figure 4.4: Example Layout



An example of what a configurable layout could look like.

The inventory management system in the facility will be focused on keeping WIP inventory to a minimum. We want to be able to adjust production dynamically to keep up with changes in demand over time. To do so, lead times need to be short and WiScooter needs to be able to shift production schedules readily. Thus, material handling must quickly and efficiently supply materials to and between processes. To do this, we propose a kanban system that automatically detects and supplies materials across the facility. Autonomous vehicles will be employed for larger quantities and smaller quantities can be distributed by hand throughout workstations. This ensures that WIP inventory stays low and that processes don't run out of materials.

Where it is advantageous, we will split production between SKUs 1, 2, and 3, 4, 5. Because these SKUs have similar parts, we can have 2 efficient process paths through the factory and then combine them for similar processes. This will be challenging to implement for a process layout, but ultimately this will increase factory throughput and ability to produce SKUs quickly.

With all of these features in mind, we plan to move forward and draft a factory layout and expansion plan for WiScooter. It will be a challenge to maintain these design concepts as we develop our design, but if implemented successfully, this design will meet all of WiScooter's and our team's priorities. We await approval from WiScooter and hope to hear back, so we can continue to work towards WiScooter's success.

5 Design Approach

5.1 Capacity Analysis and Machine Selections

We started by determining WiScooter's future machine needs with a capacity analysis. Our design focused on making the facility configurable, and splitting production between SKUs to reduce cycle times and increase flow through the facility. In order to incorporate these design concepts into the final facility layout, we'd have to make multiple layouts at different intervals and divide machines between SKUs in a way that reduced or eliminated changeover time.

To ensure that our factory was configurable, we decided to increase capacity incrementally, and thus have 4 layouts, one for each 2.5 year period over the next 10 years. To calculate the amount of machines we'd need for each layout, we used the maximum demand over each period, with a goal of meeting demand while utilizing at most 95% of capacity. We mostly used machines that were already present in the manufacturing facility to reduce the need for new training, but the deluxe pick and place machine provided excellent capacity per square foot, so we used that instead of the standard machine.

SKUs 1, 2, and 3 all use standard metal in the punch press, press break, and forming machine, while SKUs 4 and 5 use industrial metal. SKUs 1, 2, and 3 also have colored paint while SKUs 4 and 5 do not. This means that if we separate the above machines by SKU for separate processes, we can better organize flow, and eliminate changeover times in these processes. To calculate the amount of machines we needed for each of these processes, we calculated separately the amount of machines we'd need for each group of SKUs, and then added it together. With the paint booth, we simply had a single booth dedicated to colored paint, which handled all of the colored units.

With a capacity analysis completed for all 4 of the 2.5 year period over the next 10 years, we had the necessary number of machines for the corresponding facility layout. Planning for maximum demand should allow WiScooter to easily meet forecasted demand over the next 10 years, even if the estimates fluctuate over time. We do however, suggest that WiScooter continually updates its demand model and adjusts to changes accordingly.

5.2 Inventory Analysis and Shelving Layout

Our approach will utilize that of a combination Q model and economic order quantity model; this would minimize total holding costs and ordering costs via ordering accurate amounts of inventory per batch and placing these specified orders once the inventory level reaches its predetermined reorder point. We were able to utilize the demand forecasts to be able to calculate estimates on inventory numbers such as pallets of finished goods and raw materials which gave us insights into the amounts of space needed. We did this primarily by analyzing these data forecasts to find the maximum value of any month for each SKU. By using the maximum, we can safely estimate the amount of space needed without any risk of not having enough space, especially in the earlier years of the plan. Furthermore, by converting these maximum monthly demand values into daily demand estimates we can calculate the number of raw materials required and thus the amount of space required by multiplying by the lead time of each and identifying the required number of pallets.

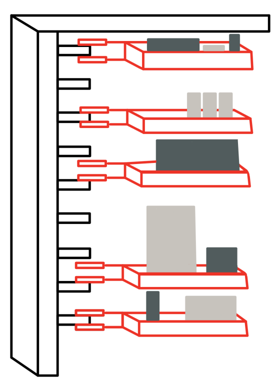
Utilizing demand forecast, the maximum monthly demand- and thus maximum daily demand- per SKU can be calculated to gauge how many parts are to be expected and thus ordered. As mentioned within inventory analysis, the maximum daily demand for the SKU’s is as follows: 856 for SKU 1, 761 for SKU 2, 456 for SKU 3, 299 for SKU 4, and 310 for SKU 5. A total of 335 pallets are needed to meet this maximum daily demand; the following inventory system (detailed below) will be implemented to account for these derived values.

Our design will utilize ‘Point-of-Use (POU) Automated Storage and Retrieval Systems’; POU systems align with lean principles as they are efficient and flexible. They help to reduce waste (i.e. transportation waste, waiting waste, etc.) via enabling operators to add value to the product efficiently by minimizing the requirement to retrieve materials as they automatically supply what good is needed. These AS/RS systems will thus enable an efficient goods-to-person (i.e. POU) principle bringing the specified goods directly to the operator via the shortest route possible thus increasing productivity. The movement of goods can then be tracked and allow for real-time data of the raw and WIP inventory; this data will be key in our flexible design enabling for a fluctuation of production dependent on the current trends of the demand. Thus, this increase in control will help to eliminate any overstock and or stock-out of needed goods even with the flexible nature of our design's production capabilities.

Not only will these systems allow for internal monitoring, but they also enable physical rearrangements; they are flexible and can be moved and or reconfigured should the inventory- and thus storage requirements- change rapidly allowing for a cost-effective, easy reconfiguration. Another key element of this inventory system that aligns with our client's needs is its emphasis on safety; with the decrease of product and employee movement, the overall ergonomic status of the facility will increase. The machines will be altered to adjust to the designated worker's specific, physical requirements to further eliminate extraneous movements such as bending and squatting. This will also increase quality by decreasing possible human error. The shelving itself will be tall and maximize the vertical dimensions of the room reaching up to that of the ceiling height and thus increasing inventory capacity through maximum floor-space utilization.

WiScooter will acquire 'vertical lift modules'- a type of AS/RS- as they are ideal for highly variable parts and inventory that are frequently altered; they maximize ceiling height and thus they often reduce wasted manufacturing floor space anywhere from 80% to 90%. It will consist of two columns of trays with an inserter/extractor in the center and withhold highly adjustable components that enable for the precise allocation of resources to the operator via the simple push of a button. As the average VLM is 10 feet wide and 10 feet deep, space is overabundant when contrasted to the sq ft taken by the required pallets and materials. Thus, about 5 units will be purchased initially- these units will be separated per SKU; each machine equates to about 100 sq feet of floor space. Each has 5,000 sq feet cumulatively (when taking into account vertical space). Our VLM's will maximize vertical space within the manufacturing facility. This is ample space per SKU as SKU 1 requires 384 sq ft of space, SKU 2 requires 464 sq ft of space, and SKU 3, 4, and 5 require a total of 976 sq ft of space. One unit will be utilized per SKU for raw materials and WIP materials as they are flexible and can be altered with the demands of our facility. The spacing between trays is customizable and thus there are ample rows of goods within each VLM; this extra space will foster growth internally within WiScooter should there be an increase in demand within the upcoming years.

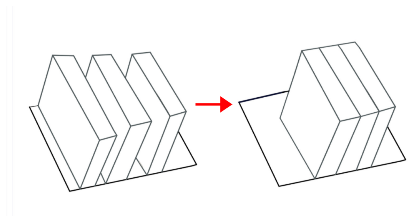
Figure 5.1: Vertical Lift Module - Tray Spacing Internal View



The customizable tray spacing on the vertical lift module enables for flexible storage options through increased slotting options and thus increased SKU management.

Finished goods will be stored and separated by SKU for organizational purposes and ease of inventory analysis in a separate storage area; thus, this will result in 5 primary shelving sections and an additional section that is to account for the flexibility in manufacturing. These shelves will have the ability to be arranged via ‘high-density mobile shelving’ through mobility features. This will allow for more goods to be stored in less space; furthermore, it will enable for quick reconfiguration should the facility need to be modified. The centralized storage also allows for an improvement in the flow of materials and reduces new storage construction downtime. The extra space can be utilized to promote expansion should there be an increase in demand.

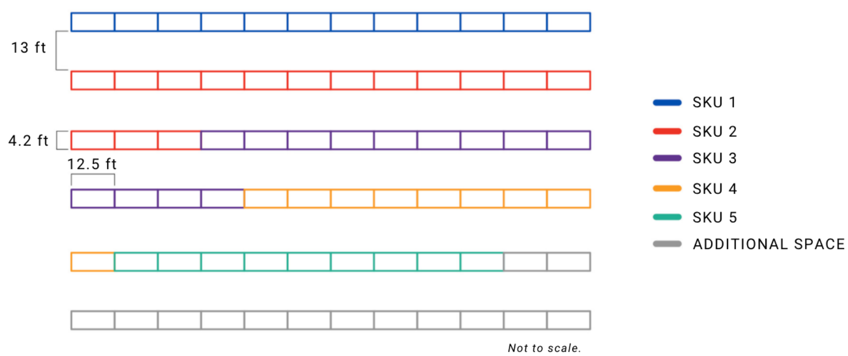
Figure 5.2: High-Density Mobile Shelving



The high-density storage capabilities can allow for a configurable way to optimize space within the manufacturing facility; this example is not to scale.

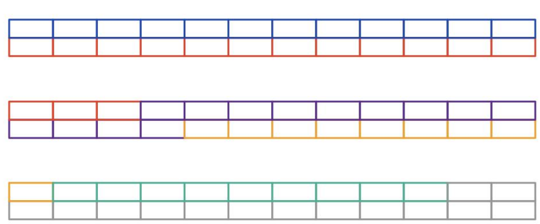
The aisle width between these shelves will be approximately 13 feet to account for the average forklift and thus enable easy accessibility to each shelf; our shelving units will be able to accommodate three 48 x 48 pallets on a one level via a welded 14-gauge steel frame and 16-gauge steel beams with a bottomless assembly. Utilizing a high-density mobile shelving approach, these units can eliminate unnecessary aisles and free up floor space as needed via the combining of units. The following number of pallet spaces is required per SKU: 72, 85, 76, 50, and 52 equaling a total of 335 pallets. As six pallets can fit per unit, roughly an absolute minimum of 56 storage units (150” x 50” x 144”) will be needed. Additional pallets will be utilized within the extra space area to account for delays and bottlenecks within transportation and flexibility within the manufacturing process. Electric forklifts will be used to transport the finished scooters from their specified SKU assembly lines to the temporary storage unit. There are 13 truckloads from Madison to Middleton per day (each carrying 26 pallets) to account for this transportation of daily demand.

Figure 5.3: Shelving Layout



The inventory is stored per SKU for organizational measures; additional space is present to account for a quick increase in demand. This shelving layout is approximately 9,750 sq ft including aisles; if fully condensed (i.e. just shelving is 7,560 sq ft).

Figure 5.3.1: Flexible Shelving Layout Example - High-Density Mobile Shelving



The inventory can be rearranged via the application of the high-density mobile shelving features to account for flexibility in design and reduce space if more shelving is required upon a sudden increase in demand and thus stored, produced goods.

5.3 M.O.S.T Analysis

In order to get an overview of the production process, we needed the cycle times of each step in the assembly process. During the analysis we assumed that each step of the assembly could be completed in 2 or fewer moves, and that all the tools used for assembly were in immediate reach of the workers. Our findings led us to split up the assembly process into 4 independent workstation cells, while keeping welding separated from the rest of assembly. Having the cycle times for the assembly steps gives WiScooter valuable metrics with which to schedule demand, allowing them to produce more reliably and effectively. We calculated the total cycle time to be 242.28 seconds. A visual representation of our MOST Analysis can be see below:

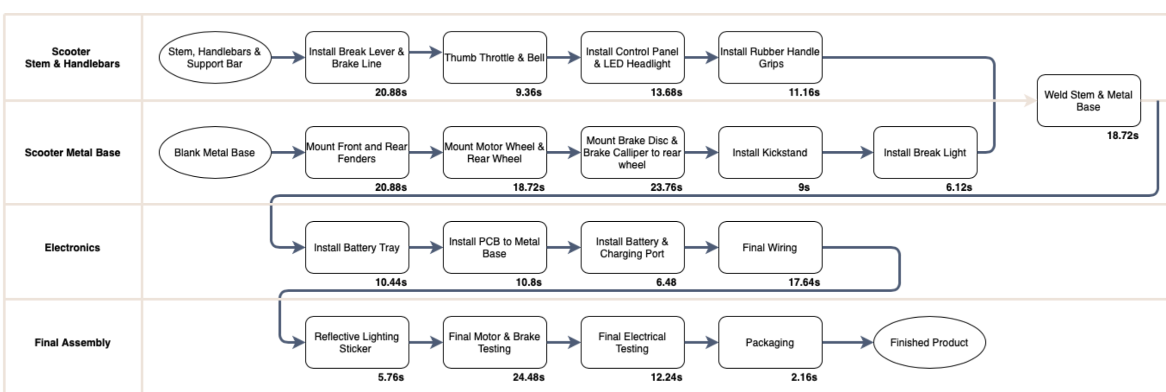


Fig 5.4 M.O.S.T Analysis

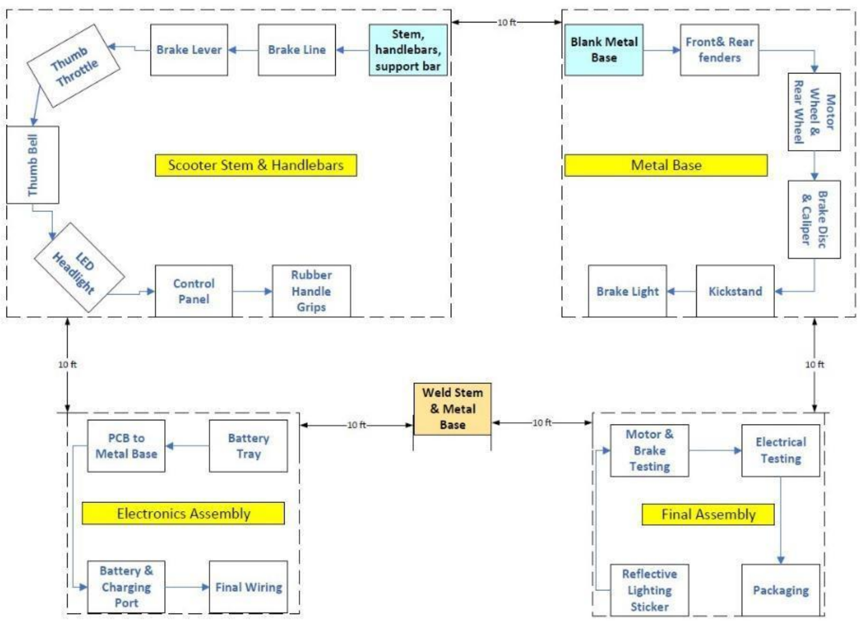
5.4 Assembly Layouts

The focus of the new layout would be improving efficiency and productivity with high safety standards following OSHA principles and CDC regulations regarding Covid-19. The layout of assembly space is associated with M.O.S.T analysis, Bill of Materials (BOM) and assembly process of Wiscooter. According to M.O.S.T analysis, there are significant differences among cycle times of assembly processes. Our approach will apply U-shaped assembly line layout to minimize the imbalance, as shown in Figure 1. By applying U-shaped line layout and hiring cross-trained operators, the assembly process will be more flexible when facing various levels of demand. When there is less demand, the number of workers can be reduced to increase productivity.

Cellular layout is another key design in our approach, and it allocates dissimilar machines into cells to produce WIP that have similar processing requirements. The advantages of cellular layout would be faster production setup and improving operator expertise. In a cell, there are limited jobs to be done, which means less tooling changes. Also, operators will only work on a limited number of different parts in a finite production cycle, so repetition of similar jobs would increase speed of learning to reduce training cost.

Based on the Assembly flow chart provided by the client, the assembly process can be categorized into four processes by department: Scooter Stem & Handlebars, Scooter Metal Base, Electronics and Final Assembly. In our design, four assembly processes are considered as four cells. Since WIP from the fabrication section will be transported to the assembly section by forklift, the general width of the aisle is designed to be at least 10 feet based on OSHA principal. Two types of WIPs would come to the assembly section from fabrication, stem, handlebars & support bar and blank metal base. To prevent backlog due to different cycle times, storage areas, shown as blue blocks in Figure 1, are designed to separately store these two WIPs in two cells, Scooter Stem & Handlebars and Scooter Metal Base. Since the welding process brings noisy and safety hazards to other cells, it is placed at the center of four cells with enough distance, shown as an orange block in Figure 1. The general material flow of the assembly process strictly follows required process and M.O.S.T analysis. In order to minimize transportation, the final assembly process is placed closest to the inventory section.

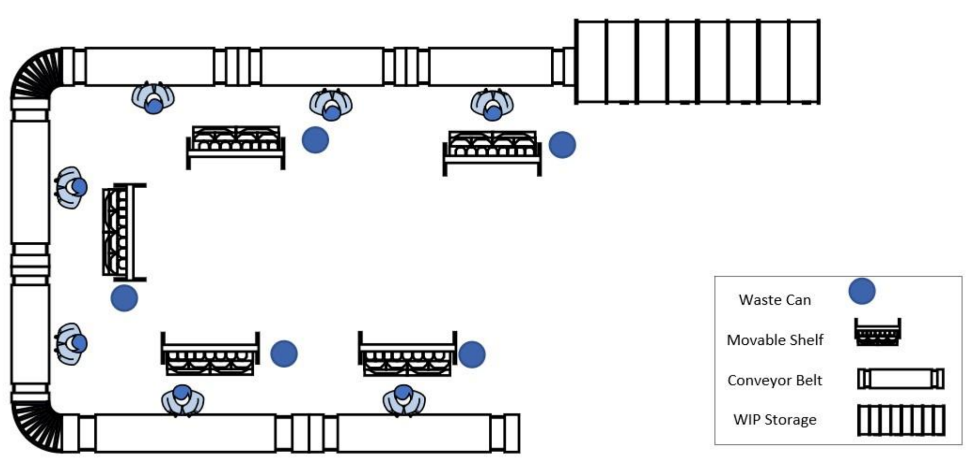
Figure 5.5 Assembly Space Layout



U-shaped assembly line layout and cellular layout are applied.

To further enhance the understanding of the design, the workstation layout is provided in Figure 5.5. Our approach emphasizes the application of assembly automation. The advantages of automation in the assembly process contributed to increased productivity, better material handling, improved safety and reduced errors. Conveyor belt is applied to transporting WIP inside each cell to maximize the benefits of assembly automation. Necessary tools and assembly parts are organized by bins and cards on movable free-stand shelves, so workers do not need to spend time on tooling change. Also, by refilling and recording the number of parts used on each shelf, it is easy to analyze the use of materials in each workstation and adjust the process to reduce waste. Waste cans will be provided for each workstation, and the types of waste cans will follow local industrial waste regulations. According to CDC health regulation regarding Covid-19, there will be hand sanitizers placed at each workstation, and the assembly space will be sterilized regularly. Due to the condition of Cvoid-19, covid safety measures might not be a long-term approach in the facility while the pandemic gets controlled, so temporary measures would be a better choice. Our team considered different strategies and included them into the assembly layout. Based on the design of workstation, movable plastic fencing could be placed if needed. There is ample space left intentionally in each workstation, so it can be used to take any further steps when Covid-19 outbreak occurs.

Figure 5.6: Workstation Layout



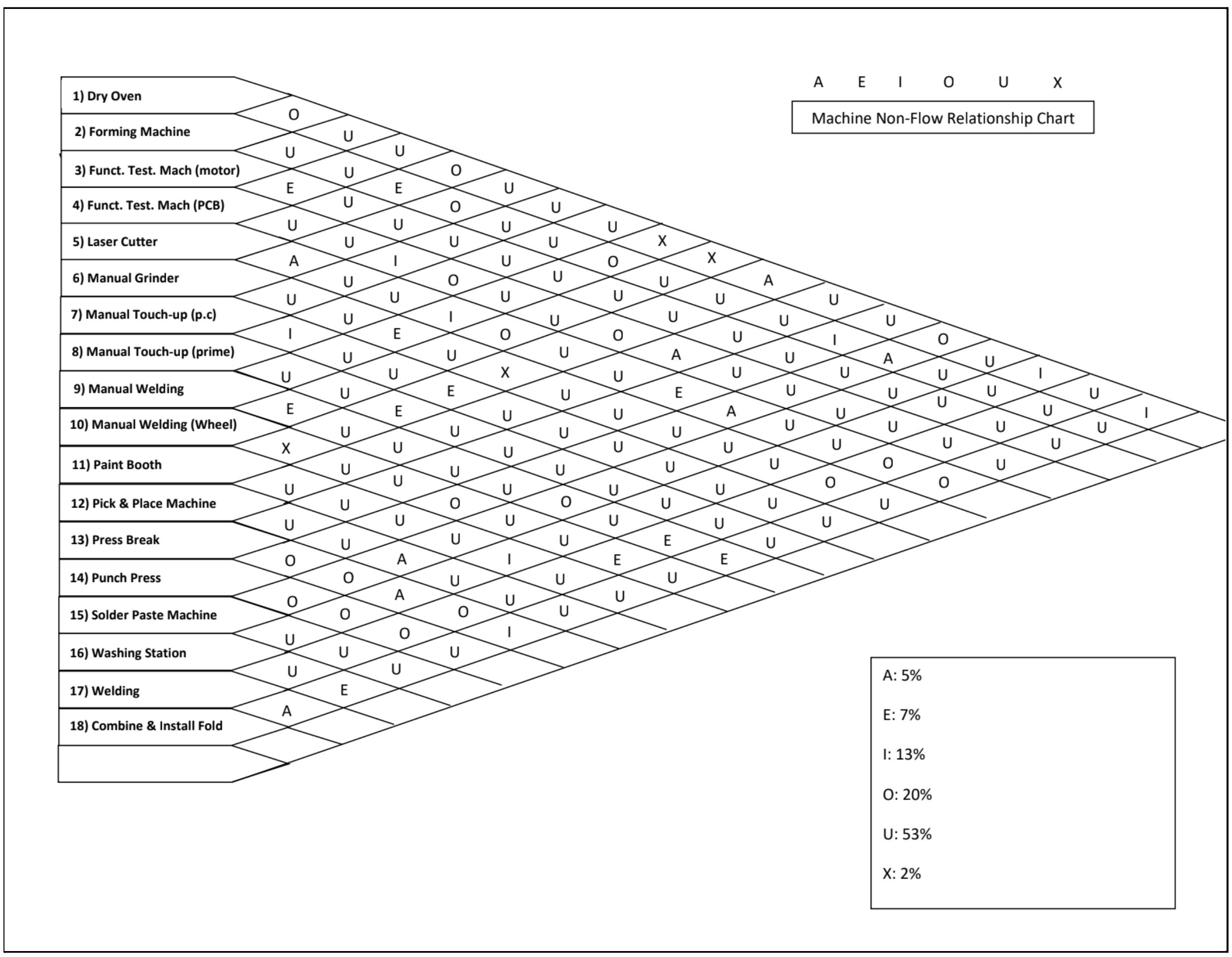
The example is not to scale. More shelves and waste cans can be added.

5.5 Facility Layouts

Here we'll go over the process behind and the key features of our final facility layouts for the WiScooter manufacturing facility. After completing our capacity analysis, inventory analysis, and MOST analysis, and completing our assembly workstation layouts, we had everything needed to put together the final facility layouts.

We started with relationship charts and a relationship diagram to get a reference for where machines should be laid out in the facility.

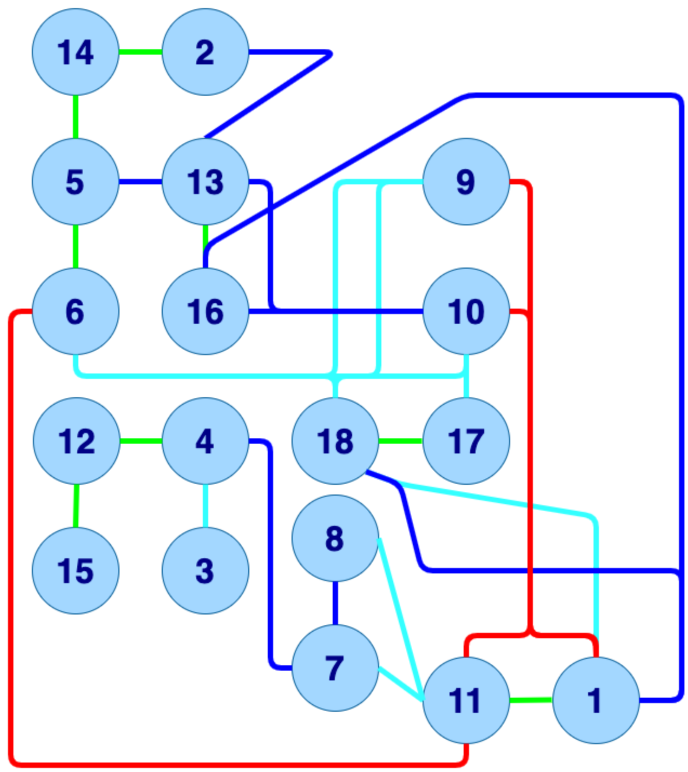
Figure 5.7: Non-Flow Relationship Chart



This non-flow relationship chart, along with the flow relationships derived from the WiScooter manufacturing details allowed us to determine which machines should be closer together or farther apart. From these charts, we created a relationship diagram to visualize these relationships.

Figure 5.8: Relationship Diagram

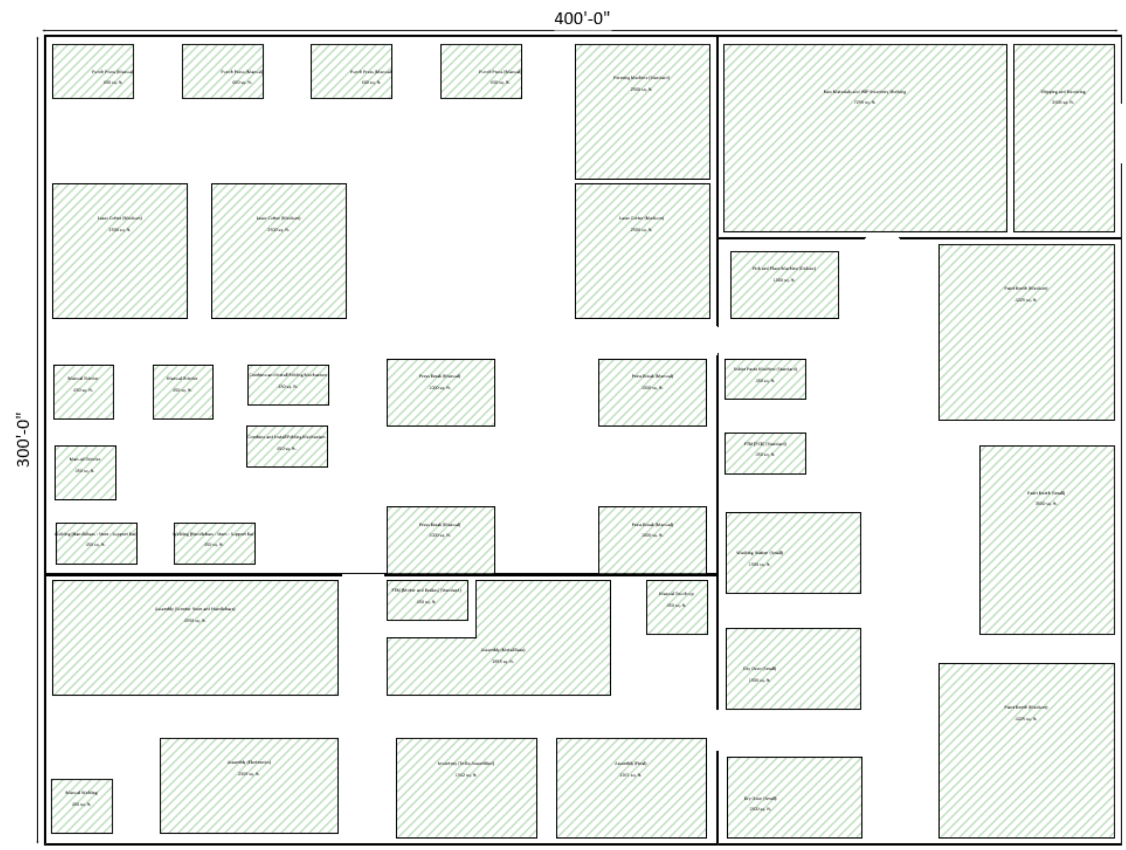
#	Machine Name
1	Dry Oven
2	Forming Machine
3	FTM (motor)
4	FTM (PCB)
5	Laser Cutter
6	Manual Grinder
7	Manual Touch-Up (powder)
8	Manual Touch-Up (primer)
9	Manual Welding
10	Manual Welding (wheel)
11	Paint Booth
12	Pick and Place Machine
13	Press Break
14	Punch Press
15	Solder Paste Machine
16	Washing Station
17	Welding (handlebars-stem-support)
18	Combine and Install Folding Mech.



This approximates where each machine should be within the facility, but fails to account for the fact that our priority is to have consistent flow throughout the production process. We therefore decided to split the shop floor into smaller work cells that contained different parts of the larger production process. For example, the press break, punch press, forming machine, and laser cutter are all within 50 ft of each other on the shop floor. These processes flow from one to the other, and we wanted to streamline relationships like these.

The final layouts were constructed after adding the assembly areas and allocating inventory space within the facility. Because we were moving finished goods inventory to another facility. We placed new machines in the old finished goods inventory area, and thus avoided major construction on a new layout for the walls and entryways within the facility.

Figure 5.9: Year 2.5 Facility Layout



It’s hard to make out the details of this layout in low resolution, but we’ll go over it in sections and we’ll be attaching the visio document files as well. The walled-in sections, from left to right then up to down are the original shop floor, raw materials inventory and shipping / receiving, assembly area, and finished goods inventory. The only area we’ve changed is the finished goods inventory, which now houses the machines focused on washing, drying, and painting SKUs; whereas the machines on the current shop floor focus on forming and manufacturing the SKUs.

The raw materials inventory and shipping / receiving area will not change except for the addition of our point of use shelving system. This inventory shelving system will be adapted across our facilities and for all types of inventory throughout our facility. The finished goods inventory in Middleton will also benefit from the new inventory shelving system, and because of it will only need a fraction of the total space in the warehouse.

The assembly area will largely be unchanged in its layout, but the layouts of the assembly workstations themselves will change. These new workstations will fit in well as we implement lean concepts into the facility, and as we start to increase capacity to meet demand.

WiScooter should transition to this new layout as soon as possible, and take steps to make sure that the transition takes place over a short period of time to minimize lost production. They can do this by renting the warehouse space now and moving inventory over to Middleton until they are free to use the space to spread out machines and add capacity.

Figure 5.10: Year 5 Facility Layout

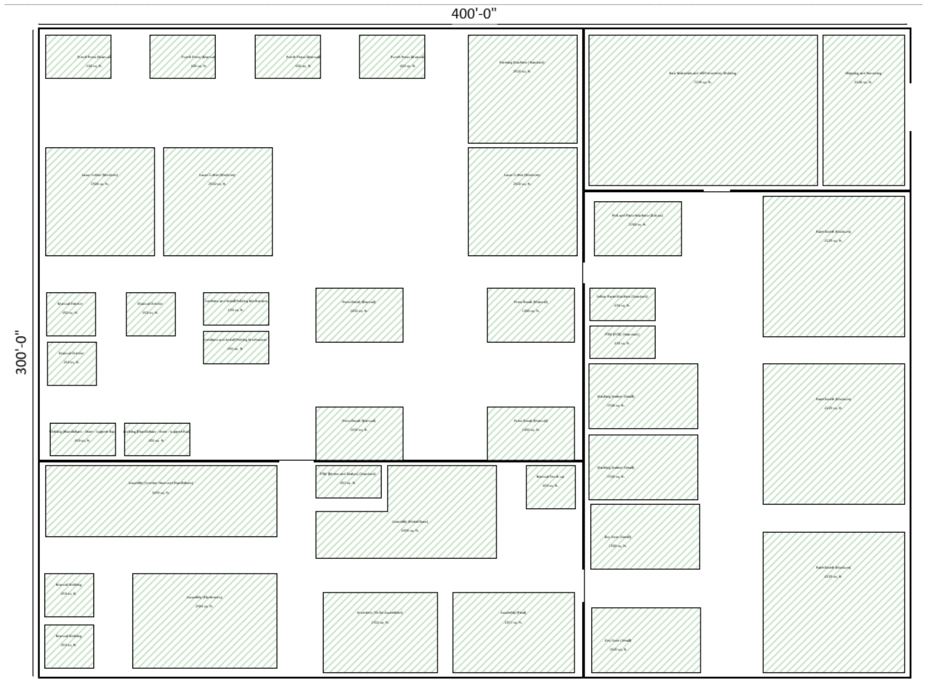


Figure 5.11: Year 7.5 Facility Layout

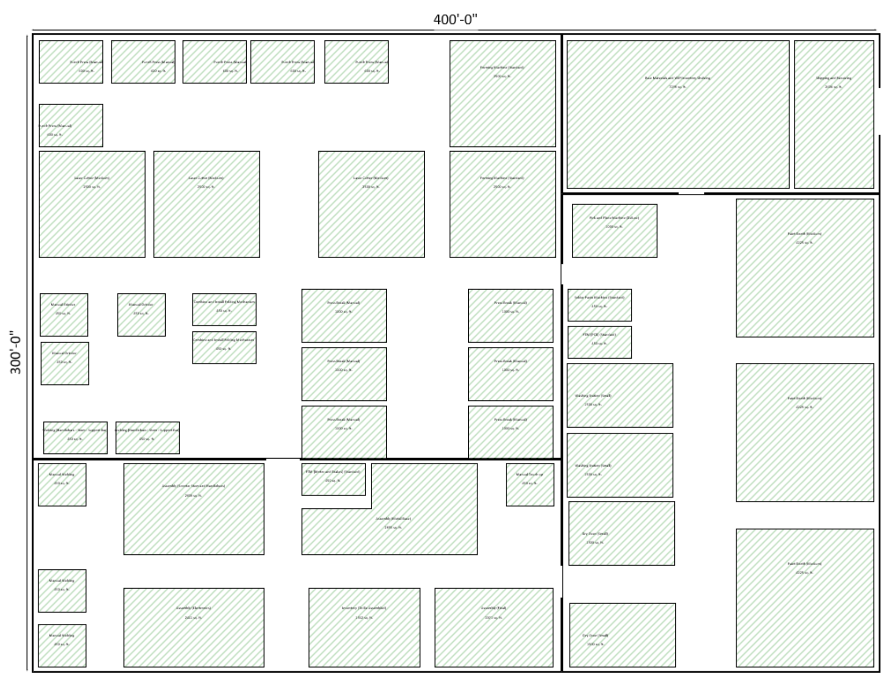
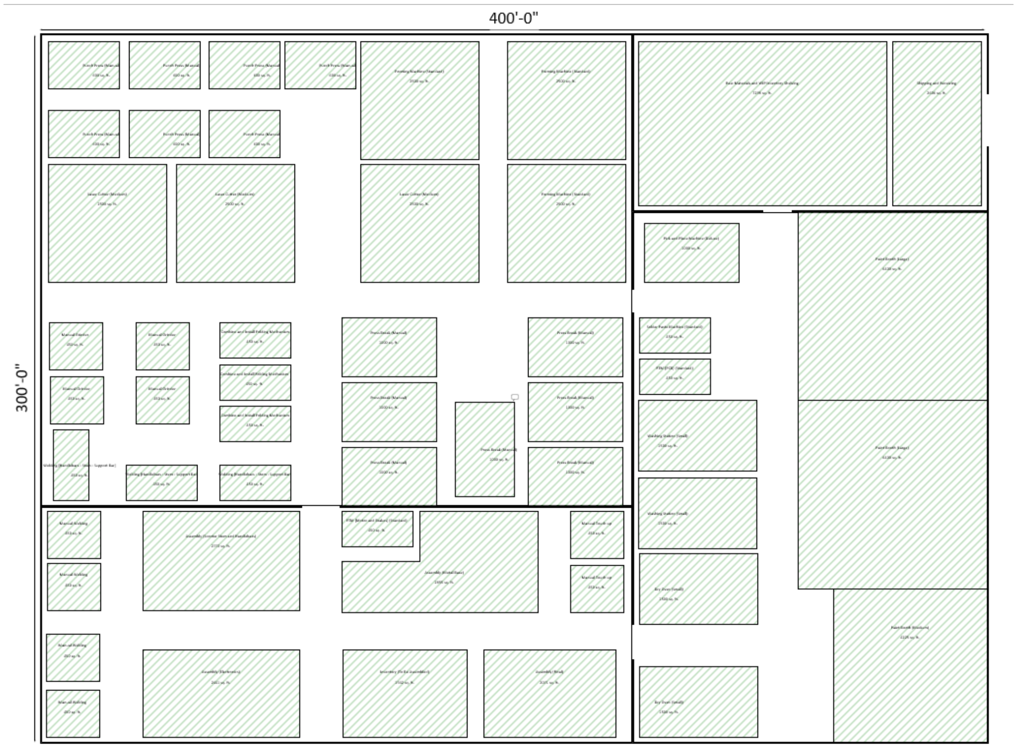


Figure 5.12: Year 10 Facility Layout



Pictured above are the layouts for the remaining 3 2.5 year periods we planned for. We can see that over the next 10 years, as COVID-19 restrictions ease, we are putting machines closer together as demand increases and our space constraints become tighter. We also maintain our wide aisle size and ease of flow throughout the facility in all of our layouts. In order to maintain this flow and facility organization, we started by designing the layout for year 10 and working backwards.

These facility layouts incorporate all of the above analyses and ensure that WiScooter can meet demand with quality products consistently over the next 10 years. These layouts also take COVID-19 safety precautions into account, and adapt to changes in regulation over time. With correct implementation, WiScooter can use these facility layouts to effectively meet their production goals over the next 10 years.

6 Project Execution

With a large project such as this one, it was imperative for the team to maintain a strictly budgeted schedule in order to remain on top of tasks and complete the project on time. The team started by identifying tasks that would need to be completed and the order in which they would need to be completed in order to finish on time. From here we were able to visualize the critical path of the project by creating an Activity Network Diagram and Gantt Chart.

Our Activity Network Diagram allowed the team to organize tasks based on progression. From this diagram we were able to estimate our critical path as being 98 days from the start of the project. Since the proposal we have not adjusted this timeframe and still intend on completing the project by the deadline.

The Gantt Chart assisted the team in creating a timeline of activities to evaluate our progression on the project, identifying which tasks should be in progress at a certain time of the week. There were no deviations to the project schedule as the team was able to divide tasks effectively and complete them by self-imposed deadlines. Each team member was made responsible for different tasks following the completion of the proposal, with the tasks that could, being completed during the time available to us in meetings. Thus, the current status of the project is nearly complete, with the drafting of the report being the final task to be completed.

7 Performance and Test Data

The current WiScooter facility is struggling to meet current demand, and thus is not meeting WiScooter's sales goals. It is also unable to meet COVID safety standards and adapt in response to the pandemic. The proposed changes to the WiScooter facility and the transfer of finished goods inventory to the Middleton warehouse facility would suitably increase throughput and allow WiScooter to maintain product quality while also implementing COVID-19 protections.

7.1 Throughput

When we inspected the current capacity of the WiScooter facility, we found that they were already struggling to meet demand. Specifically the punch press, press break, and pick & place machine were all over 500% capacity. We therefore used a capacity analysis to determine how many machines WiScooter would need in the manufacturing facility to satisfy maximum expected demand over the 2.5 year period where it is active.

This increase in machines as well as the surrounding systems will allow WiScooter to meet maximum predicted demand every month. In order to maintain the ability to adapt to demand, WiScooter must also continue to predict demand and adjust their capacity plans accordingly. WiScooter must also commit to implementing lean manufacturing so that the full capacity of the facility can be utilized.

7.2 Quality

The current WiScooter facility does meet quality standards for the products that they can produce, the main problem is its lack of capacity. Therefore, our goal is to maintain the quality of WiScooter's products while increasing capacity. While planning for capacity, we chose to use the deluxe pick & place machine, and that slightly decreased our overall defect rate. We also created a production plan that schedules parts by taking into account the compound defect rate of all the machines on the process path.

The implementation of lean concepts will also make the production process more predictable and increase overall quality over time. Along with that, our new inventory shelving system will remove human error from a large part of the inventory process. With this drastic improvement in organization and throughput, WiScooter's product quality will gradually increase, or at the very least, be maintained as capacity increases.

7.3 Cycle Time

As mentioned above, only one of our process steps decreased in cycle time, the pick & place machine. We analyzed the cycle times of the assembly workstations, but otherwise there have been no explicit improvements to the total cycle times of the WiScooter manufacturing facility. Even so, there are some implicit effects of the suggested improvements that would decrease effective cycle times.

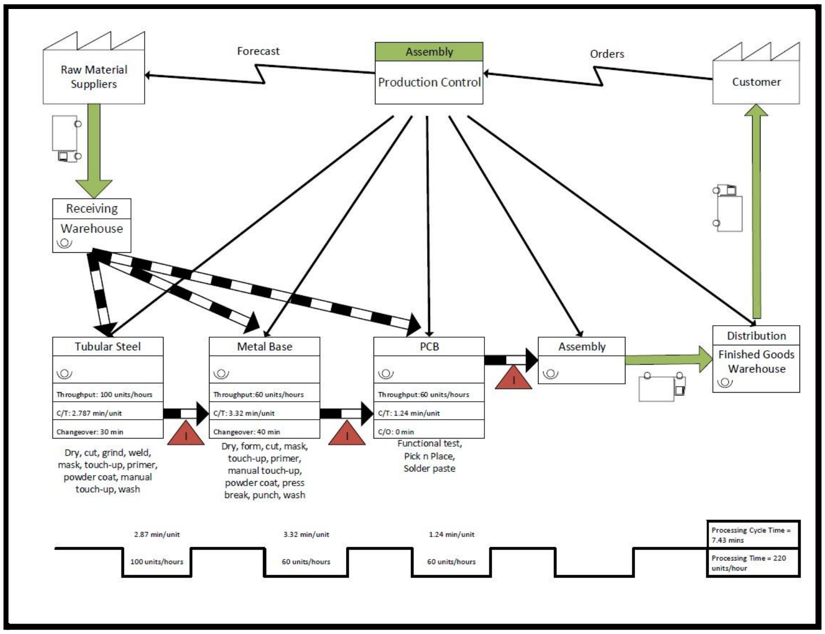
Because we separated production by 2 SKU groups on the forming machine, the press break, the punch press, and the paint booths (industrial vs standard steel and colored vs non-colored paint), we have eliminated changeover time and any lost time due to the 2 types of materials. This will lower effective cycle times for these processes significantly, and thus decrease the overall cycle time of a single SKU.

The implementation of lean allows us to gradually decrease cycle times by decreasing the amount of waste at the bottlenecks of the facility. The metrics for the assembly workstations will also be underestimates of the actual cycle times until workers are more used to the new layouts. Overall, cycle time data will look worse than it does now during the transition period for WiScooter from the existing to the new layout. However, as lean concepts are implemented and as everyone gets used to the new layout and system, cycle time metrics will converge to the theoretical metrics we have determined throughout our analysis.

7.4 Successes and Failures

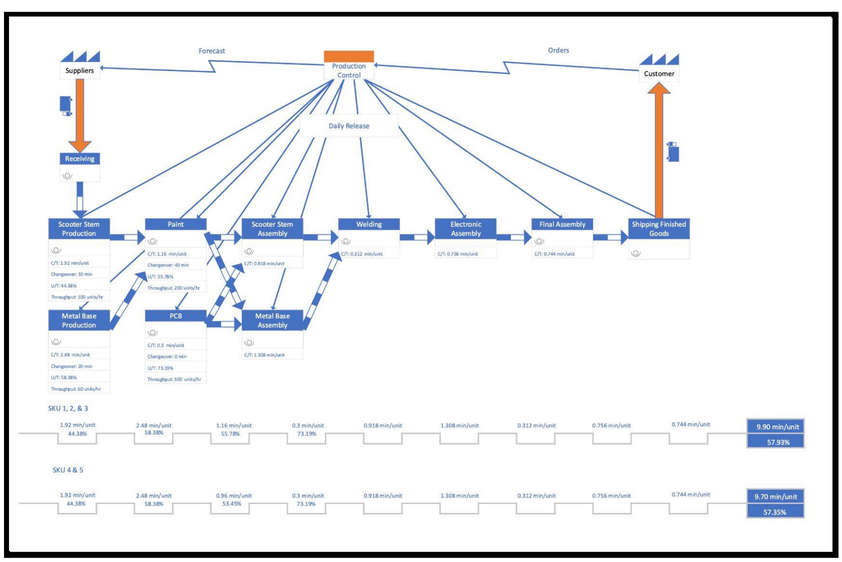
The metrics shown on our value stream maps accurately represent their respective system accurately, and will help WiScooter schedule production over the next 10 years. These metrics accurately represent a system in a steady state, but WiScooter will have to work towards these theoretical metrics when they transition between layouts.

Figure 7.1: Overall VSM for the existing facility



Shows the metrics of the current system

Figure 7.2: Year 2.5 VSM for the new facility



Shows the metrics of the suggested system

Though our suggested improvements for the WiScooter facility will greatly increase throughput and add to their ability to meet demand, our metrics and test data fall somewhat short. Although we have estimates for cycle times in a steady state, production scheduling during the transition period will need to take much more variability into account. Luckily the effects of this variability are minimized because we schedule production around maximum monthly demand. Because demand is growing over the next 10 years, we know that demand will generally be lesser during a transition period of the facility vs when they get into a steady state.

We recommend following demand models closely and adapting over the next 10 years to maximize WiScooter's ability to meet demand. With the suggested improvements and the implementation of lean manufacturing, WiScooter will be able to reliably meet demand while reacting to COVID-19 regulations and maintaining product quality.

8 Opportunities for Improvement

8.1 Immediate Plan

To provide a practicable design approach, some assumptions are made during the process, such as the success of renting a warehouse in Middleton, WI. Also, both capacity and inventory analysis are performed based on the data of the current manufacturing process. If the design approach starts to be implemented in the facility, some tasks are the priorities that our team would need to finish or follow up with the progress. First, finalize the decision of renting additional warehouses and prepare the warehouse immediately. Second, after final products can be transported to the new warehouse, our team suggests starting with machine selection and fabrication layout of Year 2.5, so new data can be analyzed in time and necessary changes can be made during the early stage.

8.2 Long-term Plan

Since the expansion will be gradually accomplished in the next 10 years, the possibility of unpredictable change needs to be considered. Therefore, the total duration of the expansion is separated into four periods with discrepancy of 2.5 years, thus the performance of the design approach can be closely monitored and altered if needed. With the permission of the client, our team would record and analyze key parameters regularly, such as machine utilization, inventory levels of different products and cycle times, to identify and address problems while the design is gradually applied. Also, considering the situation of Covid-19, all Covid measures that our design takes are temporary, so these measures would be easy to change or remove in the future.

8.3 FMEA Analysis

In order to study the potential failures within the new design approach, Failure Mode and Effects Analysis (FMEA) was performed. We brainstormed possible modes that would greatly impact WiScooter's production process and identified potential causes and consequences for each failure mode. Once finalizing the failure modes, each member confidentially rated the failure modes in three categories which are severity, occurrence, and detection. Severity is the impact a failure could have and the result it would cause. Occurrence is the likelihood of potential causes of a failure during the process. Detection is the ability to detect each failure mode. The scale of each category is from 1 to 10, where 10 represents the worst impact of a failure mode, most frequent causes, or undetectable failure mode.

$$RPN = severity \times occurrence \times detection$$

Then, the average of ratings of each category was taken and multiplied together to get the risk priority number (RPN) for each failure mode. The failure modes, potential causes, and consequences are shown in Table 8.1.

Table 8.1 Failure Modes of the WiScooter Processes

Failure Mode	Consequences	Severity	Cause	Occurrence	Detection	RPN
Defective Products	Customer Dissatisfaction	7.4	Lack of Inspection	5.4	5.8	231.768
	Customer Dissatisfaction	7	Process Failure	5.2	6.2	225.68
Failure to Meet Demand	Lost Sales	6.6	Under-Predicted Demand	5.4	7.2	256.608
	Lost Sales	6	Machine/Facility Failure	4	7	168
	Lost Sales	5.2	Loss of Production while Scaling	3.2	6.4	106.496
	Lost Sales	5.6	Not Enough Workers	3	6	100.8
Covid outbreak	Facility Shutdown	8.4	Lack of COVID Safety Measures	5.6	4.8	225.792
Inventory System Failure	Facility Slowdown/Shutdown	6	Equipment or Network Failure	4.2	6.6	166.32
	Wrong Products Received / Delay in Order Fulfillment	6.4	Incorrect Organizational Storage Tactics	4.2	4.4	118.272
Machine Failure	Worker Injury/increased down time/defective products	8.2	Lack of Machine Maintenance	4.2	5.4	185.976
	Worker injury	8.2	Lack of Safety Equipment	4.2	6	206.64

To improve the design efficiently, the risk with the high RPN would be addressed first. According to FMEA, the failure modes with the highest RPN are defective products caused by lack of inspection and process failure, failure of meeting demand due to under-prediction, covid outbreak caused by lack of COVID safety measures and machine failure caused by lack of safety equipment. These five failure modes significantly impact most aspects of Wiscooter production process, such as worker safety, sales, facility continuity and customer satisfaction.

Our team proposed recommendation actions for each failure mode to enhance the stability of the new design. To reduce defective products caused by process failure and poor inspection, implanting quality assurance initiative and quality assurance team to continuously sample and inspect WIP and final products thus decreasing final deviances from the asserted standard of quality. The quality standards of each product should be defined, and the rate of defective products need to be monitored and reported regularly. Second, to prevent under-prediction of demand, we recommend that WiScooter constantly update their demand model and track deviations in the model from actual demand. By constantly analyzing the demand of each SKU, the needs of updating and change would be easy to identify through the production process. A dynamic demand prediction system would ensure that WiScooter can expeditiously alter their production process in response to future demand. Third, Covid outbreak would cause a significant loss in the production and even force the facility to shut down if needed. Therefore, to prevent the high risk, our design approach closely followed the CDC Covid regulations and maximized the Covid safety in the facility, such as applying movable plastic fencing, space for hand sanitizer stations and ample space in the assembly workstation. Machine failure caused by lack of safety equipment is one of the major risks in the manufacturing process. It can lead to serious injuries and death. To minimize the risk, OSHA rules are applied while designing the fabrication and assembly layouts. Additionally, regular maintenance is recommended to eliminate potential machine failures.

9 Summary and Recommendations for Proceeding

Moving forward, we recommend that WiScooter implements our final design alternative. Given its performance in the selection process against the other alternatives, it is the most optimal solution of the options we generated. With WiScooter's approval, we can draft a facility layout and a plan to meet demand and COVID-19 regulations over the next 10 years.

The final design alternative is a combination of the previously described alternatives 1, 2, and 3. That is, it combines ideas focused on factory configurability, agile inventory management, and that splits production paths between SKUs 1, 2 and 3, 4, 5. To put this all together, we'll use a job shop layout and prioritize flow for both SKU production paths, since they share multiple parts and processes.

The inventory management system in the facility will be focused on keeping WIP inventory to a minimum. We want to be able to adjust production dynamically to keep up with changes in demand over time. To do so, lead times need to be short and WiScooter needs to be able to shift production schedules readily. Thus, material handling must quickly and efficiently supply materials to and between processes. To do this, we propose a kanban system that automatically detects and supplies materials across the facility. Autonomous vehicles will be employed for larger quantities and smaller quantities can be distributed by hand throughout workstations. This ensures that WIP inventory stays low and that processes don't run out of materials.

Where it is advantageous, we will split production between SKUs 1, 2, and 3, 4, 5. Because these SKUs have similar parts, we can have 2 efficient process paths through the factory and then combine them for similar processes. This will be challenging to implement for a process layout, but ultimately this will increase factory throughput and ability to produce SKUs quickly.

As shown in Figures 5.9 to 5.12, these layouts are what we drafted that WiScooter could implement for the next 10 years. These layouts account for COVID – 19 as well, over the years as COVID-19 restriction ease, we are moving machines closer together as this will help keep up with the demand.

We have divided our recommendations for improvement into 2 sections – Immediate Plan and Long Term Plan. Our Immediate Plan outlines the need to finish the decision of renting additional warehouse as soon as possible and to use the Year 2.5 plan in order to test the plan out at an early stage and make changes as needed. The Long Term Plan explains how over the next couple of years, our team would continue to monitor essential variables such as machine utilization, inventory levels of different products and cycle times.

In an effort to improve the design further, we conducted a FMEA Analysis to find any aspects of the design with a high RPN. After conducting the analysis, 4 aspects were found with a RPN of over 200 – Defective Products, Failure to Meet Demand, Covid Outbreak and Machine Failure. We have outlined certain steps that WiScooter could take in order to achieve an efficient process of manufacturing e-scooters.

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[2] Centers for Disease Control and Prevention (2021), *Manufacturing Workers and Employers*.www.cdc.gov/coronavirus/2019-ncov/community/guidance-manufacturing-workers-employers.html.

Appendices

Appendix A: Pugh Matrix Iterations

Key Criteria	Weight	Good Enough (8)	Double Trouble (2)	Becky (6)	Flexible / Split (hy)	Variable Inv / Flexible (hy)						Baseline
Workplace Safety	10	S	S	S	S	S						HY
Lead Time	7	+	+	+	+	S						HY
WIP Inventory	4	S	+	S	+	+						HY
Product Quality	6	-	S	S	S	S						HY
Sustainability	1	S	S	S	S	+						HY
Capacity (Fulfilling Demand)	9	-	S	S	+	+						HY
Layout Flexibility	5	-	-	-	S	S						HY
Material Handling	3	S	S	S	+	+						HY
COVID-19 Safety	8	-	-	-	S	S						HY
Utilization	2	-	-	+	+	+						HY
												HY
												HY
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Sum of Positives (+)		1	2	2	5	5	0	0	0	0	0	
Sum of Negatives (-)		5	3	2	0	0	0	0	0	0	0	
Sum of Sames (S)		4	5	6	5	5	0	0	0	0	0	
Positiives - Negatives		-4	-1	0	5	5	0	0	0	0	0	
Weighted Sum of Positiives (+)		7	11	9	25	19	0	0	0	0	0	
Weighted Sum of Negatives (-)		30	15	13	0	0	0	0	0	0	0	
Weighted Sum of Sames (S)		18	29	33	30	36	0	0	0	0	0	
Weighted Positiives - Weighted Negatives		-23	-4	-4	25	19	0	0	0	0	0	

Iteration 1

Key Criteria	Weight	Good Enough (8)	Double Trouble (2)	Becky (6)	Flexible / Split (hy)	Variable Inv / Flexible (hy)						Baseline
Workplace Safety	10	S	S	S	S	S						HY
Lead Time	7	+	+	+	+	S						HY
WIP Inventory	4	S	+	S	+	+						HY
Product Quality	6	-	S	S	S	S						HY
Sustainability	1	S	S	S	S	+						HY
Capacity (Fulfilling Demand)	9	-	S	S	+	+						HY
Layout Flexibility	5	-	-	-	S	S						HY
Material Handling	3	S	S	S	+	+						HY
COVID-19 Safety	8	-	-	-	S	S						HY
Utilization	2	-	-	+	+	+						HY
												HY
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												HY
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												HY
Sum of Positives (+)		1	2	2	5	5	0	0	0	0	0	
Sum of Negatives (-)		5	3	2	0	0	0	0	0	0	0	
Sum of Sames (S)		4	5	6	5	5	0	0	0	0	0	
Positiives - Negatives		-4	-1	0	5	5	0	0	0	0	0	
Weighted Sum of Positiives (+)		7	11	9	25	19	0	0	0	0	0	
Weighted Sum of Negatives (-)		30	15	13	0	0	0	0	0	0	0	
Weighted Sum of Sames (S)		18	29	33	30	36	0	0	0	0	0	
Weighted Positiives - Weighted Negatives		-23	-4	-4	25	19	0	0	0	0	0	

Iteration 2

Key Criteria	Weight	Variable Inv/ Flexible (hy)	Variable Inv/ Flexible/Split									Flex/Split
Workplace Safety	10	S	S									F/S
Lead Time	7	S	+									F/S
WIP Inventory	4	+	+									F/S
Product Quality	6	S	S									F/S
Sustainability	1	S	S									F/S
Capacity (Fulfilling Demand)	9	S	S									F/S
Layout Flexibility	5	-	S									F/S
Material Handling	3	S	-									F/S
COVID-19 Safety	8	S	S									F/S
Utilization	2	S	-									F/S
												F/S
												F/S
												F/S
												F/S
												F/S
												F/S
												F/S
												F/S
												F/S
												F/S
Sum of Positives (+)		1	2	0	0	0	0	0	0	0	0	
Sum of Negatives (-)		1	2	0	0	0	0	0	0	0	0	
Sum of Sames (S)		8	6	0	0	0	0	0	0	0	0	
Positiives - Negatives		0	0	0	0	0	0	0	0	0	0	
Weighted Sum of Positiives (+)		4	11	0	0	0	0	0	0	0	0	
Weighted Sum of Negatives (-)		5	5	0	0	0	0	0	0	0	0	
Weighted Sum of Sames (S)		46	39	0	0	0	0	0	0	0	0	
Weighted Positiives - Weighted Negatives		-1	6	0	0	0	0	0	0	0	0	

Iteration 3