

Chassis Production Process
Honors Thesis
IE 404: Senior Design Final Report

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Key Words: Lean, 5S, Industrial Engineering, Kanban System, Inventory Management, Systems Engineering, Ford Bronco, Chassis

THE UNIVERSITY of TENNESSEE KNOXVILLE

Project Background

Our team has been tasked with working alongside a company called Krawlers Edge (KE), a Bronco refurbishment startup, to help streamline their chassis building process. In the long term they are wanting disintegrate themselves from the refurbishment business and focus solely on building chassis, where we focused this semester.



Figure 1: Sample Krawlers Edge Chassis Frame

The demand in the chasis market presents the opportunity to increase sales but inefficient means of production limited their ability to meet this uptick in demand. Currently, there are two chassis that they assemble: the OEM and 4LINK. They build a very good product but right now it takes a very long time to construct, and the completion of the chassis is entirely dependent on the minds and hands of just two individuals, Thomas and Justin. To reduce the inherent risk of a process dependent on just two individuals, we, Joe Pettey, Abbi Harr, Carly Johnson, Wilson Cochrane, Jake Fountaine, and Tim Love have come in with Mr. Ostrowski and graduate student, Rahul Ravikumar, to take the process out of the minds of the builders and into a standardized quantifiable process. By doing so, we hope to remove inefficiencies of disruptions and variation within the system. We are working towards this objective through time studies, standard work documents, process flow charts, an ERP system, and a kanban system. In this way we hope to increase throughput and capacity by standardizing their assembly process to mitigate productivity loss in new hires, save time and labor, reduce variation and disruptions, and ultimately help them make more money.

Requirements Analysis

- The team shall create intelligent part numbers for all parts involved in chassis production.
- The team shall create standard work for chassis production.
- The team shall reduce lead time to 1-2 weeks.

- The team shall improve output to at least 10 chassis per month by May 2018.
- The team shall outline a plan for continued growth to 15 chassis per month past May 2018.
- The team shall determine the true cost of the chassis production.
- The team shall implement a Kanban system

First Semester Reorientation

To re-orient the reader on where we came from last semester to the step forward we made this semester, the following is an overview of last semester. To begin, Krawlers Edge has decided to go a different direction than our original work with Catalyst for their ERP system. We were somewhat disappointed in this as we put in many man hours of work into learning and developing this system for them. However, one benefit from this work was we got them thinking in terms of centralizing and planning out production while keeping better track of inventory.

Production was limited to 1 to 2 frames a month with seemingly infinite demand. See Table 1 below for the change in production numbers.

Date	Chassis per Month Goals
December 2017	5
May 2018	10
Future Growth	15

Table 1: Production Numbers Overview

We determined the lack of inventory management and standard work were the root causes of why they were not meeting demand.

Technical Performance Measures

Our team found the technical performance measures found below in Table 2 to be essential to consider while studying and generating designs for the chassis production.

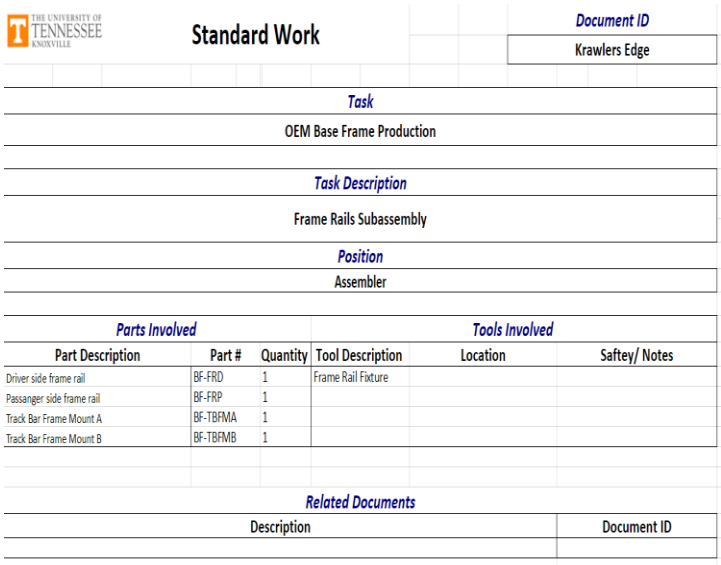
Technical Performance Measure	Quantitative Requirement ("Metric")	Current "Benchmark"	Relative Importance (%)
Lead Time (Days)	7 days (maximum)	30 days	30

Weight (Pounds)	115 lbs (base frame maximum)	111 lbs (base frame)	5
Assembly Jig Utilization (%)	85% (minimum)	50%	45
Human Factors (Error)	Less than 5% error rate per year	Unknown	20

Table 2: Technical Performance Measures

In concluding this section there were three main things we started that we expanded and improved this semester. One, we recorded inventory and created a spreadsheet of an item master with intelligent part numbers.

Two, we identified parts that could be sub assembled to create make-to-stock parts that could operate within a pull system. And three, as shown in figure one, we created standard work for both the subassemblies and the base frame model.



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Standard Work

Document ID: Krawlers Edge

Task: OEM Base Frame Production

Task Description: Frame Rails Subassembly

Position: Assembler

Parts Involved

Part Description	Part #	Quantity
Driver side frame rail	BF-FRD	1
Passanger side frame rail	BF-FRP	1
Track Bar Frame Mount A	BF-TBFMA	1
Track Bar Frame Mount B	BF-TBFMB	1

Tools Involved

Tool Description	Location	Saftey/ Notes
Frame Rail Fixture		

Related Documents

Description	Document ID

Figure 2: Original Standard Work Document

Implementing This Semester's Plan

Kanban System

As discussed earlier, a major problem holding back Krawlers Edge was the unknown of when to order parts and how many to order. Our team designed a kanban system consisting of cards, boards, and colored labels that will self-manage the inventory. There

are two types of cards in the system: sub assembly production (green) and raw material (blue). Each card contains the necessary information that the workers need to know such as the part number, name, location, reorder point, and reorder quantity. The green subassembly cards also contain information regarding a reference to the standard work documents that will inform the worker of which parts go into the subassembly. The blue raw material cards also contain information regarding the supplier, so that whoever places the order has the supplier information directly in front of them. Underneath every card is a copy of the card, only colored red, to notify workers that the card is missing, but still provide them with the information about the part.

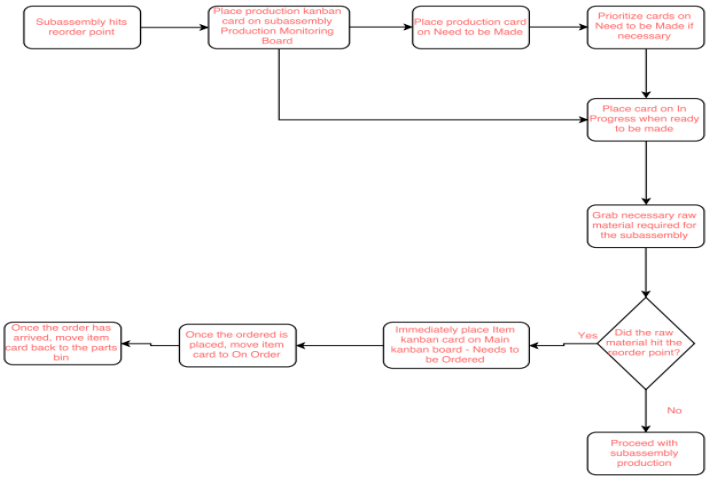


Figure 3: Kanban System Flow

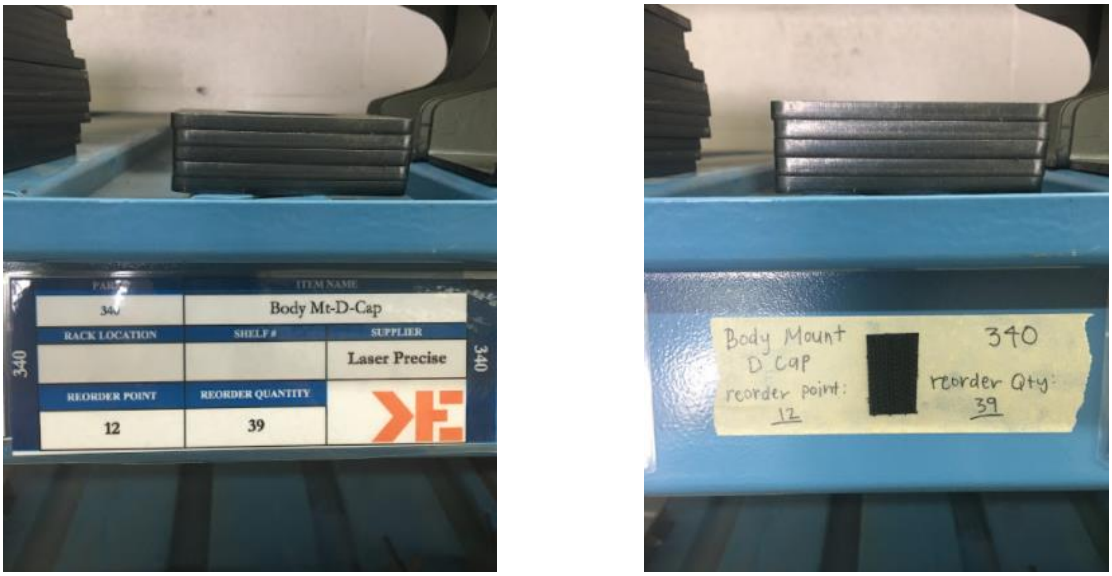


Figure 4: Kanban Cards and Placement

We have created a visual inventory management system throughout the storage shelving as part of our Kanban System. Green, yellow, and red visual control stickers are used as placeholders for each part. The colored circular stickers were placed down based on the product's calculated optimal reorder point and safety stock level. Each dot corresponds to a part, so pulling a part reveals a specific color sticker (green= do not reorder, yellow=reorder point, red = safety stock) which alerts the operator when parts need to be reordered and the respective Kanban card needs to be pulled.



Figure 5: Color Coded Inventory Level Indicators

Currently, the whiteboards outlined with markers and equipped with velcro are currently used for the main production and subassembly boards (shown below). These boards have been great for trial runs for our Kanban system, allowing us to test out the boards and make recommended alterations from experience in the trial runs. Making small tweaks and redesigns to the board based off of these recommendations, we are now in conversation with Allen Sign Company to make larger, more durable, and professional boards.

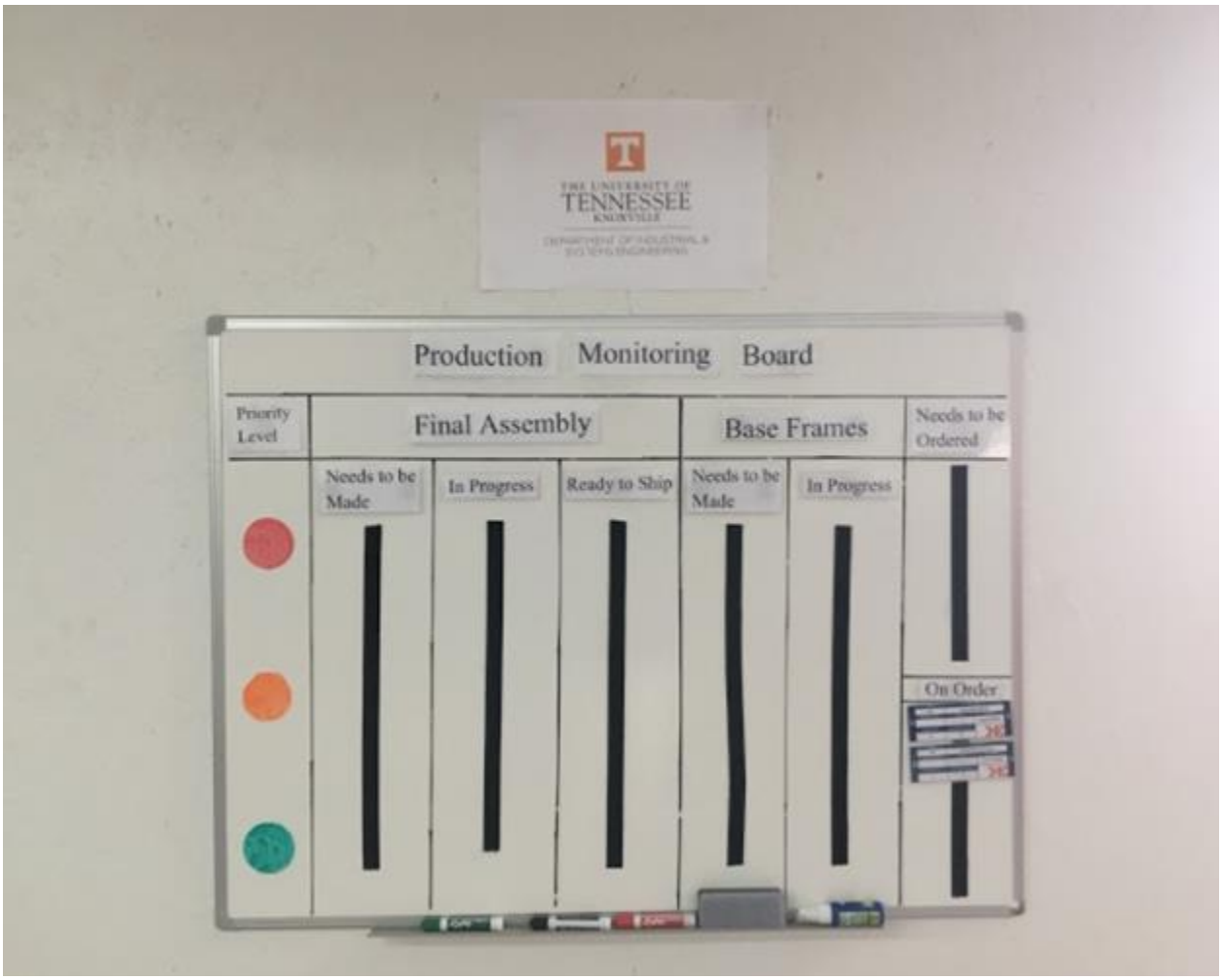


Figure 6: Main Kanban Card

Economic Order Quantities (EOQs)

A critical area that we flagged as a priority for this semester was inventory structure. Previously, Krawlers Edge lacked information regarding order quantities and reorder points associated with their annual demand. Essentially, Krawlers Edge had no consistent plan on when to order and how much to order resulting in lost production time due to out

of stock materials. To combat this problem, we consulted with both Professor Ostrowski and Rahul Ravikumar to develop an inventory strategy that was responsive to both fluctuations in customer demand and supplier lead times. At first we adopted the traditional EOQ (r,q) system; however, the optimal order quantities and reorder points for the more expensive parts seemed illogical to us. We believe this was in part due to holding cost associated with each part (more expensive and bulkier items were given the same holding cost as the smaller parts that take up significantly less space). Therefore, as a group, we pivoted away from the traditional EOQ system and formed a blend of different strategies. To start off, we conducted an ABC analysis to categorize each part as either an 'A' part, a 'B' part, or a 'C' part. We made the following assumptions with these three categories:

1) 'A' parts make up 20% of the total inventory but contribute to 80% of the inventory costs
2) 'B' parts make up 30% of the total inventory but contribute to 15% of the inventory costs
3) 'C' parts make up 50% of the total inventory but contribute to 5% of the inventory costs

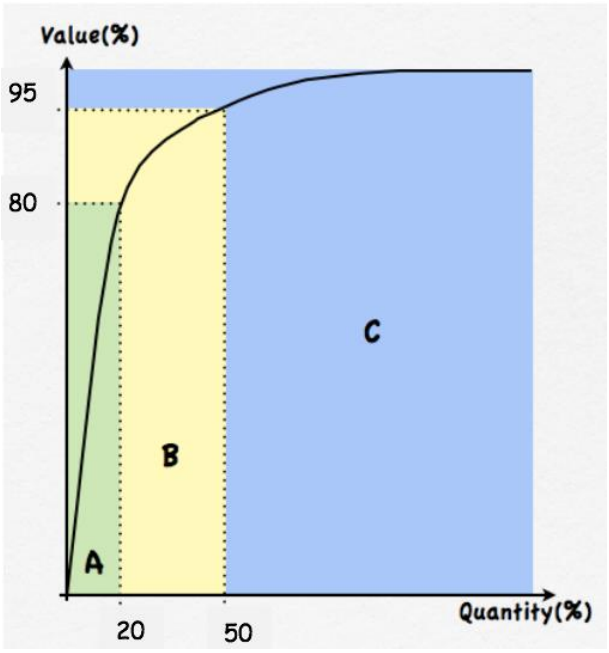


Figure 7: ABC Inventory Analysis

This allowed us to identify the parts that needed to be strictly controlled and watched (items classified as an 'A' part) compared to those that need less monitoring (items classified as either 'B' or 'C'). With this strategy in place, we were able to come up with order quantities and reorder points for the 'A' parts that would result in immediate

inventory turnovers within a consistent schedule. As for the 'B' and 'C' parts, we followed the traditional EOQ formula since these parts do not require as close of a watch.

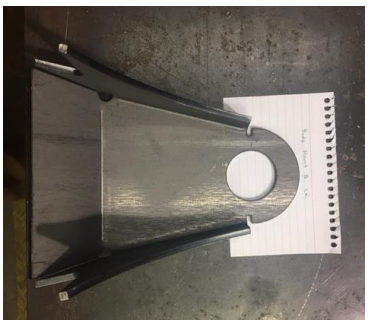
A	B	C
		
• Closely managed • Large, expensive • Low order quantities due to high holding costs	• Runs on kanban system • Medium consumption	• Runs on kanban system • Small, inexpensive • High order quantities because of low holding cost

Table 3: Sample ABC Inventory Parts

This hybrid inventory strategy has resulted in a much more realistic outcomes for our bulkier parts; however, these puts must be closely watched as their turnover ratios are extremely high. The implementation of this inventory system will take a large workload off of Thomas. Instead of managing about 75 parts, he now only has to manage about 15 parts.

Standard Work

Additionally, we worked on outlining the process, which was originally kept only in the minds of two individuals. We made sure the process was put on paper and was ready to be converted into a standard work chassis manual for new employees to reference and to reduce variation throughout the process.

Our standard work from the previous semester was re-designed to better suit the operator's needs and become more user friendly. A screenshot of one of the standard work documents is shown below. The updated standard work includes the Krawlers Edge logo,

all parts and part numbers used during the documented process, any tools required, their necessary PPE, or any additional notes, the setup tasks and their average completion time, and detailed task steps.

Chassis Assembly Manual
Subassembly # 1001 & 1002
Task: **Frame Rail Subassembly**

`Workstation: Frame Rail Jig

Part Name	Part #	Quantity	Location
Driver side frame rail	101	1	Frame Rail Storage
Passenger side frame rail	102	1	Frame Rail Storage
Track Bar Frame Mount A	303	1	Raw Material Storage
Track Bar Frame Mount B	304	1	Raw Material Storage
Bushings	104	8	Raw Material Storage

Tool Description	Required PPE/ Safety	Additional Notes
Frame Rail Fixture	Welding Mask and Gloves	Wear when welding
Hole Fixture	Gloves	
Drill	Safety Glasses	Wear safety glasses always
Drill Bushing ¼" Drill Bit	Safety Glasses	
Saw	Safety Glasses	
¾" Hole Saw	Safety Glasses	
4" Grinder	Safety Glasses	

Set Up Task	Avg Time (min)
Grab Driver Side Frame Rail from FR storage	

Figure 8: Standard Work Document Example

As the way in which the chasses were produced continued to evolve and improve, the standard work documents were required to be updated accordingly. Throughout this semester we constantly worked with the Krawlers Edge employees to keep the standard work steps up to date. Additionally, we have provided Krawlers Edge with the documents in page protectors, plastic folders to be hung by the workstations, and a template so they can continue updating them whenever needed.

Designing Floor Layout Based on Flow

In January of this year, Krawlers Edge expanded to an additional facility in Seymour, TN. This facility is primarily dedicated to chassis production. The following image resembles how the facility looked with KE first moved in in January.

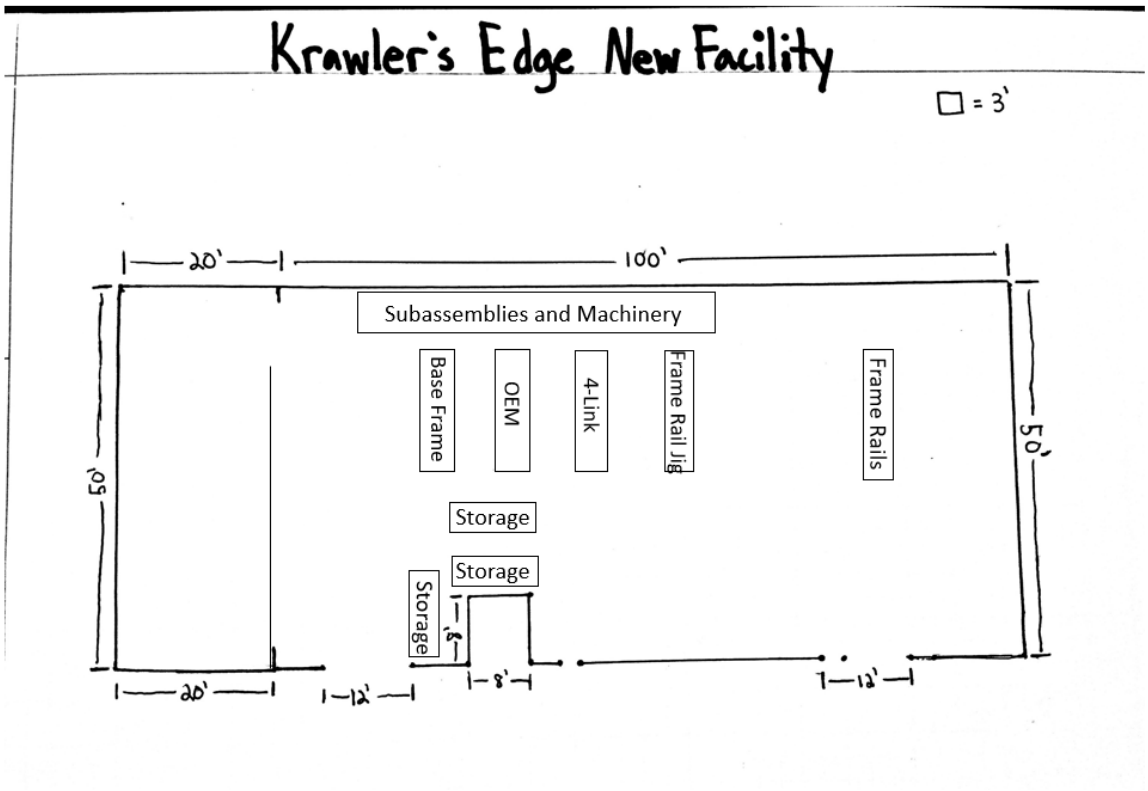


Figure 9: Original Floor Plan

There is ample space for storage and production, but the machines, tools, and storage racks were placed within with no real rhyme or reason. The employees were having to move large frame rails across the floor multiple times and spend time looking for the tools and parts that they needed at the time. Therefore, we re-designed the layout for better flow and better utilization of the storage. The redesigned floor layout is shown below:

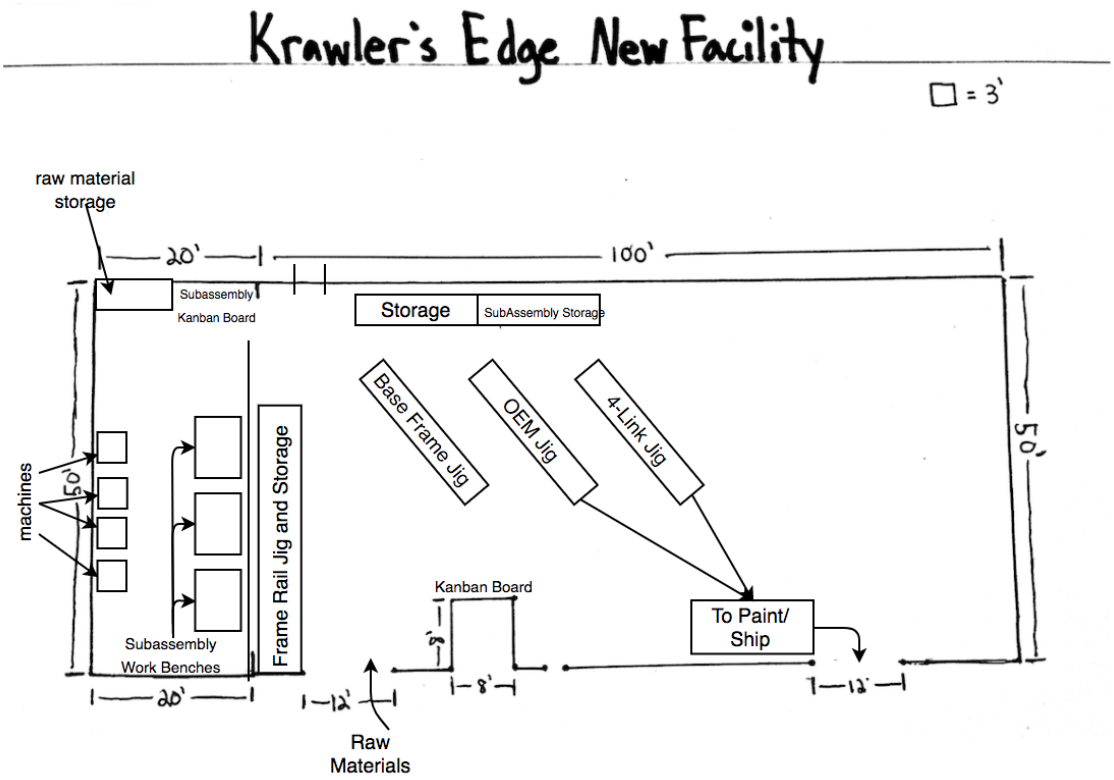


Figure 10: Redesigned Floor Plan

All raw materials and ordered parts will enter the bay doors on the left side of the shop. Upon entry, they will either go to storage or into the left side room if they are parts for subassemblies, as this room has been dedicated to subassembly production. All storage shelving has been labeled with a letter to dictate rack and a number to dictate which shelf the part is on. Everything has a specific home. The main production Kanban board is located in a centralized location, where all employees can easily access it. The subassembly Kanban board is located just at the entrance of the subassembly room. All parts, machines and tools required for subassembly production have been placed in the side room to create a centralized dedicated space for these tasks. These tasks usually involve smaller parts and do not need to be done next to the large jigs, so placing their production in the side room is ideal to utilize the space provided and keep clutter off of the shop floor. Once the subassemblies have been assembled, they will move to the subassembly storage which is located behind the fixture jigs. Now, when workers are producing a base frame or working on the final assembly of the chassis, they can easily grab and attach sub-assembled parts. Once the base frame is produced, it can easily be moved to either the OEM or 4-Link jigs, and ultimately to be placed for pickup for painting or shipping the chassis.

This new design improves the workflow of the chassis production and therefore increases efficiency of the process. Workers are not stumbling over machines, parts, and tools or

doing walking/moving, non-value added steps. This will decrease variation and disruptions within the process and ultimately decrease process cycle time and increase throughput, the ultimate goal.

Intelligent Part Numbers

During the first semester we developed a part numbering system that was based on the when each part was going to be used. For example a driver side frame rail which is used in a base frame would be BF-FRD, and an OEM part would receive before the hyphen like OEM-SSTD for a Stock Shock Tower Driver side. Our team liked this system because it was highly customizable, if the Krawlers Edge team wanted to add or change parts in their system all they had to do was make a new "number" for the new part. After we came back from winter break we had a few discussions with the shop floor operators on whether this was a system they liked and if they would actually use it. Ultimately we decided the system we developed was a little more than abbreviating the name of the parts and the operators did not see a point in just shortening the names.

Family Number	Part Family
1	Miscellaneous
2	Crossmembers
3	Mounts
4	4 Link
5	OEM

Figure 11: Part Families

This semester we developed worked with the operators and developed a new system that uses numbers with three or four digits to signal whether a part is in a raw material (three digits) or a finished subassembly (four digits). We started by breaking down the parts into similar groups or part families. Figure 10 above shows the five different part families we developed. After breaking down each group of parts we ordered them with the parts that are used at the beginning of the process have the lowest number in the family. We then gave each part a number stepping by five each time to allow room for growth and to make the numbers a little easier to remember. In figure 11 on the next page there are a few examples of all of the different ways a part can be classified.

3- Mounts	Coyote Motor Mount-Driver	300	No Subassembly	n/a
	Coyote Motor Mount-Passenger	305	No Subassembly	n/a
	Track Bar Frame Mount A	310	Track Bar Frame Mount A	3010
	Track Bar Frame Mount B	315	Track Bar Frame Mount B	3015
	Body Mt-A-Driver	320	Body Mt A-Driver SUB (0")	3020-0
			Body Mt A-Driver SUB (1")	3020 -1
			Body Mt A-Driver SUB (2")	3020-2
5 OEM Parts	Stock Rear Leaf Spring Mt-A	530	stock rear leafspring mount D&P	5010 & 5015
	Stock Rear Leaf Spring Mt-B-Left	535	stock rear leafspring mount D	5010
	Stock Rear Leaf Spring Mt-B-Right	540	stock rear leafspring mount P	5015
	Stock Radius Arm Mt-Passenger	545	Stock Radius Arm Passanger	5020
	Stock Radius Arm Mt-Driver	550	Stock Radius Arm Driver	5025
	Stock Radius Arm Bushing-Gusst	555		
	Stock Radius Arm Bushing	560	Stock Radius Arm Driver &Passanger	5020 & 5025

Figure 12: Part Number Examples

We wish to point out a few important examples from figure 11 such as the Track Bar Frame Mount A; this piece starts with the raw part number 310 until it is processed and ready to be used on a base frame. Then it gets moved to the finished inventory location and gets filed under the subassembly number 3010. When developing these numbers we wanted to make the subassembly and raw numbers very similar so it would be easy to keep track each part as they only have to remember one part number with an extra digit that is usually zero. The next example I wish to point out is after part 320 gets processed it is finished for a specific lift. So in order to signal which lift each part is for it get a hyphenated modifier that represents the lift (320 → 3020-2). The last example worth noting is in the OEM family. Parts 530 and 535 are apart of one subassembly, part 530 goes into 535 so both of these receive the same subassembly number. All of the part numbers are referenced on the standard works for the related proces. We also reorganized the subassembly inventory areas to group part families together to make them easier to find and retrieve.

Conclusion

We, with Krawlers edge, have made significant strides in increasing production to meet customer demand. The chassis production now is more standardized and has better inventory management supporting it. Through our time studies in the fall we found that KE could push a chassis frame of the line every four hours. After physically watching them do this with the subassemblies ready to go they were able to complete a frame in 5 hours. We are very pleased with this time. Assuming an 8 hour work day for 5 days a week, 4 weeks per month, expected production is 32 frames. This if far and above either us or KE thought possible in August. Granted, 32 frames a month assumes, no more personnel changes, all subassemblies are ready to go, and our inventory management system is sustained. Therefore, at this junction, 10 frames a month is there expected production. With time and sustaining the changes we have made we have no doubt this number will only increase.

Initially, the process was entirely in series. Now, Krawlers Edge has pre-prepared subassemblies, a common baseframe compatible for the OEM, 4-Link, and possible future frames, and they have expanded production to two jigs which has decreased the time at the bottleneck. Also, in August there was no standard work meaning all of the know-how to make these chassis was known by just two individuals. There are standard work documents for most steps in the process and there are multifunctional workers in several different work stations to relieve some of the stress on the main builder and take time away from the bottleneck. Finally, the shift from no inventory management to a kanban system made it easier on management to know when and how much to order to replenish raw materials on the shop floor. In August, they either didn't have the parts they needed or they had to much tying up their cash in inventory. Now, this system, makes the inventory easier to monitor just by a glance from Thomas or Sebrina.

Overall, we have met most of our Technical Performance Measure goals. First, with our verified cycle time of 5 hours, we can conclude that the lead time has been reduced from the original metric of 30 days to 1-2 days, which exceeds our original goal of 7 days. Second, assembly jigs are utilized for almost 85% of the process with new jigs being imagined and created every day. Therefore, we have met our original goal of increasing jig utilization from 50% to 85%. A lack of original and current data on human errors prevents us from claiming we reached our goal of less than 5% human errors per year. However, from conversations with Thomas, we believe errors are rare.

In addition to these manufacturing improvements, Krawlers Edge has been recognized for them. Their chassis is licensed by Ford, they have been featured the Tickle College magazine and they were just awarded the Rising Star Award from the SBDC. Krawlers edge has the customer demand the respect of the industry that can propel them to becoming a profitable company employing many more people down the road. We only hope our small part in their journey has benefited them and allowed them to grow even more.

Ideas for Future Teams

- *4LINK and OEM standard work*: While we have a strong, solid foundation for the OEM and 4LINK standard work, it can be greatly improved in further detail by a future team.
- *5S:* We also recommend implementing 5S, such as shadowboards. These will be great improvements for the overall cleanliness and organization of the facility.
- *More permanent kanban visual controls:* Currently, we have temporary visual controls for our kanban system which includes green, yellow, and red stickers on pieces of tape. We believe this can be improved to be more permanent and aesthetic once the system has been working for a few months and small issues have been resolved.

- *Continuously update standard work:* Lastly, we believe it is incredibly important for the next team to continuously update the standard work the subassemblies, base frame, OEM, and 4LINK.

Additionally, we would like to suggest the new team become familiar with the materials available in our Google Drive. Even though the standard work and flow charts will not be the most up-to-date when they receive the information, they will be useful for the team to understand the process. The part images will also be useful in their identification of parts in the kanban system.

We will also have at least one of our team members at UT in the Fall to help orient the new team to Krawlers Edge.

Individual Contribution

Abigail Harr worked throughout the past year collaborating with the faculty advisor, Floyd Ostrowski, the other members of her senior design team, and the Krawler's Edge team. At first, the biggest challenge was getting a full grasp on the chassis production process, as neither I nor any members on our team had any experience with welding or car chassis. Therefore, there was a long period in the beginning solely dedicated to understanding and documenting the process. Harr specifically worked on the standard work documents, collaborating with Krawler's Edge employees to get the step by step process written down and pictures of the parts included. Harr worked throughout the year with team member Carly Johnson updating the standard work documents throughout the year as the production process itself was updated. Now, Krawler's Edge has standard work documents for standardization of the process and further, for training their future employees.

Further, Harr worked with the entire senior design team designing the Kanban system. There are multiple ways to implement this type of system, so we had to work on what system worked best specifically for Krawler's Edge. Multiple trial runs were done (implemented by the entire senior design team, including Harr) and the system was redesigned several times until the final system was decided on. Harr helped the team label all storage shelving and parts and create the Kanban boards. Further, Harr assisted in explaining the system to employees and discuss how they were to utilize it.

It was incredible to take information learned from various college classes and apply it to a real world situation. Additionally, it was especially exciting working on such a cool project with an awesome company. After presenting our work to the Industrial Engineering faculty and colleagues, it was evident that we had made a tremendous impact on the company and

that Thomas and Sabrina (owners) were incredibly thankful for the systems that we put into place. We made all of the systems scalable, so they should be able to update and utilize them throughout their entire business life.