



Improving Production

Flexibility

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Problem Statement

Overview

Clayton Homes is a diverse building company that offers traditional site built homes, modular homes, manufactured homes, tiny homes, college dormitories, military barracks, and even apartments. With a mission statement focused on opening doors to a better life and helping families build happiness through homeownership, Clayton has continuously evolved and grown since its first sold home in 1956. By providing an opportunity to affordable homeownership, adopting green practices, and giving back to the community, they continue to shape and lead the nation's housing industry into the future. Guiding principles include statements such as:

- Our integrity and reputation come above all else.
- We strive to be extraordinary every time we interact with you.
- We are engaged and take results personally.
- We're passionate about being the best housing company.
- People are our strength and they make us better.
- We try new things and keep what works.
- We will leave Clayton and the world better than we found them.

These principles are evident the moment you walk in the door at Clayton Homes and they are recognized for their efforts, having won numerous MHI home design awards, being ISO 14001 Certified for green building standards, and having been named MHI Retailer of the Year eleven out of the past twelve years. To guarantee a great product, Clayton does not let a home leave their facility before going through quality assurance inspections such as indoor air quality, federal and local code compliance, structural strength and safety, plumbing plans and systems, and fire safety by a third-party inspector.

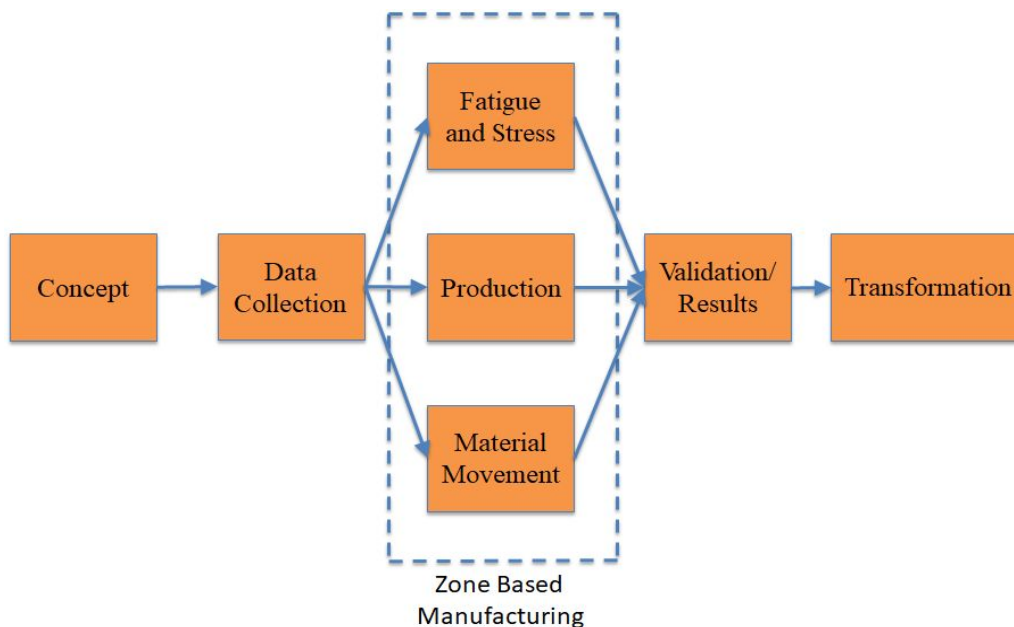
Our team of undergraduate students were assigned to Clayton Homes' Rutledge location in Tennessee at the beginning of 2018 and have continued our efforts here over the course of the year.

Needs Analysis

Over the last year, Clayton has paired with the University of Tennessee in order to increase production rates at their Rutledge facility due to a high demand for their homes. Other concerns expressed by Clayton included high employee turnover, fluctuation in demand throughout the year, and lack of space within the facility. Several teams from the University were assigned to this location with the goal of observing and increasing throughput and flexibility within the facility while considering the previously stated issues. The Rutledge location was divided into

12 primary stations in series, each of which added unique elements to each house built before being shipped to their respective locations. In order to improve production at this facility, the time each house spent in each of these stations had to be reduced.

Dr. Sawhney wanted to approach the task of increasing throughput by forming three teams. He has developed a concept he labels as Zone-Based Manufacturing (ZBM), which acts as a three-pronged strategy considering not only production processes, but also fatigue and stress, and material movement when looking to improve the overall production system.



One of Dr. Sawhney's teams was tasked with the primary, "online" production processes within each station. It was the responsibility of this team to reduce the

amount of time houses were spending in each station. A second team was given the challenge of reducing fatigue and stress on workers throughout the production improvement process, as this Clayton location struggled with retaining employees due to the physical demands required of them. Finally, a third team was tasked with analyzing and improving the current material movement within this facility. The idea was that as production increases, the flow of materials would have to improve as well to meet the increased demand within each station.

Initially, our team was paired with the graduate team responsible for observing and improving cycle times of the individual stations (the production element). This allowed us to familiarize ourselves with the overall goals of this project and gain a better understanding of how these three elements worked together to solve the production issues.

We worked together on Station 1 to identify what it would take to reduce the time it took to complete all of the necessary operations within. We performed time studies using camera footage in order to gain a better understanding of the exact job tasks and sequence of these operations. These time studies also enabled us to determine time spent on activities considered “Non-Value Added” such as time spent waiting on material or fetching tools. With zoning in mind, we then worked together to re-sequence and better divide up operations amongst workers based on location in order to reduce the time each house spent in the station. The

redesign was done under the assumption that all required materials were available, as imperfect material flow led to a significant portion of the non-value added time.

The redesign of Station 1 was completed and a pilot was performed. Staging the materials needed and implementing the operational changes resulted in a cycle time reduction from 63 minutes to under 27 minutes in total. This demonstrated the impact that Zone-Based Manufacturing could have on the facility if entirely implemented, but also displayed the importance that improved material movement played in obtaining these results.

At the conclusion of this pilot, the graduate team moved to the next station to continue the redesign of the online processes it contained. It became our team's responsibility to develop a strategy on how to best improve the offline processes feeding into each primary station in order to make this entire project possible.

Requirements Analysis

After determining the proper direction for our team's project, our next step involved creating clear, concise requirements in order to ensure the expectations of Clayton Homes would be met by the conclusion of our efforts. Our requirements were as follows.

All work shall be conducted in a manner that is consistent with the principles set forth by Clayton Homes. The principles of Lean Manufacturing shall be applied in our efforts to improve the current material flow within processes. We shall choose one station (process) to focus on initially. We shall observe and collect data on this station to gain a better understanding of the issues it faces. We shall find a solution that addresses the inefficiencies of the current material flow system within the station. We shall determine a plan of implementation for our solution. We shall design our solution and plan of implementation in a way that can be applied to other processes within the facility. We will take this solution “template” we create and apply it to other stations to show the effectiveness of our efforts. We will prioritize the well-being of employees throughout the process and align our decisions in a way that allows employees to do a better job while reducing the effort required by them.

By examining what made the Station 1 pilot a success, we determined there to be two critical components of material flow that had to be addressed:

- 1) Inventory practices must be improved, and
- 2) Sub-assemblies (offline processes) must be completed before their output is needed within each station.

In order to address both of these concerns, we identified two separate stations that best amplified each of these issues. We focused on improving inventory practices in Station 2 (Floor Decking), and we focused on sub-assemblies capabilities in Station 6 (Top Build). Using these stations as examples, our goal was to create two separate, universal templates that addressed these issues and could be applied to any station within the facility to effectively improve material flow.

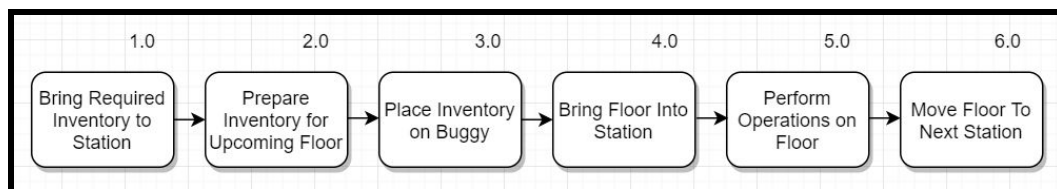
Functional Analysis

Due to the differences in our two elements of material flow, we had two separate approaches to how we analyzed these issues.

Inventory Practices

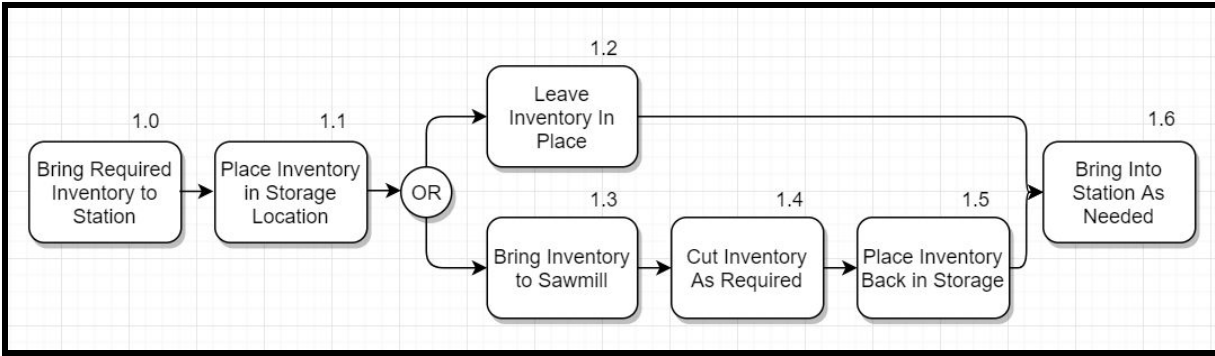
Because of the qualitative elements of inventory practices, we utilized flow diagrams to gain a better understanding of Station 2's inventory flow. The following functional flow diagrams demonstrate the processes we have observed within Station 2 at Clayton Homes. Station 2 is home to the process of floor decking, which consists of wooden boards being placed to cover incoming floors depending on the house model. The process begins with bringing the necessary inventory into the station to be prepared for upcoming houses. The inventory is then prepped by a worker within the station while other operators are working on

the floor currently in the station. Once the inventory is prepped, it is placed aside and then brought to the buggy where it waits to be used on the upcoming house. Around this time, the prior floor will be finished, picked up, and moved to the next station. The next floor is brought into the station. The buggy is then carried across the floor where the inventory (wooden boards) is placed and secured to the floor. When this process is done, the floor is lifted and carried to the next station.



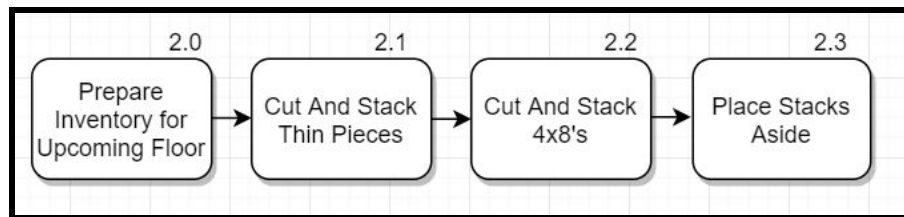
Top Level System Flow of Station 2

A further breakdown of the inventory acquirement process is shown below. The inventory of wooden boards are placed in a storage location outside of the station when it arrives at the facility. Some of these boards are brought to the sawmill room on the other side of the facility to be trimmed depending on the needs of the specific models. They are then brought back and stored again outside the station. The inventory is then brought inside the station as needed.



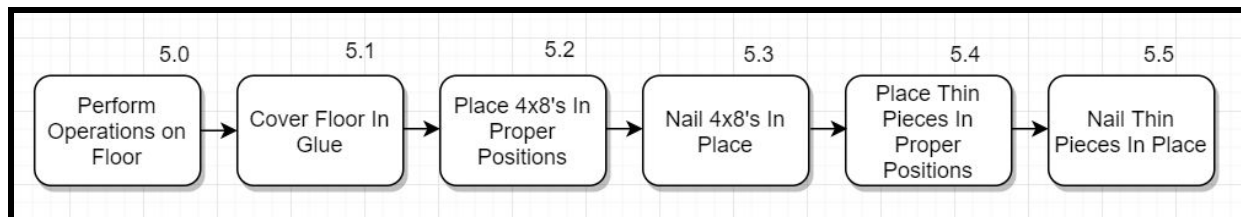
Second Level Flow

The preparation of inventory occurs within the station while prior floors are worked on simultaneously. This preparation involves looking at a book to determine what cuts and how many boards are needed for the next house model. When they have determined the necessary cuts, they take the stack of thin pieces needed for the particular model, perform the cuts while stacking the pieces in the order that they are required. The same process occurs for the 4x8 boards. When all required inventory has been prepped, they take the stack and set it outside until it is needed.

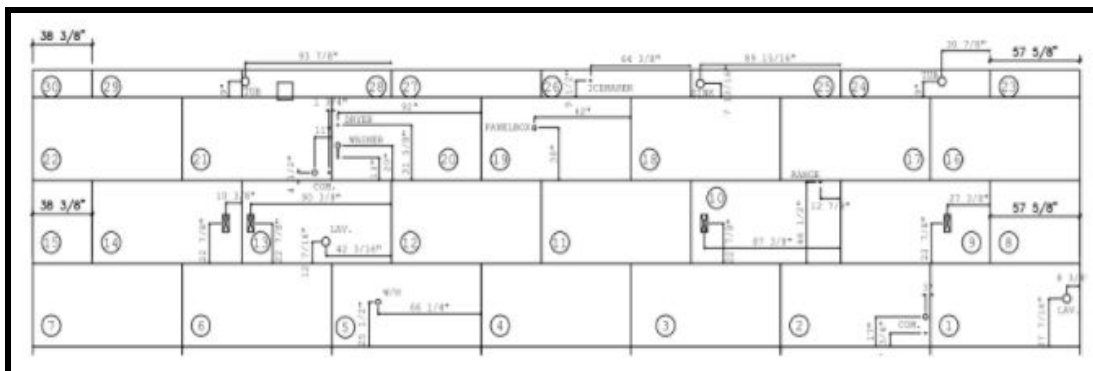


Second Level Flow

The actual operations that are done on the floor in the station are better expressed below. The floor is first covered in glue for better securing the wooden boards. The 4x8 boards are then laid in a particular order and put in place. A worker then comes through and nails these boards down with a nail gun. The thin pieces are then dragged into place and nailed in once there. An example of a floor with its required boards is shown below.



Second Level Flow

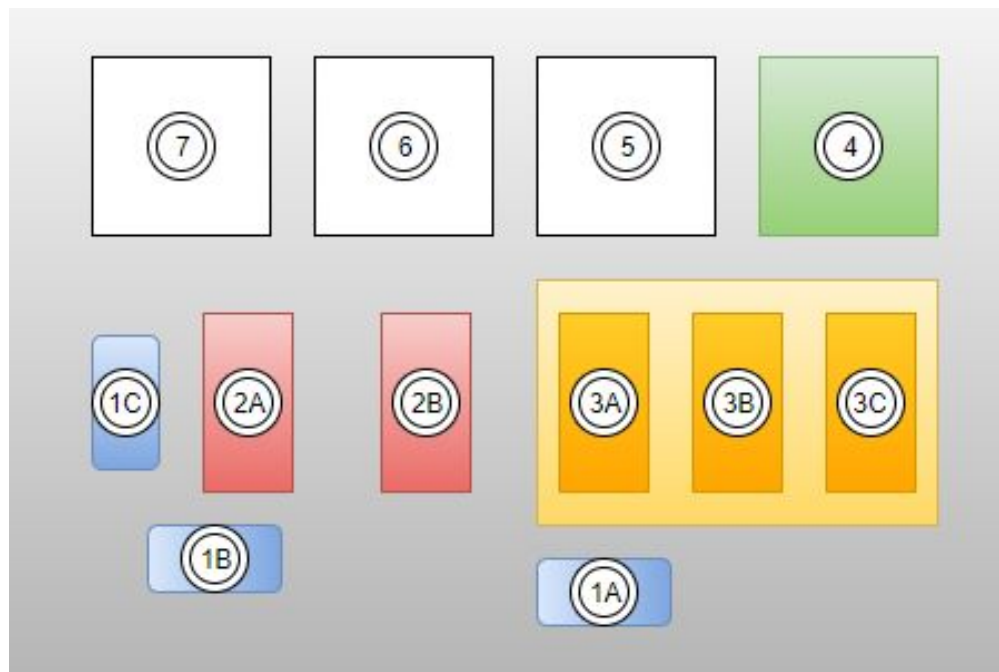


Station 2 Floor Example

(While the decking is being glued and nailed to the floor, the prep worker is either prepping the deck pieces for the next floor or helping another station)

Sub-Assemblies

Understanding the sub-assemblies that feed into the online process in Station 6 was a bit simpler. Station 6, known as “Top Build”, is home to the process of attaching the roof to each house in the station. The product of the sub-assemblies in Station 6 is the roof, assembled and divided into a front and a back half for each house. A diagram of these sub-assemblies is shown below.



Station 6 Sub-Assembly Overview

There are three primary sub-assemblies in this offline process consisting of smaller assemblies, top build jig, and prep booth. The smaller assemblies are found at locations 1A, 1B, and 1C consist of building overhangs, end trusses,

and gables to be used on each roof. The top build jig sub-assembly, found at 2A and 2B, is where the base of each roof half is constructed and where the products of the smaller assemblies are attached. Prep booth, the third sub-assembly found at locations 3A, 3B, and 3C, is where each roof half is touched up, painted, and stored before being attached in the online processes of Station 6 (located at 4 in the diagram).

The offline processes of Station 6 are critical to the overall production within this facility, and they also account for a significant amount of the floor space within the building.

Technical Performance Measures

Definition of Measures

We have listed several definitions of terms and concepts we have encountered and put to use with respect to our inventory project.

%Utilization of Offline Operators- We will calculate this by the time spent directly related with the process over the total time. A goal will be balanced utilization between offline workers within the same station.

Cycle Time of Offline Process- We will measure the time it takes to produce the materials offline and ensure it is within the minimum cycle time of the production process.

Sustainability- This will be a simple yes or no (1 or 0) whether or not our proposed solution is still functioning properly given our other TPMs. This will be observed on a bi-weekly basis once a solution has been implemented to a station. If the solution is not being maintained we will root cause the reason and address it further.

Process cycle time - The total period of time to move one unit of work from the beginning to the end of a physical process.

Value-added time - The time actually spent improving/producing a product; process time.

Non-value-added time - The time spent on a step or process that adds nothing to the finished product; wait time, move time, setup time

Takt time - The maximum amount of time to produce a product that is acceptable to meet the demands of the customer.

Cycle stock – The normal stock used during operations.

Inventory management information system – The part of a management information system that deals with the information needed for stock control.

Just-in-time – An approach that organizes operations to occur at exactly the time they are needed. $\text{Time needed} - \text{Time produced} = \text{measurement of JIT}$. We want this number to be positive and as close to 0 as possible.

Description of How Measurements are Taken/Where Data Comes From

During our work on process improvement, data was collected through the use of man machine charts and time studies. Cameras were utilized in order to collect hours of footage without needing to be present. Due to the success of this method, our team used footage of Stations 2 and 6 in order to increase our understanding of the process, identify variation, and record data.

For the purposes of Station 2, our team also requested a production schedule of the houses and delivery schedule of 4' x 8' decking boards. The production schedule covered two and a half months of production (182 houses) and was an extremely valuable resource for our team. This schedule provided us with the following pieces of information for each house:

- House Model number
 - ex) CMB28703BH - The three letters (CMB) represent the House's model line. The first two numbers (28) reveal the house width. The next two numbers (70) reveal the length. The fifth number (3) reveals the number of bedrooms.
 - A two by six model option is indicated by yellow highlighting over the run number. This option requires different components in station 2 and thus was a crucial piece of information to note for each house.
- Production start day
- Production end day

Below is a just a small segment of the production schedule we received.

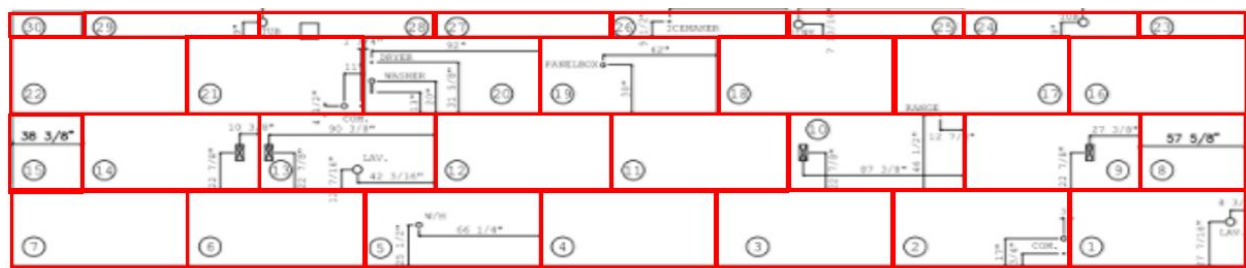
	Week of 3/19/2018															order number
SC #	Retailer	City	St	Model	Special Notes	RSO/Stock	Freight	Height	Run #	Serial #	On Line	Day	Off Line	Date Off	RY	*****
143610	Clayton Homes	Ringold	GA	RGR28563AH		Stock	28		210-18	32226	3/13/2018	Monday		3/19/2018		
010170	Clayton Homes	Georgetown	IN	CMB28703BH		Beaver	28		211-18	32013	3/13/2018	Monday		3/19/2018		
000420	Clayton Homes	Cookeville	TN	ANN28563AH	Energy star	Ritter	28		212-18	32227	3/14/2018	Monday		3/19/2018		
013160	Clayton Homes	Louisville	KY	RGR28684AH		Stock	28		213-18	32228	3/14/2018	Monday		3/19/2018		
032400	Clayton Homes	Waynesville	NC	SPL28563RH		Hipps	28		214-18	32217	3/14/2018	Tuesday		3/20/2018		
040790	Clayton Homes	Newport News	Va	CMQ32724AH		Stock	32		215-18	32229	3/14/2018	Tuesday		3/20/2018		

From this schedule we recorded the width, height, and indication of two by six option. Once all information was recorded, a small function was created in Microsoft VBA in order to create a list of each unique model number and the number of occurrences of that model over the two and a half months. The

number of occurrences were divided by the total number of houses to assign a percentage to each specific model.

Models:	Count	Percent
2856	69	37.912%
3266	7	3.846%
2852	3	1.648%
3256	3	1.648%
2854	2	1.099%
3272	17	9.341%
2868	18	9.890%
2848	16	8.791%
2872	5	2.747%
2860	6	3.297%

Above is a small section of the data table. The Model column is simply the width and length put together. A “.1” was added to the end of the model to indicate the selection of the two by six option. From our data we found a total of 24 unique models in terms of width and length size combinations, none more common than the 28’ x 56’ model shown at the top of the image above.



In the image above, each of the decking boards can be seen outlined in red and numbered. In all houses, regardless of model, the decking is arranged in 4 rows with the alignment of the decking pieces shifting each row. This particular image

shows a 28' by 56' house. The lowest row and row second from the top always start with a full 4' x 8' decking board while the middle row starts with a cut board in order to stagger the alignment. The top row always follows the alignment of the middle row, but has a width of either 15" or 17" for a 28' house. If the house is a 32 foot wide model, the top row will consist of boards either 37" or 39" in width. The width of the top row is dependent on whether the two by six option was selected or not. If it was selected, the boards will be the wider of the two options (either 17" or 39"). This information was used to record the number of 4' x 8' and cut boards used for each model.

Width	Length	# of 4 x 2	# of 4 x 4	# of 4 x 6	# of 4 x 8	Total 4 x 8
28	56	0	2	0	20	21
32	66	2	1	1	23	24.75
28	52	0	3	0	18	19.5
32	56	0	2	0	20	21
28	54	1	1	2	18	20.25
32	72	0	2	0	26	27
28	68	0	3	0	24	25.5
28	48	0	2	0	17	18
28	72	0	2	0	26	27
28	60	0	3	0	21	22.5

The "Total 4x8" column simply summed the number of 4x8's with the fraction of cut pieces used, for example $4 \times 2 = 0.25$.

top row size (in.)	X x 2	X x 4	X x 6	X x 8	4x8	Cut Total
15	0	2	0	6	2.333333	23.33333333
37	0	1	1	7	9	33.75
15	0	1	0	6	2.333333	21.83333333
37	0	2	0	6	7	28
15	1	1	0	6	2.333333	22.58333333
37	0	2	0	8	9	36

Then the number of cut pieces for the top row were recorded. In the columns “X x 2”, “X x 4”, “X x 6” and “X x 8”, the “X” is to indicate the width, 15 inches or 37 inches as shown in the first column. The “4x8” column calculates the number of 4”x8” boards required to supply the number of cut pieces. The “Cut Total” column simply adds the “4x8” column with the “Total 4 x 8” column seen in the table on the previous page to reveal the number of “4x8” boards required to complete the entire floor of each model. This cut total and 4x8 total were then multiplied by the model percentages found in the first table shown to calculate a weight adjusted amount. This was done for each model and the summation of this column revealed the weighted average number of 4’ x 8’ boards used on each house. This sum was multiplied by the average number of completed houses each day (7.5) to reveal the expected number of 4’ x 8’ boards consumed per day. This number came in just under 200 boards (199.4). Additional data processing was performed to find the consumption rate of cut pieces. This started with summing the weight adjusted cut pieces for each group of size (15”, 17”, 37”, and 39”)

	37"	39"	15"	17"
Weight Adjusted Sum:	1.343406593	0.532967033	1.730769231	0.373626374
4x8 per day:	10.1	4.0	13.0	2.8
cut pieces per day:	10.1	4.0	38.9	5.6

Above are the results of the previously mentioned calculations. These results suggest roughly ten 37" pieces, four 39" pieces, thirty-nine 15" pieces, and six 17" pieces will be consumed each day at station 2. This data helped set the foundation for the design of our pull system.

House of Quality

Our team determined that a House of Quality did not apply to this project and would not be necessary for the completion of our efforts.

Design Alternatives

Generation of Alternatives

As discussed, the goal of our project is to create a standard approach on improving the flow of materials to and from stations within Clayton Homes in a way that aligns the production improvements while considering the fatigue and

stress on employees throughout the development process. After gaining an in-depth knowledge of exactly how the processes within Stations 2 and 6 were performed, we were able to begin generating potential designs for these templates. A number of different aspects were weighed and considered for our proposed templates.

Inventory Practices

First, we wanted to look into the current flow of materials to and from the station. The 4'x8's are taken from their storage area to the sawmill to be cut into their specific measurements, then the cut pieces are taken to the production area for station 2. If the boards do not need to be cut, they are brought directly to station 2's production area.

We considered the concept of incorporating production controls. Production controls would be applied to the subassemblies in each station in order to determine when and how many units are produced. subassembly utilization percentage and inventory levels resulting from production could be lowered as a result.

We then looked at making the station a just-in-time system. Creating this type of system within the station requires that the material production, subassembly and decking assembly have zero delays and complete the operation exactly when its

unit is required. Implementing this type of system will reduce inventory levels and prevent production of subassemblies from occurring when not necessary.

Next, we focused on the concept of kitting and its applications within Clayton Homes. Each station has a list of parts and/or assembled components needed for completion. Kitting all these required elements for one floor may reduce setup and transportation time during the production at the station. In addition to better supplying the station, kitting may be useful to new employees, or those less familiar with the process. The kits would incorporate the process changes suggested by the production group.

Once kitting was considered, we contemplated creating supermarkets to supply the kitting. Supermarkets would keep all materials organized and controlled. A supermarket would integrate very well with production controls and a two bin system. Supermarkets would consolidate inventory and limit the number of points of storage.

Finally, ergonomics were given a tremendous amount of consideration for all proposed designs. The processes we are looking at closely involve lifting as well as traveling, so we want to try to reduce these motions in order to reduce the strain on employees and increase their quality of life.

Sub-Assembly Capabilities

Because of the expected reduction in the online cycle time in Station 6, we needed to understand what the offline processes feeding in were capable of. The current demand for a full roof (both halves) is approximately one every two hours (20 houses a week). Employees in these offline processes claimed that a house has never been held up by a roof not being finished under this demand.

This was good news, but we wanted to know how many roofs could be produced given that production of houses improved. In the case of Station 6, we set an ideal goal of being able to produce 40 houses a week, meaning Station 6 would demand a full roof every single hour. We knew this was optimistic but wanted to come as close to this goal as possible.

Based on our set demand, we wanted to know how many roofs the current system could produce in a week. We decided to use the simulation software Anylogic to aid us in this projection. In order to utilize this tool, the first thing we had to do was perform time studies on all of the sub-assemblies. To accurately reflect the system, we decided to collect data on at least three different models of roofs at each sub-assembly. We then took the average, minimum, and maximum times spent in each sub-assembly and used a triangular distribution in our simulation. After modeling the offline processes as closely as possible using these distributions, we ran our simulation and analyzed the results.

We were able to show that given a demand of 40 roofs a week, the current roof production capability was only about 24. While this confirmed that roof production could in fact keep up with current demand and even produce up to 4 more a week, we wanted to see what improvements we could make to this process to not only increase this number, but also address other issues such as worker fatigue and lack of space.

To do this, we analyzed the critical path of this process and identified the constraint in the system. Using our simulation, we were able to show that the bottleneck of Station 6's offline processes was in the Top Build Jig Sub-Assembly. We also found that none of the other sub-assemblies were threats to the required cycle time of one hour.

Because of this, we knew our only focus should be reducing the time roofs were spending within the Top Build Jig, where both halves of each roof were assembled simultaneously. We came up with three potential solutions to attack this issue.

- 1) Balance the operations done in each sub-assembly
- 2) Resequence/redesign the job tasks performed on each roof half
- 3) Combine front and back half assemblies so that only one roof half is worked on at a time, then resequence/redesign job tasks.

Feasibility Analysis of Alternatives

Again, we analyzed the feasibility of our proposed methods for both material flow elements.

Inventory Practices

After considering and proposing a number of different concepts we believe can potentially affect the current inventory system, we weighed the usefulness and applications of these ideas and determined which ones we would focus on when creating our final template.

The current flow of materials improvement for station 2 hinges on the location of the sawmill, so the decision on whether it should be closer to station 2 or closer to another station will depend on the percentage of material going to each station. This would be considered in the design of the future plant layout.

Production controls are something we definitely planned on incorporating into our inventory template. Focusing on the needs of each floor should be the driving factor behind when and where materials should be prepared and placed in order to reduce overproduction and other wastes caused by lack of communication between the process and respective subassemblies.

The quality of the just-in-time system can be measured by measuring the gaps between the material production, subassembly and decking assembly. The measurement should be a positive number and as close to zero as possible, but never a negative number, as stated in the Technical Performance Measures. A negative number would indicate that the next order of operation is waiting on a previous process.

The concept of kitting is one that we find incredibly useful with respect to the processes taking place within Clayton. Almost every station requires a number of different materials to be added and used on each floor. Currently, there is not enough communication between needed materials. Implementing kitting of all required parts in a clear and organized way can standardize the process for workers and reduce non-value added time in acquiring the correct materials in the appropriate order. The kits would be aligned with the process changes proposed by the production group.

Supermarkets are deemed necessary to smooth the flow of materials required within kits. Materials for each kit should be on hand such that as soon as one kit is finished, the kit-maker can immediately begin making the next kit without having to find the necessary materials throughout the station.

The ergonomics for station 2 should be improved by increasing the height of the pallet in the subassembly production. Increasing the height would reduce the degree of bending for the operator.

Sub-Assembly Capabilities

As mentioned previously, we came up with three alternatives to improving the offline roof assembly process. We worked with members from Clayton to identify the best option. Balancing operations between the different sub-assemblies was deemed not feasible by the Clayton team, so that option was eliminated from consideration.

We again turned to Anylogic to determine the impact that our two remaining alternatives would have. Using projected cycle times, we were able to show that both of these methods would raise the roof production capability to around 30 houses a week. We were pleased with these results and asked the Clayton team which idea they preferred. The deciding factor was easy for them, as our third idea of combining front and back half assemblies so that only one roof half is worked on at a time would actually free up almost 2400 square feet of floor space in the facility (30 ft by 80 ft area). If we could show that our redesign would in fact improve roof production, we would also free up a significant amount of space that Clayton could use for other purposes.

Comparison of Alternatives

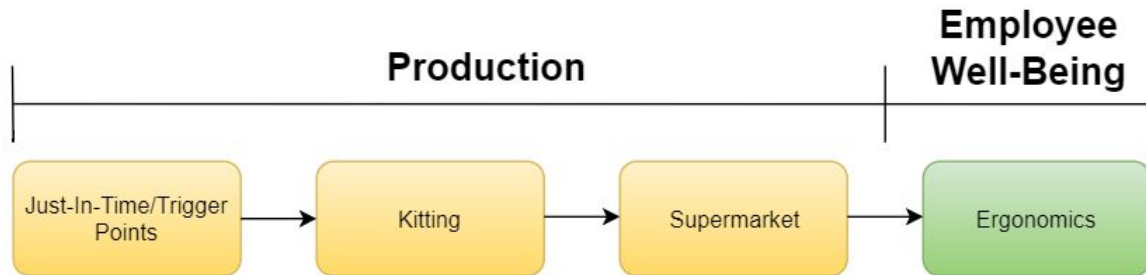
After determining the feasibility of our design alternatives for inventory practices, we have distinguished four concepts in particular that we will incorporate into our final template when looking to improve each station's inventory process. We feel that our chosen design tools will best allow us to align material reliability with production improvements.

As for the element of offline processes in material flow, we identified the Top Build Jig sub-assembly in Station 6 as the constraint in increasing roof production. We determined that the optimal solution to this issue would focus on combining the two halves of this sub-assembly so that only one half of each roof is worked on at a time. This allowed us to resequence/redesign the job tasks amongst 4 workers instead of 2, which increased flexibility and allowed us to overlap some of the required operations in order to reduce the cycle time. This design would also free up as much as 2400 square feet of additional space to be used for other purposes within this facility.

Analytical Models

The following model is our proposed inventory practices template. This was generated after weighing the usefulness and practicality of the different design

alternatives we considered in our generation process. We go into further detail on our template in the design development stage.



As for our sub-assembly template, a detailed list of steps we took and overall methods are explored in the design development stage as well.

Cost/Economic Benefits

Potential financial benefits of increasing the capacity of Clayton Homes is tremendous. Clayton currently produces about four houses (7.5 - 8 floors) every day. Conservatively, the goal set by Dr. Sawhney and the graduate team is increasing throughput to 10 floors a day, which means making five houses a day instead of four. This goal would theoretically increase the revenue of Clayton Homes by 25% every year (an increase of \$6.25 million). Based on the early results of some of the production changes being made by the graduate team, given that inventory can be staged and in place when needed, the goal of making

a additional house every day is definitely possible. This speaks to the importance of our role in creating an inventory system in which material is always “staged”.

Aside from the increased revenue provided by increasing throughput within this facility, we also weighed the value of the additional floor space our redesigned sub-assembly would generate. The Rutledge facility brings in an average revenue of \$50 million a year. Because this facility is roughly 90,000 square feet, the average annual revenue per square foot is approximately \$556. Assuming we are able to free up the expected 2400 square feet of space after implementing our redesign, the value this redesign will create is upwards of \$1.3 million a year.

Final Design

Develop Design of Recommended Alternative

Inventory Practices Template

The Data we collect will allow us to identify the constraint on throughput in the current system. The redesign of the station 2 process will then proceed with a focus on relieving the constraint. The following phases will be performed in order to complete a full redesign of the inventory system at station 2 in order to create a pull system:

1. Design for Just-In-Time for all materials used at station 2.

- Material processing performed at the sawmill will be orchestrated to respond to the consumption rate of the materials.
- 2. Develop a method for kitting the necessary materials for each house.
 - each material needed and in the order it will be used all in one stack.
 - numbering and color coding used to identify location of materials on the house.
- 3. Design supermarkets to supply the materials for each kit.
 - All material needed to develop kits will be organized and easily tracked.
- 4. Develop a two bin supermarket system for the kits to be placed in.
 - kit builder will be two houses ahead and only begin work on another kit when one is removed from the two bins.
- 5. Incorporate ergonomics into the manual work performed at this station.
 - Introduce mechanical aids to reduce the bending, pulling, pushing, and lifting of heavy pieces.

Sub-Assembly Capabilities Template

(See Separate Attachment for Comprehensive Template)

Implementation

Implementation Overview

After analyzing the different issues that comprise inventory practices and sub-assembly capabilities within stations 2 and 6, we were able to generate two general templates that address these issues within a given station. We then looked back at these two stations to demonstrate how these templates should be implemented. For the inventory practices template that we developed, the applications of this process within station 2 were discussed throughout the previous sections.

As for our sub-assembly capabilities template, some of the applications to Station 6 were also discussed previously. We mentioned how identified the sub-assemblies, found the constraint, and selected the best method of redesigning the identified sub-assembly. The next step for our implementation was to resequence all of the required job tasks for each roof half in a way that more efficiently utilized all four workers while reducing the total time spent on each one.

Similarly to the redesign of Station 1, we created man-machine charts that documented every single operation done for a single roof half, as well as the time

that each of these operations took. Below is an example of what these charts looked like.

Man 1						Man 2					
Step	Process	Time Start	Time End	Total Time	"v" or "n"	Step	Process	Time Start	Time End	Total Time	"v" or "n"
1	peeling paper off drywall	11:40:03	11:41:02	0:00:59	57	1	cutting boards in prep	11:39:34	11:41:09	0:01:35	56
2	prepping buggy and moving into place	11:41:02	11:42:07	0:01:05	56	2	idle	11:41:09	11:42:36	0:01:27	55
3	idle	11:42:07	11:42:36	0:00:29	55	3	placing drywall	11:42:36	11:46:05	0:03:29	54
4	placing drywall	11:42:36	11:46:05	0:03:29	54	4	walking	11:46:05	11:47:07	0:01:02	53
5	walking	11:46:05	11:46:51	0:00:46	53	5	measuring	11:47:07	11:48:19	0:01:12	52
6	take measurements	11:46:51	11:50:50	0:03:59	52	6	more measuring	11:48:19	11:49:05	0:00:46	51
7	placing joists	11:50:50	11:51:06	0:00:16	51	7	retrieving long boards	11:49:05	11:50:35	0:01:30	50
8	more measuring	11:51:06	11:53:08	0:02:02	50	8	placing and cutting long board	11:50:35	11:51:16	0:00:41	49
9	retrieve tape measurer	11:53:08	11:53:29	0:00:21	49	9	waiting	11:51:16	11:51:45	0:00:29	48
10	retrieve tool/item	11:53:29	11:54:09	0:00:40	48	10	cutting out section of drywall	11:51:45	11:54:21	0:02:36	47
11	set item on side of drywall	11:54:09	11:54:25	0:00:16	47	11	removing cut pieces	11:54:21	11:56:23	0:02:02	46
13	placing trusses	12:29:58	12:31:11	0:01:13	46	13	placing trusses	12:29:58	12:31:11	0:01:13	45
14	retrieving trusses by hand	12:31:11	12:32:42	0:01:31	45	14	straightening trusses	12:31:11	12:34:03	0:02:52	44
15	walking	12:32:42	12:33:29	0:00:47	44	15	cutting section out of trusses	12:34:03	12:35:19	0:01:16	43
16	retrieving truss by hand	12:33:29	12:34:26	0:00:57	43	16	idle/straightening trusses	12:35:19	12:37:02	0:01:43	42
17	retrieve truss	12:34:26	12:35:34	0:01:08	42	17	walking	12:37:02	12:37:33	0:00:31	41
18	retrieve truss	12:35:34	12:36:58	0:01:24	41	18	retrieving and placing extra trusses (2)	12:37:33	12:39:20	0:01:47	40
19	idle	12:36:58	12:38:00	0:01:02	40	19	retrieving tool/item	12:39:20	12:42:51	0:03:31	39

Operational Sequence Using Two Employees

After using this information to understand the exact number of operations, number of people required to do each, and the sequence that they must be done in, we attempted to split these operations in a more efficient manner that utilized four workers instead of two, because we proposed to combine the two halves of the sub-assembly. When doing this, we gave heavy consideration to the location that each operation must be done and where material should be retrieved from in order to minimize the stress on the employees involved.

An example of our redesigned sequence of job tasks between four different employees instead of two is displayed below. Performing this redesign on a 72 ft roof model, we were able to reduce the sub-assembly cycle time from 1 hour 50 minutes to 1 hour 20 minutes. While our ideal goal of 40 roofs produced a week would demand a cycle time of 1 hour, we were still able to drastically improve the

current capabilities with this projection. This proposed sequence is awaiting a pilot.

Man 1			Man 2			Man 3			Man 4		
Process	step time	total time	Process	step time	total time	Process	step time	total time	Process	step time	total time
Place Drywall from carrier onto roof platform	0:05:36	0:05:36	Place Drywall from carrier onto roof platform	0:05:36	0:05:36	have the ridgebeams positioned and inner rim beams	0:03:00	0:03:00	have the ridgebeams positioned	0:02:30	0:02:30
Place and position end truss at end of roof (travels on carrier with drywall)	0:00:30	0:06:06	Place and position end truss at end of house (travels on carrier with drywall)	0:00:30	0:06:06	cutting insulation dam and placing under house	0:01:50	0:04:50	brings small blocks for problem walls next to house (not onto house, done prior to drywall placement)	0:01:00	0:03:30
walk carrier back to other side of roof to be loaded with trusses	0:01:03	0:07:09	place 1x4 on house	0:01:00	0:07:06	retrieve plywood squares	0:00:30	0:05:20	retrieve 1x4 and place next to point of use	0:01:00	0:04:30
after carrier is loaded with trusses, walk the carrier back to other side of house	0:01:30	0:08:39	place small blocks for problem walls onto house	0:01:00	0:08:06	stretches tape measure out	0:00:20	0:05:40	retrieve and place lift blocks next to point of use	0:01:00	0:05:30
places fall protection chain onto drywall	0:00:15	0:08:54	place lift blocks onto house	0:00:30	0:08:36	mark line for trusses on drywall	0:01:00	0:06:40	measuring front side of roof	0:03:08	0:08:38
secure/nail end truss to side of roof facing interior of plant	0:00:49	0:09:43	waiting	0:00:18	0:08:54	drawing specific markings on back side (inner side)	0:00:33	0:07:13	have rim rails positioned	0:01:00	0:09:38
grabbing truss off of carrier, standing upright on tick marks, and letting go when men 3 and 4 grab it.	0:06:30	0:16:13	Nail near side end truss	0:00:49	0:09:43	cuts small rectangles out of drywall edges and place plywood squares and load blocks where needed	0:02:30	0:09:43	waiting	0:00:05	0:09:43
Retrieving and placing "backbone" framing within roof. (do not position it yet)	0:00:45	0:16:58	grabbing truss off of carrier, standing upright on tick marks, and letting go when men 3 and 4 grab it.	0:06:30	0:16:13	Nailing trusses aligned by Man 1 & 2	0:06:30	0:16:13	Nailing trusses aligned by Man 1 & 2	0:06:30	0:16:13
Secure/nail end truss on edge of roof facing plant exterior	0:01:00	0:17:58	Retrieving and placing "backbone" framing within roof. (do not position it yet)	0:00:45	0:16:58	nailing ridge beams and rim rails to inner side of roof	0:02:40	0:18:53	nailing ridge beams and rim rails to inner side of roof	0:02:40	0:18:53
using level and nailing trusses to merging beams (other guy uses tape measurer)	0:01:51	0:19:49	Secure/nail end truss on edge of roof facing plant exterior	0:01:00	0:17:58	positioning "backbone" framing	0:03:05	0:21:58	Nail the rim rail boards to the outer edge of the roof	0:07:20	0:26:13
nailing plywood squares and insulation guides to ridge beams	0:02:30	0:22:19	preparing house for gable	0:11:08	0:29:06	nailing backbone framing	0:05:51	0:27:49	secure gable to crane	0:02:00	0:28:13
nailing insulation dam along inner edge	0:03:04	0:25:23	positioning and securing gable (steps back briefly to let glue pass)	0:15:50	0:44:56	Glues from outside edge starting near side	0:07:05	0:34:54	Glues from outside edge starting far side	0:05:22	0:33:35
place rim rail splice blocks	0:01:00	0:26:23				gluing while standing within roof interior	0:08:47	0:43:41	Positions and secures gable alongside Man 2	0:11:21	0:44:56
Blocking and gluing the rim rail splice	0:02:31	0:28:54				Aid Man 1 in securing crane to roof	0:01:15	0:44:56			
nail beam for overhang support at end truss facing plant interior (connects end truss to other trusses)	0:00:30	0:29:24									

Operational Sequence Using Four Employees

Issues with Implementation

While we feel that the templates we generated to improve both inventory practices and sub-assembly capabilities will be highly effective in improving

Clayton's ability to increase production capacity and flexibility, there were implementation challenges for each.

For the inventory practices template, many of the components rely on additional space that is not yet available in this facility. An expansion of the Rutledge plant is in the works but will not be completed for at least another two years.

As for the sub-assemblies template, we have shared our proposed redesign of Station 6's Top Build Jig sub-assembly. Clayton is in the process of scheduling a pilot but this relies on several factors including retraining of designated employees, the right time of the week, and the specific model of home that must be used in the pilot.

Evaluation

Final Measurements of System

Ultimately, the goal of working with Clayton Homes has been to increase production capabilities while also improving the quality of life of the employees that comprise this facility. As discussed earlier, improving the material flow to the online processes in each station is critical to making this possible. We believe that both of our templates do exactly this. We wanted to come up with a solution that for each issue was specific enough that it could be implemented on any

given station, but also flexible enough that it could be applied to many different operational processes.

Our inventory practices template contains four critical components focused on implementing a pull system for each station in order to increase throughput while minimizing wasted resources. Concepts such as Just-In-Time material, kitting, supermarkets, and ergonomics all work together to ensure that materials are in the right place at the right time while considering the effects this will have on employees.

Our sub-assembly capabilities outline enables anybody in Clayton Homes to identify a station to focus on and immediately go about measuring and improving maximum capacities within the respective sub-assemblies, while also considering how employees are affected.

Evaluation of Implemented Solution

As mentioned previously, if we were given more time, we feel like we would be able to successfully pilot both templates not only in Stations 2 and 6 but at any given station Clayton felt needed improvement. Unfortunately, we did not get the chance to go forward with our pilot during our project window due to logistical issues with making these happen. However, we were able to share our ideas for both Stations 2 and 6 and demonstrate how our templates should best be applied

to a new station. We have given our templates to Clayton to use in the future and hope that they will utilize the tools we have left them. Given their feedback and the savings that implementing these templates would yield them, we believe they will in fact move forward with the outlines we provided with them, starting with piloting the results we projected in Stations 2 and 6.

Recommendations for Future Work/Future Projects

As discussed, we believe that Clayton's next steps should be moving forward with the pilots of our ideas for Stations 2 and 6. Assuming they achieve the results we have projected, we hope that they will scale up these efforts to a factory-wide improvement project. If it is truly their goal to improve production flexibility and reduce the stress that their employees constantly face, we feel that implementing these templates throughout the facility would be the ideal starting point.

Appendix

Industrial Engineering Senior Design Check List

Project Title: Clayton Homes Inventory Project		
Sponsor: Dr. Sawhney	Term: Spring 2018	
	Planned	Implemented
Constraints		
Economic	✓	
Environmental		
Sustainability	✓	
Manufacturability	✓	
Ethical		
Health and Safety	✓	
Social		
Political		
Other ()		
Standards		
IE/Engineering Tools		
Supermarket	✓	
Ergonomics	✓	
Man-Machine Charts		✓
Gantt Charts		✓
Pull System/Just-In-Time	✓	
Kitting	✓	