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DEMCO Side-dump Trailer Final Assembly Line Improvement: A Case Study

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DEMCO Side-dump Trailer Final Assembly Line Improvement: A Case Study

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this Creative Component. The Graduate College will ensure this Creative Component is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I would like to dedicate this thesis to my parents Thangavel Palanisamy and Kalpana Thangavel, my brother Rahul Raj Thangavel, and my cousin Priya Somasundaram without whose support I would not have been able to complete this work.

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NOMENCLATURE

VA	Value Added
NVA	Non-Value Added
SVA	Semi-Value Added
SFV	Shop Floor Viewer
MES	Manufacturing Execution System
TCM	The Construction Manager
MPM	Manufacturing Process Management
eBOM	Engineering Bill of Material
mBOM	Manufacturing Bill of Material
$\Delta cycle_{max}$	Maximum difference in assembly line times
MSME	Micro Small Medium Enterprises

ACKNOWLEDGMENTS

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ABSTRACT

This case study focuses on Dethmers Manufacturing Company (DEMCO), located at Spencer, Iowa, where they manufacture semi-trailers. Their semi-trailer sales have rocketed up to a 200% increase compared to last year. Offering diverse model options (over 45 different models and 500 different options) without standard operating procedures, the operators have a hard time understanding the process and assembly. This leads to an exponential increase in the overall lead time and creates bottlenecks in the process. Currently, the facility is working on expanding its product line and bringing in larger assembly line improvements. The project initially aims to create detailed process work instructions and identify opportunities to improve the overall efficiency and throughput of the side-dump final assembly line by 30% using an MES system.

The project's current state was measured by conducting an observed time study, which helped identify the bottlenecks in the assembly line. The time study results show, only 38% of the work done in the final assembly was value-added. Over 80% of the non-value-added times were wasted in - operator being idle, taking excess breaks, and waiting for parts.

In the future state design, identified problems were addressed using an MES system, carrying out assembly line balancing and various continuous improvement activities reduced the NVA time by 52%, which increased the production efficiency by 43%, and reduced the workforce by 25% - saving Demco potentially $315,460.00 a year.

CHAPTER 1. INTRODUCTION

1.1 About DEMCO

Dethmers Manufacturing Company (DEMCO), located at Boyden and Spencer, Iowa, was first established by Robert Dethmers in 1950. Today, Demco is the leader in manufacturing agricultural applications and harvest equipment. Their main product line includes a wide range of semi-trailer models, RV towing, and trailer components. Over the years, Demco has acquired several different brands to become part of the Demco Family. Some of these include Maurer Manufacturing, Hijacker 5th Wheel Hitches, Circle R Manufacturing, and SMI Manufacturing. Since the acquisition, Demco has become a leader in the agricultural industry. From agriculture and towing to brake manufacturing, Demco continues to produce the best products available without compromise. The company currently has 291 employees altogether.

Figure 1.1 Demco spencer aerial view

1.2 DEMCO Spencer

This project focuses on the Spencer location, where they currently manufacture over six different agricultural and industrial trailers. These trailers are used for tractor equipment, grains, liquids, and building materials. The facility has a total area of about 1,400,000sqft, and this includes eight different buildings: warehouse, fab, weld1, weld2, prep, blast, paint, and final assembly, as shown in Figure 1.2. In addition to that, the facility has 94 employees altogether. Table 1.1 shows the facility details.

Area (Sq. ft)	Open	**1,266,000**	**Total**
	Closed	26,051	Warehouse
		16,200	Prep
		2,592	Blast
		7,500	Paint
		11,664	Weld2
		44,813	Weld1
		18,432	Fab
		20,250	Finish
		147,502	**Total**
	Offices	4,440	Warehouse
		150	Prep
		6,418	Weld1
		495	Fab
		3,640	Finish
		15,143	**Total**
Employees		27	White Collar
		67	Blue Collar
		94	**Total**
Production Units 2020		**387**	**Total**

Table 1.1 Facility details

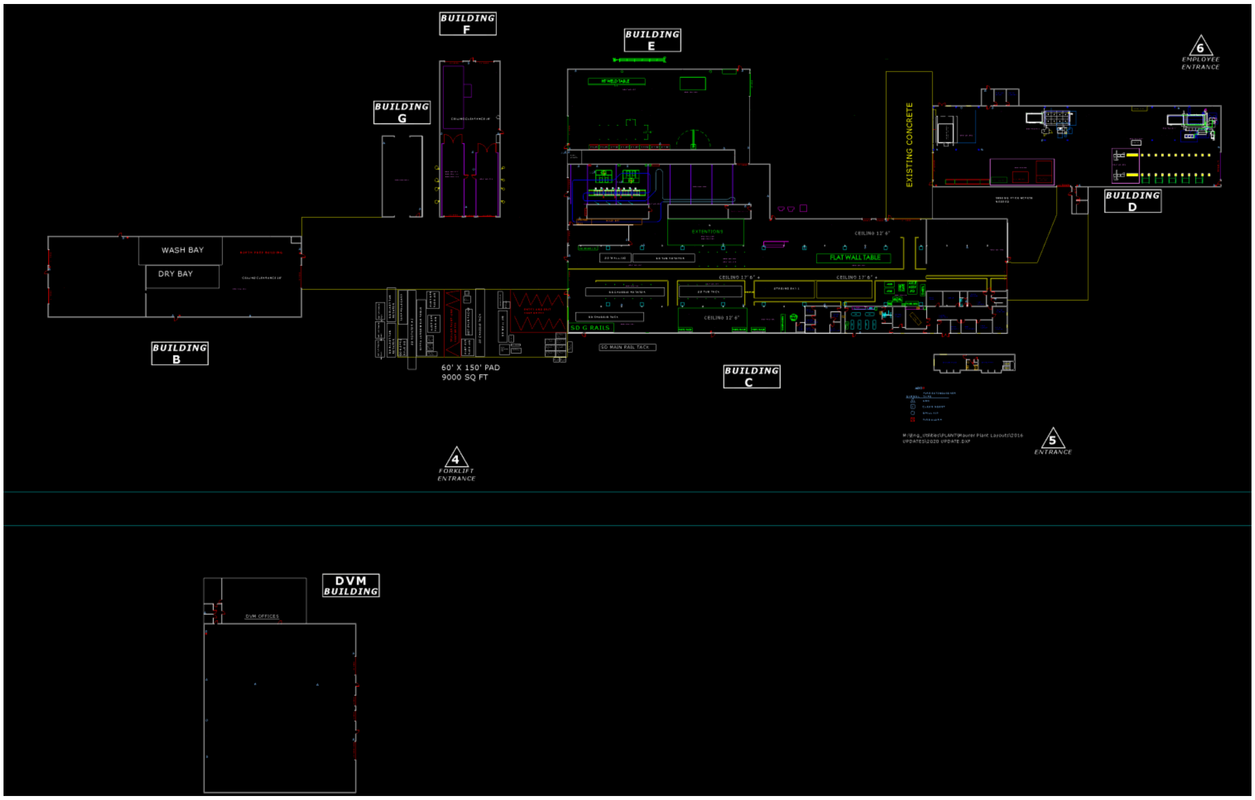


Figure 1.2 Demco spencer layout

1.3 Products

Trailers such as steel grain trailers, liquid tender trailers, side-dump trailers, steel drop deck trailers, and gondola scrap trailers were manufactured in this facility. Each product has a wide range of models and options available for the customer, and such variety makes Demco a unique manufacturer amongst their competitors with high variety, low volume product features. The production is done according to the customer order and stock units, with manual production planning. Besides having multiple model variants, the customers can also add a great variety of options to each model, ranging between 100 to 500 options. Table 1.2 shows the current product line and the number of models associated with that.

Product	Models
Side Dump	45
Drop Deck/ Liquid Tender	47
Gondola	40
Head Trailer	28
Grain Trailer	9

Table 1.2 Products and variants

1.4 Background

The trailer production at Demco, Spencer, is done at six main buildings, including 43 workstations and 60 operators. The operational classification of the production system is shown in Table 1.3.

Department	No. of Stations	Workers	Building	Work
Fab	6	11	D	Sheet metal cut, bend, and saw
Weld	24	30	C	Main and sub-assembly weld
Prep	2	4	B	Wash and debur the welded items
Blast	1	1	G	Sandblasting
Paint	3	5	F	Painting and drying
Finish	5	9	DVM	Final assembly and inspection

Table 1.3 Operational classification

The steps of a trailer manufacturing process can be summarized as the following. The trailer production starts at the fab department at Building D, where the sheet metals are processed into the laser cutting machine and cut to specified dimensions. Those sheets were further bend, sawed, and sent to the weld department for welding at Building C. The significant components like chassis, tub, grain trailer, gondola trailers have its own product lines and stations at weld. All the subassemblies were welded parallelly at substations. After welding, the parts are taken to the prep department in Building B, where the welded components are deburred and washed to ensure there are no sharp edges and foreign particles on the trailer parts before painting. Next, the cleaned parts will be sent for sandblasting at Building G, and after that, the trailer and its components are painted and dried at Building F. Finally, the final assembly will be carried out in the DVM building.

This is where all the bolt-on parts, wiring, suspension, hydraulics, and tires were assembled. Each product line has separate workstations associated with that product. The team lead finally inspects the trailer after it is assembled completely. The finished trailers are then sent to the finish lot outside, and they sit out there until the unit is delivered to the customer.

1.5 Area of focus

The focus of this case study was on the side dump final assembly line, on the stations DVM 2 and DVM 3. The current state layout of the DVM building can be seen in Figure 1.3.

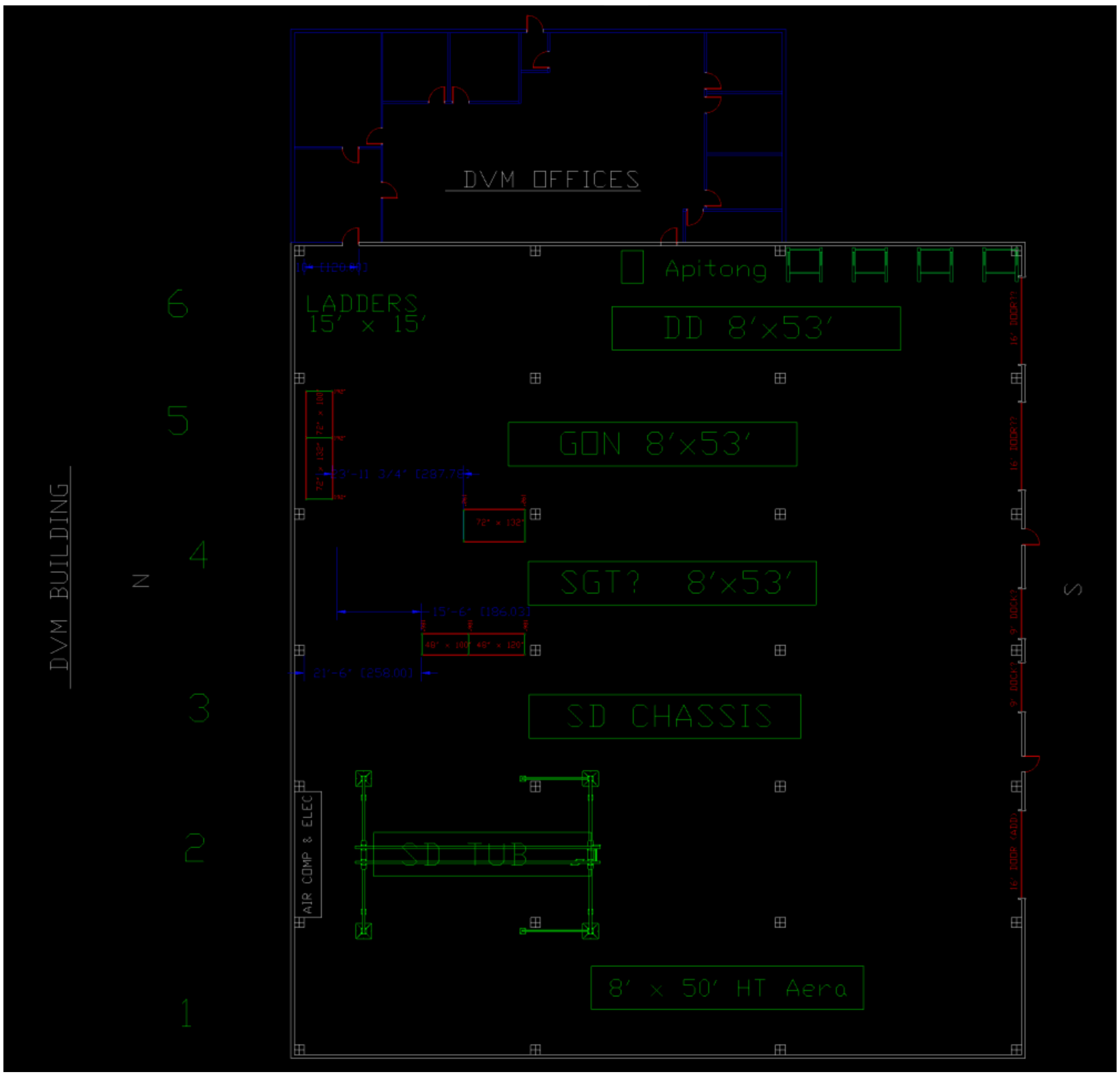


Figure 1.3 Current state DVM building layout.

The sales of semi-trailers have been rocketed up exponentially 200% increase compared to last year. Currently, the facility is working on expanding its product line and bringing in larger assembly line improvements. With the sudden surge in demand and having multi-model options for each trailer (over 45 different models and 500 different options), the management is currently facing many bottlenecks in meeting the demand. Workers have a hard time understanding the process and assembly, leading to an exponential increase in the overall lead time. The exact lead times cannot be quantified for specific production orders. They have one generic lead time, which is commonly used on all orders for scheduling purposes. The team leads do not know whether they are on track or off track in their departments. They needed a tool to track and monitor their process in the fab, paint, and final assembly lines. Currently, they do not have any tool to measure and validate data. Time studies were not practiced ever before in the final assembly line. Having multiple bottlenecks in the final assembly line and with side dump being the most complicated assembly made us choose the side dump final assembly line as the area of focus for this project.

1.5.1 Side-dump production

The value stream map gives us the entire overview of production process flow from start to stop. It is an important industrial improvement methodology that captures both inter and intra level details in visualizing the entire process, apprehending material and information flows with the timeline [1]. The Demco does not have any prior Value Stream Mapping (VSM) done on their product lines. Instead, they had processing times in the excel file that was last updated a couple of years before, and their times were off. The currently used production time data is shown in Appendix Figure 1. In order to capture the current status of the manufacturing process, a new current state value stream map has been created, as shown in Figure 1.4. The team leads in each department of the side dump production were given a process sheet and asked to capture the overall process times of the trailer model 9CCR463ARRL3424. The collected data was used to create the current state VSM.

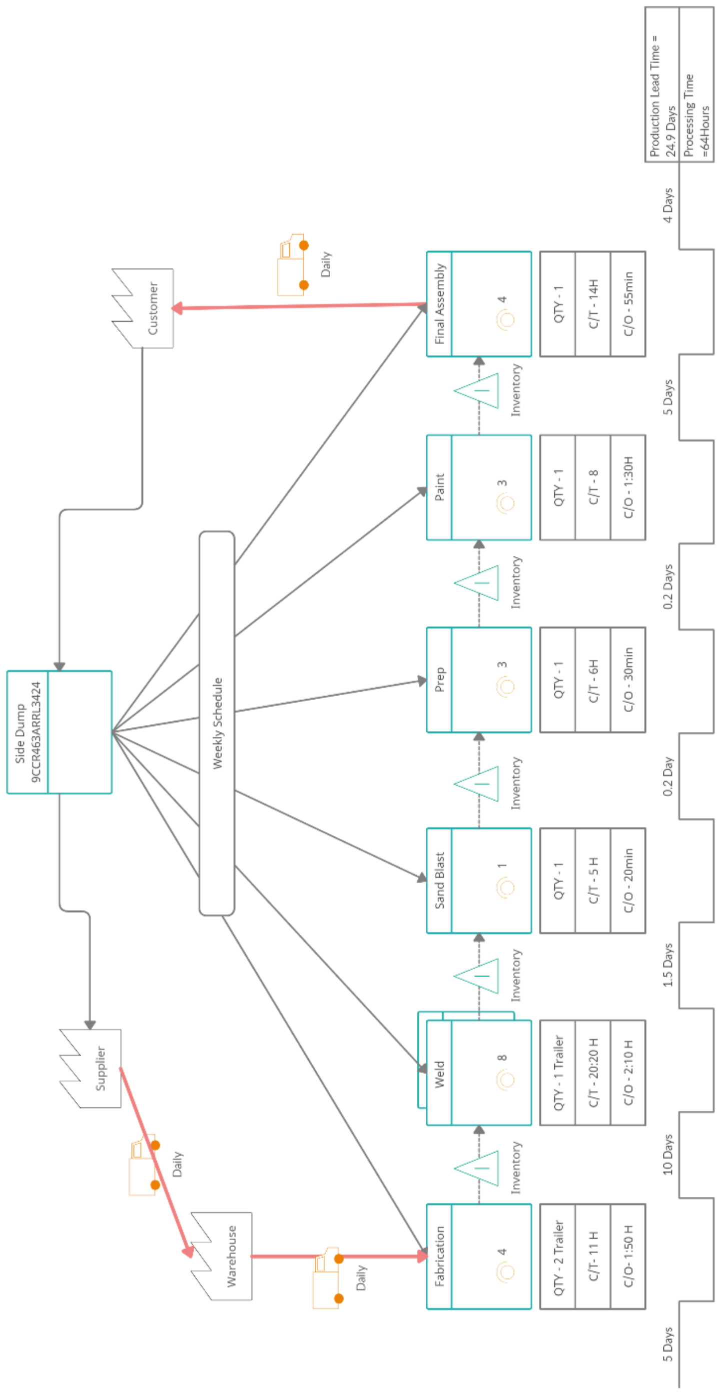


Figure 1.4 Current state VSM

The side dump manufacturing process starts with the processing of sheet metals in the fab department. The fabrication needs to be done ten days prior to the welding start date. The sheet metals were laser cut and sent to the weld department for welding. Welding usually takes 20 hours to weld the entire trailer components, including the chassis, tub, and other sub-assemblies. After welding, one-half of the components were sent to sandblast, and another half were sent to prep building for deburring. The prep building deburs the sharp edges and removes dust from the welded components. The prep and sandblasting processes were linked to save the intermediate time before painting. The total processing time for sandblasting and prep takes 11 hours together.

At the painting booth, chassis, tub, and sub-assemblies were painted separately. It takes eight hours to paint and dry the entire trailer and its components. The painted components are then moved out inventory lot for a minimum of five days since the final assembly line cannot meet the production demand on time. Finally, at the DVM building, the trailer and its components will be assembled together. It takes 15 hours to complete one trailer with four operators involved to assemble the entire chassis. The overall production lead time for manufacturing one trailer from fab to finish takes approximately 25 days, with the processing time of 65 hours having 22 operators involved in various stages of production.

1.5.2 Side-dump final assembly

The side-dump final assembly is done in two static stations DVM2 and DVM3, as shown in Figure 1.3, with four operators. The operators in the final assembly work four days a week, 10:30 hours a day with a one-hour break. The overall lead time of the side-dump final assembly is approximately 15 hours. Since the trailer type has multiple models and options, the process engineers could not calculate the exact production lead time. The chassis is pre-assembled separately in station DVM3, with three operators working on it, and the tub is assembled the same way in station DVM2 with one operator. The warehouse will kit all the components, parts required for the assembly before the start of production. Once the pre-assemblies are done, the tub will be mated with the chassis in DVM2. After the assembly, the team lead does a quality inspection, and the trailer is pulled out to the customer for delivery.

CHAPTER 2. OBJECTIVE

The project goal is to analyze these problems and develop solutions to meet the management team's objectives. The objectives are categorized into: -

Primary objective:

1. Conduct a case study on benefits and challenges in implementing Manufacturing Executing System (MES) at a small industrial equipment manufacturer.
2. Suggest innovative ideas/ design in enhancing current MES features, which satisfy business requirements.

Business objective:

1. Increase the overall throughput of the side dump final assembly from 1.5 days to 1 day and establish a well-balanced assembly line.
2. Increase the assembly line efficiency by 30%. To achieve so, 45% of the non-value-added time needs to be eliminated, primarily of the operator being idle, waiting for either parts or another operator.
3. Create detailed work instructions and establish a centralized location for process data through an MES system. This system will reduce the non-value-added time by establishing standard work, monitoring, and tracking anomalies in the process.

2.1 Assumptions

With every project, there is information that needs to be assumed. All assumptions have been confirmed with JCK and Dillon White, who are both manufacturing engineers at the DEMCO facility located in Spencer. The following are assumptions we observed in our current state: -

- The production target is 104 side dump trailers per year.
- Side dump has 45 different models and 500 different options, which go under each model.

- There is no prior time study data available in the final assembly line.
- The production floor does not have any standard work instruction reports. Operators use CAD drawings for crucial assembly instruction.
- On average, it takes 15 hours to assemble one full trailer, with four operators working on it.
- Currently, four workers are working on the side dump final assembly. However, it varies based on the sales demand.
- Scheduling is done manually; this often fluctuates due to variations in lead time.
- The team lead is responsible for bringing in the parts for assembly from the warehouse.
- Stock trailers get only basic options. Assuming options will be added further once it gets sold.
- The worker gets 60 minutes of break and 30 minutes of cleaning time for each shift.
- The facility works on a 40 hour/week schedule, with the shift works 10 hours each from Monday through Thursday. Based on the demand and meeting target dates, the operators get to work overtime on Friday for extra 10 hours.
- The Assembly line operator gets paid 25$/hour.

2.2 Constraints

In this project, we have faced lots of hurdles in the form of constraints, which narrowed down our project scope to focus on one product line and one model variant. The major setback was on the Bill of Material (BOM) data. The engineering BOM (eBOM) and manufacturing (mBOM) had a lot of dissimilarities, which needed major BOM restructuring to automate The Construction Manager (TCM) - ProPlanner integration. The primary constraints include,

- The project scope was restricted to the side-dump final assembly line, particularly to their most common 9CCR463ARRL3424 model, because of the time and BOM constraints.
- The eBOM part numbers do not match with mBOM part numbers. The mBOM part numbers have prefixes in front and their mBOM was flattened to eliminate manual processing of data. Therefore, needed BOM restructuring for integrating TCM to ProPlanner.
- The side-dump assembly files do not have all the parts which go into it. The wiring and air pipes were not included in the design.
- The BOM and design changes cannot be made currently.
- Need to use only the ProPlanner MES system for project solutions.
- Due to space and resource constraints, the assembly line can hold only two workstations.
- Tub assembly and tub mating can only be done in station DMV2.
- Recorded time study videos were saved default in Audio Video Interleaved (AVI) format. However, assembly planner software only accepts mp4 format.

2.3 Standards

An observed time study technique was used to measure the current and future state design for this project. Used observed time study methods and lean standards for color and symbology of value-added (VA), non-value-added (NVA), and semi-value-added (SVA). The standards followed are,

- Work sampling study methods
- Observed time study methods
- Lean standards such as VSM, VA, NVA analysis methods
- ProPlanner software formats

- Legacy Material Requisition Planning (MRP) system - TCM

2.4 Project timeline

The project timeline was split into three phases. The current state analysis was executed in the first phase, and necessary data for the project was collected. Secondly, the collected data was processed and authored to the MES system, and in the final phase, the data was published to the MES system and tested live with the operators, and the obtained results were verified. The Gantt Chart is shown in Figure 2.1.

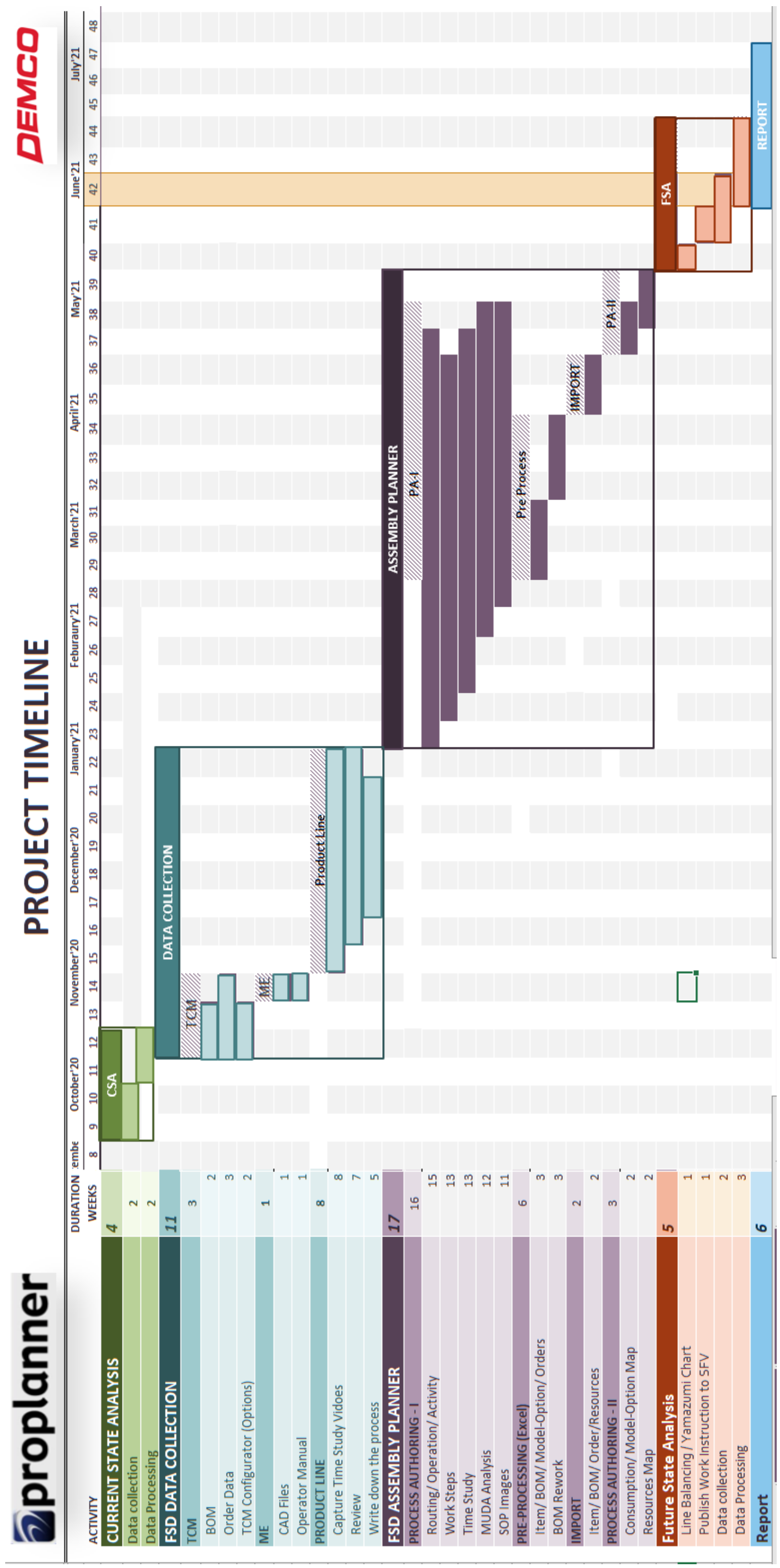


Figure 2.1 Project timeline

CHAPTER 3. CURRENT STATE ANALYSIS

3.1 Methodology

Work sampling is an industrial engineering tool for analyzing work. By analyzing the work through work sampling, the amount of work content in terms of the percentage of available working time can be calculated, and it can be used to evaluate the proportions of the total time of work devoted to the various activities [2]. Knowing the operator's idle percentage will be the base of improvement, from where we should reduce it. Work sampling data can also analyze the non-value adding activities and their percentage of occurrence and analyze optimal workforce allocation.

Initially, we started our study with the work sampling evaluation, focused on the following three parameters: value-added (VA), non-value-added (NVA), and semi-value-added (SVA) activities. It was observed that there were more than usual NVA observations. In order to have an in-depth analysis of the times, work sampling evaluation was replaced with observed time studies. The observed time study observations were grouped into VA, NVA, and SVA time. The value-added times consist of any directly added work activity to the trailer, such as assembling, fastening, torquing, sticking, etc. The non-value-added activity is any time spent on the assembly process that adds nothing to the finished product. The amount of time operator's searching for parts or tools, break intervals, idle time, rework time, waiting time, and cleaning times are some of the NVA activities. The semi-value-added activities category comprises the actions that need to be completed for production to flow but do not necessarily add value to the machine—the amount of time the operator spent on walking, positioning, etc.

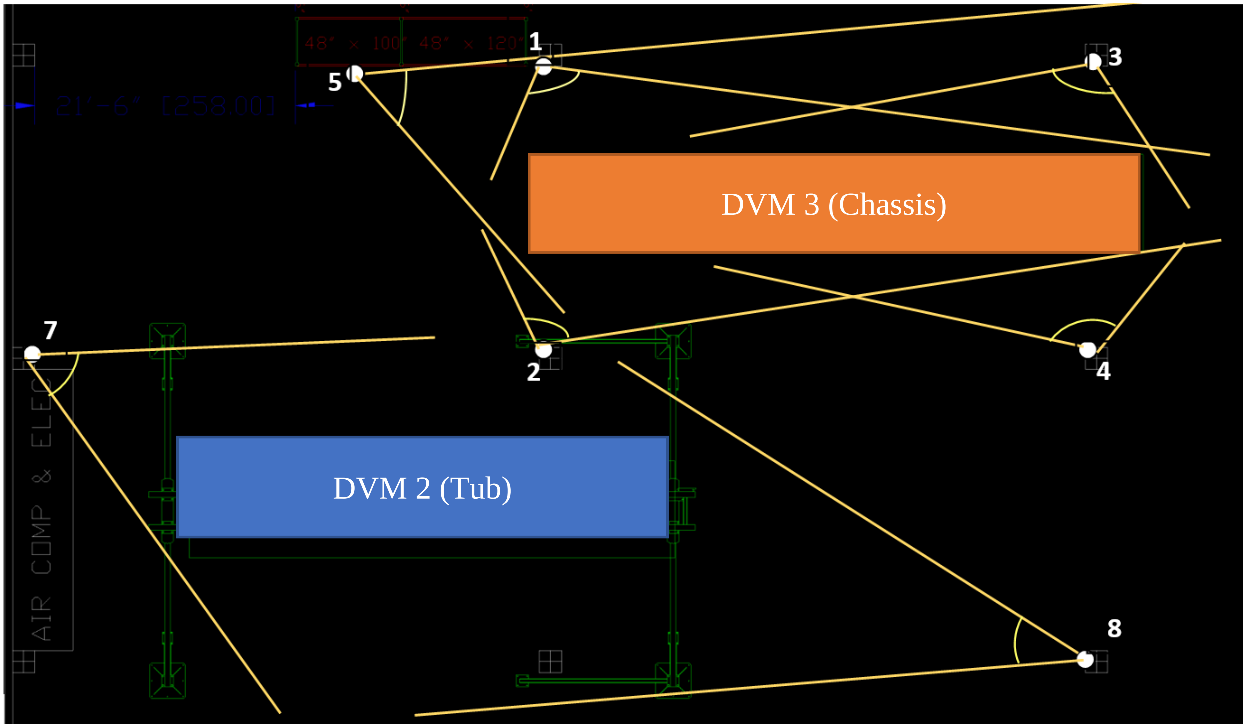


Figure 3.1 Camera layout

To perform an observed time study on the side-dump final assembly line, seven cameras were placed. Five cameras were placed on the station DVM2 (tub assembly and tub to chassis mating) and the remaining two on the station DVM3 (chassis assembly) to capture work, as shown in Figure 3.1. The wide-angle "camera 5" and "camera 7" mainly were used for our study since it covers the overall assembly view. Two weeks' worth of data was collected from 12/8/2020 to 12/15/2020 between morning 6 AM to evening 5 PM, involving four final assembly line operators. For the analysis, the operators Mike, Joel, and Jose, were randomly selected and observed on two different trailers, CR3281 and CR3287, of the same model 9CCR463ARRL3424, as shown in Table 3.1. The trailer CR3281 is heavily optioned compared to the trailer CR3287. All the selected operators have the same level of expertise, and they have a minimum of two years of experience on the side-dump final assembly. The study finally ended up having six different observations with 90 hours' worth of data. All the times were reported directly from the captured videos, from beginning to end of production.

Unit Serial No	Order No	Model ID	Model Description	Schedule Date	Options
CR3281	644673	9CCR463ARRL3424	CRL Side Dump Lead Trailer	12/9/2020	2C000018,2C000040,2C000041,2C000051,2C000056,2C000064,2C000136,2C000247,2C000255,2C000288,2C000290,2C000308,2C000351,2C000382,2C000409,2C000476
CR3287	650640	9CCR463AR3424	SIDE DUMP LEAD TRAILER	12/12/2020	2C000018,2C000032,2C000041,2C000051,2C000076,2C000104,2C000351,2C000393,2C000409,2C000476

Table 3.1 Order data

The collected time study videos were processed in the Assembly Planner software, which has an observed time study tool. With this tool categorizing times on various capabilities was quickly processed and analyzed. The selected operators were observed from start to end of the selected trailer final assembly, which is approximately a 15-hour task with four operators working. The observations were grouped based on VA, SVA, and NVA categories.

3.2 Results and analysis

The observed time study data collected from trailer CR3281 is shown in Table 3.2. It took around 15.2 hours to get the trailer fully assembled, with four operators working on it. The task and operation times were categorized based on our predefined time categories. On average, 36.5% of the time spent was VA, 19% of the time spent was SVA, and the remaining 44.5% was NVA. Operator B has the highest work percentage of 60.9%, while Operator C has the least work percentage of 48.7%. Approximately the Operator B works more than two hours compared to Operator C.

The result from trailer CR3287 is shown in Table 3.2. It took 14.5 hours to get the trailer fully assembled with four operators working on it. Trailer CR3287 was assembled 40 minutes quicker than the trailer CR3281 because of different options. The task and operation times were

Observed Time Study		**CR3287**						**CR3281**					
Side Dump Final Assembly\ Operator		**A**		**B**		**C**		**A**		**B**		**C**	
Task	**Category**	**Min**	**%**	**Min**	**%**	**Min**	**%**	***Min***	***%***	***Min***	***%***	***Min***	***%***
Operator Idle	NVA	96.7		144.1		190.3		105.2		173.8		274.8	
Excess Break	NVA	75.2		47.6		44.5		100.4		57.3		50	
Waiting for parts	NVA	56.9		48.2		72.4		44.5		54.5		62.1	
Cleaning	NVA	30.5		19.8		17.2		60.6		20.1		15.8	
Talking	NVA	19.3	40.4	21.5	40.3	11.8	44.3	25.4	43.0	16.1	39.1	31.7	51.3
Waiting for operator	NVA	18.8		9.7		13.4		24.6		11.8		14.7	
Rework	NVA	24.7		26.2		8.6		10.3		15.5		3.1	
Searching	NVA	8.6		5.7		3.2		11.9		4.3		4.5	
Study	NVA	3.0		2.4		1.8		4.8		3.3		1.8	
Walking replace/ bring	SVA	193.3	21.5	176.1	19.3	164.7	18.4	200.3	22.2	164.6	18.0	148.4	16.6
Work	VA	343.1	38.1	368.2	40.4	332.5	37.2	312.4	34.7	390.8	42.8	286.1	32.0
Total Min		**870.1**		**869.5**		**860.4**		**900.2**		**912.1**		**893**	
Hrs		**14.5**		**14.5**		**14.3**		**15.0**		**15.2**		**14.9**	

Table 3.2 Observed time study (CR3281 and CR3287)

categorized based on our predefined time categories. It was found that, on average, 38.6% of the time spent was VA, 19.7% of the time spent was SVA, and the remaining 41.7% of the time was NVA. The average work time was 7% efficient than the previous trailer. Operators A and B have near equal highest work percentage of 59.7%, while Operator C has the least work percentage of 63.7%. Compared to the previous trailer, the operators performed reasonably well in this trailer.

By analyzing the observed time study results obtained from the two different trailers, CR3281 and CR3287 revealed that approximately 43% of the work done in final assembly is non-value added, as shown in Figure 3.2. They varied from a high of 51% for Operator C to a low of 39% for Operator B. Most non-vlue-added times correspond to longer lunch breaks, a worker being idle for a longer time, unusual waiting and cleaning times. While comparing the semi-value-added times, the worker walks 19% of their time on average. This varied from the highest of 22% for Operator A to the lowest of 17% for Operator C. Only the remaining 38% of the time spent on actual work is Value-added. This ranges from the highest of 43% for Worker B to the lowest of 32% for Worker C. While comparing the work efficiency of the operators, Operator B has the highest percentage of vale-added time 42%, followed by Operator A being 36% and Operator C being very least at 35%.

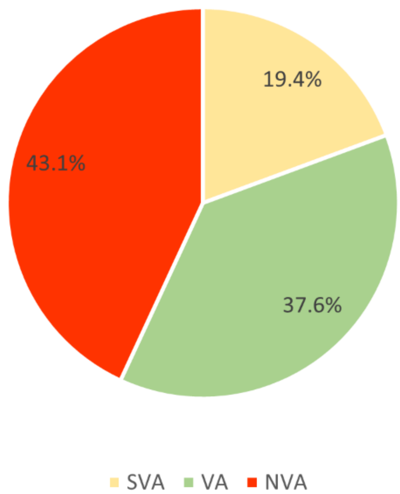


Figure 3.2 Current state pie chart

The current state line balance scenario was created using the collected time study data from the two different trailers. The study was done only for Operators A, B, and C categorizing their time specifically into VA, SVA. At the same time, due to some technical difficulties Operator D time was not observed, his overall time was accounted as uncategorized time. The average time taken by the two trailers was considered for this current line balance, as shown in Figure 3.3. While analyzing the line balancing times between the operators, the NVA times were excluded to get exact work times. It is observed that the maximum time difference between the work times ($\Delta cycle_{max}$) is 87 min. This tells us there is a huge possibility for assembly line improvements by properly distributing works among the operators. While looking at the takt times, the required takt time to achieve Demco's 104 plan is 761.2 min, but the actual takt time obtained from the current state analysis was 891 min which is 129.8 min behind the required takt time.

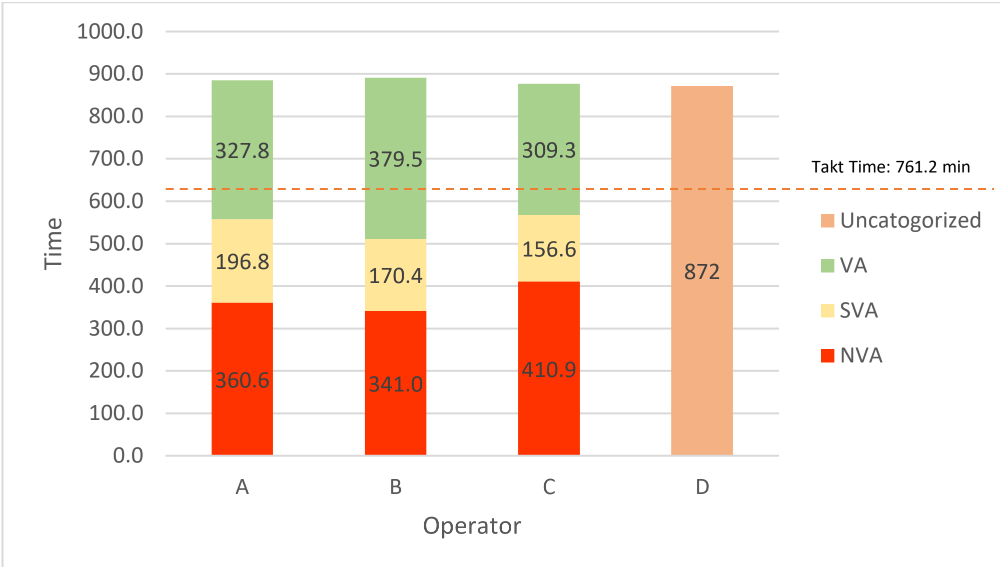


Figure 3.3 Current state line balance (Δcyclemax= 87 min)

Having nearly 45% of the overall time as NVA could immediately be eliminated without any implications for product quality, which would allow for an average of 370 min of added production time each day that could be spent on value-added processes.

3.3 Problems

Production is a dynamic process with multiple dimensions, i.e., products, operations, operators, material handling, production planning, machines, assembly line characteristics etc., and a production system needs to adapt itself to changes that occur in any of these dimensions as quickly as possible to minimize losses [3].

While analyzing the NVA work from the side dump final assembly line, the most time-consuming NVA was sorted using the Pareto chart, as shown in Figure 3.4.

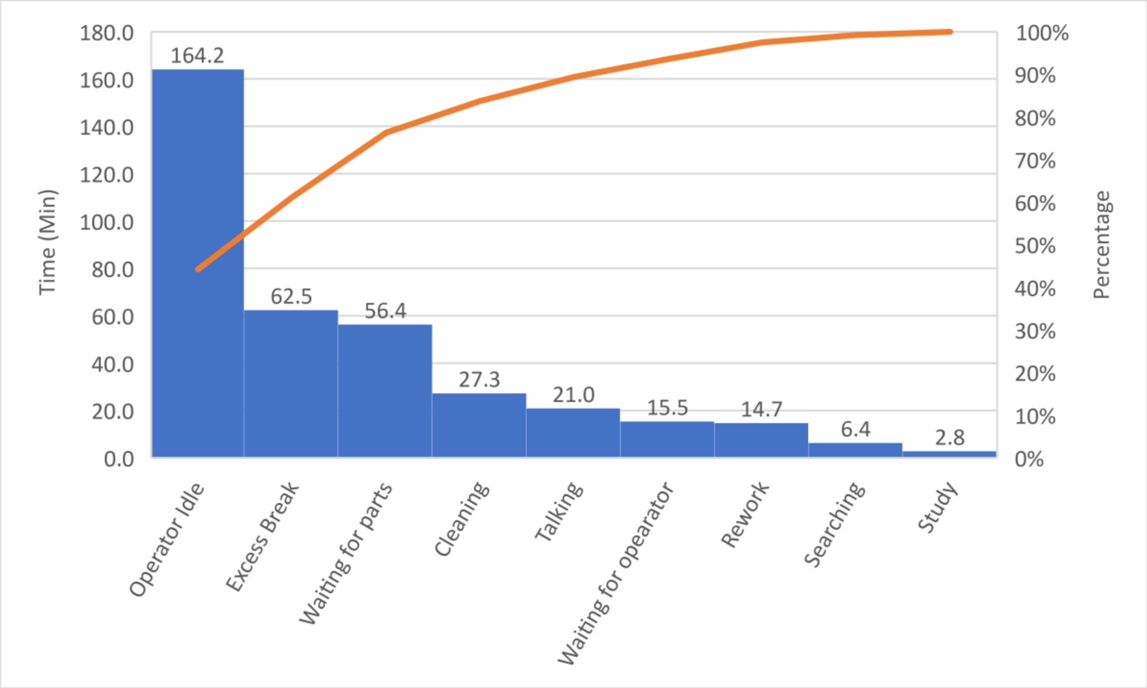


Figure 3.4 Pareto chart

3.3.1 Operator idle

The observations from the time study videos show that the operators spend most of their time idle without any activity. Idle time indicates there is line balancing losses at the stations. In our study, almost 50% of the time wasted in NVA was the operator being idle. To achieve a better balance, the difference between the idle time at different stations should be as low as possible [3]. The improperly balanced assembly line is shown in Figure 3.3. By taking the VA and NVA into account, the difference between the idle time was calculated. The idle time difference between Operators B and C was estimated to be 84min ($\Delta cycle_{max}$= 84 min). This significant difference in time is because the operators themselves had split their work unequally (Chassis Air, Chassis Hydraulics/Wiring, Bolt-on, and Tub) between four of them. Also, because the line produces trailers with multi-model options, the exact operation times might differ for different trailer models. When the less complex model comes for production, the operator finishes his task quickly and remains idle until other workers finish their task.

In addition to the balancing issue, it has been identified that the operators tend to stay idle when other operator gets into any production issue. For example, when one operator is waiting for parts, the other operator joins with him and stays idle until the part arrives even though there is no direct link between their activities. Also, it has been noted that operators arrive at the facility early morning at 6 AM, but they wait until 6:45 AM or until all the operators start working in order to start their routine assembly. Almost 30-45 min of each day shift is spent like this.

3.3.2 Excess break

Each operator is given 30 min of paid (15 min + 15 min) and 30 min of unpaid break intervals each day. In addition to the provided break time, the operators take an additional break time of 45min/ day on average. It's found that their 15min break times went to 20-25 min, lunchtime went for 45 min instead of 30 min, and workers took additional breaks in between.

This issue is because the final assembly building is far away from the main building. The facility has no higher officials or engineers based on the final assembly. The team lead was responsible for the production efficiency of the final assembly department, but he does not know this problem until this study.

3.3.3 Waiting for parts

Missing parts for the assembly and operators waiting for parts is the next common issue the operators face on the production line. On average, each worker spends almost an hour waiting for parts. Once the trailer is fully assembled, the operator pulls out the trailer, and then he gets the new chassis, tub, and other parts for assembly. It usually takes about 45 min for one operator to get all these parts pulled up. Production is stopped until all the parts arrive for assembly, with the remaining three workers waiting for parts.

3.3.4 Cleaning

Demco allots 30min each day at the end of shifts for cleaning and sorting the workplace as part of 6S standards. It has been observed that the workers sort their stations regularly in between operations to leave early. The operators leave their station by around 4:15 PM instead of 4:30 PM by finishing the cleaning operations in 15 min.

3.3.5 Waiting for the operator

Few activities in the trailer assembly such as underride and bumper assembly, tub to chassis mate, high-capacity mount assembly, tire assembly, tarp assembly, and hydraulic testing require more than one operator. For these activities, the operator must wait for the other operator for their help. So, the operator goes idle until the availability of a helping worker.

3.3.6 Issues reported by operators

Other than the above issues observed from the observed time study, an interview was conducted with the final assembly operators to obtain the production issues that hinder lead time. Below mentioned are some of the issues brought up by the workers:

1) With the production line been variable with multiple models and options, the operators feel hard to remember which activity goes to which model, and at times they go wrong with their assumptions, which leads to longer rework time. Moreover, they might need to scrap the part.

2) Since the operators do not have work instructions, they need to search for the drawing sheet in order to find what exactly goes into the model they are working on currently.

3) They do not receive the correct parts for the model that they are working on. Sometimes they receive excess, or they do not receive any. The assembly line worker has to travel to the warehouse, which is on the other end of the facility, to get the parts. It is hard for the

operators to remember the part ID of the missing part. Much time is wasted searching for part ID and bringing the kit from the warehouse.

3.3.7 Other production and management issues

The Demco management brought up the issues which they are currently facing in the production line. The issues are: -

1) Lack of detailed process documentation on the workstation.

2) Inconsistencies within engineering and manufacturing bill of materials (eBOM and mBOM).

3) Limited capability in scenario simulation, analytics, and supply chain visibility.

4) Manufacturing Engineers at Demco carry out time studies with a stopwatch and store it in excel. In the final assembly, the time studies were never carried out before.

5) Line Balance is carried out in Excel. However, it does not have updated times, and they have only one model. They cannot do line balancing for their thousands of model options.

6) Missing work instructions for the shop floor.

7) No digital quality network and gates.

8) No live digital tracking of part consumption and units.

9) Lack of communicating engineering changes to the shop and collecting data from the shop floor.

CHAPTER 4. FUTURE STATE DESIGN & ANALYSIS

The problems and issues stated in the current state analysis were addressed by executing a Manufacturing Process Management (MPM) tool, Manufacturing Execution System (MES), and various continuous improvement projects on the side dump final assembly line. Once the improvements were made, the future state work sampling study was done, and the results were analyzed.

4.1 Literature review on MPM and MES

According to the objective statement, Demco aims to achieve manufacturing with low costs, high quality, and short lead times in the current competitive environment. The traditional production technique might not be sufficient to meet the demands of today's digitalized manufacturing system. As a result, advanced technologies and software solutions need to be used by Demco to deal with their constant changes in product and demand.

With Demco being manufacturers of high variety, low volume content, they would need a centralized process planning database which can enable a high degree of flexibility in the assembly process planning based on the demand, improve the workforce efficiency, reduce the waste, and overall manufacturing cost. With Manufacturing Process Management (MPM) systems, this can be done instantly and at a high level of detail [4]. The fundamental potential of MPM systems relates to importing the BOM with optional and model-mix content and then identifying and mapping the manufacturing process information to the components on the BOM, which are produced by, and consume, those components. In this way, it is possible to precisely determine the specific resource and time commitments, and costs associated with every product model and option. The MPM data model being process-centric, displays strong and bi-directional relations for producing and consuming components to the product's BOM and product and process data.

These data can be integrated with line balancing, time estimation, work instructions, manufactured costing, and quality FMEAs/ control plans [4]. Furthermore, the MPM system is incorporated with Manufacturing Execution System (MES) solutions to bridge the gap between production planning and manufacturing [5].

Why MES?

Most of the MSME (Micro Small Medium Enterprises) companies currently stick with their ERP (Enterprise Resource Planning) solution for manufacturing. The author [6] substantiates why the only ERP-based solutions do not meet the actual requirements of the manufacturing industry and the need for an MES in an industry specifically designed to facilitate shop floor processes. The MES plans, controls, and monitors the execution of real-time physical processes that turn raw materials into finished end products. It can also provide feedback on process execution, support component traceability, and integrate it with process history [7].

The substantial savings of reducing machine downtime and failure, effective monitoring of the working time of the machines and operators in specific workstations is one of the fundamental reasons why manufacturing industries engage in MES systems [8]. It is anticipated that the new MES will give additional real-time data to operational departments by providing an overall picture of all the resources engaged in the manufacturing process and will serve as a manufacturing cockpit (dashboard) [9]. Furthermore, advanced cloud-based MES assist with product traceability in dispersed production. The workflows of multiple facilities can be coordinated globally, enabling the plant managers with real-time monitoring, visibility, and control over multiple plants [10].

Industry 4.0 has introduced a new idea to enterprises, transforming industrial processes, business strategies, and outcomes. Industries are seeking solutions that will allow them to automate specific business operations. Typically, automation is used to automate repetitive tasks, such as monitoring, reporting, and delivering relevant information to assist managers in decision making. In Industry 4.0, data interchange refers not just to machine-to-machine communication but also to machine-to-human communication. As a result, industries are looking for core solutions in terms of quality, performance, and efficiency in their process, where the MES has proven beneficial in this regard [11]. The MES bridges the gap between Industry 4.0 and lean manufacturing. By so, the industries will become lean due to the requirement of having a well-defined process structure [12].

4.1.1 Recommendation 1: Assembly Planner

The current state time study results show that over 80% of the NVA times were due to process inconsistencies, unstructured assembly sequence, mis-consumption of parts, and uneven work split-up between the workers. Without having any standard work instruction, the operators had a hard time understanding the process and assembly, leading to an exponential increase in the overall lead time. In addition to that, operators wasted a considerable amount of time walking and searching tools/ parts for each activity.

The ProPlanner software would be a perfect fit for Demco's current assembly line issues. The ProPlanner, located out of Ames, IA, is a leading process engineering and management software company that gives solutions for various manufacturing industries on manufacturing optimization using modern industrial engineering techniques. The ProPlanner suite includes the most unique and innovative products build particularly for manufacturing assembly [13]. Their products include: -

- Advanced Planning & Scheduling

- Manufacturing Execution System (MES) - Shop Floor Viewer, Factboard And-On, and DC Torque Tools.
- Assembly Planner - Process authoring, time studies, line balancing, FMEA, control plan, ergonomic studies, scheduling, and sequencing.
- The Material & Logistics Planning - PFEP (Plan for Every Part), Flow Planner, eKanban, and eKitting.

To address the project Objective 3, the ProPlanner's Assembly Planner software is used to demonstrate its capabilities on the Demco's side dump final assembly. In order to get the MES up and running, it is essential to have all the process data authored and mapped to the activity in the Assembly Planner. The Assembly Planner needs process routing, operation, activities, time studies, SOP images, and work steps which consume mBOM to generate work instructions and define parts. However, Demco did not have any prior process routings defined or work instructions, which needed clean state process authorization for the side-dump production line. The workflow needed for integrating the Assembly Planner software into Demco's manufacturing process is shown in Figure 4.1.

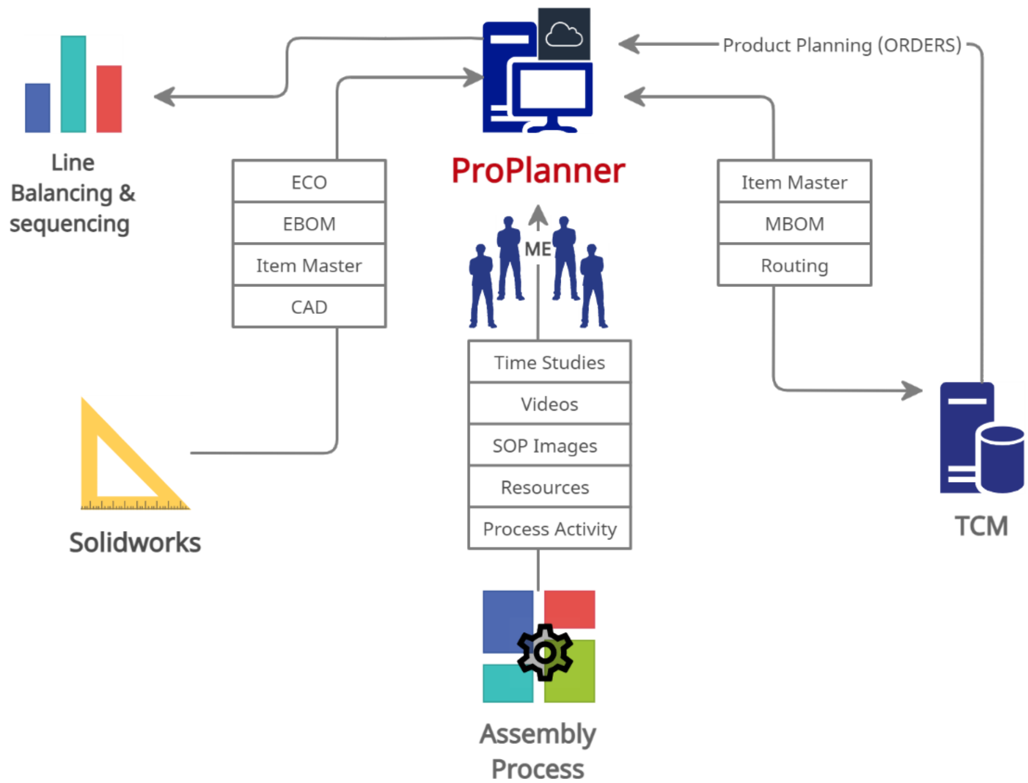


Figure 4.1 Assembly planner workflow

Authoring side dump process data to Assembly planner:

1) Data collection: The data collection for authoring the side-dump manufacturing process came mainly from three sources.

- SolidWorks – CAD files of 20 different models, their assemblies and eBOM's.
- TCM MRP System– Item master (685 items), mBOM (9CCR463ARRL3424 model), and order data (ten orders of the same model but different options).
- Manufacturing line– Videos for time studies were captured on seven different cameras following the four trailers of the same model (90 hours' worth of data), product manual, resources data (174 resources), SOP images, plant, and stations layout.

2) Import data: The item master, BOM data, and order data collected from the TCM, processed in excel, and imported to assembly planner software. The initial file imports ended up failed because we were dealing with multiple models there were many part duplicates involved. It took us several attempts to figure out the exact procedure for data processing and import. The import process followed is attached to Appendix Figure 2-4. Figures 4.2, 4.3, and 4.4 show the sample import data of item, BOM, and orders.

ID	Revisior	Description	Description2	ItemType	PrimaryU	IsModel	IsOption
2C000288	A	46' CHASSIS 34' BODY AR,	TRIPLE AXLE, REAR LIFT	Phantom	EA		TRUE
9CCR463ARRL34:	A	46' TRI, AIR RIDE, REAR LIFT	SET BACK 34' TUB	EndItem	EA	TRUE	
2C000382	A	46' CHASSIS, TRIPLE AR	W/ REAR LIFT, 34' BODY	Phantom	EA		TRUE
5C010481	A	CHASSIS, 46' TRI-AX, AIR RIDE/	REAR LIFT	Assembly	EA		
8C010286	A	CR463AR-RL-3424 INST MAN		Document	EA		
4C000001	A	DOCUMENT HOLDERS		Assembly	EA		
4C000002	A	MANIFEST HOLDERS MWW ASSY		Assembly	EA		
1AU00000011	A	MANIFEST HOLDERS MWW		Purchased	EA		
1AFBP3612	A	NUT, HEX LOCK, 3/8"-16 ZINC	TOP-LOCK	Purchased	EA		

Figure 4.2 Item import sample

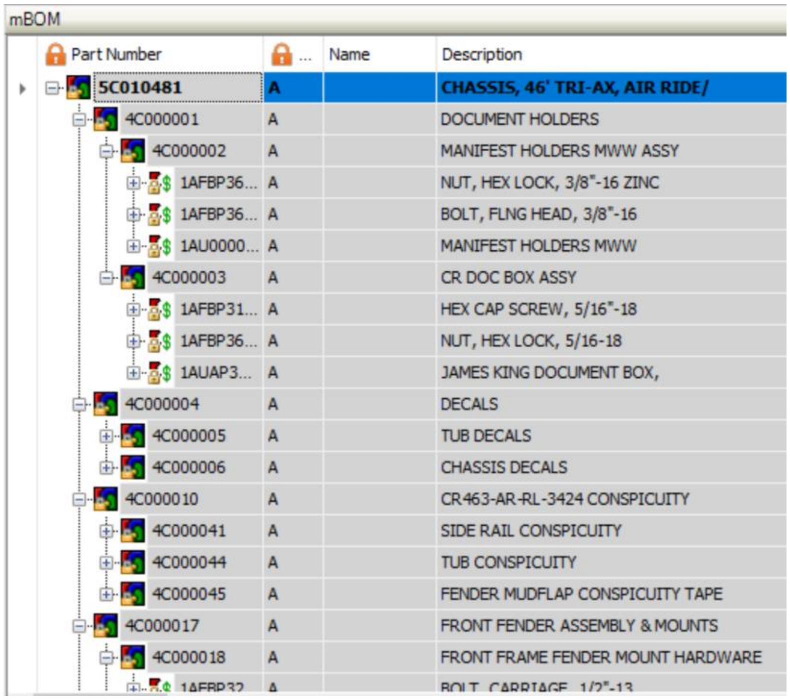
ID	Revision	ParentID	ParentRevision	EffectiveFromDate	EffectiveToDate	Quantity
9CCR463ARRL3424	A	2C000288	A	02/08/2017	12/31/9999	1
5C010481	A	2C000382	A	08/07/2019	12/31/9999	1
5C080002	A	2C000018	A	11/03/2016	12/31/9999	1
4C000079	A	2C000064	A	1/1/1901	12/31/9999	1
4C000080	A	2C000290	A	1/1/1901	12/31/9999	1
4C000081	A	2C000247	A	1/1/1901	12/31/9999	1
4C000082	A	2C000255	A	1/1/1901	12/31/9999	1
5C090018	A	2C000136	A	11/11/2016	12/31/9999	1

Figure 4.3 BOM import sample

Jnit Serial N	Order No	Model ID	Model Description	Schedule Date	Options
CR3241	629307	9CCR444ARRLS3424	CIRCLE R LEAD TRAILER	4/1/2020	2C000018,2C000032,2C000042,2C0
CR3251	634458	9CCR443AR60RL3424	CIRCLE R LEAD TRAILER	5/14/2020	2C000018,2C000032,2C000042,2C0
CR3252	634460	9CCR443AR60RL3424	CIRCLE R LEAD TRAILER	5/14/2020	2C000018,2C000032,2C000042,2C0
CR3253	634461	9CCR444ARRLS3424	CIRCLE R LEAD TRAILER	5/14/2020	2C000018,2C000032,2C000042,2C0
CR3249	634869	9CCR474ARFLRLS3726	CIRCLE R LEAD TRAILER	6/3/2020	2C000018,2C000042,2C000051,2C0
CR3262	637501	9CCR463AR128RL3424	CIRCLE R LEAD TRAILER	7/31/2020	2C000018,2C000032,2C000042,2C0
CR3264	638037	9CCR444ARRLS3424	CIRCLE R LEAD TRAILER	6/29/2020	2C000018,2C000032,2C000042,2C0
CR3266	638874	9CCR444ARFLRLS3726	CIRCLE R LEAD TRAILER	7/10/2020	2C000018,2C000042,2C000051,2C0
CR3268	641259	9CCR445ARFLSRLS372	CRL Side Dump Lead Trailer	6/23/2020	2C000018,2C000025,2C000042,2C0
CR3283	645627	9CCR463AR128RL3424	CRL Side Dump Lead Trailer	9/2/2020	2C000018,2C000040,2C000041,2C0
CR3270	642195	9CCR443ARRL3726	SIDE DUMP LEAD TRAILER	12/8/2020	2C000018,2C000042,2C000051,2C0

Figure 4.4 Order import sample

Figure 4.5 shows the sample view of imported BOM in the Assembly Planner.



mBOM

Part Number	...	Name	Description
5C010481	A		CHASSIS, 46' TRI-AX, AIR RIDE/
4C000001	A		DOCUMENT HOLDERS
4C000002	A		MANIFEST HOLDERS MWW ASSY
1AFBP36...	A		NUT, HEX LOCK, 3/8"-16 ZINC
1AFBP36...	A		BOLT, FLNG HEAD, 3/8"-16
1AU0000...	A		MANIFEST HOLDERS MWW
4C000003	A		CR DOC BOX ASSY
1AFBP31...	A		HEX CAP SCREW, 5/16"-18
1AFBP36...	A		NUT, HEX LOCK, 5/16-18
1AUAP3...	A		JAMES KING DOCUMENT BOX,
4C000004	A		DECALS
4C000005	A		TUB DECALS
4C000006	A		CHASSIS DECALS
4C000010	A		CR463-AR-RL-3424 CONSPICUITY
4C000041	A		SIDE RAIL CONSPICUITY
4C000044	A		TUB CONSPICUITY
4C000045	A		FENDER MUDFLAP CONSPICUITY TAPE
4C000017	A		FRONT FENDER ASSEMBLY & MOUNTS
4C000018	A		FRONT FRAME FENDER MOUNT HARDWARE
1AFBP32	A		BOLT, CARRIAGE, 1/2"-13

Figure 4.5 Imported mBOM sample.

3) Process authoring: A new routing describing all the operations of the assembly line was created, and process data such as activities, work steps, time studies SOP imaged were added to the system and mapped the consumption data to the activities. In total, 151 activities were created for this trailer model, and the process was authored completely. The below illustration shows the process of authoring an example of one activity.

- Work Steps: It is the first set of data that need to be entered into the activity fields. The current process followed by the operators is studied, and work steps were created as shown in Figure 4.6.

Properties | Custom Fields | Media | Time | Work Step | Resource | Consumption | Model Option Mapping | Do

	Step No	Description	SOP Page	SOP Image
1	1.00	Collect required parts and tools.	1	00000532_sopimage_3.png
2	2.00	Place the Roll of Yellow Air Line on top of chassis above the Air Lift Control Valve.	1	
3	3.00	Holding one end of the hose to the compression fitting on the compressor valve (1A) measure required hose by feeding along the chassis wall back to the chassis wall above the Lift Control Valve (1B). Cut hose and set aside. See Image 1.	1	
4	4.00	Hold hose in mounting position above the Air Lift Control Valve (2A) and measure down to the straight compression fitting on the Air Lift Control Valve (2B) to determine length and cut hose. Set hose aside. See Image 1.	1	
5	5.00	Bring end of the Yellow Airline Hose back to the Air Lift Control Box (3A) and lightly insert the hose into the Compression Fitting on back of box to hold in place. See Image 2.	2	00000532_sopimage_5.png
6	6.00	Keeping Hose in the back of the Control Box, draw the hose to wall of chassis on the driver's side. Hold in place and draw additional hose required to reach chassis wall above the Air Lift Control Valve (3B) and cut to length. See Image 2.	2	

Figure 4.6 Work steps

- SOP Images: The supporting images are added to the work steps, as shown in Figure 4.7. The image editor in the assembly planner helps to create the annotations easier. This gives the operators better visualization of work and improves the work speed and quality.
- Observed time study and MUDA analysis: For the created activity list, the observed time studies were created, as shown in Figure 4.8. The captured video of the assembly was imported to the assembly planner software, and the time study observations were made. Further, MUDA analysis was carried out for each observed time study. It uses lean standards for color and symbology of VA, NVA, and SVA to better understand the times, as shown in Figure 4.9.

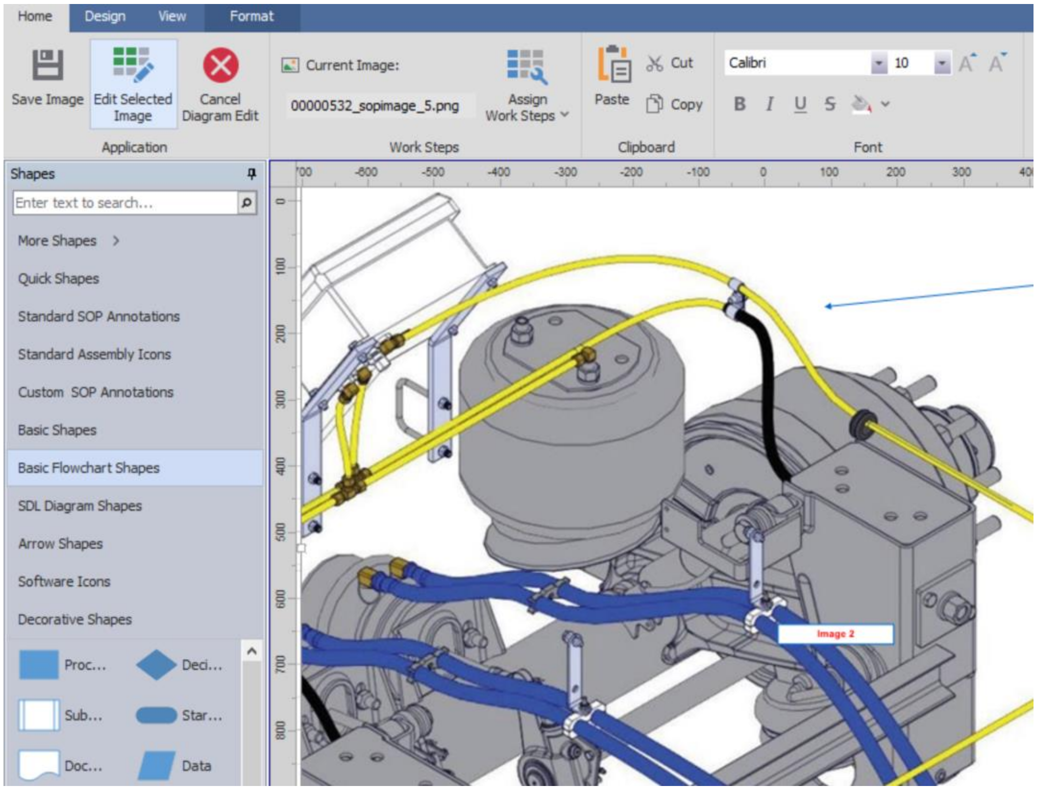


Figure 4.7 SOP image

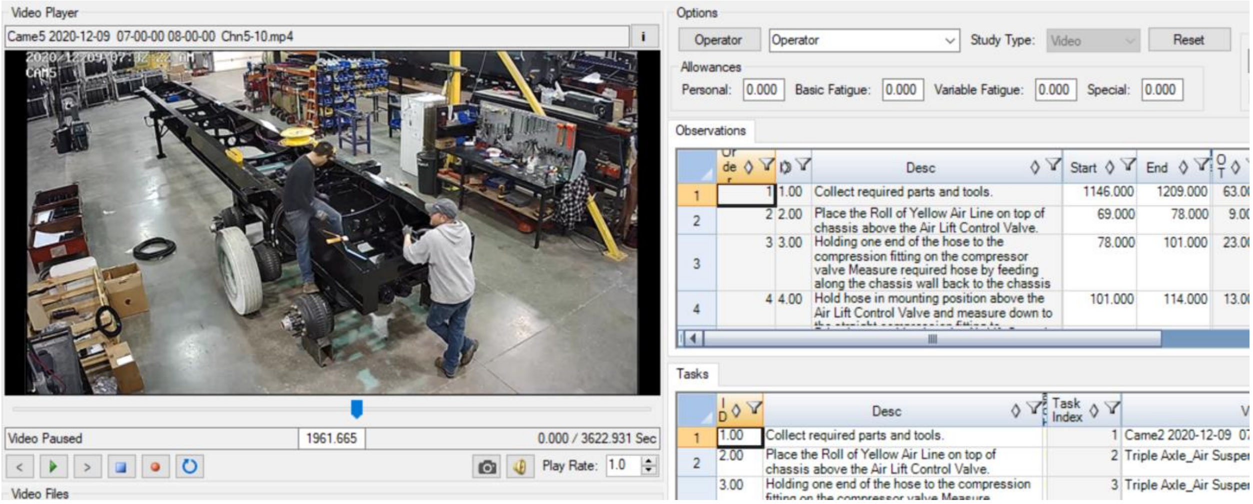


Figure 4.8 Observed time study

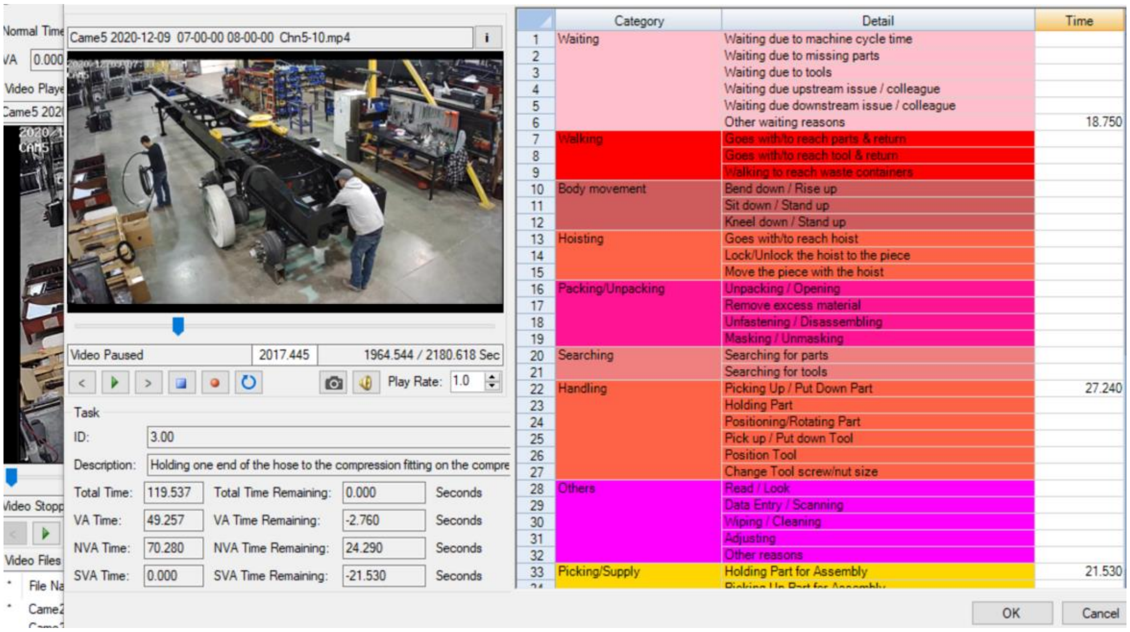


Figure 4.9 MUDA analysis

- Consumption and model option mapping: This process links the process activities to the BOM. The consumption can be added directly from the BOM along with its quantities. An example of consumption mapping was shown in Figure 4.10. Finally, the auto-build model option mapping was done to map the process to the build orders.

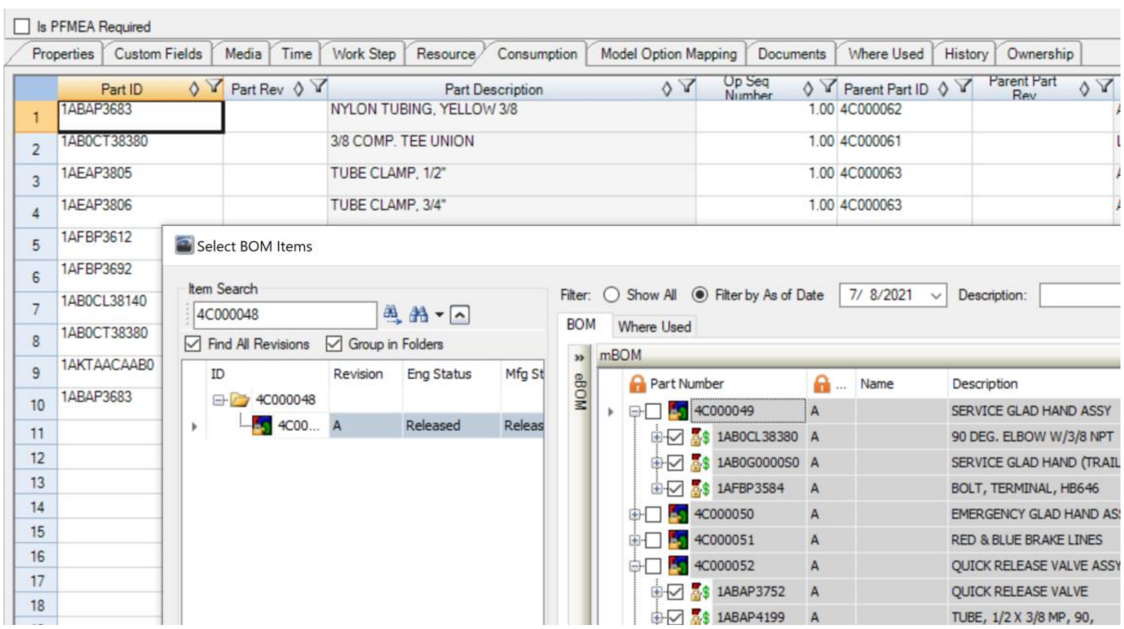


Figure 4.10 Consumption mapping

4.1.2 Recommendation 2: Line balancing

The results from the current state analysis show that about 50% of the calculated NVA times occurred because of the assembly line being not well balanced and work is not evenly distributed among the workers. This is the main reason for the operators to be idle for an average of 160 min per trailer. In order to address Objective 3, the separate multi-model line balancing needs to be created for each set of orders in Assembly Planner.

Line balancing is the process of distributing work evenly among all operators on an assembly line. The Line balancing module in Assembly Planner software helps distribute the work across stations and operators automatically and manually, in either a single or mixed model environment. The Assembly Planner uses the concept of a line balancing scenario, which is created from a snapshot of routing data. It allows you to create multiple alternate configurations of the same line without affecting the routing data stored in the database. Before starting to do assembly line balancing, it is mandatory to have all the assembly sequence, precedence, resources, work zones, task groupings, and operation times authored to the created routing. The following are the constraints that need to be mapped to automate the line balancing and its task distributions among the operators.

Precedence: It is assigning dependency between the tasks. The precedence defines the order in which the tasks can be done or must be done. In any assembly process, there are tasks that can be performed parallelly or in series. The precedence diagram in the Figure 4.11 shows the end-to-end side dump final assembly process.

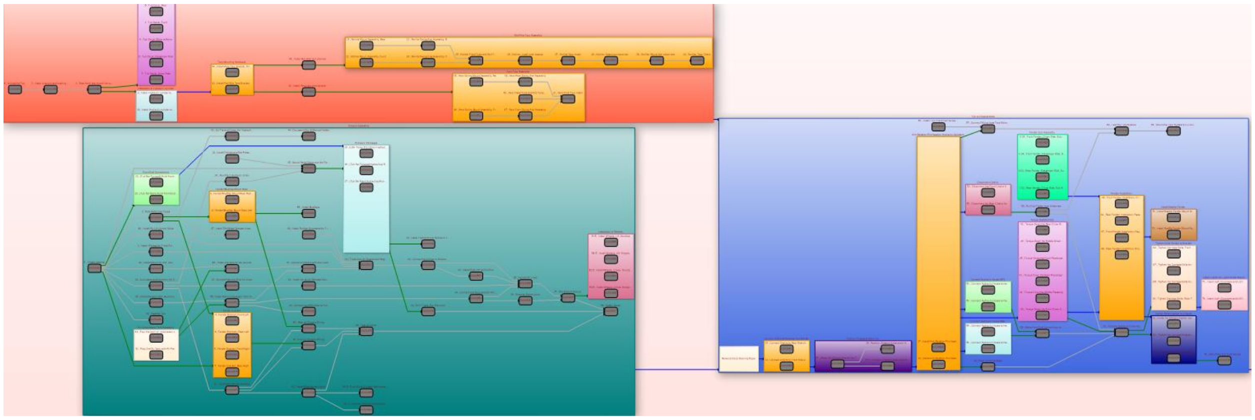


Figure 4.11 Precedence: Side dump final assembly

Each node (grey box) in the precedence is considered as an activity, and these activities can be further grouped to form clusters nodes (colorful box). The entire 151 activities of the side dump manufacturing process were mapped in the precedence. The example of an enlarged precedence map is shown in Figure 4.12.

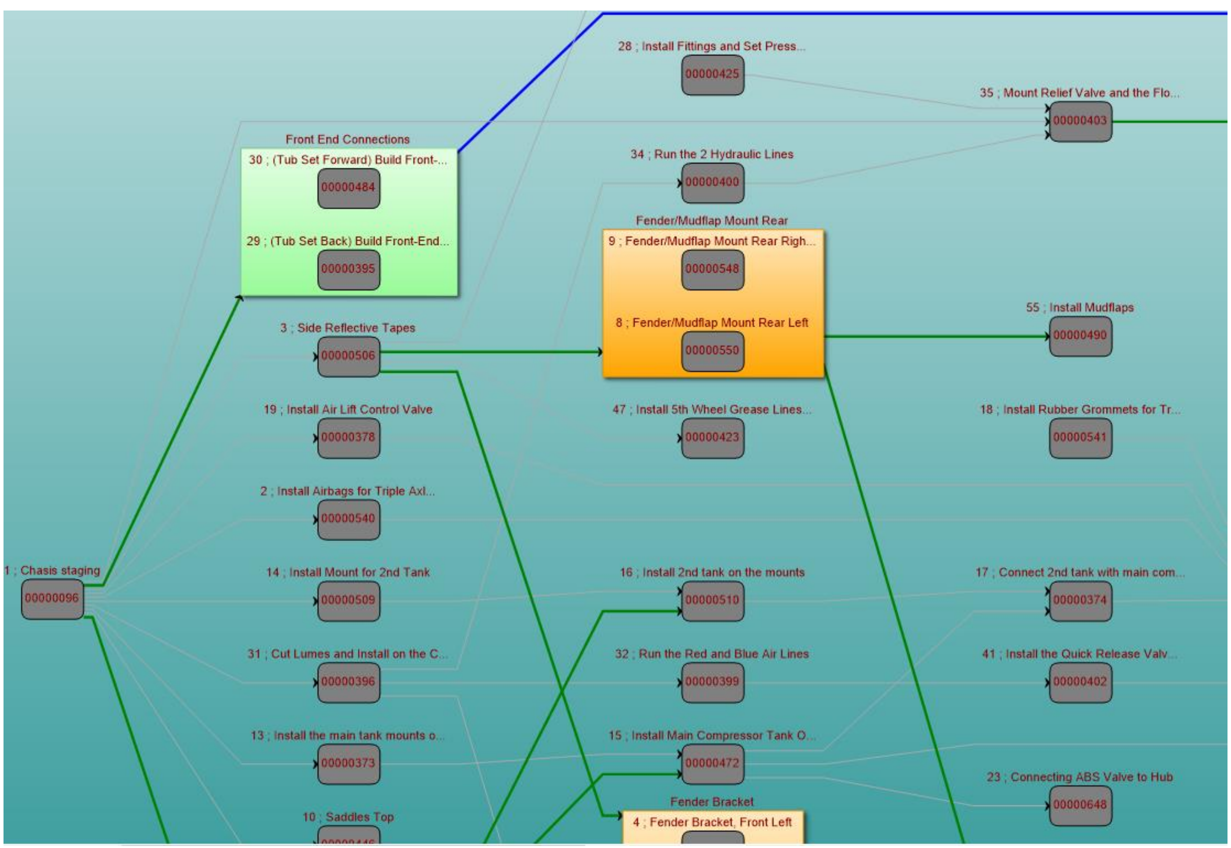


Figure 4.12 Enlarged precedence map

Work zones: With the work zones, work can be constrained to specific locations or operators. Assigning a work zone to a task means a task must be performed in a station with that work zone or an operator assigned to that work zone.

Task Groups: It is used to force tasks to be performed together. If certain tasks need to be performed in the same station or by the same operator, it can be a group. So, if one task in the group is moved, all tasks in the group are moved.

In addition to the above, other data inputs are needed to be specified. It includes: -

1) Scenario details (target date, time rank, product line type, and line type)
2) Order details
3) Routing details (Routing, Model, Model option mapping)
4) Task details
5) Station details (Order, ID, operator count, work zones, setup time)
6) Operator details (Parallel Operator, ID, Station)

After mapping all the mandatory fields, the current state assembly line-balancing scenario was generated, as shown in Figure 4.13. The current and future state line balancing times were calculated based on the aggregated process activity times from Assembly Planner. It is seen that the current assembly line was not well balanced. Four operators are working on the line, with one operator working for 501 min and the other operator is working only 279 min. The maximum work time difference $\Delta cycle_{max}$ between the operators is 222 min. This uneven work balance allows the workers to be idle, and this caused inefficiencies in the production line.

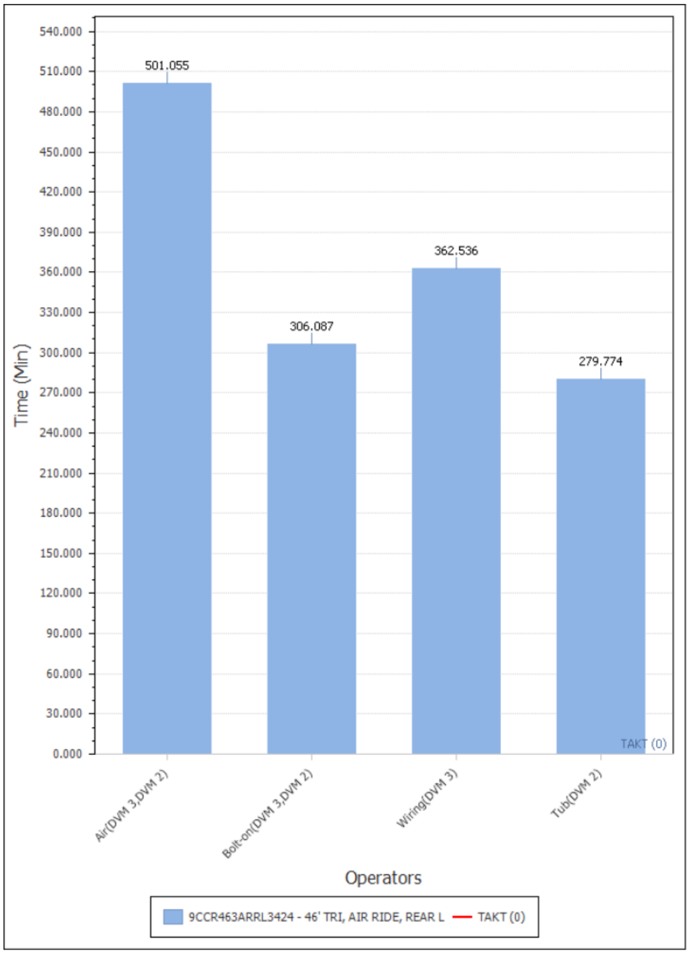


Figure 4.13 Current state line balance ($\Delta cycle_{max}$= 222 min)

On the flip side of things, the current assembly line was manually balanced to minimize the cycle time based on the weighted average method. The application came up with a well-balanced assembly line where all the tasks and resources were distributed correctly to the operators based on the precedence and task groupings. The output of the balanced assembly line is shown in Figure 4.14. The algorithm optimized the total operator count from four to three and distributed the tasks evenly among the operators. The takt time remained the same even after reduction of one worker. The maximum difference between the work times of operators $\Delta cycle_{max}$ reduced from 222 min to 10 min. This properly balanced scenario wipes out the idle time issue that we observed from the observed time study.

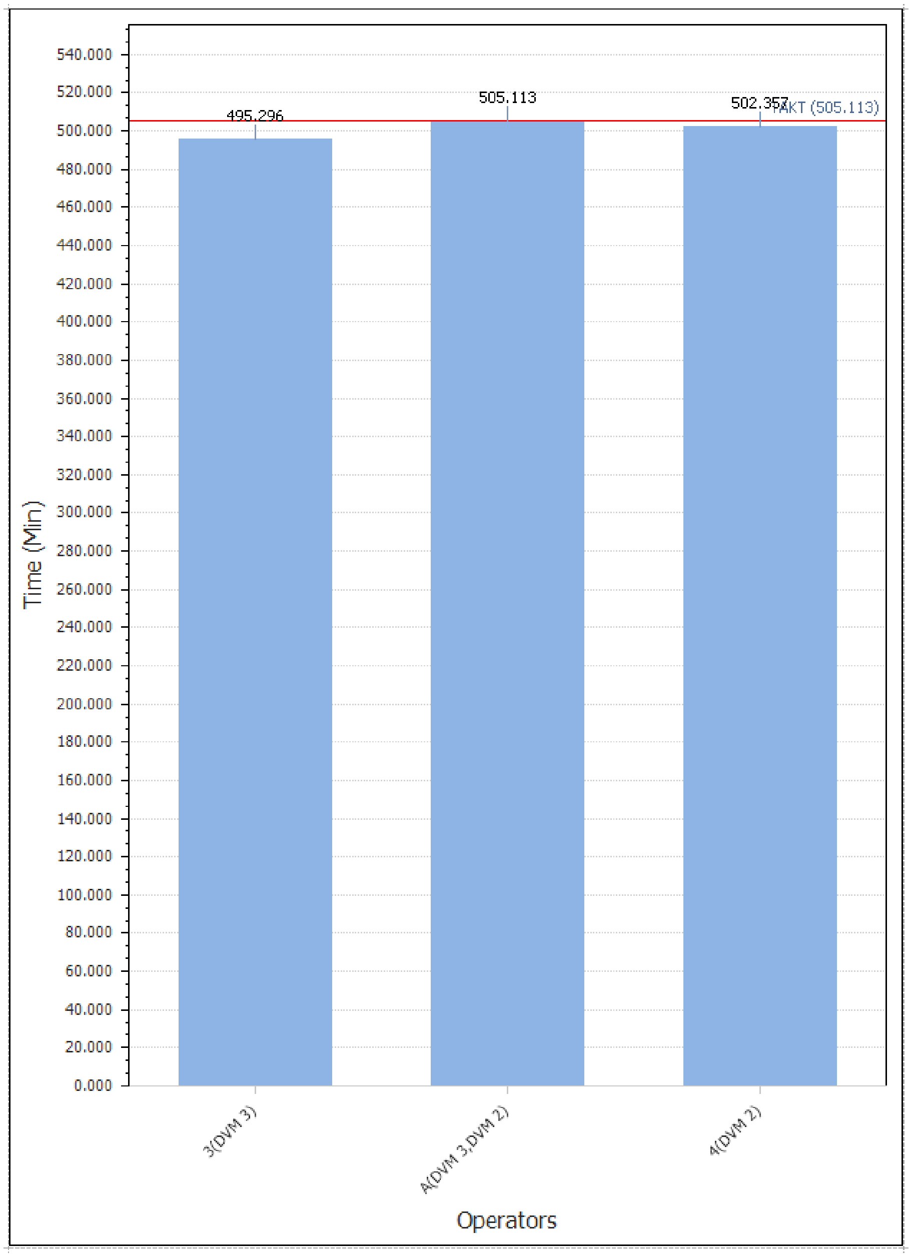


Figure 4.14 Future state line balance (Δcycle$_{max}$= 10 min)

By proper multi-model assembly line balancing, the potential non-value-added time such as operator idle time and waiting time can be eliminated. Which would save approximately nine labor hours per trailer. Which in turn can potentially increase the overall production efficiency by 25%.

4.1.3 Recommendation 3: Manufacturing Execution System

With the highly varying product line, the final assembly line operators at Demco are having a hard time understanding the assembly process without any standard work instructions. The ProPlanner helps Demco to electronically link the product and process design through Manufacturing Execution System to improve product quality and reduce the lead times from design to manufacturing. The capabilities of the ProPlanner MES system are shown in Figure 4.15. The data stored in the Assembly Planner's process engineering database is pushed to the MES system, where the Shop Floor Viewer, Factboard Andon, e-Kanban, e-Kitting, and productivity reports can be generated and utilized. The SFV is deployed in the production line, which potentially can reduce the NVA times caused due to rework, studying, and walking.

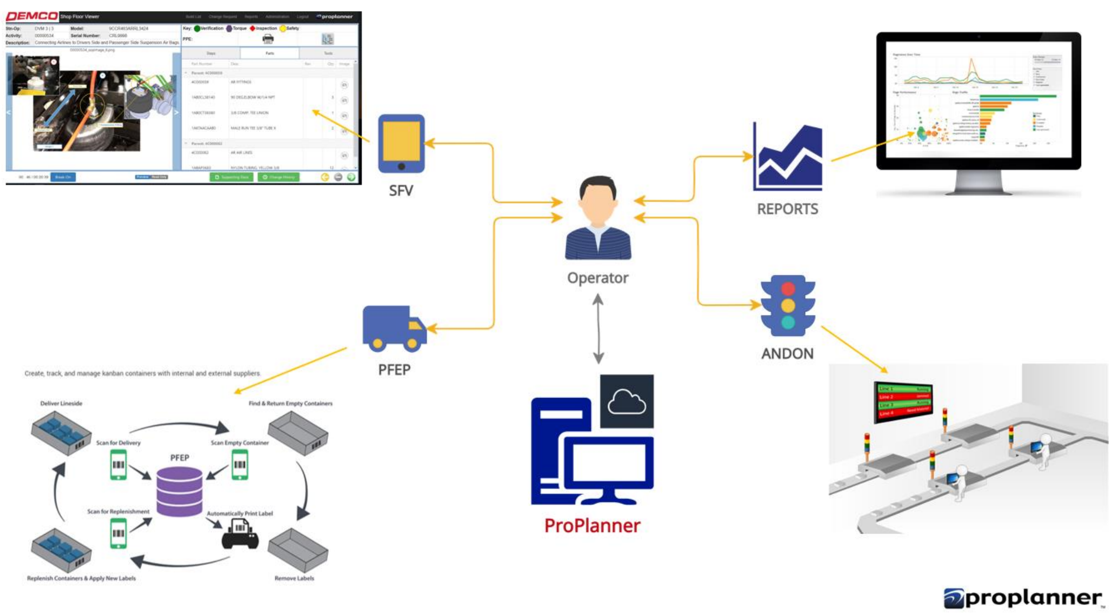


Figure 4.15 MES overview

Shop Floor Viewer (SFV):

- **Work Instructions:** The final assembly operators spend approximately 30 minutes on reworks, searching and studying, and three hours walking per trailer. Mainly because, the operators do not know how the part gets assembled, where and how, what components and tools they require for completing an activity. Thus, they walk back and forth from the tools/ parts station to the work zone. The ProPlanner's digital work instructions will give more clarity to the operators on what they need to do exactly.

- The work instructions were created in the Assembly Planner and published to SFV to address NVA times. The MES automatically generates unit-specific digital work instructions for each operator based on each order's model and options list. The instructions consist of annotated SOP images, assembly videos, work steps, required parts and tools, and tracking operator activity times. Figure 4.16 – 4.18 shows the work instruction displayed in the SFV with images, work steps, parts, and tools.

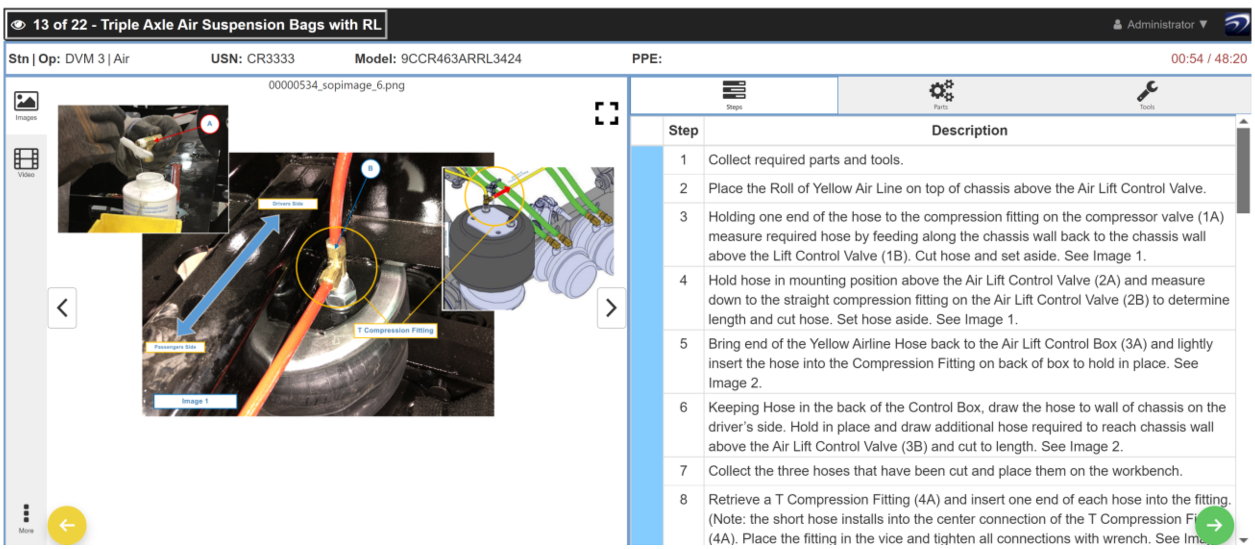


Figure 4.16 SFV: Work steps

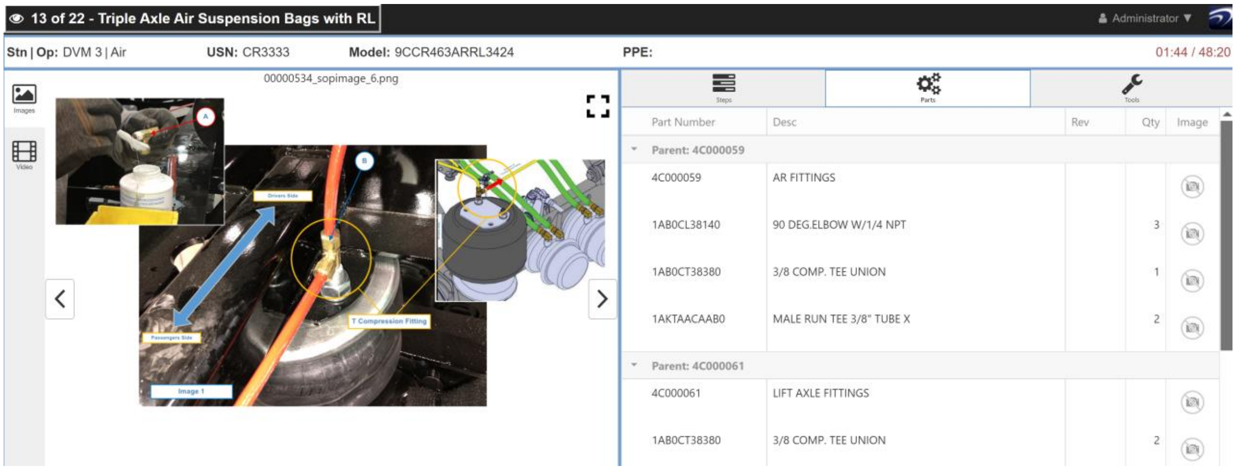


Figure 4.17 SFV: Parts

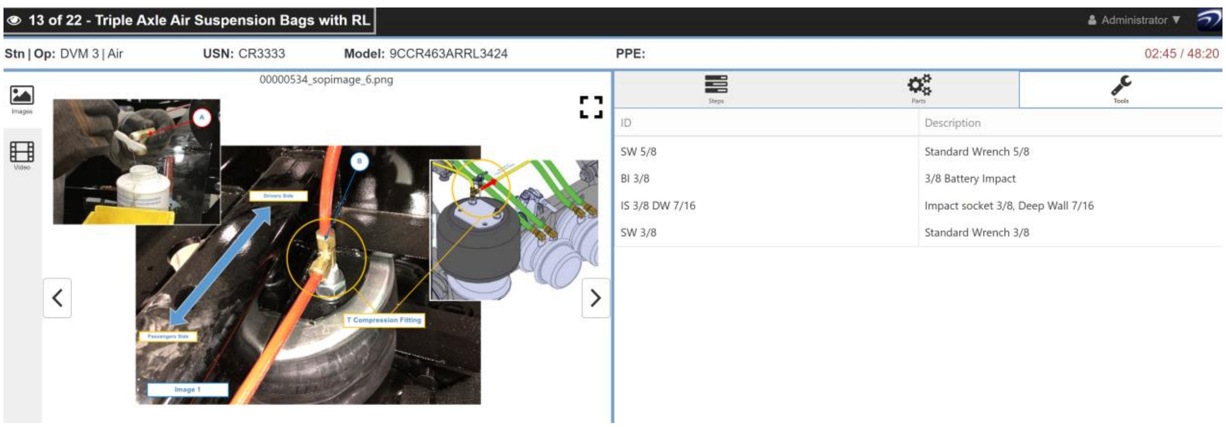


Figure 4.18 SFV: Tools

- **Quality documents:** At Demco, the quality documents were currently filed as paperwork by the operators. There were many issues where the operators do not pay attention to paperwork, and some critical quality parameters go unnoticed. There are cases where errors occurred in data duplication. The digital test inputs in SFV eliminates the need of paperwork and data duplication. The image shown to the left of Figure 4.19 is the hard copy of the quality document currently used in Demco. On the flip side of the image, the same content was digitalized in SFV, and the data can be tracked. In addition to that, enforce role-based signoffs for critical to quality tasks can also be created for critical activities. This feature is still in the testing phase.

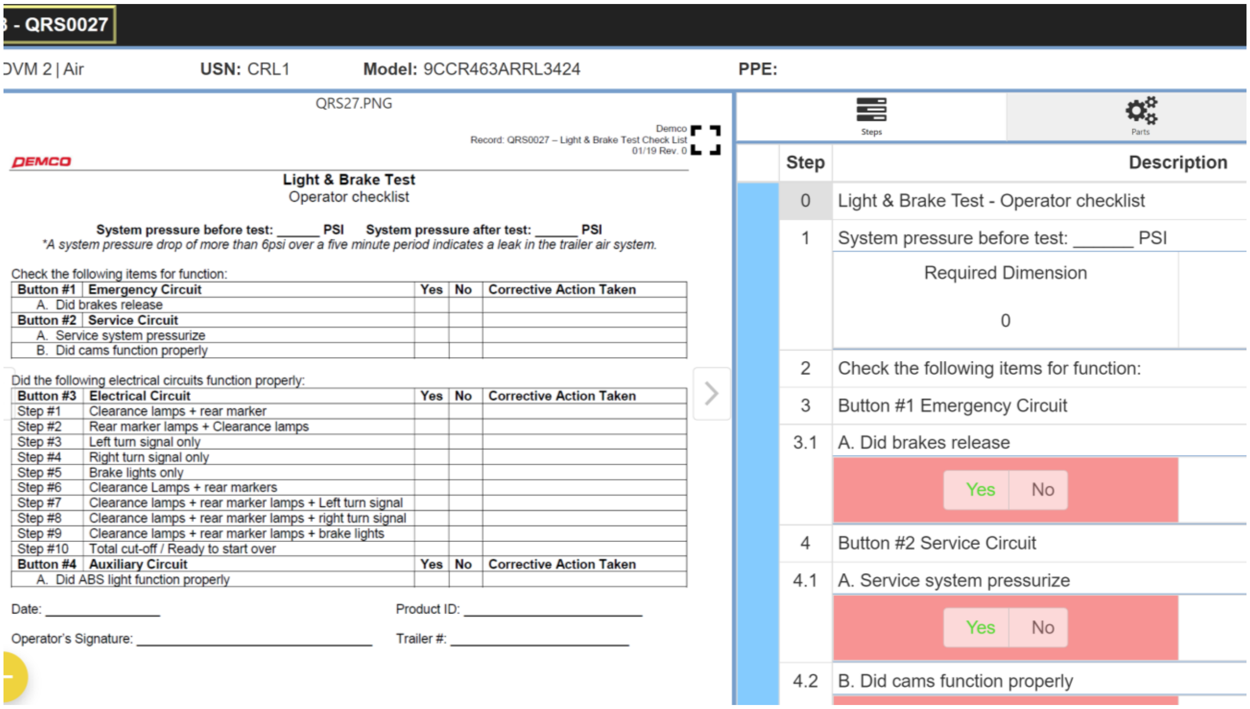


Figure 4.19 Digital quality document

- **Hot issues:** At Demco, unplanned downtimes are currently handled ineffectively. Downtime is when a machine is not in production because of breakdown, missing parts, production issues, errors, etc. There were many cases where operators miss parts for assembly, and they need to run to the warehouse and get the missing parts.

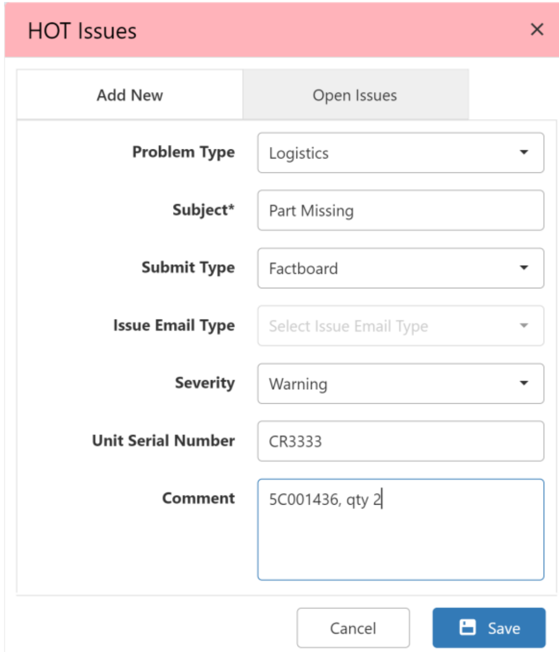


Figure 4.20 SFV: Hot issues

With the hot issues function in SFV, the worker can file a hot issue that can be sent to the warehouse, and the material handler can bring him the parts. Meanwhile, the operator can continue his tasks, such that time lost due to missing parts can be saved. The downtime data can also be closely tracked and monitored for later improvements. Figure 4.20 shows the hot issues page from SFV.

4.1.4 Additional issues found during FSD

In addition to the initial objective statement, two more objectives were added at the ending of the future state design phase. It includes,

- The quality documents need to be digitalized in order to eliminate paperwork and data duplication.
- The production reports need to be created to track the operator's productivity and their downtimes.

4.1.5 Recommendation 4: New layout for parts storage in DVM building

From the current state observed time study, it was observed that the final assembly operators were needed to perform material handling activities, which affected the production efficiency. The material movement is highlighted in the current state layout of the DVM building as shown in Figure 4.21, and its time study data is shown in Table 4.1.

Material	Location	Distance (M)	Time (Min)	Handling Resource
Finished trailer	Stock lot	350	20	Shag truck
Chassis	E Prep	280	14	Shag truck
Tub	N Paint	210	17	Forklift
Bolt-on components	S Prep	180	14	Flatbed/ Forklift
Assembly parts and tires	Warehouse	500	25	Flatbed/ Forklift

Table 4.1 Current state material handling time study

Once the trailer is fully assembled and inspected, the operator pulls out the trailer to the stocking lot, located 350 meters away from the DVM building. This consumes 20 min of the operator's time depending upon the availability of the shag truck. In addition to that, the operator needs to bring in the new chassis, tub, and bolt-on components from their respective inventory lot. It takes the operator approximately 15 min to make each trip, which sums up to 45 min. Furthermore, the parts kit and tires need to be brought in from the warehouse located 500 meters away from DVM. This adds additional 25 min of the operator time. In a nutshell, depending upon the shag truck/ forklift/ drop deck availability, it takes an operator a minimum of 90 min for material handling activities.

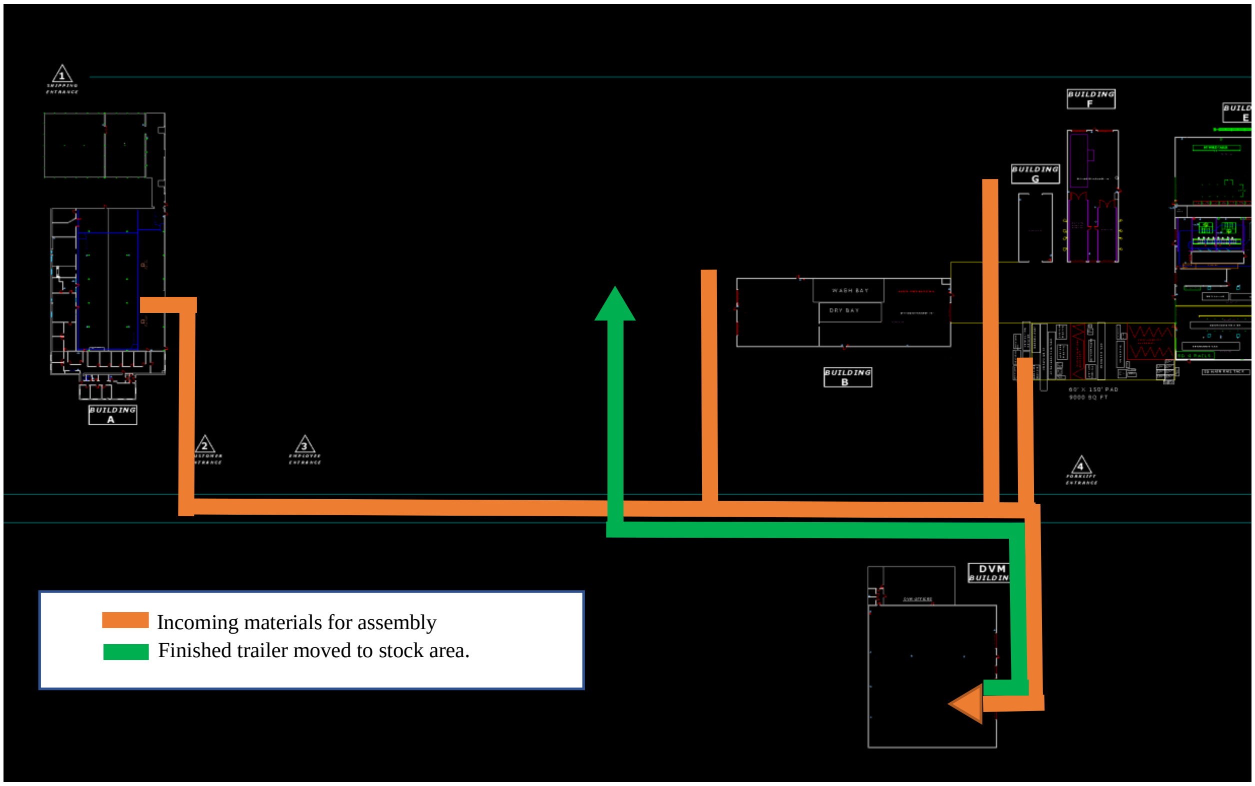


Figure 4.21 Current state layout

When the final assembly operator was involved in material handling activities, the remaining two workers on the assembly line stayed idle until all the materials were received. This was the major reason for increased operator times in the current state-observed time study. In order to reduce the material handling times, the current DVM layout and the process related to the material handling were redesigned. The changes include,

1) Storage spaces were created inside and outside the DVM building to accommodate the parts/ chassis and tub needed for the next production unit.
2) Instead of bringing in the new parts/ components for assembly after completing the existing trailer, the materials needed for the next production unit are brought and stored in the new storage spaces well ahead.

3) A new water spider (a material handler in lean terms) for material handling activities was appointed. Such that the final assembly operators can work on their assigned tasks.

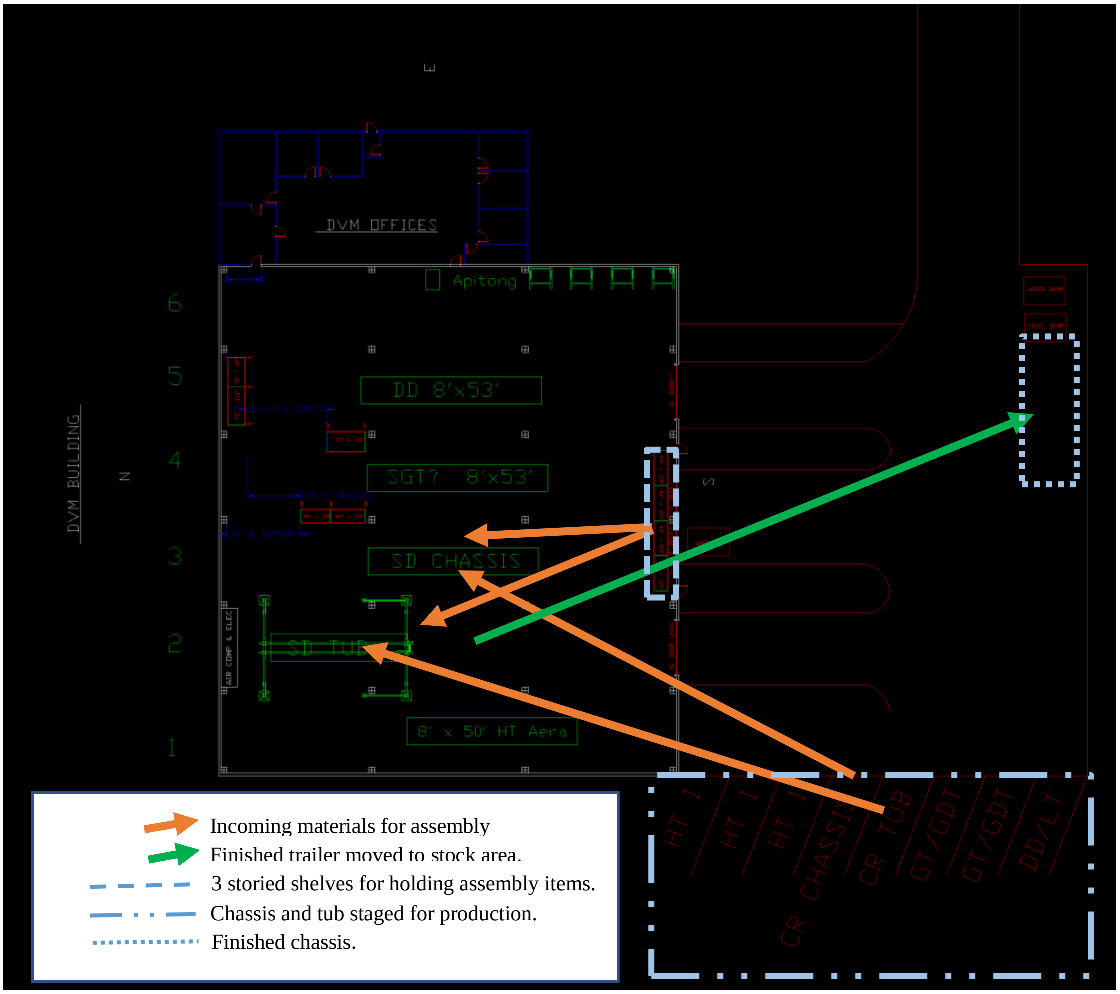


Figure 4.22 Future state layout

The future state layout in Figure 4.22 shows the newly added storage spaces and the material movements. The future state material handling time study is shown in Table 4.2. The layout change had a huge impact on the material handling distance covered and the times saved. The total time used for material handling in the CSA was 90 min, whereas only 23 min were spent for material handling in the future state, which increased the overall material handling efficiency to 75%.

Material	Location	Distance (m)		Time (Min)			Resource used
		CSA	FSA	CSA	FSA	Time Decrease	
Finished trailer	E DVM	*350*	15 to 20	*20*	7	75%	Shag truck/ Trailer caddy
Chassis	W DVM	*280*	16 to 20	*14*	5	65%	Shag truck/ Trailer caddy
Tub	W DVM	*210*	17 to 20	*17*	5	71%	Forklift
Bolt on components	DVM	*180*	18 to 20	*14*	3	79%	Drop deck/ Forklift
Assembly parts and tires	DVM	*500*	19 to 20	*25*	3	88%	Drop deck/ Forklift

Table 4.2 Future state material handling time study

4.2 FSD work sampling study results and analysis

The future state observed time study was conducted after successfully implementing the above recommendations. To perform the study in side-dump final assembly line, four cameras were placed on the stations DVM2 and DVM3. Ten days' worth of videos was collected from 6/21/2021 to 6/30/2021 between morning 6 AM to evening 5 PM, involving three final assembly line operators. For the analysis, the Operators Mike, Joel, and Jose were selected and observed on the trailer CR3341 of the same model 9CCR463ARRL3424 used in CSA but with different options, as shown in Table 4.3. The future state line balancing scenario reduced the operator count from four to three. Thus, the tub Operator Dough was removed from the final assembly line. All the selected operators are the same workers from the current state study.

Unit Serial No	Model ID	Model Description	Schedule Date	Options
CR3341	9CCR463ARRL3424	CIRCLE R LEAD TRAILER	6/23/2021	2C000017,2C000023,2C000032,2C000041,2C000051,2C000058,2C000065,2C000136,2C000259,2C000288,2C000292,2C000308,2C000327,2C000351,2C000382,2C000409,2C000476

Table 4.3 FSA: Order details CR3341

The future state time study data collected from the trailer model CR3341 is shown in the Table. 4.4. The CSA time shown is the average time of six operators from the current state, and the FSA time shown is the average time of three operators from the future state analysis. All these times were directly reported from the video time study. The implemented line balancing scenario significantly reduced the overall lead time, and it took an operator 10.8 hours on average to fully assemble the trailer. The task and operation times were categorized based on our predefined time categories. The time studies were further grouped into four categories: improvements from ProPlanner's SFV, line balancing, Demco management, and improvements from continuous improvements and line balancing.

- **Improvements through SFV:** The tasks such as operator waiting time, rework, search, study, and walking times were grouped since they attribute to better work instructions. Having the operators use SFV decreased the NVA times by 24%. On average, the digital work instruction saved 50 min of the operator times in the future state. While narrowing the results, the time spent on rework, searching, and waiting for the operator was primarily because of the operator not being sure how to assemble. In such a case, SOP images and work steps in the digital work instruction reduced the time wasted in learning the assembly procedure by 24%.

  In addition to that, the operators often forget to bring necessary parts/ material for assembly, and this made operator walk multiple attempts in between each activity. In this case, having a list of tools and parts needed for each activity in an online instruction reduced the walking time by 13%.

- **Line Balancing:** Through better line balance, distributing the work equally among the operators, better management, and continuous improvements increased their productivity rate by 19%, increasing in 64 min of value-added work time. In addition to that, effective line balancing reduced the workforce by 25%, reducing one full-time assembly operator.

- **Management:** The tasks such as operator taking an excess break, cleaning times, and taking times were brought under the Demco top management. From the CSA, it was observed that the workers were more lenient because there was no higher authority to monitor them.

Current State Analysis vs Final State Analysis					
Task	**Category**	**CSA**	**FSD**	**Time Savings**	**% Decrease**
Improvements from SFV					
Waiting for operator	NVA	17.0	4.0	13.0	76
Rework	NVA	9.6	0.0	9.6	100
Searching	NVA	6.9	4.4	2.5	37
Study	NVA	3.3	0.0	3.3	100
Walking replace/ bring	SVA	171.1	149.1	22.0	13
Total (Min)		207.9	157.5	**50.4**	**24**
Line Balancing					
Work (Min)	VA	329.8	393.8	**64**	**19**
Management					
Excess Break	NVA	69.2	47.2	22	32
Cleaning	NVA	32.2	26.4	6	18
Talking	NVA	24.4	8.5	16	65
Total (Min)		125.8	82.0	**43.7**	**35**
Continuous Improvement and Line Balancing					
Operator Idle	NVA	184.6	28.4	**156**	**86**
Total time		**901.8**	**686.7**	**215**	**23**

Table 4.4 FSD: Observed time study CR3341

One of the senior manufacturing engineers was assigned responsibility for monitoring the operator break times in the future state. The future state outcome came out positive, which decreased the wasted time by 35%. The average time effectively spent by operator was 43 min.

- **Continuous Improvement and Line Balancing:** The operator being idle – not knowing what to do, and longer changeover times, was addressed in the future state by changing the material handling process and better balancing the assembly line. In addition to that, the online work instruction gave them what activity they need to perform next. This helped them keep engaged with the production. Thus, the future state results show that the operator idle time was drastically reduced from 185 min in the current state to 29 min in the future state, a 85% decrease in idle time.

While looking at the future state results of time shared between the VA, NVA, and SVA activities, it was found that 57% of the time spent was VA, 21.6% of the time spent was SVA, and the remaining 21.4% of the time was NVA, as shown in Figure 4.23. The value-added time significantly increased by 20% in the future state.

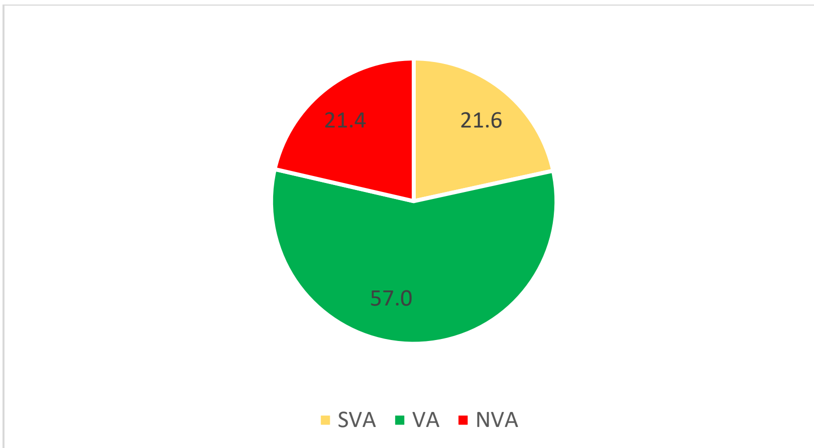


Figure 4.23 FSD: Pie chart

The improvements made in the final assembly line significantly increased the overall production efficiency by 43%, reducing the workforce by 25%. Table 4.5 shows the overall time and operator savings summary.

	Operator	Duration
CSA	4	15.0
FSD	3	11.4

Table 4.5 FSD: Overall time and operator summary

4.4 Post FSA operator comments

The assembly line operators were interviewed post-future state analysis and were asked what went well, what they did not like. Their responses were,

What went well:

- The operators felt SFV was a smart tool for them since it tells what activity they need to perform next. Earlier, the operators felt it hard to remember all the processes for different models and options.
- The annotated SOP images were handy for them to understand the assembly even better. Having a visual representation of the end product improves the quality of work done in the assembly line.
- With the help of required parts and tools data, the operators know exactly what they need for their working activity. In this way, they can carry the parts/ tools all at once to the work zone instead of walking back and forth multiple times to bring the parts/ tools of the same activity.
- With the help of raising hot issues in SFV, the operators felt their issues might solve quicker than usual.
- They can foresee what all the tasks lined up next for them are, which helps them keep prepared for the following task.

What does not go well:

- Some operators did not like the way how assembly line balancing was done. They wanted to do the same activities that they were doing earlier. The main reason for this is that they were not cross-trained. So, they feel comfortable with the activities that they know.
- Felt annoying to click next for every activity. This setting can be changed such that they do not need to click the Next button each time.
- The network issue slows down the SFV website.
- The experienced operators feel SFV reduces their productivity.

- Few of the standard times were off. The few observed time studies needs to be reevaluated.
- Currently, only one model is available in the SFV. It would be great if it includes all possible models and options.

CHAPTER 5. CONCLUSION

The observed time conducted on the current state analysis clearly showed the inefficiencies at the final assembly line. Further analyzing the issues observed from the operators and the Demco management, future state recommendations were proposed and implemented successfully. Deploying the ProPlanner MES tool in the assembly line and various continuous improvement projects carried out by the ME team at Demco doubled the production efficiency from what we thought initially. Demco claims that, more than the MES tool, the Assembly Planner software helped them identify the inefficiencies in the process and drive continuous improvement projects quicker than usual, where they see a lot of benefits from a process planning tool. The business benefits are summarized below: -

1) The non-value-added times were reduced from 43% to 21% in the final state, which is a 52% reduction in production wastes.

2) By better balancing the assembly line, better management, and establishing proper material handling process, reduced the required workforce in the side dump final assembly from four workers to three workers, without increasing the assembly of lead time.

3) The overall assembly line efficiency was increased by 43%. Exceeded our initial target of 30%.

4) The detailed process work instruction was created and established a centralized location for process data in Assembly planner software.

5) The SFV was successfully tested on the side dump final assembly line.

6) Improvements to kitting process eliminated idle time due to the operator waiting for parts.

In addition to that, the primary objective of conducting a case study on the benefits and challenges in implementing the MES system was met.

5.1 Economic impact

Currently, DEMCO has a target of manufacturing 104 side-dump trailers in a year. With the 43% increase in the assembly line efficiency, now DEMCO can make approximately make 148 trailers a year, assuming 200 workdays a year. It has been calculated that 25.8 labor hours can be potentially saved with the increase in production efficiency.

Labor savings based on current production efficiency: 25.8 (hour saving/ trailer) * 148 (total no. of trailer produced) * 25 (hourly labor rate) = $95,460.00 a year. In addition to that, now DEMCO can produce 61 trailers more than their current rate. It is assumed that DEMCO has a profit of $5,000.00 per trailer, assuming the rest of the other side dump lines operating equally efficiently. Total profit would be 5000 * 44 = $220,000.00 a year.

To sum up, a 43% increase in their assembly line efficiency would potentially save DEMCO $95,460+$220,000= $315,460.00 a year, just from the side dump product line.

5.2 Challenges and overcomes

Deploying MES on the Demco's side dump final assembly line was unprecedented earlier. Before this project, there were no standard work instructions, no time studies, line balancing was never done before, the operator times were not tracked, the process activities were not captured, and the exact lead times were never known. The side dump model being their huge production line, offering various models (45) and options (500), and the assembly line not having any base, deploying an MES was not straightforward. The major challenges faced while executing the MES are grouped into the following categories: -

Data collection:

- The workstation was huge with 55 ft, and having operators switch between the stations, and it was challenging to capture the overall process. With the strategy of placing multiple cameras in different views and using one wide range camera, the overall process was captured easily.
- Their eBOM and mBOM do not match. The mBOM was flattened in order to create and use a shop order as the process routing. In addition to that, the part IDs in the mBOM had prefixes in front of them. So, it was hard to map both their BOMs. Since Demco does not want to change its design, a different route was found to tackle this issue. The ID issue was solved by adding metadata to the part numbers such that, ProPlanner software can pull out the metadata and change the part ID as per the assigned rules.

Data import:

- Since the product line has 45 models and 500 options, one modeled trailer can have anywhere between 15 to 25 different options and is heavily customizable. This is where the ProPlanner's model-option feature becomes handy. The BOM was imported into the Assembly Planner software based on models and options separately. But we faced data duplication issues on the imported BOM since the same part numbers were used in multiple different options with different quantities. This issue was solved by preprocessing the original data and deploying a parent ID-based import. With handling, It took several weeks to find the correct import method. The import process was documented and shown in Appendix Figure 3.

Process authoring:

- The entire process authoring for 151 activities was created from scratch by analyzing the process lively through multiple videos, cad assemblies, and BOM. In addition to that, created activities were sequenced, grouped and optimal precedence was created. It took us several months to achieve this stage.

Deploying SFV:

- After process authoring, line balancing was done, and three worker scenario was applied back to the routing and published to the SFV. During the initial few trials, we got negative feedback from the operators. Since the operators were new to the digital environment, it was hard for them to navigate through the system. Their comments include: -

  i) They did not like the way how the line balancing distributed the work between the operators. Their major claims were, this activity should be done by him and not by me, this is not my task, I do not know how to do this one, etc.,

  ii) Operators do not want to click next for every activity. They believe this makes them less efficient.

  iii) They do not want to carry the tablet, which displays the work instruction all over the work zones.

The report generated from SFV showed that the operators did not sign in and sign out on the activities properly. The break times were showing more than unusual times. This is because they did not know how to navigate correctly in the SFV. To address the issues, management stepped back and decided to distribute the work between operators as per their activity suggestion. We thought of having this operator-driven assembly line until the operator gets familiarized with the SFV.

During that phase, the operators were given training on how to navigate through the modules. Also, the operators were trained on how to submit the reports through SFV features like digital quality documents, hot issues, change review, and change management. The operator carts in the workstations have also been equipped with the tablet holder.

Finally, after applying the actual line balancing scenarios, the operators were asked to follow the task based on the SFV. All the training and improvements helped the operators get familiarized with the system and adopted it. The results of using digital work instructions are as follows,

i) Because they were able to view the parts/ tools required, they saved 13% of their walking time to get a different tool/part.

ii) Because they had detailed work instructions with SOP images and work steps, they did not need to ask any questions or redo activities, which saved 24% of their time.

iii) Because they knew all the tasks needed to be performed (by them) on the trailer, they did not need to depend on other operators.

iv) Because they can use hot issues, their downtime can be reduced by 80%.

5.3 Contributions

In addition to the MES deployment, a potential feature that can be added to the current MES solution was proposed. It can potentially solve the operator productivity tracker and filing digital quality document requirements of Demco.

Live operator productivity report:

Our current state analysis observed that the operator's idle times and their break times were too long. In order to monitor the operator's productivity, Demco was looking for some tracking system that can tell the productivity of an Operator. Given that most of the time, data were already captured by the SFV, I came up with the idea of generating a live operator productivity report with the preexisting data. The proposed report is shown in Table 5.1. By utilizing the downtime, breaks, standard, and actual lead times, line productivity and operator efficiency can be tracked and monitored. This feature is currently being developed by ProPlanner, where the standard time fields were not being generated currently, and the developers are working on getting this work.

This report, when implemented, will be very much helpful for the team lead in analyzing the productivity of each worker. Less efficient operators can be easily identified and questioned, applicable for labor costing, line productivity, and downtimes can be easily tracked and monitored.

From Date:			**Plant:**			***Operator Productivity Tracker***				
To Date:			**Building:**							
Station	Op ID	Date	Excess Break Time	Standard Cycle time	Actual Cycle Time	Hot Issues: No. of issues	Hot Issues: Down Time	Work Time	Line Productivity	Efficiency
DVM 2	1	7/1/2021	10	104	125	2	17	98	-16.8	5.8
	2	7/1/2021	15	95	105	1	15	75	-9.5	21.1
	3	7/1/2021	12	142	164	0	0	152	-13.4	-7.0
DVM 1	1	7/1/2021	15	111	118	0	0	103	-5.9	7.2
	2	7/1/2021	30	105	109	0	0	79	-3.7	24.8
DVM 3	1	7/1/2021	5	134	148	0	0	143	-9.5	-6.7
	2	7/1/2021	0	118	121	1	8	113	-2.5	4.2
	3	7/1/2021	8	125	130	0	0	122	-3.8	2.4

Work Time = Actual Cycle Time - Downtime |
Line Productivity = ((Standard Cycle Time - Actucal Cycle Time)/ Standard Cycle Time)*100 |
Efficiency = ((Standard Cycle Time - Work Time)/ Standard Cycle Time)*100

Table 5.1 Proposed operator productivity tracker

Digital quality documents:

At Demco, the quality documents were currently filed as paperwork by the operators. There were many issues where the operators do not pay attention to paperwork, and some critical quality parameters go unnoticed. There are cases where errors occurred in data duplication. During our process authoring phase, the quality documents were authored to the Assembly planner. The outcome of the results was not what we wanted because currently, the software can allow only Yes/No and number inputs, but the quality documents at Demco have text inputs. I did come up with the idea of enabling the string inputs and image capturing the quality issues and the quality document. This feature is currently in the development phase with ProPlanner. When gets implemented, this will satisfy the digital quality requirements of Demco.

5.4 Next steps

Due to BOM flattening issue, the mBOM restructuring is needed to bring in the remaining 44 side dump production models into Assembly Planner. The pending SFV developments – SFV reports and digital quality documents will be implemented. Additional ProPlanner features such as sequencing, scheduling, virtual build, and e-kanban are to be implemented in the upcoming phases.

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APPENDIX A. ADDITIONAL MATERIAL

DEMCO

SIDE DUMP

SIDE DUMP
FAB- 12.5 HRS
WELD - 98.4 HRS
PREP - 6 HRS
PAINT - 10 HRS
FINISH-60 HRS

PRODUCTION TRACKER

TRAILER ID/UNIT NUMBER	Shop Order	START DATE	START STAGE	FAB NESTING	FAB LASER 7.5	FAB SAW 2.5	FAB BRAKE 1.25	FAB Drill 1.25	Weld Chassis Sub Assy. 10.77	Weld Tub Sub Assy 20.88	Weld Chassis Assy 13.83	Weld Tub Assy 52.92	Prep Grind Chassis 3	Prep Grind Tub 3	Paint Black Parts	Paint Chassis 5	Paint Tub 5	Finish 60	05-03 thru 5-07	05-10 thru 05-14	05-17 thru 05-21	05-24 thru 05-28
																			447	346.1		
			SD FAB																14	16.6		
			SD WELD																20.9	186.0		
			SD PREP/PA																34.5	23.5		
			SD FINISH																240	120.0		
CR 3314	660785	1/19/2021	FINISH															60				
CR 3317	661330	4/19/2021	FINISH															60				
CR 3318	661331	5/17/2021	FAB	1.5	7.5		1.25	1.25														
CR 3319	661332	5/17/2021	FAB	1.5	7.5		1.25	1.25														
CR 3325	662781																					
CR 3335	662994	3/16/2021	FINISH															60				
CR 3337	664737	4/12/2021	FINISH															60				
CR 3338	665695	4/5/2021	FINISH															60				
CR 3339	666485	4/13/2021	FINISH															60				
CR 3340	667101	4/19/2021	WELD SUB						10.77	20.88	13.83	52.92	3	3	2.5	5	5					
CR 3341	668238																					
CR 3342	668787	4/19/2021	FINISH															60				
CR 3343	669069	4/21/2021	PREP											3	2.5		5					
CR 3344	669077	4/22/2021	FAB							20.88		52.92		3	2.5	5	5					
CR 3345	669848	5/3/2021	FAB	1.5	7.5	2.5	1.25	1.25														
CR 3346	669854		FAB	1.5	7.5	2.5	1.25	1.3	10.77	20.88	13.83	52.92										
CR 3347	671528																					
CR 3348	672700																					
CR 3349	672946																					
CRTB007	663900	4/5/2021	WELD					1.25				52.92	3	3	2.5		5	60				
CRTB 008	666485	4/29/2021	WELD SUB					1.3														
CRFT 0002	665696	4/5/2021	WELD SUB					1.25		20.88		52.92										
CRFT 0003	666855	4/13/2021	WELD SUB							20.88		52.92										
CRTB 009	669632																					
CRTB 010	669634																					
CRTB 011	670469																					
CRTB 012	671520																					

Appendix Figure 1: Currently used production times

ITEM IMPORT

Wednesday, February 10, 2021 3:43 PM

Process to be followed

- [ ] **Merge** the entire BOM together
- [ ] Remove the duplicates based off the **ID** (Data>Data Tools>**Remove Duplicates**)
- [ ] Arrange the data according to the following template and save it (Make sure the column names are same)
    - ID
    - Revision (*A if not have previous revision)
    - Description
    - Description2
    - ItemType (EndItem, Phantom, Assembly, Purchased, Manufactured, Item, SubAssembly, Document)
    - PrimaryUnitOfMeasure
    - IsModel (True /leave blank)
    - IsOption (True /leave blank)
- [ ] Navigate to Proplanner> Data Mgmt> Import Data>
    - Select Import Type : **ITEM**
    - Select Import File: Browse and select the saved file to import
    - Select Import Mode: **Add New** (For the first time)/ **Merge** (Update or adding existing items)
    - Auto- Numbering Scheme: **None**
    - **Check** - Replace Blank Item Revisions With Current Item Revisions
- [ ] Hit Import

Appendix Figure 2: Item import process checklist

BOM IMPORT

Thursday, February 11, 2021 7:52 AM

Process to be followed

- [ ] Export the entire BOM data from TCM and open in Excel
- [ ] Remove unwanted rows and keep the following columns
    - LVL
    - Comp ID
    - Des
    - Des2
    - Qty-Per
    - UM
    - Beg-Eff-Dte
    - End-Eff-Dte
- [ ] Insert a new column "ParentID" and paste the following formula on the first LVL 1 row.
    - **=IFERROR(LOOKUP(2,1/($A$2:A3=(A3-1)),$B$2:B3),"")**
    - -A refers to LVL
    - -B refers to Comp ID
- [ ] Make sure to copy the "Parent ID" column and re-paste it (Use Pate Values only--- to remove the applied formulas)
- [ ] Now, remove the LVL, Des and Des2 columns and re-name the existing columns as
    - Comp ID - "ID"
    - Parent ID - "ParentID"
    - UM- "PrimaryUnitOfMeasure"
    - Qty Per- "Quantity"
    - Beg-Eff-Dte - "EffectiveFromDate" (If NA, add date 1/1/2000)
    - End-Eff-Dte- "EffectiveToDate" (If NA, add date 12/31/9999)

    Insert two more columns;
    - "Revision" - A if not specified (default)
    - "ParentRevision" - A if not specified (default)
- [ ] **Filter** the "ParentID" based off "Blanks, 1, 2C, 3C, 4C, 5C, 6C, 7C, 8C, and 9C" and move the data to new file and name it accordingly
- [ ] In each of the above files, **remove duplicates** based off
    1) WRT all the columns - Check no. of duplicates removed
    2) WRT - ID, ParentID and QTY - Check no. of duplicates removed
    3) WRT - ID and ParentID - Check no. of duplicates removed
- [ ] If all the above 3 values match - The file is ready to be Imported
- [ ] Navigate to Proplanner> Data Mgmt> Import Data>
    - Select Import Type : **BOM**
    - Select Import File: Browse and select the saved file to import
    - Select Import Mode: **Replace**
    - BOM Type: **mBOM**
    - Auto- Numbering Scheme: **None**
    - **Check** - Replace Blank Item Revisions With Current Item Revisions
- [ ] Hit Import

Appendix Figure 3 – BOM import process checklist

ORDER IMPORT

Thursday, February 11, 2021 9:09 AM

- [ ] Pull the order data exported from TCM
- [ ] Reorder the columns as follows,
  Example:
  Unit Serial No - CR3241 (Unique)
  Order No - 629307 (Unique)
  Model ID - 9CCR444ARRLS3424
  Model Description - CIRCLE R LEAD TRAILER
  Scheduled Date - 4/1/2020
  Options - 2C000018,2C000032,2C000042,2C000051,2C000082,2C000105,2C000353,2C000385,2C000409
- [ ] Convert the file to .xls file
- [ ] Navigate to Proplanner> Order Data Mgmt> Order List> Import

Appendix Figure 4: Order import process checklist