MichiganEngineering

Manufacturing System Design for a Car Assembly Process

EXECUTIVE SUMMARY

We have been assigned the task of designing the manufacturing system for the assembly of a simple vehicle. The manufacturer wishes to anticipate any changes in demand, and also wishes to know the impact of reliability at the system and machine levels (100% system and 95% machine reliability). As a result, three scenarios of demand and reliability were considered: (1) 50,000 units per year with 100% reliability, (2) 50,000 units per year with 95% machine reliability and lastly (3) a 75,000 units per year with 95% machine reliability. This task has been completed.

By performing tasks in parallel at the same station, the total number of stations required for assembly was reduced to 7. In turn, the system reliability was increased in order to meet the yearly demand. Specifically, for scenario 1, the plant can operate a single 8 hour shift for 51 weeks per year. For scenarios 2 and 3, respectively, two and three 6 hours-a-day shifts for 49 weeks per year can be used to meet the yearly demand. Lastly, a future state map is included to implement lean manufacturing methods and reduce the costs of operation. The approach, costs and recommendations regarding the assembly designs are discussed in this report.

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1 PROBLEM STATEMENT

We have been tasked to design the manufacturing system for the assembly of a simple car. It is projected that the manufacturer will need to produce at least 50,000 units per year during the first years of operation. One case is considered for 100% reliability, while another for 95% machine reliability. The manufacturer wants to anticipate changes in demand which may quickly rise to 75,000 units per year. The manufacturer wants to know what system setup will meet the manufacturing goal under three discreet conditions, shown in Table 1, below.

Table 1: Demand and Reliability Scenarios

Scenario	Units per Year	Machine Reliability
1	50,000	100%
2	50,000	95%
3	75,000	95%

Additionally, we have been informed of the following conditions regarding financial and physical details of the manufacturing system.

Table 2: Variable and Fixed Costs for the System (in USD)

1	Average Cost per Station	$100,000
2	Average Cost per Buffer	$10,000
3	Maximum and Minimum Working Hours per Shift	8 hours/day (max) 5 hours/day (min)
4	Labor Cost and Overtime Labor Cost	$40 per hour (normal) $60 per hour (overtime)
5	Car Length	4.5 m
6	Distance Between Station Center Points	9 m
7	Line Width (incl. corridors)	13.5 m

2 COMPONENTS AND MANUFACTURING TASK INFORMATION

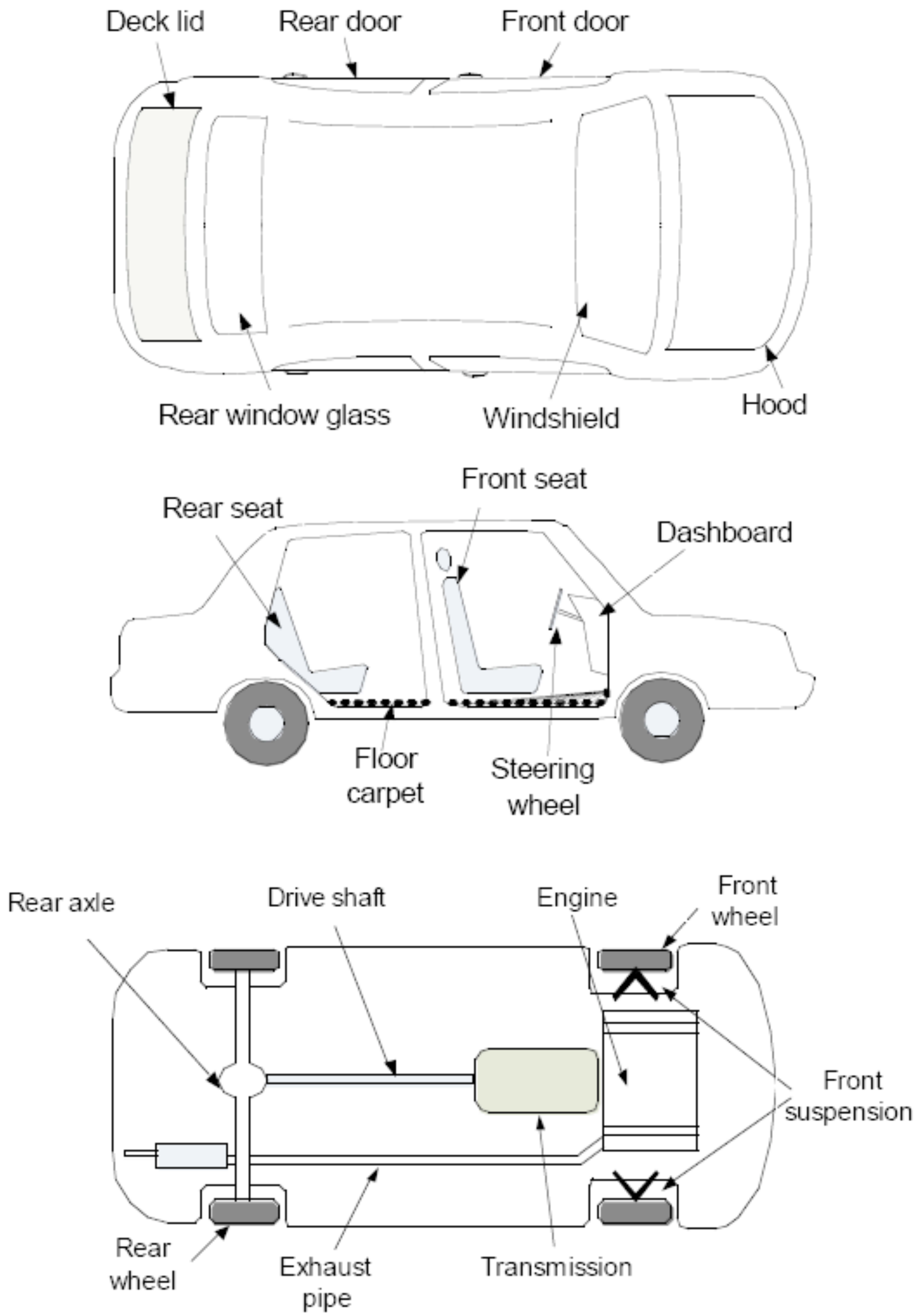

Figure 1: Schematic of car components and sub-assemblies

Table 3: Task breakdown and information

	Task number	Task Name	Task Time (seconds)	Operators Required	Predecessor Tasks
1	1.1	Install 2 front suspensions	43	2	
2	1.2	Install 2 front wheels	26	2	1.1
3	1.3	Install real axle	42	2	
4	1.4	Install 2 rear wheels	26	2	1.3, 2.4
5	2.1	Insert the engine	27	2	
6	2.2	Secure the engine	47	2	2.1
7	2.3	Insert /secure transmission	55	2	2.2
8	2.4	Install the drive shaft	31	1	1.3, 2.3
9	3.1	Install the exhaust pipe	44	2	2.2
10	4.1	Install wiring harness*	75	2	
11	4.2	Attach dashboard	42	2	4.1
12	4.3	Attach steering wheel	32	1	4.2
13	5.1	Attach front and rear windows	35	2	
14	5.2	Seal windows	45	4	5.1
15	6.1	Install 2 front seats	26	2	4.3, 6.3
16	6.2	Install the rear seat	31	2	6.3
17	6.3	Install floor carpet	94	2	4.1
18	7.1	Attach hood	12	2	2.2
19	7.2	Attach deck lid	17	2	
20	7.3	Install 2 front doors	43	2	6.1
21	7.4	Install 2 rear doors	44	2	6.2
22	8.1	Fluid fill	102	4	All except 9.1
23	9.1	Inspection	145	2	All others

Total Task Time	**1084 seconds, ~18 minutes**

* Wiring harness goes under the floor carpet along the cabin

3 ASSUMPTIONS

Based on the given task information as described in Section 2, several assumptions were made to facilitate the construction of a liaison diagram. The assumptions made are listed below.

Working Hours

1. Shifts can be 6 to 8* hrs/day, 5 days/week, 49 to 51* weeks/year

   * Varies with design scenarios

Manufacturing Operations

2. Inspections done in a different, quiet and clean zone
3. Task time includes all mounting and un-mounting during installation of components

Machines

4. Each task needs 1 machine
5. Each station used has 95% efficiency (Design #2 & Design #3)
6. Failure of one machine does not cause the failure of another machine

Employee

7. Any operator can work on any station, and operators will complete a scheduled rotation for all stations
8. Workers will not be absent for sick days or vacations

Sub-assembly supply

9. There is uninterrupted flow of sub-components and parts
10. The engine comes with its own sub-wiring harness
11. The ECU comes with the wiring harness as it is installed
12. The vehicle body is present at each station of the assembly

The assumptions relating to cost and profit calculations are discussed in the Designs section.

4 TASK ANALYSIS

In order to design the manufacturing system for this application, the assembly tasks have been analyzed and simple heuristics were used to create a precedence graph and a production line scheme. Task information, task times and number of operators were taken into account, as well as the components needed to complete a task and the predecessor tasks for each task.

4.1 Precedence Graph

According to task information, a precedence graph was drawn, as shown in Figure 2, below.

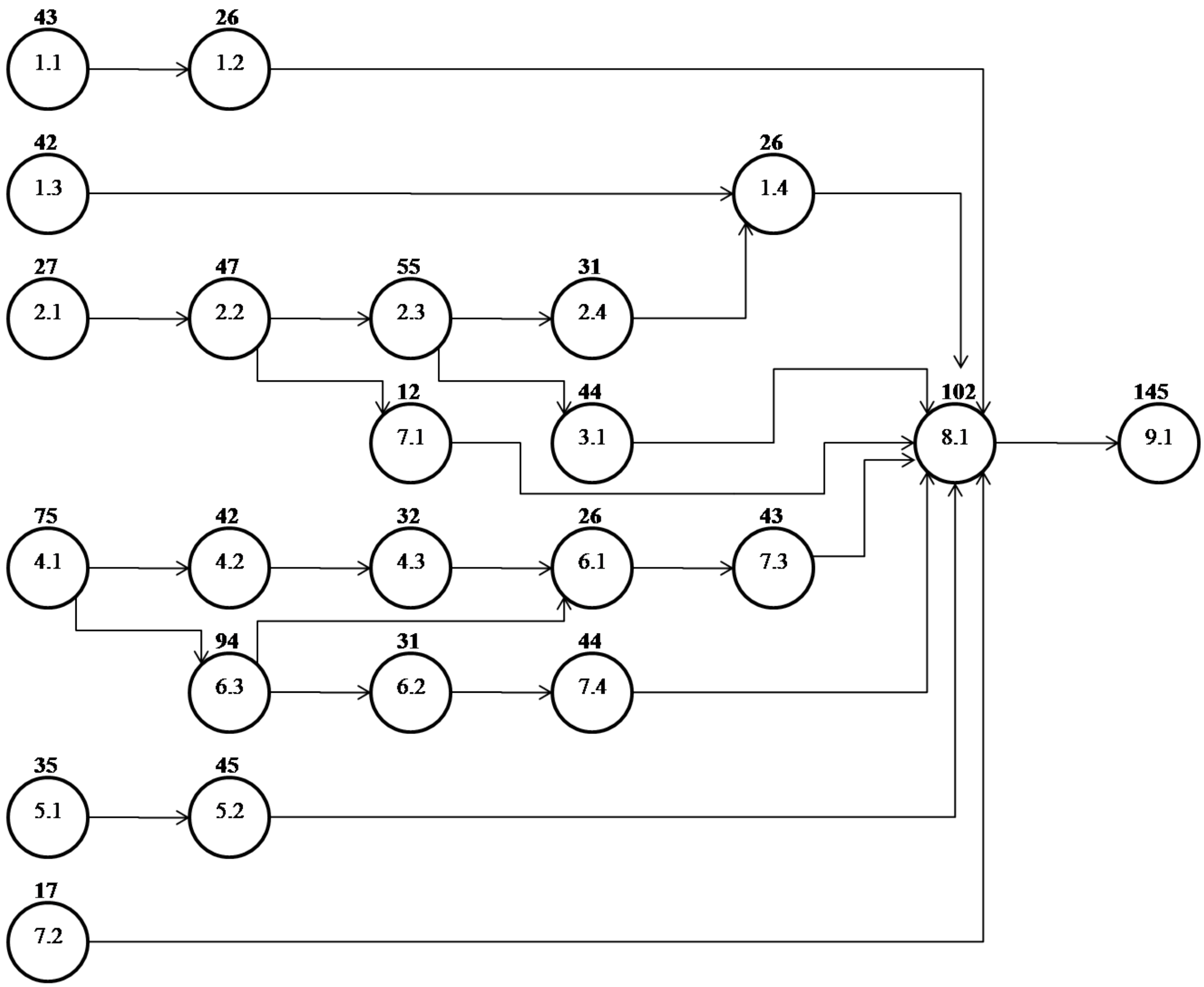

Figure 2: Task precedence graph

4.2 Production Line Scheme

A production line schematic was generated for each design and is shown in Figures 3 and 4, below. These were drawn in accordance to space requirements listed by the manufacturer. The space occupied for Design 1 is 972 m^2, while Designs 2 and 3 occupy 1215 m^2. The approach used to create the production line schemes is detailed in section 5.1.

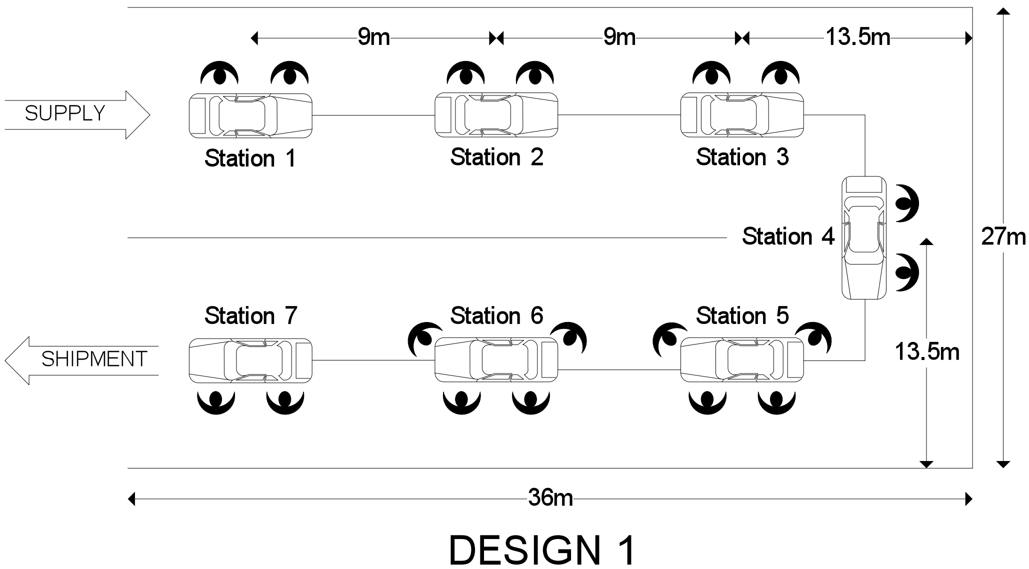

Figure 3: Production Line Scheme for Design #1

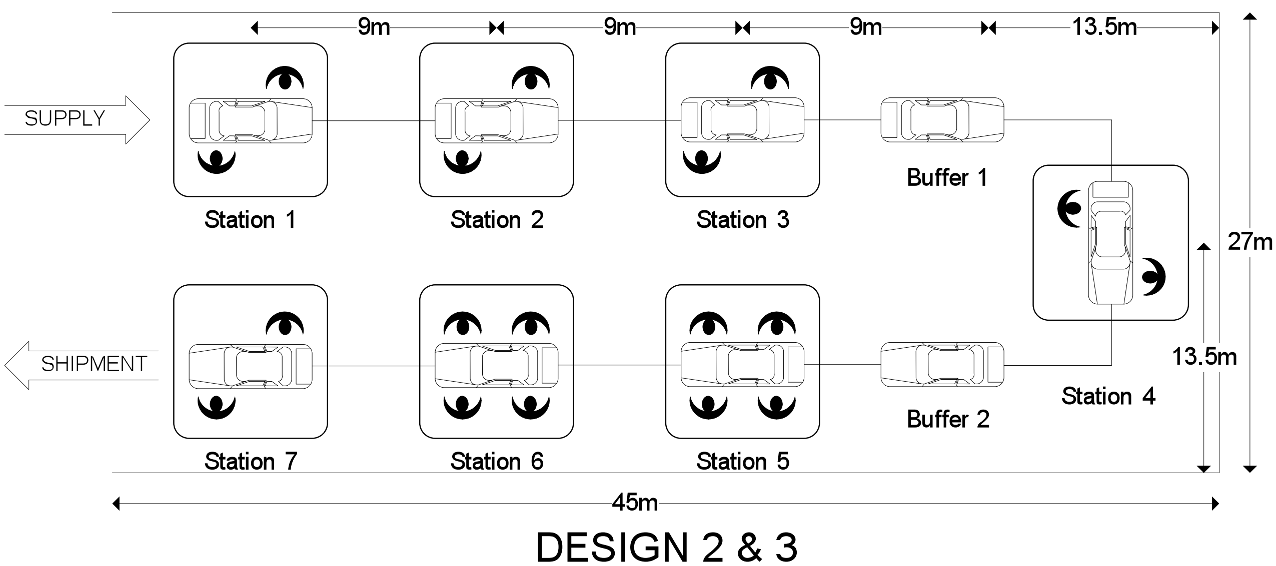

Figure 4: Production Line Scheme for Design #2 & #3

5 DESIGNS

This section outlines the approach, implementation and outcome of the three demand and reliability scenarios discussed in Section 1.

5.1 Approach

To obtain a possible task group according to takt time, Ranked Positional Weight (RPW) heuristics were performed for the manufacturing process design. The results of RPW can be seen in Table 4, below. When assembly order was determined, we considered the difference in number of operators for each task along with task precedence. For example, task 5.2 requires 4 operators and must be done after task 5.1. So the four operators of task 5.2 can perform two other two-operator tasks in parallel, after task 5.1 is completed. With more operators, it was possible to do tasks in parallel at the same station. These are indicated by tasks that are grouped in parentheses. Thus, it was possible to use 7 assembly stations, with only one instance of significant idle time in station 5.

Table 4: RPW Results

Station	Assigned tasks	Idle time	Process time	Required operators	Buffer size
1	4.1, 2.1, 4.2	2	144	2	
2	6.3, 2.2	5	141	2	
3	2.3, (4.3 & 2.4), 5.1, 7.2	7	139	2	1*
4	6.2, 1.1, 6.1, 1.3	4	142	2	1*
5	5.2, (3.1 & 1.2), (1.4 & 7.1)	31	115	4	
6	(7.4 & 7.3) 8.1	0	146	4	
7	9.1	1	145	2	

* Buffers apply only to Designs 2 and 3.

5.1.1 Buffer Implementation

Using PAMS software version 4.2 to verify and improve our assembly process, we determined that we should incorporate two buffers into Designs 2 and 3, between stations 3 and 4, and 4 and 5. The size of each buffer should only be 1 car, and the implementation of buffers would result in a higher system reliability and throughput. The PAMS approach is further discussed in Appendix A.

5.1.2 Modification of Labor Hours

With the decreased machine reliability of Designs 2 and 3, it is essential to decrease the number of stations and maximize the system reliability. Using seven stations in series, the overall reliability is 0.95^7 or 69.8%. To counteract the impact of significantly decreased production, three labor hour modifications were made: (1) a shift was added, (2) the length of the work day was reduced and (3) the number of weeks of operation per year was decreased. This will allow the manufacturer to produce more than 50,000 units per year and fulfill the requirements of Design 2, without implementing a second assembly line and without changing the task assignment order.

In order to reach the production goal of 75,000 units for Design 3, a third shift can be added and will work with the same reliability of Design 2. The production outcome and labor hours of each design can be seen in Table 5, below.

Table 5: Production Results with Modified Labor Hours

Design #	Production	# of Shifts	Hours/shift	Weeks/year	Labor Hours
1	50301.37	1	8	51	36720
2	50624.67	2	6	49	52920
3	75937.01	3	6	49	79380

5.2 Cost of Production

The costs of production for each of the proposed designs can be seen in Table 6, below. Each design requires 7 stations to be constructed, while designs 2 and 3 require two buffers to be added. The labor costs are determined from the number of hours in production as well as the number of operators on each station. To implement designs 2 and 3, no machine reconfiguration is required, since the layout is very similar with the difference being the addition of two buffers.

Table 6: Variable and Fixed Cost Breakdowns

	Cost	Design 1	Design 2	Design 3
Station	$100,000	7	7	7
Buffer	$10,000	0	2	2
Labor	$40 / hr	36720 hrs/yr	52920 hrs/yr	79380 hrs/yr
Overtime	$60 / hr	0 hrs/yr	0 hrs/yr	0 hrs/yr
	Total Cost	**$2,168,800**	**$2,836,800**	**$3,895,200**

5.3 1 Year and 5 Year Profit Forecast

For the first year of production, scenarios 1 and 2 will incur losses financially. After 5 years the profit should start to exceed the initial investment cost. Design 3 will be profitable from the first year. A profit analysis can be seen in Table 7, below. In order to calculate the profit margin after both 1 and 5 years, we assumed the following:

1. Overhead cost to make each car was $3,200.
2. Value of the material in each car was $10,000.
3. The Manufacturer Suggested Retail Price (MSRP) of the cars is $14,800 for Designs 1 and 2, and $14,480 for Design 3.
4. The cost of marketing the car was $70 million for the first two Designs, but greater for Design 3 because of the quantity needed to be sold.
5. Administration costs were $5.5 million per year, regardless of number of cars sold.
6. The cost to rent or own the factory was $3 million, regardless of cars sold.
7. All cars that were produced were sold.

Table 7: Design 3 will be profitable after 1 year, Designs 2 and 3 after 5 years

		Design 1	Design 2	Design 3
Overhead/car	-$3,200	50301.37	50624.67	75937.01
Material/car	-$10,000	50301.37	50624.67	75937.01
MSRP of car	$14,800*	50301.37	50624.67	74295.13
Marketing/yr	$ -70,000,000	1.00	1.00	1.20
Administration/yr	$ -5,500,000	1.00	1.00	1.10
Factory rental/yr	$ -3,000,000	1.00	1.00	1.00
Total profit for 1 year:		**$ -186,608.22**	**$ -337,326.66**	**$ 254,168.00**
Total profit for 5 years:		**$ 1,866,958.90**	**$ 1,193,366.68**	**$ 4,150,840.01**

* This price is decreased to $14,480 for Design 3, because of the quantity sold

6 CONCLUSIONS AND RECOMMENDATIONS

We were asked to create a process design for the assembly of a car that composed of 23 different tasks. Through the implementation of doing tasks in parallel at the same station, we were able to reduce the total number of stations to 7. Minimizing the number of stations for assembly had a significant impact on system reliability, given the reduced machine reliability of 95% for scenarios 2 and 3.

In order to meet the 50,000 unit demand per year for scenario 1, Design 1 can be implemented. This entails operating the plant for 51 weeks per year, with a single, 8 hour daily shift, using the production line scheme shown in Figure 3, on page 9. To meet the demand of scenarios 2 and 3 with their respective machine reliability of 95%, we altered the labor hours while keeping the same task assignment order. Specifically, Design 2 uses two 6 hour daily shifts for 49 weeks per year, under the production scheme shown in Figure 4, on page 9. Lastly, Design 3 uses three 6 hour daily shifts for 49 weeks per year, under the same production scheme.

6.1 Future State Map

Applying value stream mapping enables us to generate a Future State Map of the manufacturing process, as seen in Figure 5, below. The following explains the lean manufacturing principles that are implemented.

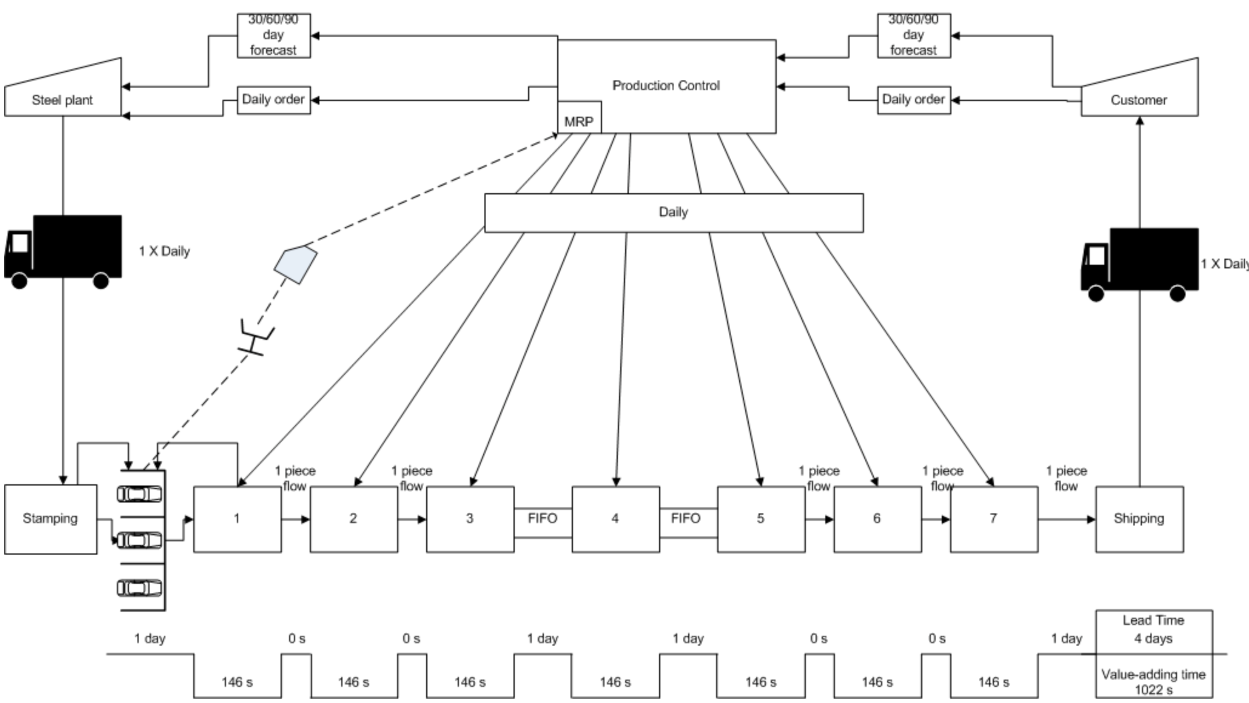

Figure 5: Future state mapping uses principles of lean manufacturing to reduce waste

Utilizing a supermarket after the stamping process, we will be able to set a "pull" system through the manufacturing line. 1 piece flow and first-in-first-out part flow are implemented between stations, increasing the system's predictability and reduces inventory. The customer also sends 30, 60 and 90 day forecasts, as well as daily orders to the production control, which in turn sends the aforementioned information to the steel plant. This enables just-in-time manufacturing which greatly reduces inventory. After each batch of orders produced, the supermarket will also send a production Kanban to the production control to have constant update of production information.

APPENDIX A - PAMS Analysis

We used PAMS to help verify that our system designs would function as we thought they would in our initial calculations.

Iterative Approach in PAMS System Design

We initially created a 7 station system using PAMS as shown below, in Figure 6. We gave each station the processing time shown in Table 4, on page 10. For Design 1 with 100% efficiency, we achieved our expected throughput as shown in Table 8, on page 15. For Designs 2 and 3, we assumed each station would break down twice per shift. In an attempt to give each station a 95% reliability, we gave each station a MTBF of 180 minutes and a MTTR of 9.5 minutes. This yields approximately 95% reliability since Reliability = MTBF / (MTBF + MTTR). However, in the PAMS simulation we were only achieving a breakdown rate of about 4%, yielding a 96% reliability.

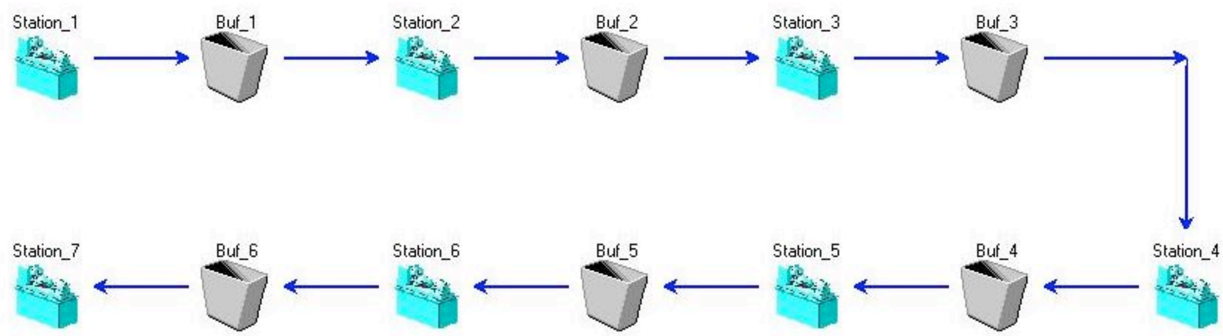

Figure 6: PAMS manufacturing system layout

In order to increase the breakdown rate to 5%, we increased the MTTR incrementally until we achieved a 5% breakdown rate in the PAMS simulation. However, once this goal was accomplished, we found that our throughput was below the target throughput.

In order to improve our throughput, we decided to add buffers. To determine the best place to add buffers, we ran a PAMS simulation which improved throughput given a buffer size of 5. It focused the buffer size at Buf_3 and Buf_4 as shown in Figure 6, above. Using the PAMS output regarding the best placement and size of buffers, we added one unit to Buf_3 and Buf_4 and left the other buffers at 0. By doing this, our target demand per year was met. The average work in progress (WIP) can be seen in Figure 7 below. Throughput for each design can be seen in Table 8, below.

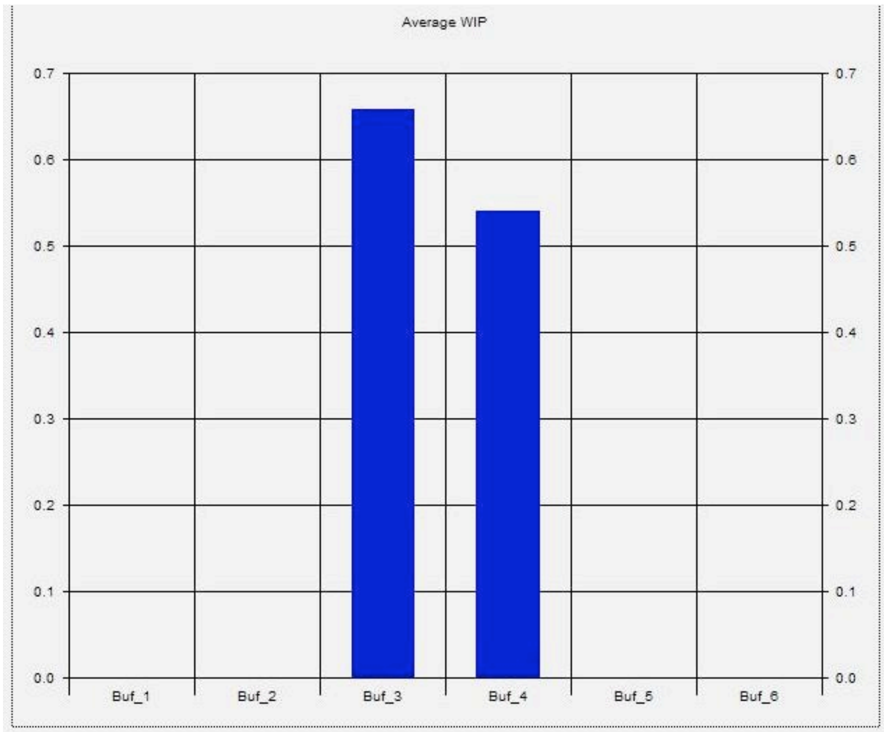

Figure 7: The average WIP in each station for Designs 2 and 3

Table 8: Throughputs using PAMS simulation for each design

	Design 1	**Design 2**	**Design 3**
Throughput (parts/min)	0.411	0.284	0.284
Shifts	1	2	3
Shift duration (min)	480	360	360
Days/week	5	5	5
Weeks/year	51	49	49
Cars/year	50306	50098	75146
Cars/day	197	204	307