Improving Productivity under Cost Constraints - A Discrete Simulation Case Study

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Abstract

The objective of this study is to perform system analysis of an automotive manufacturing facility, to show productivity losses and investigate options to improve process output within a strict budget. The base model mimicked an actual automotive manufacturing facility at one of the Big Three (Ford, General Motors, and Chrysler LLC) automotive facilities. Information was collected from the actual facility for 1201 stations within 3 different departments (body, paint, and general assembly) and utilized to build the simulation model. The base simulation model was able to perform identically to the actual system. The top system bottleneck stations were identified. The proposed simulation model considered two main scenarios that are within the given budget. The first option was able to improve the process throughput by 2.4 jobs per hour (JPH) and the second option was able to improve throughput by 0.4 JPH.

Keywords
Simulation, Manufacturing process, Productivity Improvement, Automotive industry

1 Introduction

The automotive assembly process is a complex system. The stages with in this system are identical across all automotive companies. Automotive manufacturing companies use similar machines and or technology, and in most case exactly the same processes and equipment suppliers. The assembly facility is divided into three shops and or departments: body shop, paint shop, and general assembly consecutively, as illustrated in Figure 1. Each shop is connected to the next through a conveyor some times indicated by manufacturers as the tunnel connection. Stage one: the body shop is responsible for building the vehicle shell which consists of the floor pan, quarter and side panels, door pillars and roof, illustrated in Figure 2. Prior to shipping to paint via tunnel, the vehicle body must undergo detailed inspection, repair, cleaning, drying. Thereafter, the automobile body shell is loaded to selection conveyors at the end of the body shop and based on the model mix it is loaded to the paint shop via tunnel (body to paint conveyor). Stage two: the paint shop is responsible for painting the shells of the vehicles and shipping it to final assembly, as illustrated in Figure 3. At the end of the paint shop vehicles are loaded to selection conveyors awaiting model mix selection to be loaded to the tunnel (paint to general assembly conveyor). Stage three: the general assembly, is divided into a three step process: *Trim department* which builds the interior of the vehicle, *chassis department* which builds the underbody system of the vehicles, and the final assembly department which is responsible for marrying the trim and chassis part in order to complete the vehicle build process, test and ship vehicles, as illustrated in Figure 4. While the painted shells arrive to the trim department from the paint shop, all other parts coming into the final assembly stage are shipped from the component and power train facilities.

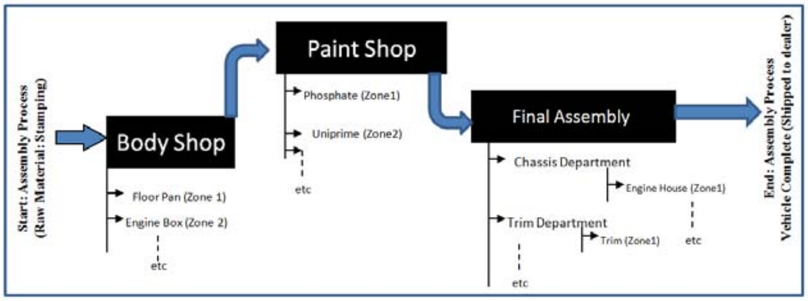

Figure 1: Assembly facility (plant) process flow

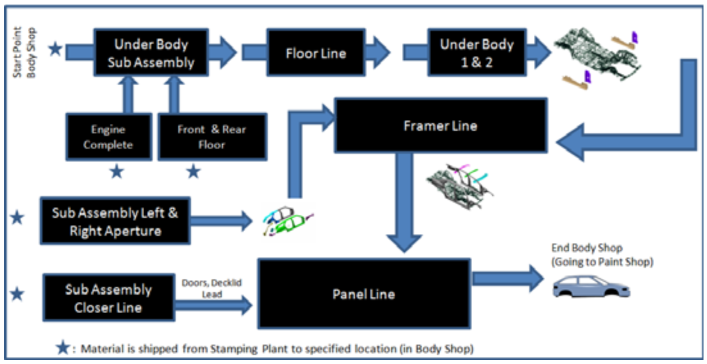

Figure 2: Body shop process flow

Automotive manufacturers will utilize different versions of the process explained above. The main differences among manufacturers are associated with body shop process flow and corresponding systems (Olsen and Cabadas, 2002). Some manufacturers produce different model on separate lines with in the same facility and some produce them on the same line.

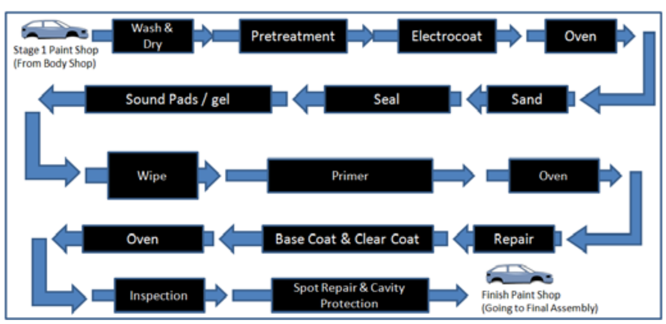

Figure 3: Paint shop process flow

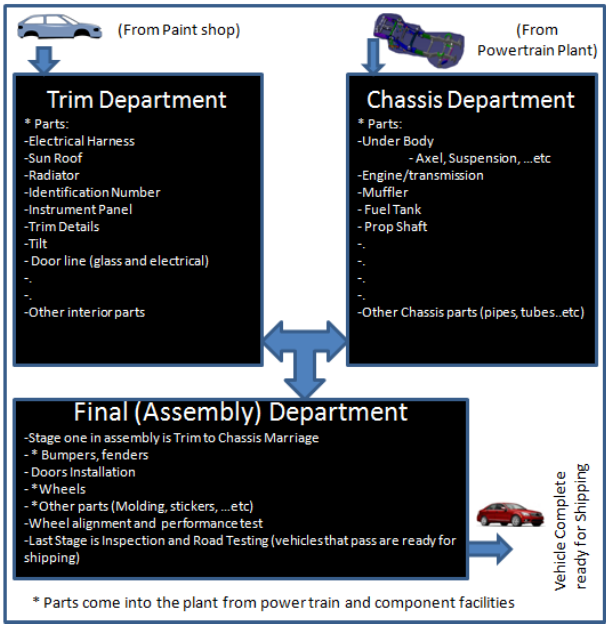

Figure 4: General assembly process flow

This research sponsoring company has been experiencing strong market competition and continuous customer demand fluctuation, mainly driven by the global economic problems. As customer demand change the company must adjust accordingly. The automotive assembly facility studied was originally designed at a capability of 71.5 jobs per hour (JPH) or a cycle time of 45sec/vehicle. Inefficiencies such as downtime, defects, scrap, lack of buffer, etc., are reducing the system actual productivity to an average of 63.7 JPH. The facility cost for each vehicle lost is about $9,800 (provided by the facility controller office), this number includes the following: labor and overhead cost required to make up for the lost capability and potential revenue. Providing solutions for resolving inefficiencies will provide cost savings and will support the task of improving system optimization and increase productivity. The facility studied objective is to identify the bottleneck process and identify alternatives to improve throughput within a certain cost limitation.

This paper presents a case study in which computer modeling and simulation was utilized in order to optimize a manufacturing systems design. The study presented in this paper was conducted at an automotive assembly facility that produces two different segments of vehicles (trucks and sport utility vehicle). The objective of the case study was to determine the top bottle necks with in the process and provide alternatives that allow the system to achieve maximum efficiency within budget constraints. The base model data was obtained from a current automotive assembly facility at one of the Big Three in Detroit, Michigan.

2 Background and research methodology

Computer simulation provides a cost effective tool for optimization of manufacturing system (Usubamatov *et al.* 2013). It allows manufacturers to design a model that is capable of mimicking an actual manufacturing process and provide the ability to conduct analysis, experiments and test "what if situation" with the model. The discrete event simulation is one of three different type of computer simulation (Helm *et al*. 2011). The other two types are:

1- Kinematic: used to study mechanical interference of equipment within systems such as work cells.
2- Continuous: used for modelling continuous manufacturing processes such as painting, molding, and manufacturing of glass.

Discrete event simulation is used to simulate systems that are stochastic and dynamic such as automotive assembly process. It allows users to analyse the "dynamic behaviour of manufacturing systems" and the interactions between its elements. The simulation methodology utilized in this research involved several tasks, as illustrated in Figure 5.

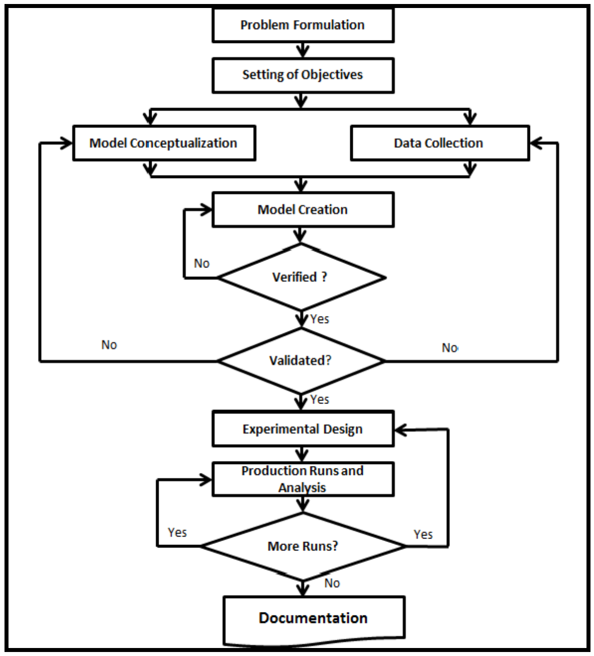

Figure 5: Simulation Methodology

The simulation methodology utilized in this model is not strictly sequential process. Several steps can be conducted in parallel. For example building the model can be conducted in parallel with data collection. The main challenge in building the assembly facility model presented in this research depends on the ability to identify system constraints and propose solutions within a certain budget constraint that is capable of improving overall system efficiency.

3 Process Data

The assembly process schematics are described previously in the introduction. Total number of stations with in the assembly system is 1201 divided between the three different departments within which there is manual and automated station, as illustrated in Table 1. The body shop and the paint department are constructed as two loop assembly carrier lines (i.e. the vehicles is constructed on a carrier that travels on a conveyor with in each department) and the delivery system between the two department loops is decoupled (palletized conveyor). The paint shop delivers vehicles to the trim department (general assembly) via palletized conveyor. The general assembly process is mainly a decoupled palletized loop conveyor. The body shop is the most automated department and the general assembly is the most labor intensive, illustrated in Table 1. At the end of the body shop and paint shop there is a staging area (selection bank). The body shop have two selection banks conveyors or lines with a capacity of 20 vehicles and for the paint shops there is three lines with a capacity of 8 vehicles each. These selection banks will ship vehicles to the next stage based on the model mix requirement, each of the selection banks can be dedicated to a product or can be mixed.

Table 1: Assembly facility departments number of stations manual and automatic

Department	Number of Stations	Number of Manual Stations	Number of Automatic Stations
Body Shop	415	31	384
Paint Shop	184	75	109
General Assembly			
Trim	280	268	12
Chassis	211	205	6
Final	111	103	8
Total	**1201**	**682**	**519**

The input data obtained from the facility for simulation was organized in an Excel sheet that fed the data to the simulation model created in Witness (simulation software). This Excel sheet includes variables such as mean time to repair (MTTR), mean time between failures (MTBF), scrap rate, cycle time (min, average, and max), etc, a sample to the data illustrated in Table 2.

Table 2: Sample of Data sheet used for the simulation model input

Station ID	Station Name	Manual/Auto	CT1	CT2	CT3	SCRP	MTBF	MTTR	Availability %
Department: Body Shop									
1	Assemble Dash (Sta DRP 3)	A	33.2	33.8	34.1	0.04	760	2.4	99.7%
12	Front Floor (Sta UB 6)	A	33.4	34.2	35.3	0.02	670	4.2	99.4%
21	Install shelf (Sta FP 11)	A	34.1	35.7	37.4	0.01	694	1.4	99.8%
26	Aperture Assembly (Sta AP6)	A	47.6	48.4	49.2	0.01	411	6.5	98.4%
32	Framing Process (Sta FRP 3)	A	48.1	48.5	49.3	0.02	312	7.4	97.7%
44	Install Deck lid (Sta FRP 14)	M	30.5	31.7	35.8	0.01	680	1.1	99.8%
Department: Paint Shop									
1	Apply Phosphate (Sta APP 4)	A	34.7	36.6	38.1	0.03	740	2.2	99.7%
11	Sand Process (Sta SPP 2)	A	41.6	42.2	43.5	0.01	655	6.4	99.0%
20	Seal Process (Sta PMS 1)	M	16.9	19.5	20.7	0	850	1.5	99.8%
26	Primer Flash (Sta PPF 7)	A	19.1	20.1	21.2	0.01	642	2.8	99.6%
32	Finesses Inspection	M	20.2	21.6	22.2	0.03	0	0	NA
Department: Final Assembly									
1	Trim body wire harness (Sta 12)	M	44.3	44.9	47.5	0.04	760	2.4	99.7%
22	Marriage Process (Sta 34)	M	45.0	47.4	48.9	0	550	12.2	97.8%
35	Chassis Install Brake fuel lines (Sta	M	43.9	44.7	46.4	0.01	640	2.1	99.7%
41	Door inspection (sat 21)	M	44.2	45.1	47.1	0	744	6.2	99.2%
53	Dynamic vehicle Test	M	44.8	44.8	48.7	0	632	3.2	99.5%
Cycle time is in sec CT1 =Minimum Cycle CT2 =Average Cycle and CT3 = Max cycle MTBF and MTTR in minutes, Availability = MTBF/(MTBF+MTTR) Scrap = number of parts per shift divided by 572 parts (Total production/shift) = % of scrap/shift									

4 Model conceptualization

The base model constructed was designed to mimic the current actual facility.

4.1 Simulation model approach

The modeled machines were also assigned to be in any one of the following conditions:

1- Down: due to unscheduled failure,
2- Blocked: due to station downstream being slower and no buffer space is available or due to machine downstream being down for repair,
3- Busy: due to work being conducted (work on a vehicle),
4- Starvation: due to part shortage or due to faster cycle time in comparison with machine upstream.

4.2 Simulation model assumptions

The model constructed assumed the following:

1. Infinite storage capacity at the end of the assembly line (i.e. after general assembly).
2. The system produced two different models. All station assumed similar cycle time except for 62 stations (35 in the body shop, 6 in paint shop, and 21 stations in the general assembly). The simulation model will use the cycle time different cycle times based on the model mix specified.
3. The facility report did not include information on downtime data for several machines and stations (74 stations), therefore data was obtained from the shop floor based on observation (over two month period), time to repair (TTR) and time between failures (TBF) was determined, and the best-suited distribution was established by station, Table 3 present a sample of the distributions by department and station name.
4. Interactions between all the elements of the system were modeled in order to verify the base or current body shop process. The basic elements of the model are labor, robots, body part components, conveyors, pallets, machines, technicians, and buffers. In order to measure the effectiveness and performance of the model created, the following output variables were utilized:
   - Jobs per hour (JPH) throughput;
   - Work in Process (WIP);
   - Total finished vehicles produced per day.

Table 3: Sample of data (conducted manually)

Department	Operation Name	Sample size	TBF distribution	TTR distribution	Standard deviation
Body Shop					
	AP 03 (*R & L)	625	Gamma	Lognormal	1.18
	FRP 06	544	Gamma	Lognormal	1.32
Paint Shop					
	PMS 1	220	Weibull	Gamma	1.02
	PMS 2	320	Gamma	Lognormal	1.71
General Assembly					
	MH 04	475	Gamma	Lognormal	1.44
	FLL 2	475	Gamma	Lognormal	1.44
* Right side and left side part					

5 Analysis and Proposed Process

In order to ensure that the base model created is accurate and it provides an identical representation of the actual system verification and validation was required.

5.1 Base model verification

The following steps were taken to ensure that the base model mimics the actual manufacturing and assembly process:

1- The components of the manufacturing and assembly process of the base model system were developed to mimic an actual assembly facility at one of the Big three plants.
2- The process of construction went through several stages, and each stage was checked separately for accuracy and process flow. The stages were: by station (separately), by zone (separately), by department (separately), by process (all components combined). Each stage station, zone, department was given its separate JPH counter to check for accuracy.
3- Microsoft Excel spread sheet with all input data was created to control simulation data feed.
4- Witness software debugging feature was utilized to check for system error. Simulation model created utilized animation in order to ensure proper process flow within the model.
5- Facility managers were utilized in order to verify the accuracy on model assumption and input data as well as the accuracy of the model representation of the actual system.

5.2 Base model validation

The data output generated by the simulation model was compared to the actual manufacturing facility data. Operating at 7.15 working hours per shift with two working shifts per day and 5 working days per week, the average simulated base model throughput was 63.4 JPH (based on 5 replication runs), as illustrated in Table 4.

Table 4: Base model output with 5 replications

Replication no.	Number Shipped (per Week/two shifts)	Throughput (JPH)
1	5025	62.8
2	5064	63.3
3	5097	63.7
4	5085	63.6
5	5079	63.4
Mean	5070	63.36
SD	27.8	0.4

Two sided t-test was utilized to compare the simulated model average throughput with the actual facility average throughput. The test verifies the null hypothesis $H_{\circ}$ that both averages are equal:

$$H_0 : \bar{X}(n) = \mu_0$$

$$H : \bar{X}(n) \neq \mu_0$$

The student's t distribution calculated value is determined using the following equation:

$$t_0 = \frac{(\bar{X}(n) - \mu)}{S/\sqrt{n}} \quad (1)$$

If $|t_0| < t_{\alpha/2,n-1}$, therefore H_0 cannot be rejected, and the model is valid. Where S is the standard deviation, $\bar{X}(n)$ is the model output variable average, μ is the real system average, t_0 is the calculated value of t at the specified distribution, n is the number of runs and $t_{\alpha/2,n-1}$ is the critical value of the student's t distribution at $(1-\alpha)$confidence level.

The actual facility throughput of the system based on the data obtained ranged between 62.4 and 66.1 JPH (facility data obtained between May 2012 and February 2013). The test statistics obtained was $t_0 = 1.6$. The critical t value at 95% confidence level is: $t_{0.975,4} = 2.78$. Since $|t_0| < t_{0.975,4}$ we cannot reject H_0 at 95% confidence level. This implies that the model created is valid. Actual facility system weekly throughput generated was compared with the Witness simulation model throughput, as illustrated in Figure 6. The throughput data comparison of actual and simulation "model" confirm that the simulation model is accurate and that it mimics the actual body shop system performance and throughput.

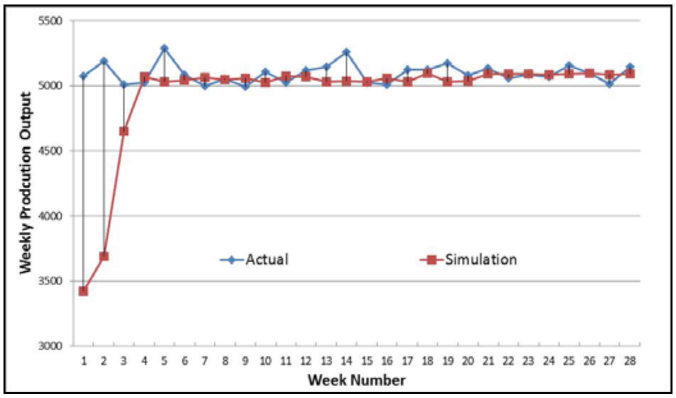

Figure 6: Actual Weekly output vs. Simulation model output

5.3 Base model analysis

The base model actual system throughput average was 63.4 JPH. The system was purchased to operate at 71; therefore the system overall efficiency is 89%. The actual facility data report distribute the losses as follow: 7.8% for starvation and blockage 1.3% scrap and 1.9 % other (i.e. maintenance related issues, production late starts, etc.). The data obtained from the facility by department indicate that the body shop efficiency is the lowest at 78%, as illustrated in Table 5. The top 3 system bottlenecks by departments (as a standalone station) are:

1- Number 1 bottle neck station is the Body shop Framing system station number FRP3 at an average cycle time of 48.5sec
2- Number 2 bottleneck station is the Body shop Aperture station AP6 at an average cycle time of 48.4 sec. The designed cycle time for the body shop system is 37.6 sec.
3- Number 3 bottleneck station is the General Assembly Marriage process station number 34 with an average cycle time of 47.4 sec. This process is a manual station that involves 8 operators and their task is to locate and assembly 16 studs (2 studs per person) that join the frame to the body of the vehicles (SUV and Trucks). The operator is required to look at proper whole alignment between the two vehicle parts and insert the bolt through. This station was monitored for three weeks on both shifts and the following was observed:
   - The average cycle time for the first two hours both shifts is around 45.2 sec.
   - The average cycle time in the last two hours of the shift is around 48.5 sec.
   - Employees interviewed indicate that the job is complicated and require better tools to support the task required.

Table 5: Department JPH Capability vs. Actual

Department	Capability JPH	Actual JPH	Efficiency JPH
Body Shop	85.6	66.4	78%
Paint Shop	77.5	65.2	84%
General Assembly	71.5	63.7	89%

5.4 Results and Analysis

Driven by the cost constraints two scenarios were considered. The first scenario focused on alternatives or solutions for the three top bottlenecks and the second scenario focused on optimal model mix.

Scenario one:

Driven by the starvation data, a significant improvement in the overall system throughput is expected through body shop early start strategy. Since the top two bottleneck stations are in the early stages of the manufacturing process (i.e. Body shop department) and their average cycle time is higher than any other station in any department, in addition implementing any equipment changes to reduce the cycle time in the top two bottleneck station is costly, alternatives such as early shift start were considered. This strategy requires starting the body shop department shifts one hour before paint and general assembly (maintaining the 7.15 working hours per shift for body shop). This will eliminate the starvation problem of the tunnel between the body shop and paint shop department.

The third bottleneck station impact can be reduced significantly by improving employee efficiency through job rotation. Utilizing the above two scenarios (i.e. early body shop start and team rotation on the marriage station) the new model was simulated for 5,000 continuous production hours. The results indicated the following:

- Early start of the first shift improved the system overall efficiency from 89% to 90.8% (an increase of 1.3 JPH).
- The implementation of Job rotation improved (assuming the early body shop start) the efficiency from 90.8% to 92.6%. The JPH will improve from 64.4 to 66 JPH.

The simulation result indicates that the implementation of the two recommendations above will result in a 2.6 JPH improvement. For calculating the return on investment (ROI) associated with the proposed scenarios the following information was utilized.

- The throughput improvement was 2.6 JPH.
- Working days per year 245 with 2 operating shifts per day and 7.15 working hours per shift, the total annual production will increase by 9,109 vehicles annually (at 66 JPH).
- Net profit per vehicle is about $9,000.
- The ROI equation (1) utilized:

$$ROI = \frac{CS - C}{C} \qquad (2)$$

Where: C is the cost of the design change during product life cycle and CS is the cost saving that is driven by the new process during product life cycle. All data utilized for the calculation of ROI was verified by the facility comptroller.

CS = $9,000 per vehicle x 9,109 vehicles per year = $ 81,981,000 million

C = $ 4.2 million (shift start one hour early before other department start time include 65 employees) + $1.8 million (pay for training employees of job rotation include 210 employee in the increasing marriage station area) + $1.8 million other cost (indirect labor and overhead cost) = $ 7.8 million/annually. ROI = ($82-$7.8)/$7.8 = 951%.

Scenario 2:

The original model mix base on the current system is running at 48% Trucks and 52% SUV's. In order to investigate the optimal model mix 8 different combinations or model mixes were tested at 8 replications each. Based on the results obtained the highest throughput was achieved at 50% / 50% mix, as illustrated in Table 6.

Table 6: Model mix results

Model Mix	Truck = 48% SUV=52%		Truck = 50% SUV=50%		Truck = 52% SUV=48%	
	Jobs/hr	Jobs/day (2 shifts)	Jobs/hr	Jobs/day (2 shifts)	Jobs/hr	Jobs/day (2 shifts)
Average in 8 Replications	63.4	1014.4	63.8	1020	63.5	1016
95% Confidence Interval	(63.1, 64.6)	(1010, 1034)	(62.9, 64.8)	(1006, 1036)	(63.1, 64.2)	(1009.6, 1027.2)
Gross	71.5	1144	71.5	1144	71.5	1144
Uptime	88.7%	88.7%	89.2%	89.2%	88.8%	88.8%

Based on the simulation model mix created there are several issues that need to be considered in regards to batch size, efficiency and selection banks for each department:

1- Body shop selection banks must be dedicated. At the end of the body shop there are two selection banks that can hold 20 vehicles each and both feed the tunnel conveyor that feeds the paint shop. Due to cycle time variance between the two different products produce (SUV and Trucks) and in order to insure high efficient work load, the batch size must run with in the following limits: SUV (lower limit 4 and upper limits at 12), Trucks (lower limit 15 and upper limits at 31.5) others wise 12 manual stations will operate above line cycle time.

2- The paint shop has 3 selection bank lines; each line can hold a max of 8 vehicles. Two lines must be dedicated (one for each product) and one can be mixed. The batches with in the paint shop can follow the same mix criteria as the body shop. But, if the batch size runs at a high mix for trucks (any batch in access of 22 trucks) two stations in the paint booth (with in paint shop) will run above cycle time and require 1 additional technician to stay with in cycle.

The cost improvement of running the 50% mix is = $1.3 million/annually. The main disadvantage of scenario two is that it assumes that the demand for 50% / 50% demand exist. In addition increasing the model mix of SUV's require additional manpower in the body shop and general assembly.

6 Conclusion

The two main scenarios considered provided a significant improvement in process efficiency. Scenario one that considered changing the shift start time for the body shop improved throughput by 9,109 vehicles annually ($7.4 million) and second scenario that focused on optimizing the model mix improved throughput by 1,401 vehicles annually ($1.3 million). In both cases the system performance for the manufacturing facility is expected to improve within the budget constraint given.

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Biography

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