

# **Impact of Flexibility on Operational Performance: A Case from US Automotive Manufacturing Facilities**

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## **Abstract**

Manufacturing activities play a major role in stimulating economic affluence. Increasing manufacturing competitiveness demand greater focus on developing new and advanced manufacturing capabilities. Since early 21<sup>st</sup> century, Flexible Manufacturing Systems (FMS) philosophy has become one of the main pillars of competitiveness criterion for the manufacturing companies worldwide. Little research has investigated the impact of FMS on operational performance metrics. The following paper presents a discrete simulation study which investigates the contribution of certain FMS dimensions in supporting internal organizational competitiveness (i.e. cost, quality, productivity, etc). This study took place at one of the Big Three (Ford, Chrysler, GM) manufacturing plants in North America that produce two types of vehicles (Trucks and SUV's). A model was developed aiming at emulating the actual manufacturing process within that assembly facility and then, it was altered through implementing specific FMS dimensions (labor, machine, and material handling) at bottleneck stations. Three different proposals were considered. The analyses reveal that the proposed implementation of the three types of flexibility will lead to 12% improvement in Jobs per hour (JPH), 12.6 % enhancement in quality-DRL (direct run loss) and 17% increase in Return on Investment (ROI).

## **Keywords**

Automotive manufacturing, Simulation, Process modeling and engineering application, Flexible manufacturing systems, Operations Management

## 1. Introduction

Economic turbulence during early 21<sup>st</sup> century forced US manufacturing companies to drastically change the way they conducted business. The US Bureau of Statistics indicates that the US manufacturing employment dropped from 19 million in 1980 to around 13 million in 2019 (BLS 2020). This decrease is mainly related to the intense competition from low-wage foreign manufacturers and productivity growth. The 2016 U.S. government council on improving manufacturing competitiveness report indicates that one of the main drivers for improving competitiveness depends on the ability of manufacturers to adopt new philosophies and innovations (Giffi *et al.* 2016). The latter, when accurately implemented while using the pertinent tools and techniques, would help organizations in achieving global competitiveness, sustainability and improvement of the overall performance (Table 1).

**Table 1:** Competitiveness and performance as improved by new philosophies, innovations and techniques

Philosophy/Innovation/Technique	Organizational implications	References
<ul style="list-style-type: none"> <li>- <b>Managerial discretion</b></li> <li>- <b>Strategic planning</b></li> <li>- <b>Innovative capabilities</b></li> <li>- <b>Sharing economy</b></li> <li>- <b>Management decision</b> (buffer/batch sizes, bottleneck stations alternatives)</li> <li>- <b>Discrete event modeling simulation</b></li> </ul>	<ul style="list-style-type: none"> <li>- Increased competitiveness on national-level</li> <li>- Enhanced performance</li> <li>- Improved process efficiency/productivity</li> </ul>	(Haj Youssef <i>et al.</i> 2019) (Fahed-Sreih and El-Kassar 2017) (Maalouf <i>et al.</i> 2020) (El-Khalil 2014) (El-Khalil 2015) (El-Khalil and Darwish 2019) (Haddad <i>et al.</i> 2016)
<b>Lean Management</b>	<ul style="list-style-type: none"> <li>- Improved operational performance metrics (quality, customer satisfaction, cost, productivity, lead time, efficiency, employee safety and moral)</li> <li>- Process standardization</li> </ul>	(EL-Khalil 2018) (EL-Khalil <i>et al.</i> 2020) (El-Khalil 2020) (Haddad <i>et al.</i> 2016)
<b>Flexibility</b>	<ul style="list-style-type: none"> <li>- Improved operational performance metrics</li> <li>- Achieving global competitiveness</li> </ul>	(Dubey and Gunasekaran 2015) (EL-Khalil 2018) (Elmoselhy 2013) (El-Khalil and Darwish 2019) (Vinodh <i>et al.</i> 2010)
<b>Sustainability</b>	<ul style="list-style-type: none"> <li>- Enhancement of sustainable performance</li> <li>- Sustainable capabilities</li> </ul>	(Singh and El-Kassar 2019)
<b>Agility</b>	<ul style="list-style-type: none"> <li>- Sustainable development</li> <li>- Reduction of time and cost</li> <li>- Higher efficiency and competitiveness</li> <li>- Strengthening firm performance</li> </ul>	(Tarhini <i>et al.</i> 2018) (Chan <i>et al.</i> 2017) (Dubey and Gunasekaran 2015) (Ramesh and Devadasan 2007)
<b>Resilience</b>	<ul style="list-style-type: none"> <li>- Better operational performance outcomes</li> <li>- Higher efficiency</li> <li>- Improvement of customer responsiveness</li> </ul>	(Lotfi and Saghiri 2018)

To improve their competitiveness, the Big Three (Ford, General Motors, Chrysler LLC) automotive companies have been investing heavily in new and creative philosophies to improve lead time, quality, cost, and flexibility (Macaluso 2014, Camacho-Miñano *et al.* 2013, Vinodh and Prasanna 2011). Flexibility also known as Flexible Manufacturing Systems (FMS) is a philosophy that is designed to absorb problems with minimum or no impact on the overall process output (Slack 2005, Chang 2012, Narain *et al.* 2000, Pakdil and Leonard 2017, Vokurka and O’Leary-Kelly 2000, Yu *et al.* 2005; Zhang *et al.* 2014. Sethi and Sethi (1990), Nahavandi (2013) and Lyngso (2014) indicate that flexibility is a multidimensional and complex concept but if implemented correctly can lead to maximization of investment efficiency and significant improvement in operational metrics. Sohal and Egglestone (1994), Narain *et al.* (2000), Liker (2004) and EL-Khalil (2009) indicate that FMS philosophy includes 15 different types of flexibilities. According to EL-Khalil (2013) and Lyngso (2014), those types of flexibilities are divided into three broad categories. Each category addresses a different problem and is designed to focus on three different classifications (i.e. operational, tactical and strategic), as illustrated in Table 2. Each type in the FMS philosophy serves a specific objective, as shown in Table 3.

Sohal (1996), Slack *et al.* (2004), Slack (2005) and Tamayo-Torres *et al.* (2014) indicate that the two primary variables leading to maximization of investment efficiency and operational metrics in manufacturing systems are improved planning and design. EL-Khalil (2013) illustrates that those variables can be obtained through understanding systems objectives and ensuring that every element within the system is optimized to its highest efficiency.

**Table 2:** Flexibility types by category and focus based on (Narain *et al.* 2000)

Level	Necessary Flexibility	Sufficient Flexibility	Competitive Flexibility
<b>Constituent Elements</b>	1- Machine 2- Product 3- Labor 4- Material Handling 5- Routing 6- Volume 7- Automation	1- Process 2- Operations 3- Program 4- Material	1- Production 2- Expansion 3- Market 4- New Design
<b>Class of Problems Addressed</b>	Class A	Class B	Class C
<b>Focus</b>	Operational	Tactical	Strategic

**Table 3:** The Flexibility type and definition

<b>MANUFACTURING FLEXIBILITY: FIFTEEN INDEPENDENT TYPES</b>		
Manufacturing Flexibility (Vokurka and O’Leary-Kelly 2000)		
#	Flexibility Type	Definition
1	Machine	Refers to the ability of the system to switch operation without requiring major effort
2	Material Handling	The ability to move different part types efficiently for proper positioning and processing
3	Operation	The ability of the part to be produced in different ways with alternative process plans
4	Automation	The capability of the automation to perform different operation and or add operation
5	Labor	The ability to change number of workers, tasks performed by workers, and responsibility
6	Process	Relates to the set of part types that the system can produce without major set-up
7	Routing	The ability to produce a part by alternative routes
8	Product	The ease with which new parts can be added or substituted for the existing parts
9	New Design	The ease by which the system produces a product with different shapes and/or dimensions
10	Delivery	The ease to transporting material to the manufacturing facility, as well as to operation within the facility
11	Volume	The ability to be operated profitably at different product overall output levels
12	Expansion	The ease with which the capacity and capability can be increased when needed
13	Program	The ability of the system to run virtually untended for a long enough period
14	Production	The universe of part types that the FMS can produce
15	Market	The ease with which the manufacturing system can adapt to a changing market environment

Driven by the complexity of the vehicle manufacturing and assembly process and the optimization problem through FMS implementation, discrete event simulation approach was utilized in this paper. This approach is a total system approach. It’s a method that studies the dynamic and stochastic behaviors of the system, individual zones, sub-assemblies, and interactions between the different elements of each.

The sponsoring facility has been experiencing intense competition mainly driven by customer demand fluctuation. As the demand changes and is coupled to a certain level of uncertainty (Bandaly *et al.* 2018), the facility needs to adjust its operations in-order to produce different types of vehicles. This adjustment requires the implementation of FMS at several bottleneck stations which were identified after an initial simulation assessment and reviewed by senior managers at the studied facility. The sponsoring company identified the need to implement three types of flexibilities: machine, labor, and material handling. The facility currently produces two types of vehicles at a capability of 78 Jobs Per Hour (JPH). External and internal variables such as downtime, changeovers, defective parts, scrap and other quality related issues caused the actual throughput to deteriorate to 61.3JPH (average for 2017-2019). The facility cost for each vehicle lost is \$9,450 (given by the facility finance department). After meeting the senior managers at the studied facility, the following are some of the issues at concerns identified:

- 1- Collect detailed information on labor, stations, departments, zones, conveyors, repair process, scrap, reject rate, machine cycle time, downtime, ... etc to mimic exactly the current assembly process,
- 2- Identify major bottleneck stations throughout the facility to confirm their predictions, review and get concurrence from facility managers,
- 3- Benchmark other manufacturing companies to identify potential solutions. Obtain data through benchmarking in order to utilize it for the simulation to identify improvements.
- 4- Review finding with facility managers and run different simulation scenarios,
- 5- Identify best alternative based on optimal simulation model achieved.

The following paper presents a case study where modeling and simulation were utilized to study a manufacturing system for vehicle assembly. The objective of the case study is to determine the impact of FMS philosophy implementation on maximization of efficiency. The base assembly model data was obtained from one of the facilities currently in operation at the Original Equipment Manufacturer (OEM) sponsoring company. This facility is located in Detroit, Michigan. Benchmarking visit was conducted to several facilities that have been investing in FMS implementation for the past 5-10 years. Those facilities were identified by managers from the OEM companies (domestic and foreign) contacted for this study. Benchmarking visits were conducted to local companies such as GM, Ford, and Chrysler in addition to foreign manufacturing assembly facilities at companies such as Toyota, Honda and Nissan.

## 2. The Case Study

The sponsoring manufacturing company has been pushing its facilities to implement new and innovative processes/philosophies to reduce cost and improve operational metrics. The departments within this organization are asked to optimize the assembly process to its highest efficiency.

The studied manufacturing and assembly plant produce two types of vehicles (Trucks and SUV's). The assembly facility is divided into three main departments/shops (Trim, Chassis and, Final) within each there are several zones, as illustrated in Figure 1. The facility is operating at two shifts per day with 8.9 hrs. per shift with 0.9 hrs., allowance (24 min breaks + 24 min lunch + 6 min team meeting) for a total of 8 hrs. of actual operating time. The assembly processes capability is designed to operate at 78 JPH for Final Assembly, 89 JPH for Paint Shop (12% over speed), and 94 JPH for Body Shop (20% over speed rate). The current customer demand requires the facility to operate at 67 JPH in comparison to an actual throughput of 61.5 JPH. Reasons for inefficiencies are due to several variables such as downtime, changeovers, scrap, employee late start and early finish, and absenteeism (Srouf *et al.* 2017).

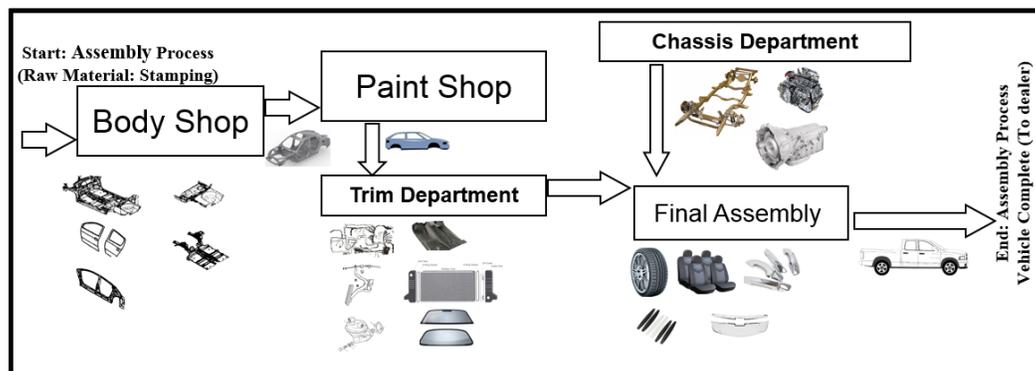


Figure 1: Assembly Process Flow

This research presents a case study that applied FMS to consider its impact on improving manufacturing performance utilizing discrete modeling and simulation. The more specific objective of this case study is to determine the effects of implementing production, labor, and material handling flexibility to the top bottleneck stations on maximizing investment cost and systems efficiency. The original simulation model was designed to mimic a current facility at one of the Big Three assembly plants in Detroit, Michigan. All data and information utilized to study alternatives to the existing system that is presented throughout this research (for local and domestic manufacturers) were obtained through a benchmarking visits conducted between 2017-2019 to domestic and foreign automotive facilities in North America (US, Mexico, and Canada). The processes emulated from benchmarked facilities were altered to fit sponsored facility requirements. Some of the alterations are confidential information (i.e. will not be presented in this paper). All

alterations recommended (confidential or not) went through a detailed review with sponsored facility managers to confirm feasibility.

### 3. The manufacturing and assembly process

As previously stated, the studied facility currently produces two different vehicle platforms/segments (Trucks and SUV's). The production mix of models is determined by the material handling department base on a schedule that optimizes throughput to its highest level. The facility utilizes 1189 employees per shift, 922 non-skilled and 267 skilled. Each shop contains different amount of manual and automated stations, as illustrated in Table 4.

**Table 4:** Number of stations (Robots, Auto, and Manual stations)

Shop	Number of Robots	Automated (non-robotic)	Manual Stations
Body	764	14	55
Paint	84	16	176
Final			
Trim		14	346
Chases		8	240
Final		12	105
<b>Total</b>	<b>848</b>	<b>64</b>	<b>922</b>

The original model was created to reflect the current model mix that was running at 56% Trucks and 44% SUV's. The system overall throughput average for the past three years (Nov 2017 to Aug 2019) is 61.3 JPH. Each station was studied separately to determine variables such as; cycle time, Mean Time To Repair (MTTR), Mean Time Between Failures (MTBF), scrap rate, stand-alone capabilities, inefficiency drivers, and others. The top two bottlenecks in each shop were identified, as shown in Table 5. Top three quality (problem) stations in each department/shop was identified.

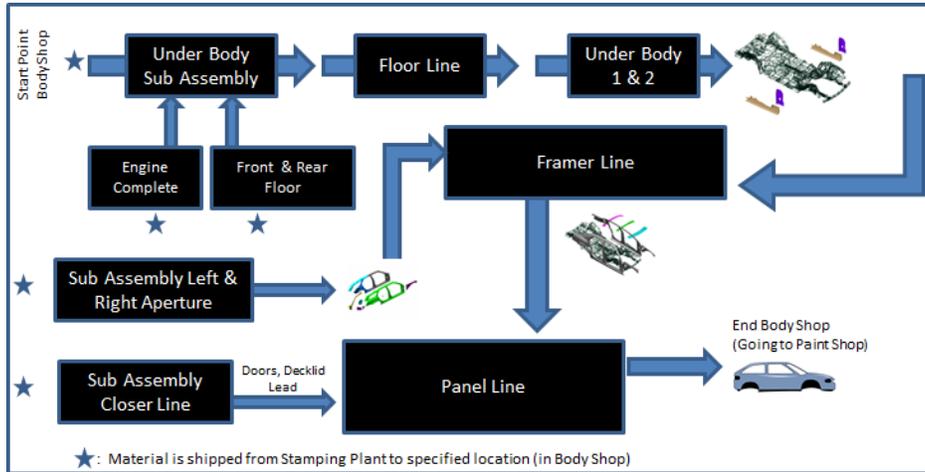
**Table 5:** Top two bottlenecks by shop and zone

Department		Description	JPH Capability	JPH Actual	JPH Losses	Bottleneck Ranking	Main problem/cause
<b>Body</b>							
	Zone 6	Framing	94	61.5	32.5	1	Changeover Frequency Driving slow cycle and Robot Downtime (67.2%) + Material Shortage (19.8%)
	Zone 3	Aperture R/L	94	62.8	31.2	2	
<b>Paint</b>							
	Zone 5,6	Sand/Seal	89	65.2	23.8	6	Slow Robot Cycle
	Zone 8,7	Wipe/Primer	89	66.4	22.6	7	Labor + Equipment
<b>Final</b>							
Trim	Zone 14.1-14.8	Wire Harness, ... Fixed Glass	78	65.4	12.6	5	Down Time due to labor (40%) and material shortage (25%) (Top issue is late start/early finish)
Final	Zone 1	Marriage	78	63.6	14.4	3	Complexity (manual station) job require high level of finesse (slow cycle)
Chassis	Zone 18.1-18.5	Install Brake..., Prop Shaft Install	78	64.3	13.7	4	Down Time due to labor (34%) & material shortage (21%) (Top issue is late start/early finish)

#### 3.1 The Body Shop

The body shop is the first stage in the manufacturing and assembly process. The body shell of the vehicles gets welded together about 4900 spot welds per vehicle is applied (utilizing 764 robots). The process is divided into several stages, as illustrated in Figure 2. Material/parts are delivered from stamping facility to the body shop by forklifts. Stamping

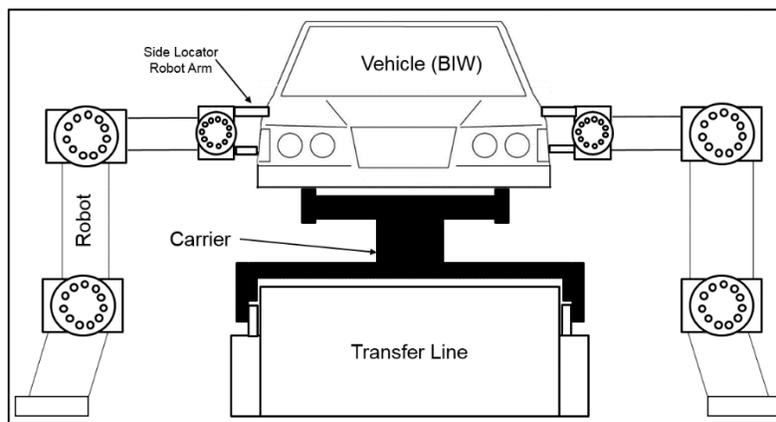
facility is in proximity from the assembly facility. The Body Shop is highly automated (856 Robots) with the lowest amount of the labor force (10%) out of the three shops. The body shop system was designed with a capability of 94 JPH. The actual shop throughput is 61.5 JPH due to several bottleneck issues. The main bottlenecks are the Framers Line (station # 4 - Framing aperture to pan) followed by the aperture Sub Assembly L/R. The number one quality problem station was identified as the net form and pierce station (32%) followed by the framing station #4 (25% of quality problems).



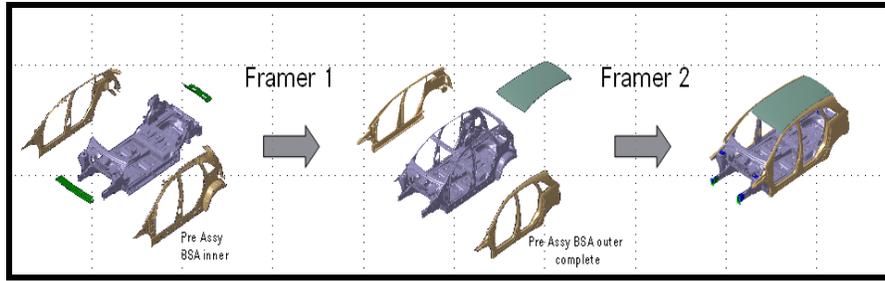
**Figure 2 :** Body shop assembly process stages

The framer line station # 4 welds the two side apertures to the floor pan, illustrated in Figure 3. The issues contributing to this inefficiency are due to the following:

- 1- The side framer/locator arm size. The locator arm size prevents/restricts welding robots' access (limits welding to particular locations). This process runs at an average of 61.54 JPH (as a separate /stand-alone shop). The principal contributor to low throughput is high cycle time (85%) and machine downtime due to changeovers (15%). The time taken to locate and dislocate arms to aperture is consuming 41% of the process cycle time.
- 2- The framing process of welding the Body Side Aperture (BSA) inner and outer to a floor-pan is done in two separate stages, as illustrated in Figure 4. This process is running at 62.8 JPH. The robots utilized by this process have the highest downtime of all body shop robots (due to complexity and mix). This stage runs at 62.8 JPH. Inefficiency is driven by; downtime (70%), material handling (16%), defects (4%), and others (10%).



**Figure 3:** Framers Line Station #4

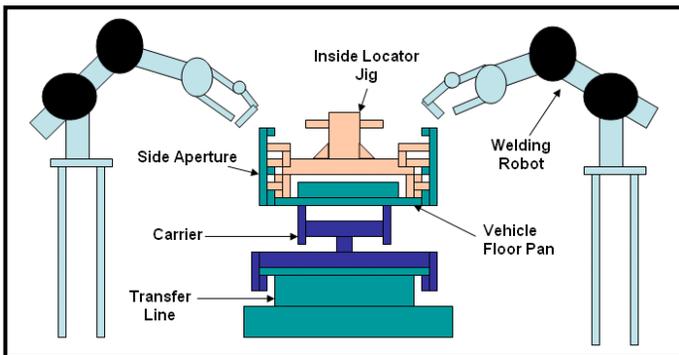


**Figure 4:** Current Framing process of Body Side Aperture (BSA)

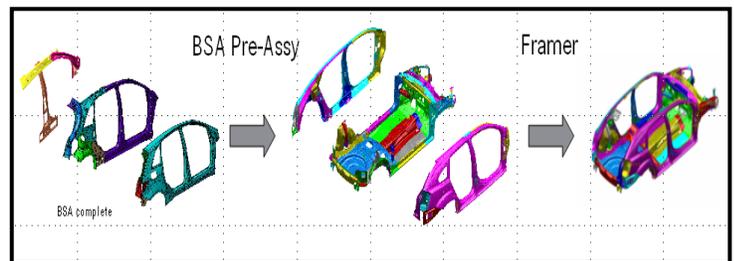
The implementation of production flexibility will provide a feasible alternative to resolve this issue. Automotive facilities such as Toyota Manufacturing in Georgetown, Kentucky, Ford Rouge Assembly in Dearborn, Michigan, and GM Lansing Grand River Assembly in Lansing, Michigan, utilize an FMS “GBL” (Global Body Line) that uses an inside locator jig (illustrated in Figure 5) which allows the system to:

- Produce a wide range of parts (vehicle platforms). Have the ability to produce all five different vehicle segments (i.e. Trucks, vans, sedan, SUV, crossover).
- Eliminate the use of the robot arm locator (that was illustrated in Figure 3) and utilize an alternative system, as shown in Figure 6.
- Remove significant number of robots (40%) based on framing the aperture inner and outer as a sub-assembly before attaching them to a floor pan.
- Resolve the number one quality problem station “Net form and pierce”. Several alternatives were studied with the help of suppliers. For example, eliminating net form and pierce process and replacing it with PLP (primary locating point) process. That will remove more than 12 robots but will add to the cost of carriers. In PLP carriers will play the role of locating parts of the body shell and their displacements from each other based on specifications.

Material handling issues in the body shop can be resolved by allocating certain parts delivery (with highest down time) to Automated Guided Vehicles (AGV’s). TMMK facility utilizes such process to deliver parts from stamping plant to automatic body shop feeding station (with no labor involvement at 99.7 % efficiency). The AGV process can work for all midsize and large parts throughout the facility.



**Figure 5:** FMS inside locator Jig (El-Khalil 2009)



**Figure 6:** Body Side Aperture (BSA) on stage process

### 3.2 The Paint Shop

In the paint shop, the vehicle shell that was produced at the body shop gets painted. The shop is composed of several stages, as illustrated in Figure 7. This shop is designed to operate at a capability of 89 JPH. The actual throughput is 65.2 JPH (as a separate /stand-alone shop). The bottleneck zones (seal, sand, wipe, and primer) are related to the inefficiency losses due to the following issues:

- Down Time (72.5%). The downtime issue is broken down as follows: Technician late starts & early finish (58%), equipment (24.5%), material handling (11%), and others (6.5%).
- Scrap (11.8%).

- Defects (8.4%).
- Buffers (4%).
- Other (3.3%).

The paint shop process overall throughput is capable of providing the customer requirement numbers of 65JPH. Resolving the body shop bottlenecks (listed above and in Table 4) can be achieved through the implementation of flexible workforce (and team concept with knowledge sharing (Kiomjian *et al.* 2020). Implementing labor flexibility will lead to the ability to change employee responsibility, task, and number of technicians required without impacting system overall throughput. Benchmarked facilities utilizing labor flexibility indicates higher quality improvements (in paint shop) that average 36% in comparison to sponsored facility.

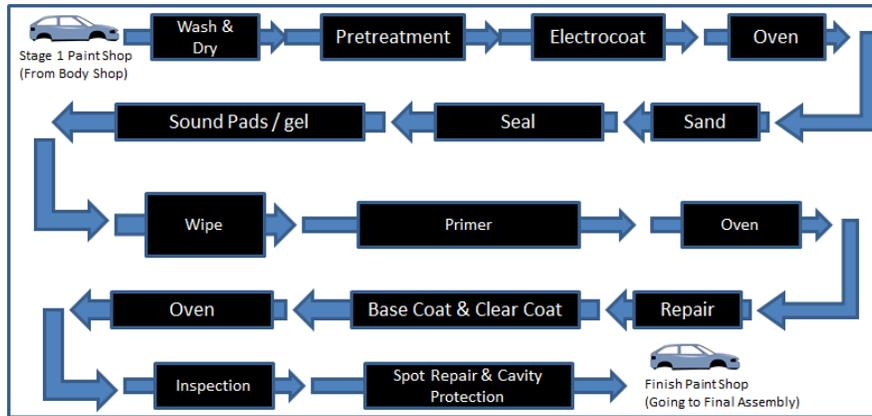


Figure 7: Paint shop processing sequence/stages

### 3.3 Final Assembly Shop

The final assembly shop/area is divided into three main departments, trim, chassis, and final (El-Khalil and El-Kassar 2016). The three units are designed with a capability of 78 JPH. The Final assembly process is the most labor intensive, as illustrated in Table 4. Trim and Chassis departments feed into the final where the bottom half of the vehicle is married to the top. The term married is used to indicate the process of attaching the vehicle shell (for SUV's and Trucks) to chassis (chassis includes components such as engine, transmission, and prop-shaft). The number one bottleneck in this shop is the marriage station (final department) at 63.6 JPH. Followed by the Chassis zone 18 (Brakes and Shaft Install) at 64.3 JPH and Trim area 14 (Wires and Glass Install) at 65.4 JPH. The following are the main drivers of inefficiencies:

- Marriage station (final department) efficiency losses are 45% over-cycle due to operator misalignment, improper installation, and misfeed. The operators (6 operators) have to use manual aligning eight pins to insure that the shell drops on chassis at proper locations. The operation needs highly skilled operators. This operation is semi- automated. 20.5% down due to late start operation (operators not at the station when line start). 9% due to rejection (parts), 6% scrap, 11% maintenance, and 8.5% others.
- Trim and Chassis departments' efficiency losses are 62.8 % Starvation and blockage (of which 85% due to operator late start or early finish), 14.3% maintenance, 13.6 % scrap, and 9.3% materials.

Several alternatives are available to resolve the above issues. The marriage station can utilize a fully automated system such as the one used at the Nissan Canton, Mississippi Facility (produce: Titan and Frontier). This system is running at 95% uptime and only one operator for quality inspection. Toyota San Antonio, Texas (TMMTX) also utilizes an automated marriage station with 96.5% uptime (automated control). Resolving the problem of downtime driven by the late start and early finish require the implementation of labor flexibility. The following are the concepts considered as alternatives:

To resolve this issue between shifts we will:

- Create teams of five members that will rotate to different areas within the same zone (team concept). This will provide all employees in the same zone the experience to operate all stations.
- Establish a tag policy (also known as pass the baton policy). An employee from the first shift will not leave work at the end of the shift unless the worker from the other shift is physically available to take over (tag). We will utilize the baton concept. The production will not stop at the end of the first shift. The operator of the shift will hand the work to the operator for the next shift (similar to the 4x400 baton race). One of the

main problems with this concept is that the employee who will work over his eight working hours due to second shift employee being late will get paid time and a half for every hour of overtime.

- To resolve this issue at the start of the shift, we utilize:
- Team leaders to operate the station until employee shows to the station.
- Inspectors to be trained in case support is required.
- Utilize part timer employee (based on historical data to forecast the number required).

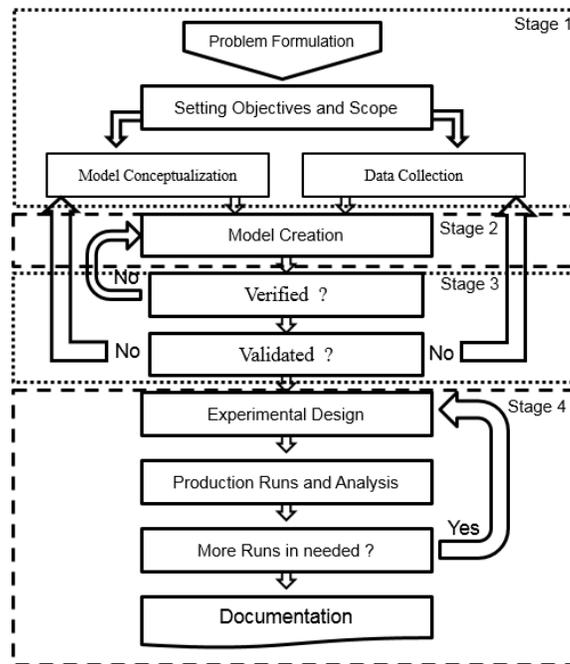
Those concepts are new to the current facility. To ensure their feasibility they were tested in particular areas (i.e. decoupled areas) such as door line, engine dressing line, axle dressing line, aperture sub-assembly, and paint booth.

#### 4. The Modeling and Simulation Study

Traditionally, manufacturers relied on trial and error, actual system testing, prototypes, and other means to analyze or proof their systems capability (Greasley 2005). The traditional process was very costly, inefficient and in most cases ineffective (Löhdorf *et al.* 2014). The advancement of technology and computers simulation provided an economical and efficient mean for optimization (Melouk *et al.* 2013). The manufacturing process is stochastic and dynamic in nature, and changes within the process occur as a variable of time or random (Jain *et al.* 2013, Kusiak 1987). The utilization of discrete modelling and simulation is ideal to analyze behavior, predict performance, study alternatives, recommend changes, and investigate labor and machine changes on the output of a manufacturing process (Zhang *et al.* 2014, Cappanera *et al.* 2014, Greasley 2005, Löhdorf *et al.* 2014, Melouk *et al.* 2013, Gupta and Snyder 2009, Migdadi and Abu Zaid 2016, Gupta *et al.* 2012, Gupta and Gupta 1991).

##### 4.1 Methodology and Simulation model formulation

The base simulation model was designed to mimic the actual process at the facility studied, illustrated in Figure 1.



**Figure 8:** Simulation Methodology

To establish a framework for the simulation model a process map was created that detailed every element within each zone such as labor, machine, and automation. This process map was also connected to an Excel sheet that was then connected to the simulation model to feed information required to run the simulation. Figure 8 illustrates the simulation methodology followed.

##### 4.2 Simulation model translation

The simulation conducted in this study utilized WITNESS visual interaction modeling (VIM). WITNESS is a discrete simulation model that is used in goods and service sectors since early 1990's (Zhang *et al.* 2014). WITNESS simulation models have the capability to detail all facility variables such as equipment and labor. Data required for

the model can be manually entered or can be designed to feed on other files such as Microsoft Excel spreadsheet. The simulated facility managers requested the utilization of Excel sheet (more user-friendly than direct input). The data for the model used was collected from the facility data system that records all data for all station. The robot data was obtained from each robot control unit that keeps track of all data. After the process map was drawn, several station data found to be missing (by cross checking-52 stations missing) and for those stations, actual floor data was recorded for 3 months.

#### **4.3 Simulation model verification and validation**

The model created was designed to mimic the actual facility at the sponsoring company. At the problem formulation stage 1 in simulation methodology, each idea, recommendation and or change to current base model was reviewed with sponsored facility managers and engineers to ensure feasibility before adopting the concepts in the simulation model. To ensure accuracy, the following was conducted:

- Individual stations, sub-zone and zones were constructed and checked for accuracy, logic, process flow, and output before being connected to the system.
- Stations were given JPH counter and downtime tracker to ensure accuracy.
- WITNESS (VIM) debugging feature was utilized to resolve model errors.
- Excel speed sheet was used to input and control data feed.
- The simulation model features such as animation for labor, robots, parts, machines, scrap parts, inspection, and conveyors was utilized to observe system behavior (i.e. blockage, starvation, downtime) and ensure accuracy.
- All data and model variables created was verified and validated with facility managers to ensure accuracy.
- Simulation output was checked for accuracy over a range of input parameters.
- Quality DRL is calculated as follows: A = number of vehicles to the end of final line (final assembly), B = Number of vehicles to off-line repair (defects), C = A-B (Number of defect-free vehicles), and D = Number of re-run vehicles (re-introduced or re-inserted), E = C+D (to be rerolled/retested), F = C/A x 100 (% of number of defect-free vehicles divided by the total number of vehicles processed).

Simulated production runs were utilized to validate existing model. The throughput data generated by the model created was compared to the actual assembly output. Based on eight working hours per shift, two shifts per day, the average simulation model throughput was 61.9 JPH. The two-sided Student test was used to compare the averages simulated output to the actual performance. The test verifies the null hypothesis that both averages are equal. The facility actual average throughput from Nov 2016-Nov 2018 range between 61.9 and 60.7 JPH. The test statistics shows that we cannot reject  $H_0$  at 95% confidence level. Therefore, our model is valid.

### **5. Experimentations: New Simulation Model**

Based on the issues identified previously, the following are the proposed flexible philosophy scenarios considered.

Scenario 1: Replace current Framing Station (production flexibility and operation flexibility) with the Toyota Flexible system utilizing data obtained from Toyota George Towne, Kentucky Facility, illustrated in Figure 5. Replace the current aperture framing with process presented in Figure 6, using data obtained from Ford Rouge Dearborn Facility.

Scenario 2: The following three changes were utilized for the 2<sup>nd</sup> scenario:

- Replace the current marriage station (final department) with Nissan Mississippi facility process using data obtained from the Nissan facility in addition to several other add-ons such as automated robotic alignment and detection.
- Implement AGV (material handling flexibility) process for delivering medium and large size parts for Body shop and Final assembly shop (i.e. trim, chassis, and final departments).
- Implement the labor flexibility (baton and teamwork) concepts presented previously in all departments. This concept will utilize data obtained from testing those two concepts on the sub-assembly door line at the current facility.

Scenario 3: Implement all the above scenarios at the same time.

The data obtained from the benchmarking trips conducted in 2016-2018 to the facilities indicated throughout this research was utilized in-order to study the above three scenarios. Before testing each scenario, a meeting was held with engineering and production managers to ensure that all systems impacted by this change are considered and accounted for. For the cost of such implementation, we relied on quotes from supplying vendors or on an estimate given by the benchmarked facility.

## **6. Simulated scenarios results**

The following results were obtained after running the simulation for eight replications of 30 days with a one-day warm up period. The financial information was verified with facility financial department to ensure the accuracy. Also, vendors were contacted in-order to obtain a quote on the cost associated with new processes implementation (i.e. AGV's, GBL, new aperture sub-assembly, and body to chassis marriage station)

### **6.1 Scenario 1**

The framing system and the aperture system were replaced in the base model by the new system mimicking the benchmarked facilities (at TMMK and Ford Rouge facilities). The system was improved by introducing new concept such as overhead welding robots and eliminating net form and pierce process. The results indicate that the new bottleneck within the body shop will be the aperture marriage at 74.3 JPH. The framer station will perform at 78.4JPH. The overall body shop output will improve from 61.5 JPH to 73.2 JPH. Quality improvement (DRL) will be 12.6 %. The overall annual improvement will be 48672 vehicles annually or about \$460 Million annually (\$9,450 per vehicle). The total cost of implementing the new framing and aperture system based on an estimate obtained from KUKA Robotics is around \$798 million. The Return on Investment (ROI %) for such a project will equal to 400% (5-year program).

### **6.2 Scenario 2**

This scenario applied multiple changes. Changes included the following:

- Final department marriage station (Chassis to Body shell) was replaced by the Nissan Mississippi system marriage process (automated system instead of manual).
- Forklift delivery was replaced for some large, medium, and small size part by AGV delivery. The decision of which part and which department will utilize AGV delivery was made jointly with material handling and production managers. The simulation model uses AGV's based on the following:
  - Body Shop: large (40%), medium (50%), small (75%). The number of stations impacted is 51.
  - Paint Shop: None.
  - Final Shop: large (45%), medium (30%), small (40%). The number of stations impacted is 168 stations.
- The data utilized for AGV's delivery, efficiency, uptime,...etc., was based on input given by material handling department from the studied facility based current AGV process utilized by the sponsored company at a different location (data was also verified with sponsoring company AGV supplier).
- Labor flexibility was also applied in this model in all stations involving labor. The concept of teamwork and pass the baton was tested on a sub-assembly station (door line) for three months and the data obtained was utilized in this simulation model.
- After implementing the above changes in the new simulation model and running the simulation model for 12 replications of 24 days each with two days warm up period. The following results were concluded (as a stand-alone shop):
  - The body shop JPH will increase from 61.5 JPH to 62.9 JPH (2% Improvement).
  - The paint shop stand alone will increase from 65.1 JPH to 67 JPH (3% Improvement).
  - The Final shop improved from 63.6 JPH to 72.6 JPH (12 % Improvement).

The overall facility system will improve by 2% or 5824 vehicles annually (\$275 million for five-year program). The cost of such implementation is \$86 million (final marriage station) + \$102 million (AGV's) + \$42 million (team and baton concept: training, over time, additional labor ...etc) = \$230 million (5-year program). The ROI % will come up to 17 % Improvement.

### **6.3 Scenario 3**

The implementation of both scenarios 1 and 2 shows significant improvement in shop individual uptime (throughput). However, the overall facility throughput showed a slight deterioration in comparison to scenario 1. The system increased from 61.5 JPH to 71.8 JPH. The system was also tested at different model mix, and the following was the result:

- At 44% SUV and 56% Trucks throughput was 71.1 JPH.
- At 50% SUV and 50% Trucks throughput was 72.1 JPH.
- At 56% SUV and 44% Trucks throughput was 71.5 JPH.

Scenario 3 simulation model indicated that the combination of the two scenarios would lead to problems such as:

- 1- Paint shop blockage. This blockage was driven by manual stations over cycle in chassis and trim shops. About 47% of manual stations are impacted by mix change.
- 2- Mix change will result in improvement above 72.1 JPH if trucks run at 58% mix or above (Higher Truck mix will result in lower employee efficiency). Then, production control managers indicated that this mix would create material handling and supplier problem in addition to demand related issues.

## **7. Discussion**

This case study has described a DES (discrete event simulation) study of a vehicle manufacturing facility. The study provided recommendations on improving performance through the implementation of different FMS philosophies. Achieving the objectives of the improving operational performance at the studied facility required several issues such as:

- Benchmarking other operations (for data and recommendations). This process was the most time-consuming since it required traveling to different facilities and spending the time to understand how they work and obtaining data.
- Consulting different managers from the studied facility and other benchmarked facilities on options. Understanding their experience and the various issues they have to deal with to make the process work. Understanding the advantages and disadvantages of each option was considered.
- Contacting suppliers to get information and data on FMS utilized.

The DES simulation study conducted utilized visual animation in order to provide a better understanding of how the process works and to be able to analyze or visually identify constraints. The utilization of an Excel sheet to feed the simulation model was a tool that can be utilized in the future by facility manager to study any recommendations for improvement. Throughout this research, it was obvious that DES cannot substitute for engineering judgment. The simulation separately cannot find solutions for all manufacturing problems. Successful DES requires understanding the process, designing alternatives, consulting process specialists, conducting analysis, experimentation...etc.

The simulation model cannot do the following:

- Describe system characteristics that have not been explicitly modeled.
- Mechanical interferences of equipment
- Production quality issues related to how operators or machines perform tasks.
- The simulation scenarios indicated several system problems/issues that need to be addressed:
- Existing buffer system capability need to increase at 16 stations in the body shop, nine stations in paint including bank selection, 24 stations in Final assembly shop. This increase is driven by; 1) compensate for downtime issues 2) buffer capacity for selection 3) Repair
- Additional manpower is required to implement the team concept in all shops. This requires nine people in body shop, 13 in the paint shop and 22 in the final shop (non-skilled employees).
- Increase in floor space for the body shop and final department. This increase will be used for the framing system and the final marriage system. The total increase is about 24 thousand square feet.
- If AGV's are used an increase of 45 thousand square feet is required for AGV's (increase aisle size in certain areas, AGV's hub, etc).
- Additional skilled trade will be required for implementing any of the three scenarios. Scenario 1 requires 22 skilled trades and for scenario 2 requires 10.

## **8. Conclusion**

This study shows the significant impact that FMS philosophy can achieve in improving the operational performance of manufacturing processes. Each flexibility type is designed to serve different objective. In addition to the benefits achieved from implementing FMS, the simulated scenarios indicated that there is a tradeoff in flexibility. This tradeoff is considered when planning the strategic framework of the organization. For example, the sponsored facility is faced with a major question on adopting production flexibility because implementing such a process (at the body shop) will increase the number/types of vehicles that can be produced but at the same time, it will limit the capability of the facility. The combination of flexibility in automation and labor provided an improvement in quality, and at the same time, it will require newly trained, improved and skilled work force. This type of tradeoff forces managers to prioritize flexibility-based benefits required. Overall FMS provides manufacturing facility with a tool to overcome process disturbance and will lead to significant improvement in operational metrics. DES is a powerful tool that can assist in analyzing the impact of system alterations. It will give managers the ability to make rational decisions to improve their manufacturing process performance.

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