

# **BIW Process Modeling and Simulation Analysis**

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## **Abstract**

The manufacturing industry successfully used the simulation modeling and digital engineering toolbox to improve the production efficiency. In this paper, development of automotive body shop layout design and the assembly processes is presented for a typical Body-in-White (BIW) vehicle. The overall BIW assembly consists of four BIW major assembly lines. They are Underbody line, Body side Aperture lines left and right, Framing line and the Panel line. A simulation model is developed depicting the body shop plant layout and processes to analyse the production output. This paper makes an earnest attempt to model the complete body shop processes using simulation software. The stations uptime and down time, conveyor speed and the path, process stations, process cycle times were used per the processes layout to predict the output. The simulation model prediction results were compared with the typical production output from the plant.

## **Keywords:**

BIW Process, Simulation, Uptime/Down time, Plant layout

## **1. Introduction**

The automobile manufacturing plant is very sophisticated, and complex in nature with highly automated equipment and robots. The body is spot welded by robots to form a "Unibody" chassis assembly or a "Body on frame" vehicle. Assembly of the vehicle takes place along a highly efficient assembly line. The robot and the manual labourers' work side by side to maximize the productivity. Programmable logic controllers (PLCs) drive assembly line equipment. The automotive assembly plant typically produce about 60 vehicles per hour. Annually, 150,000 to 250,000 units are produced by a single-line plant depending on the shifts and the number of workdays per week. Annual production rates are usually based on 250 workdays per year. The automotive assembly plant really consists of three side-by-side plants, Body shop, Paint shop and the Trim, Chassis and Final (TCF) assembly shop. Some facilities may have a stamping operation or powertrain assembly on site. However, almost all the TCF sub assembled parts are "Received- in- assembly" (RIA) at the plant. A new body shop production-line needs to be set up for almost every new vehicle (car, truck, minivan or SUV) model. Due to the relatively short product life cycles, the planning process of body shops can almost be regarded as continuous. Often, the optimization of a new body shop is carried out manually, supported by a simulation model to analyse the impact of different cycle times and buffer sizes.

After the vehicle S0, S1 and S2 pilot build processes are finalized; advanced manufacturing engineering (AME) department develops the production processes. The AME have dedicated group of engineers and managers to deliver the equipment and processes for each plant shop: BIW, Paint and TCF. The assembly plant personnel are tasked with meeting the daily production meeting the quality requirements. Plant personnel are busy dealing with the day-to-day production tasks. The automotive assembly line process stations are highly automated with robots

controlled by Programmable Logic Controllers (PLC). A typical automotive body shop employ about 110 assembly line operators, however, more than 700 robots at work performing various complex high-speed operations such as, material handling, welding, sealing and inspection of the framed body. The manual processes are limited to minimum to keep up with the high-speed production demands. The assembly plants are running more than one model in the plant. The vehicle types and the quantity changes weekly based on the sales volume. This becomes a challenge for the plant personnel to run the plant. The plant production is affected by the station down times. The plant personnel are always chasing the shortage of materials, work force issues, machine breakdowns, and production losses. The simulation engineer may have the necessary modeling skills but may lack the knowledge in complex manufacturing processes of building a vehicle. There is a huge disconnect between the plant personnel understanding of the simulation results and the simulation expert understanding of the plant layout, tooling and the processes.

This paper is unique because it is developed by using the authors' vast professional automotive experience combined with expertise in simulation modeling software. A simulation model is developed to predict the shift production based on process times, conveyor length and the station uptime and down times. The verification and validation becomes a challenge since, the modeling expert do not understand the plant day to day plant issues and the plant personnel do not understand the modeling process. In this paper, various "What-If" scenarios are presented to improve the throughput in the plant. The challenges involved in understanding the production processes, model development and simulation are addressed.

## **2. Literature Survey**

There are lot of research work done by subject matter experts on Discrete Event Simulation modeling and techniques. There are many approaches used for validation and verification of the simulation model. Various validation techniques such as conceptual model validity, model verification, operational validity, and data validity and minimum recommended procedure are discussed by Sargent (2004). Model accreditation standard (DoDI 5000.61) is available from Department of Defence (DOD) for specific application.

Das et al. (2014) proposed Assembly Transfer Function (ATF) as an integration of three critical response functions of assembly process: (i) modelling non-ideal parts and its response to part fabrication errors; (ii) modelling n-2-1 fixture and its response to non-ideal parts; and (iii) modelling part-to-part joining process and its response to n-2-1 fixture. The ATF identified fault in design stage, reduced uncertainty in assembly and provided diagnostic control in manufacturing by using an industrial case study of automotive door assembly with remote fiber laser welding joining process. Camelio et al. (2003) developed a methodology to evaluate the sheet metal dimensional variation propagation in a multi-station compliant assembly system based on linear mechanics and a state space representation. Three sources of variation: part variation, fixture variation and welding gun variation are analysed. The proposed method is illustrated through a case study on an automotive body assembly process. Vasudevan, and Devikar (2011) identified the criticality of abstraction level of complex simulation models for large manufacturing systems. In this paper 'why' and 'how' these choices in abstraction level of a simulation model at various stages in a project's life cycle results in answering the objective function more precisely using several automotive manufacturing case studies.

Jack Hu and Stecke (2009) offered parallel and hybrid combinations and their trade-offs that improves productivity and dimensional quality compared to traditional assembly systems for automotive bodies that have been designed using serial configurations. Guidelines are developed to aid the selection of a system configuration that is appropriate for total system performance. Bottleneck causes most of the productivity losses. Roser et al. (2001) developed a novel method to detect the bottleneck in a discrete event system by examining the average duration of a machine being active for all machines. The machine with average uninterrupted active period is considered the bottleneck. Dessouky et al. (2007) presented a simulation based productivity study to compare the performance of the conventional and Shorter Trailer Combination Vehicles (STCV) operations with respect to a stochastic Multi-Vehicle Pickup and Delivery Problem (MVPDP) in which the demand is random with random delivery due dates.

They determined the number of trucks and trailers, the pickup-and-delivery dispatch rule, and the type of transportation operations (conventional vs. STCV) that optimise various performance measures. Tjahjono et al. (2008) proposed a methodology to assist experimentation procedures. The methodology entails the 3 key stages to increase productivity of the line namely: bottleneck detection, bottleneck reduction/elimination and efficiency. Cycle time, machine reliability, and buffer allocation (or removal) variables are weighted into the calculation effort. By constantly validating the model by inputting real time data, efficiency can be improved with production disturbance system in manufacturing systems based on discrete event simulation is studied by Ingemansson et al. (2004).

We rarely encounter real-life sampling situations in which the correct form of distribution is “known”. Another issue we encounter in automotive assembly line is unbalanced cycle times due to product and process mix variations. Shaaban and McNamara (2009) studied the impact of unpaced, unbalanced lines with respect to both their mean operation times (MTs) and Coefficients of Variation (CVs) were simulated with different lengths, buffer capacities, degrees of imbalance, and patterns of imbalance. Idle Time (IT), throughput and Average Buffer Level (ABL) data were generated and analysed. The best patterns provided generally superior performance to that of a balanced line counterpart. Another important factor in automotive assembly process is ergonomic issues that contribute to vehicle build issues. In order to gain from existing ergonomics knowledge within a company, the possibility to implement such wisdom in the current simulation software becomes important.

Pandian and Ali (2011) illustrated how to improve robotic automotive body shop throughput by feeding back actual plant data for input variables for entities to improve discrete simulation model prediction and validation. They also proved that the mean time to repair and mean time between failures critically affect the throughput. Pandian and Ali (2014) predicted using the plant failure data that the equipment down time had more effect on the plant throughput compared to the uptime of the equipment using the DOE analysis. Pandian and Ali (2015) proved that the average MTBF/MTTR, as the best maintenance strategy is wrong for the layout based on the simulation model prediction using the actual production monthly data. They identified that the MTTR plays a major role in improving production output.

K.T. Hung, J. K. Liker (2007) used the simulation approach to study the batch size effect on production lead-time in a multi-stage assembly pull system considering the combined effect of these production conditions. They found internal and external production conditions have significant impacts in reducing the responsiveness of a pull system.

### **3. BIW Process Flow layout**

In this section, the design and development of the Body-in-White (BIW) assembly Process sequences to build the sheet metal body BIW vehicle is presented. Please refer the Figure 1. The four BIW major assembly lines are Underbody line, Body side aperture (BSA) lines, Framing line and the Panel line that produce the BIW vehicle. The Ladder line, Dash line, Engine Box line that feed into to make up a Underbody complete assembly line. The Body side Inner line, Body side outer line that feed into to make up a Body side aperture complete assembly line. There are left and right side Body side aperture lines. The Underbody complete assembly and Body side apertures left and right are feed in to the Toy-tab assembly line. After Toy-tab, the bodies are feed into the framing assembly line to geometrically frame the body. The roof is put on the framed body in the roof assembly line. The framed body conveyed down to the Net, form and pierce (NFP) station line to get punched holes for the hang-on panels installation. The body conveyed down the panel assembly line where manual labourers install the lift gate, fuel door, rear door/sliding door, front doors, hood and the deck lid.

The welded BIW body conveyed to the next paint shop building for paint and then conveyed to the Trim, Chassis and Final assembly building for final buy-off before shipment to the dealer ship.

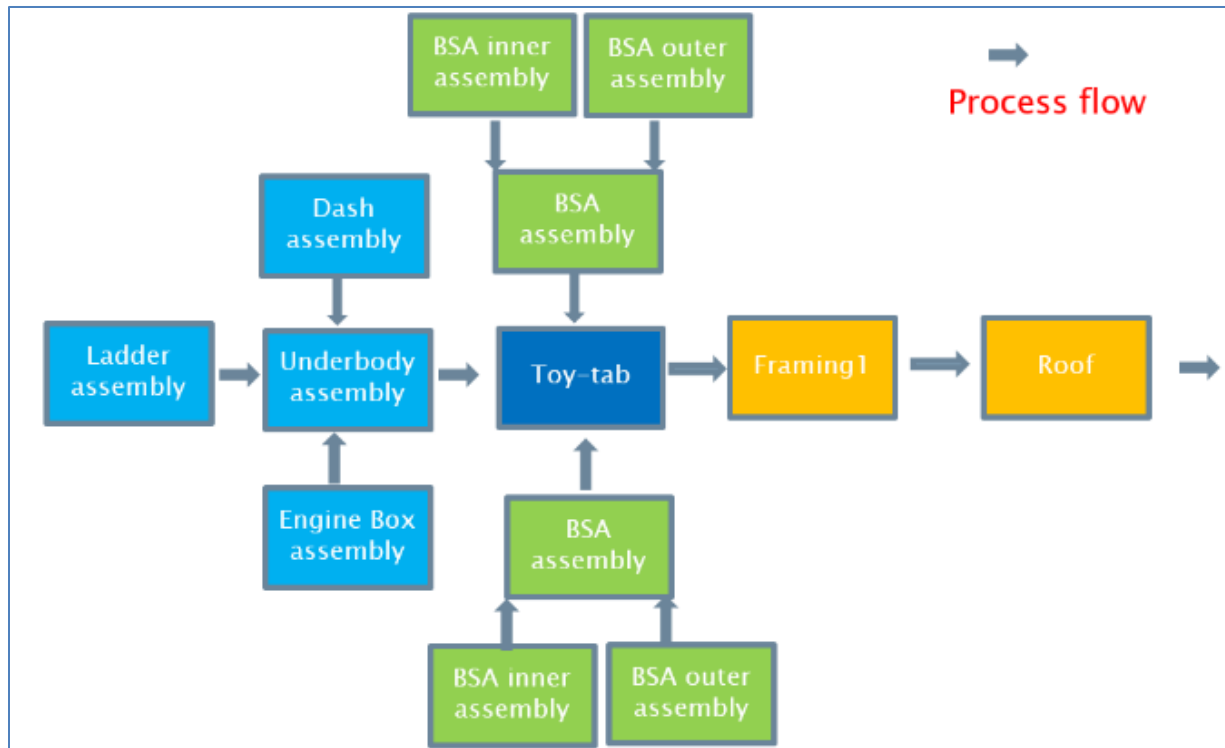


Figure 1. BIW process flow (stage 1)

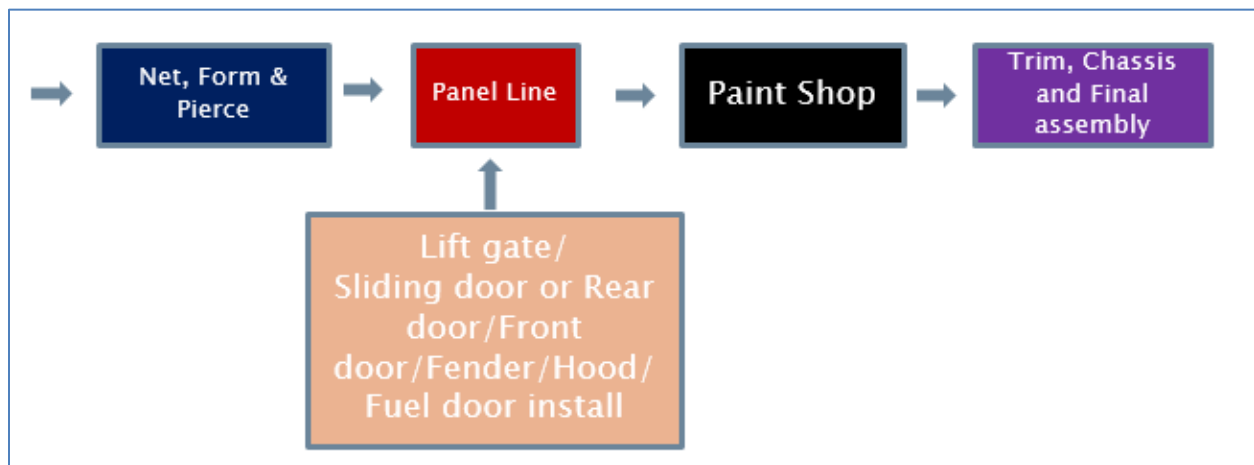


Figure 1. BIW process flow (Stage 2)

The production layout heavily depends on the product configurations, location of the activities, logistics, production process, and available real estate (dimensions). The layout must consider the new products, change in demand, changes in product design, new technology, bottlenecks, too large a buffer, too long transfer lines. The

types of layout are developed based on fixed product layout, product layout (flow shop-high volume-short distances) based on processing sequence, group layout and process layout. The development of the layout for the Body-in-White (BIW) assembly Processes to build the sheet metal body BIW vehicle is presented below. A typical body shop layout is shown in Figure 2.

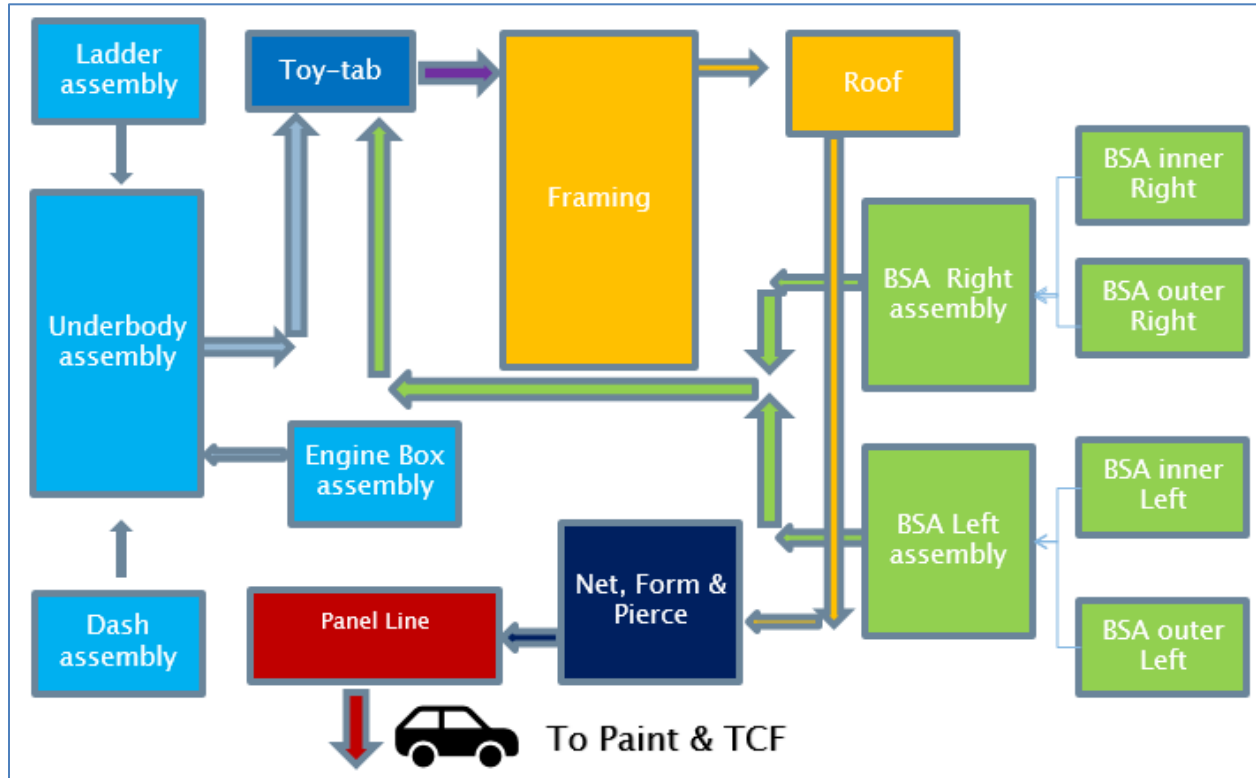


Figure 2. Body shop layout

#### 4. Production requirement

The automated manufacturing system is so complex to understand the intricacies of the process tooling, process sequence, process variables, buffer limitations and the process intensive bottleneck stations. A typical automotive body shop plant employ about 110 assembly line operators but, more than 700 robots at work performing operations such as, material handling, welding, sealing and inspecting the framed body. A great deal of communication and understanding required between the simulation model developer and the plant personnel to interpret the model results to implement the simulation recommendations. At a high-speed build assembly plant, the assembly line tooling and processes generally designed to build high volume per eight hour shift with 7.15 hrs of actual production time in the plant excluding the lunch and breaks. However, the plant generally was able to deliver about 450 bodies to the paint shop. The unforeseen equipment breakdowns, materials shortage, operator slow cycle times, station starvation, and conveyors contribute production chaos and low output. The assembly plant is always seeking cost effective solution to increase the throughput in the plant without affecting the quality and the vehicle delivery schedule.

## 5. Simulation Development

A simulation model is developed depicting the body shop plant layout and the processes to analyse the output for one shift operation. In this study, the cycle time is about 40 seconds is assumed delivering about 90 jobs per hour (JPH) for the assembly lines: underbody, body side and framing line, roof line, Net, form and pierce and the panel line. The simulation model for the complete body shop is developed using Arena 14.70 version software. This software version has some limitation (<150 modules) on the number of modules that can be modeled. Developing an accurate simulation model requires a great deal of understanding of the body shop process stations layout, process sequence, station cycle time, station uptime and down time, and conveyer assumptions. In this study, an earnest attempt is made to provide valuable information to forecast the plant throughput using simulation modeling.

The development of the BIW assembly process simulation model is shown in Figure 3. The entities are created with appropriate arrival rates and the entities are assigned with cumulative discrete probability function, each entity type is identified with colours. The entities (parts) are released through the assembly line using entity sequence leave module. The ladder, dash and Engine box (Ebox) sub-assemblies are feeding to the underbody (UB) complete process station (cell10). The body side inner left (BSIL) and the body side outer left (BSOL) sub-assemblies are feeding to the body side left (BSL) aperture complete process station (cell14). The body side inner right (BSIR) and the body side outer right (BSOR) sub-assemblies are feeding to the body side right (BSR) aperture complete process station (cell15). The underbody complete assembly, body side aperture complete left and right assemblies are feeding to the toy-tab (Tab) process station (cell 11). After Toy-tab process completion, the body sent to the framing process station (cell 12) where the body is geometrically framed. The body is sent to the roofing process station (cell 8) to weld roof on the body. The body then sent to net, form and pierce operations (cell 13) stations to punch holes for the installation of instrument panel, side view mirrors etc. The doors, deck, hood, fuel door is installed by manual labourers in the panel line assembly process line (cell 9).

The resources are assumed to be unit assembly line process station. The assembly lines up and down times are modeled with typical plant failure data. The assemblies are conveyed thru the accumulating loop conveyer with 20 feet per second. The conveyor segment length is modeled as 300 feet between the assembly lines. The assembly line load and unload time from the conveyor is modeled with 5 seconds.

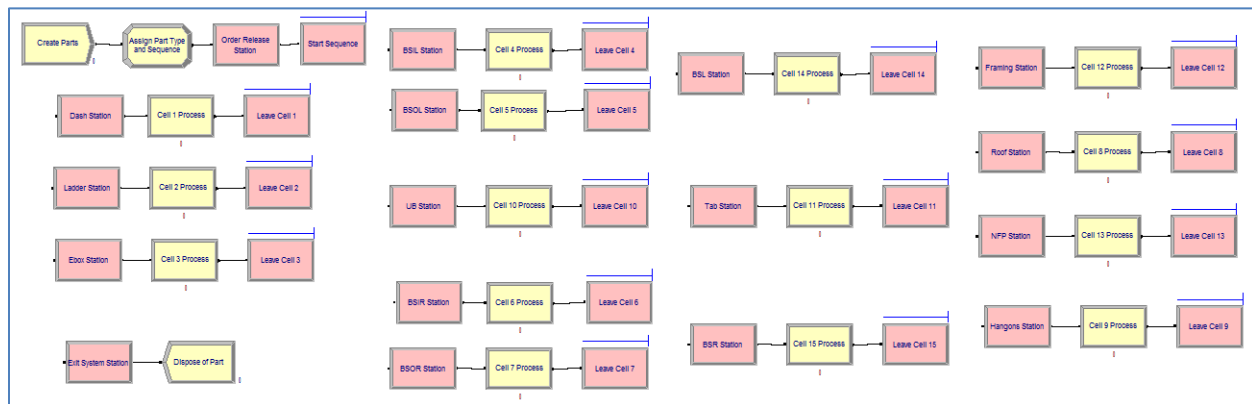


Figure 3. Simulation model design

The model station resource data matrix is shown in Figure 4. The process stations are modeled with 200 minute uptime and 1.25 minute down time based on the typical plant data.

Resource - Basic Process									
	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	Cell 1 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
2	Cell 2 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
3	Cell 3 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
4	Cell 4 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
5	Cell 5 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
6	Cell 6 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
7	Cell 7 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
8	Cell 8 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
9	Cell 9 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
10	Cell 10 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
11	Cell 11 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
12	Cell 13 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
13	Cell 12 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
14	Cell 14 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓
15▶	Cell 15 Machine	Fixed Capacity	1	0.0	0.0	0.0		1 rows	✓

Figure 4. Resource matrix

Equation 1 is used to find the number of simulation runs required for the production data. The number of replications required for the simulation run close to actual mean prediction values are shown in Table 1.

The number of replications is determined using the Equation 1 per Kelton (2007).

$$n = \left(\frac{Z \cdot s}{p}\right)^2 \quad \dots (1)$$

Where,

n = Number of replications

Z = Z value taken from the Normal Probability table with % of confidence interval

s = Six sigma Standard Deviation

p = Value, how close to actual mean

Table 1. No. of Replications required

<b>Typical 1st shift production</b>	BIW
Production Mean =	450
Desired Standard Deviation =	6σ
6σ deviation (Range/6) =	30

How Close to Actual Mean (Production)	CI= 90% ( $\alpha= 10\%$ )	CI= 95% ( $\alpha= 5\%$ )	CI= 99% ( $\alpha= 1\%$ )
1	2435	3457	5968
5	97	138	239
20	6	9	15
30	3	4	7
40	2	2	4
50	1	1	2

To get to the actual mean within +/- 1 vehicle, the simulation model must be replicated ~ 3457 times for 95% confidence interval (CI). In this paper, the investigation is conducted based on the actual mean value (400 vehicles) within +/- 50 vehicles output with 95% CI. Just one run is sufficient to test the model accuracy @95% CI. Due to software version limitation, up to 4 replications were performed.

The investigation is performed by running the simulation model for one production shift. The simulation model study is conducted and entity animations were observed visually to understand the queue behaviour at each process station. The simulation model animation is recorded and captured through AVI file. The various model parameters are analysed and evaluated.

## 6. Model Analysis

The developed simulation model predicted 579 vehicles for 430-minute simulation time. The simulation results produced average cycle times for each station, instantaneous station utilization, conveyor utilization, wait times, work-in-process (WIP). The average WIP was about 4 parts for the entire operation. The cell 9 (Panel line assembly) had the highest average wait time 13.5 minute compared to less than a minute wait time in other lines. The resources utilization ranged from 10 – 90% and conveyor utilization was less than 4%. The simulation results proved that the production output can be predicted using simulation modeling software. The professional software would be able to analyse the various what-if scenarios to predict the plant throughput. Suppose, if the results showed an improvement of 80 vehicles per shift that would have tremendous effect on the company bottom line. An assembly plant with 2 shift operation schedule for 200 working days would produce 16,000 more vehicles increasing profit for the company. Improving the plant production is very critical for that plant survival as well as the company's survival. This simulation modelling study verified and validated with the typical plant production data.

## 7. Discussions and Recommendations

Understanding of the actual assembly build processes is very critical to find the best solution to the problem in the automated assembly system. The assembly plant staffs are always under pressure to minimize the scarp, rework, the inventory of the spare parts, and the manpower. However, the plant staffs need to maintain the required daily and monthly production. The plant staff must understand the simulation results and act upon the simulation recommendations to improve the production. To meet the daily production, the plant may schedule overtime for the shift workers. Scheduling the over time is never a good idea. It has a domino effect on the overall vehicle quality, preventive maintenance schedule and the operator fatigue. It is very critical that the production department closely work with the simulation experts to achieve the production goals thru various what-if analyses.



This paper has demonstrated how to develop a simulation model using Arena simulation software with proper input parameters. Based on the modeling results, it is proved that the whole-body shop assembly processes can be modeled to analysis the plant throughput. This simulation study accurately predicted the throughput based on the system uptime and downtime data. Further investigation is needed to understand the effects of the other variables such as buffers and line balancing of the upstream and downstream processes.

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## **References**

- Camelio, J., Hu, S.J. and Ceglarek, D., "Modeling Variation Propagation of Multi-Station Assembly Systems With Compliant Parts", *Journal of Mechanical Design*, Vol. 125, No.3, pp. 673-681, 2003.
- Das, A., Franciosa, P., Prakash, P.K.S., Darek Ceglarek, D., "Transfer Function of Assembly Process with Compliant Non-ideal Parts", 24th CIRP Design Conference, *Procedia CIRP* 21 ( 2014 ) 177 – 182.
- Dessouky, Y., Tsao, H.S.J., Patel, M.H., Zeta, J.B. and Zhou, L., "A simulation study of the productivity of large trucks with shorter trailers", *International Journal of Industrial and Systems Engineering*, Vol. 2, No. 3, pp. 261–285, 2007.
- Hu, S.J. and Stecke, K.E., "Analysis of automotive body assembly system configurations for quality and productivity", *International Journal of Manufacturing Research*, Vol. 4, No.3, pp. 281–305, 2009.
- Ingemansson, A., and Bolmsjo, G.S., "Improved efficiency with production disturbance reduction in manufacturing systems based on discrete-event simulation", *Journal of Manufacturing Technology Management*, Vol. 15, No. 3, pp. 267–279, 2004.
- K.T. Hung, and J. K. Liker, "A simulation study of pull system responsiveness considering production condition influences", *International Journal of Industrial and Systems Engineering*, Vol. 2, No. 2, pp. 123–136, 2007.
- Kelton, D.W., *Simulation with Arena*, Sixth Edition, McGraw Hill, 2014.
- Pandian, A. & Ali, A., "Automotive Robotic Body Shop Simulation for Performance Improvement Using Plant Feedback", *International Journal of Industrial and Systems Engineering*, InterScience Enterprises, Ltd. Vol.7, No.3, 269-291, 2011.
- Pandian, A. & Ali, A., "The Effects of System Failures in a Robotic Assembly Line- Simulation Modeling and DOE Analysis", *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*, Bali, Indonesia, January 7 – 9, 2014.
- Pandian, A. & Ali, A., "Investigation of Maintenance Assumptions for an Automotive Production line using Simulation Modeling", *Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management*, Dubai, March 3-5, 2015.
- Roser, C., Nakano, M. and Tanaka, M., "A practical bottleneck detection method", *Proceedings of the 33rd Conference on Winter simulation*, December 09-12, 2001. Arlington, Virginia, pp. 949–953, 2001.
- Shaaban, S. and McNamara, T., "The effects of joint operations time means and variability unbalance on production line performance", *International Journal of Manufacturing Technology and Management*, Vol. 18, No.1, pp. 59–78, 2009.
- Tiwari, M.K., Saha, J. and Mukhopadhyay, S.K., "Part-selection and machine-loading problems in a flexible manufacturing system environment: a heuristic approach based on reallocation paradigm", *International Journal of Computer Applications in Technology*, Vol. 32, No.2, pp. 142–157, 2008.
- Tjahjono, B. and Fernandez, R., "Practical approach to experimentation in a simulation study", *Proceedings of the 40th Conference on Winter Simulation*, December 7-10, 2008. Miami, Florida, pp. 1981–1988, 2008.
- Vasudevan, K., Devikar, A., "Selecting Simulation Abstraction Levels in Simulation Models of Complex Manufacturing Systems", *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, pp. 2268-2277, 2011.

## **Biography**

**Annamalai Pandian** is an Associate Professor and Director of B.S. in Engineering Technology Management program in the Department of Mechanical Engineering at the Saginaw Valley State University, Michigan, USA. He earned his B.Eng. & M. Eng. Degree in Mech. Eng. from University of Madras, Chennai, India, and M.S. Degree in Mech. Eng. from Louisiana State University, Baton Rouge, LA, USA and D. Eng., Degree in Manufacturing Systems from Lawrence Technological University, Southfield, MI, USA. He has wide range of industrial experience in sheet metal stamping, robotic welding, automation, product design, project management, six sigma and lean manufacturing methods. Dr. Pandian has worked in Advanced Manufacturing Engineering division in Chrysler LLC, Auburn Hills, MI, USA for 13+ years. He has wealth of experience in automotive tooling design and manufacturing. He has taught several design and manufacturing engineering courses including Engineering Mechanics, CAD, Jigs & Fixtures, Robotics & Machine Vision, Manufacturing Process Eng., and Manufacturing Systems Design and Simulation. Dr. Pandian's research interests include Sheet metal forming, 3D printing, Simulation, DOE, Robotics, ARMA and ANN. He is a member of ASQ, ASEE, and IEOM. He is also a member of the editorial advisory board for the International Journal of Quality and Reliability Management. Paper reviewer for many International Journals.