CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In any research study, the work done in the past forms the foundation of the work to be carried out in future. It is very much important to understand the past work for two major reasons, first the past work gives the trend and pattern followed in the past and next it helps to avoid duplication of any work carried out in the past and throwing lot of insights to develop the current focused area.

The investigation of the past work on automotive body quality and productivity is identified in five major areas. They are

1) Body dimension variation analysis and methodologies followed to address various quality issues

2) Various investigations carried out to improve productivity and quality in body shops

3) Lean manufacturing & optimizations carried to solve manufacturing issues

4) Investigations carried out with design of experiments methodology to solve various problems.

5) Resistance spot welding optimization

Certain key research papers which are of greater importance with possibility of practical applications are taken up for review.
2.2 BODY DIMENSIONAL VARIATIONS

While assembly of body in white (BIW), various sub-assemblies & parts are welded together by holding them with the help of different fixtures. To achieve the quality, fixtures should be with proper design and geometry. Accuracy of body in white (BIW) assembly depends on the accuracy of fixture and processes.

Body assembly sheet metal dimensional variations due to various welding sequences was studied and the author has recommended few design guide lines to the sheet metal designers to select weld sequences to set appropriate geometry, design guide line provided to make stress free welding and stress relief patterns for different joineries [28]. The dimensional variation effects of positional variation of spot weld was studied by Mali et al and he has concluded that; “Spot weld position variation control is essential to maintain proper assemble dimensional accuracy” [29]. Liu et al has studied the panel surface resistance and observed that the quality of spot weld varies with change in surface contact. Thus, quantity of surface contacts and magnitude of surface contact play an important role in the weld and dimensional integrity of the BIW [30]. Doshi has done a case study based research to implement the statistical process control method in different suppliers and observed difficulties due to process variations, also identified the root causes for process variations [31]. He has tried to resolve the process variations by implementing various action plans at supplier locations that also indicates the possibility of process variations in an automobile manufacturing facility. Johan has studied weld spot distribution among the robotic welding stations and he has mentioned that “the spot distribution between the robotic stations and sequence of spots plays a significant role in dimensional quality and throughput [32].”

A computer-aided intelligent system was developed by Guanlong et al, which will automatically generate the optimal joint types and assembly sequences for the best dimensional quality for any given assembly. This is an
aid tool for designer to develop assembly joineries based on the existing library, a best suitable configuration can be obtained from the system [33].

Optimization of welding process and how it leads to the quality in manufacturing was studied by Hardikar, He has taken an overview of various techniques used to achieve minimum distortion during the metal parts are being assembled and concluded that “Reducing dimensional variation is of critical importance to improve the final product quality”. Software simulation helps to improve the accuracy of the product in terms of cost, quality and dimension [34]. Complications of shimming in multi model lines to control body manufacturing quality was studied by Carsten and recommended force controlled shimming method to overcome the manufacturing dimensional quality setting issue in multi model lines [35].

Every spot has its own position as constraint for the dimensional quality and each sub assembly dimension decides the quality of the final assembly. kristina Warmefjord et al considered that, there are many factors affecting the final geometrical outcome of a BIW, spot welding sequence is one of the identified factor considered to be critical. It is better to choose a welding sequence that can optimize the variations and deviations of the final assembly. The author has investigated about the correlation between offset and standard deviation for different welding sequences. She has presented the investigation report of number of spot welds required to lock the geometry with industrial case studies [36].

Geometric variation of an assembly affects the functional points as well as the quality of the BIW. Rikard soderberg et al described about the virtual geometric assurance tool for verification of the geometric characteristics using variation simulation model. He has discussed about that all manufacturing processes are afflicted by variation which implies that the nominal value of a manufacturing dimension may not be expected at all the times. The manufacturing dimension may rather be described by an expected range and a probability distribution [37].
The diagnosis of dimensional variation can be controlled through root cause analysis. The resulted variation of an assembly depends on component variation and locating tool, hence a methodology was developed to diagnose the multilevel hierarchical assembly variation by Johan [38]. In the manufacturing process, pre-controlled methods are essential for process improvements as well as the body quality. Sanches Jr et al described about the sub assembly pre-controlled methods like master sample preparation, assembly fixture calibration, process validation and gauge inspection for the improvement of BIW dimensional stability [39].

Kang et al elaborated about how dimensional variation propagates through manufacturing process. They have created a new methodology based on finite element analysis by using parametric model. It is used to incorporate the input variation from different variables [40].

2.3 PRODUCTIVITY AND QUALITY IMPROVEMENTS

Geometry setting in an automotive body shop is a critical process and requires an adequate method to plan and execute any new model introduction. Productivity enhancement is one of the key focused areas in the current trend of automobile manufacturing. Maximum benefits must be obtained in every aspect with a minimal environment foot print, Minhaj et al [41]. A manufacturer faces unpredictable changes in the market and the market demands a lot of product launches [42]. Jadhav has given a roadmap for lean principles implementation in the Indian automotive component manufacturing industry. In this study, the author observes that the Indian industries need to make a paradigm shift in their strategies and approaches to improve production capabilities, productivity, quality and scalability [43].

Amir has studied, Hours-Per-Vehicle (HPV) reduction for North American automobile Industry and reduced around 54.75 minutes on average each year to improve productivity [44]. Selvaraj et al studied the simplification of sheet metal components design and manufacturing processes. They have discussed the ways to reduce the number of sheet
metal components through parts integration [45]. Mahmoud et al studied productivity improvement and resource optimization of an automobile manufacturing shop [46].

In the competitive automotive market condition, reduction of production cost is very essential to meet customer demands [47]. Indian manufacturing industries are focusing to deliver low cost, improved quality and diverse products with superior performance, Kanwarpreet et al [48]. Al-Zaher studied and recommends the implementation of the strategy of low price with high quality factors. The manufacturing ecosystem is one of the areas which directly affect the control over capital and revenue expenses in a new model introduction [49]. To control initial investment and to lower the operational cost; optimization of equipment and process is essential in body shop process planning. Reduction of geometry stations in a body shop directly contributes to reduction in capital investment.

Cycle time balancing between body shop welding stations were carried out by Ali with a multi model objective queuing method. From the developed model, two results were obtained. First, the process time balancing between the stations resulted in increased production quantity and saved 7.81 minutes per day. Second, the reduction in transfer lead-time resulted in reduction of 5.81 minutes per day, also the author has mentioned that the lead time reduction was not focused in the previous investigations [50].

Robot weld load balancing for multi model line was studied by Johan and proposed a novel generalized simulation-based method for automatic robot line balancing for robot positioning [51]. Impact of different cycle times and buffer sizes of the body shop was simulated and validated with a case study by Sven et al and explained that the maximum utilization of available cycle time with the possible reduction of production equipment [52].

Jianjun shi et al proposed a process navigator for quality control and assurance system. It includes the real-time data collection, online
tracking and fault identification, inspection data base, variation pattern animation and knowledge based diagnosis. He provided an effective measurement tool for productivity as well as quality improvement [53].

DonHee Lee et al empirically studied the effects of manufacturing systems by using data from the survey of global manufacturing research group. They have described that “the operational performance can be improved through best quality management practices and competitive priorities”. They have tested the research data using structural equation modelling for hypotheses from various multinational firm from different countries [54].

Modern revolution has demanded the quality and productivity at a similar rate. Vinod S. Gorantiwar et al described the importance of various Critical Success Factors (CSF) and its impact on total quality management (TQM). The integration of various critical success factors can help the manufacturing industries in achieving sustainable quality improvement with the TQM approach [55].

Flexible manufacturing is the boon for automobile industry, quality management and just-in-time makes the better products to the customer on time. Chi Anh Phan et al done an empirical analysis by ANOVA and hierarchical regression from survey data of various manufacturing plants. They have suggested that the manufacturing plants should highly focus on Quality Management (QM) and Just in Time (JIT) to explore the linkage and synergy of operational practices [56].

2.4 LEAN MANUFACTURING & OPTIMIZATION

Optimization is one of the major focus areas to meet the business requirements. There are some optimization initiatives developed and deployed in automobile industries; some of those process optimization solutions are discussed below. Assembly line balancing problem was studied by Mohd and it was quoted in his thesis that “Research works focus on the integration of manufacturing optimization between the process planning
stage and manufacturing process stage remains limited” [57]. It is evident from his quote that the scope for improvement is very wide in the integration of process planning and the execution.

To maximize the production, Chuan has developed an efficient buffer design algorithm subject to a production rate constraint and provided valuable insight about production line design to manufacturing system practitioners [58].

Different research activities were carried out with various approaches to optimize the processes. BIW geometry setting and process optimization is a very wide subject, where there is a huge scope for improving the unresolved issues and partially addressed issues. Variation simulation for optimization of manufacturing process is essential for quality parameter establishment [59].

Rakesh has discussed the need of lean manufacturing implementation to improve the operational parameters such as productivity, quality and cost. Manufacturing process, layout, supplier, training of work force and scheduling are considered as main factors in the study. The results were concluded with that, the plants which uses Quality Management and Just in Time techniques achieves high performance [60]. Quality control cost optimization issue was studied by Jian and recommended to decrease the rate of false alarm to improve the economic condition in body manufacturing [61].

Jaiprakash Bhamu et al described the systematic way of reducing the wastes in lean manufacturing by value stream mapping. He demonstrates the effects of value stream mapping through case study and concluded that lean implementation is a tool for improving productivity and quality of a company [62].

As stated by Ashish gupta et al, during process planning stage in an automotive vehicle development process (VDP), one of the tasks is to select tools such as weld guns and fixture from large tool library and assign
them to individual manufacturing operation. Software packages merely pick and validate individual library items to find a solution. Further, no design assistance is provided to configure a valid new tool. Currently in automotive industry, the tool selection process is manual, local & subjective. It leads to proliferation of tool variants resulting in increased costs and reduced operational flexibility [63]. In his paper, he has proposed an approach for automated and optimized method of selection of tools.

According to Osma m Erfan et al, the complete elimination of waste is the target of any qualified system. This concept is vitally important today. Since, in today’s highly competitive world there is nothing we can waste. Value stream mapping tool was used to expose the waste and identify a proposed plan for improvement. This results in the system of being more productive, flexible, and smooth and with high quality service [64]. From his analysis it is clearly observed that elimination of waste such as excess inventory in the system is very critical.

According to Endris et al, Lean Product and Process Development (Lean PPD) is an emerging paradigm wherein lean thinking is considered in the design and development of engineering products. Although lean design and lean product development have received attention in previous works, process development has received little; research in this area is necessary to improve the concurrency of product and process development. Integration of manufacturing knowledge at the conceptual design stage is of paramount importance to increase the designer’s awareness of manufacturing capabilities and opportunities. As a result, design rework can also be minimized and possible manufacturing plans can be effectively explored [65].

Arnout Pool, et al has concluded through various case studies that it is impossible to create a theory to describe or predict the leaned system & it is a continuous activity [66]. Karlsson et al suggested a check list for what to aim at when trying to implement lean production. In his study he has concluded that lean should be a direction, rather than as a state to be
reached after a certain time and, therefore, the focus should be on the changes in the determinants, not on their actual values [67].

Yu Cheng Wong et al has studied the adoption of lean manufacturing in the electrical and electronics industry. They have considered 14 key areas of lean manufacturing in their study, scheduling, inventory, material handling, equipment, work processes, quality, employees, layout, suppliers, customers, safety and ergonomics, product design, management and culture, and tools and techniques [68].

Rose et al has studied the lean implementation in Malaysian auto components industries to understand the level of perception and implementation of lean manufacturing. Most of the surveyed companies agreed on the importance of lean practices in their companies, but the level of implementation was not perceived by them in the same ways. To improve this condition, implementation of lean manufacturing across all the industries is considered critical [69].

Om Prakash Yadav, et al has investigated the level of lean implementation in the global automotive industries. Also, the study explains about the various learnings from the actual implementation practices particularly in the USA, UK and Indian automotive sectors [70].

2.5 DESIGN OF EXPERIMENTS

The impact of an input variable on a process can only be quantified by a series of experiments that are performed with varying levels of the input. Ricardo B P et al observes that the trial and error procedure involved in the conventional process of experimentation can be avoided by structuring the flow of experiments using Design of experiments (DOE) [71].

The objective of the Taguchi method is to measure the sensitivity of the output to the variation of input parameters. Thus, it is critical to choose only the parameters that have the highest impact on the outcome, figure 2.1 [72]. Spot quantity, welding surface contact, spot sequence and spot position
were selected for the study due to the significance of the parameters on the output in the study presented in this thesis.

Rao et al observed that, in the selection of the appropriate orthogonal array for DOE, the total number of experiments should be equal or higher than the total number of levels of all the parameters. This ensures equal occurrence of every parameter combination. Hence, for this study, an L-27 Taguchi orthogonal array is selected [73].

**Figure 2.1 Flow chart of Design of Experiments**

Niranjan Kumar Singh et al presents a systematic approach to determine the optimization and effect of weld process parameters by Taguchi method. He described the optimum weld parameters determined by L32 Orthogonal array experimental method. ANOVA and F-test is selected for determining the significant parameters affecting the spot weld parameters [74].
Optimization of a process requires evaluation of the effects of various process parameters on the output. This entails sequential experimentation using various input parameter combinations. Taguchi method which was developed by Genichi Taguchi, Mikovik et al provides an experimentation process which can achieve the objective of process optimization with minimum iterations. The goal of this method is to use the output of the experiments to find the Signal: Noise (S/N) ratio of the input parameters. The S/N ratio shows the quantum of the impact the input has on the process [75].

The S/N ratio can be measured in three categories; “Larger is better,” “Nominal is better” and “Smaller is better.” An appropriate category should be selected based on the requirement, Fazeli et al [76].

2.6 RESISTANCE SPOT WELDING OPTIMIZATION

Resistance spot welding is widely used for BIW manufacturing all over the globe. The recent research trend has focused for optimization of spot welds for a better quality of the sheet metal assemblies. Hsien-Yu Tseng proposed a solution for welding economic design problem. He applied the general regression neural network for economic welding design construction and can select the optimum weld parameters based on genetic algorithms [77].

Soo-Won Chae et al developed an optimal design system using adaptive meshes for spot weld process optimization. He has proposed an h-version background meshes for optimization of spot welding process [78].

Coriteac Let al showed that spot welding optimization can be done with algorithms by finite element models. In his case study, the optimization factors were explained for increasing production volume and cost reduction [79]. The strength of the spot weld depends on the weld parameters (weld pressure, current, weld time). Shruti Naik et al explained the rupture of spot welds and suggested that aluminum material is preferred for spot welding, but it requires much higher tip forces than steel [80]. Yong Xia et al have analyzed the concept of design for manufacturing. The optimization in spot
welds, results that the structural torsion stiffness is relatively sensitive to the layout of spot weld. He has done a foundation research towards the structural performance assessments and the weld layout design [81].

The optimization and performance evaluation tools are inevitable for manufacturing processes. Tempelmeier developed an algorithm system software, which is helpful for the planners to plan manufacturing process in less time [82]. Heui-Bom Lee et al done the distortion analysis in spot welded area of Body-In-White. The distortion from welding sequence can be minimized, if clamping system is perfect. The weld force originating from the assembly tolerance is a critical design factor that determines the weld sequence and the clamping system for minimum distortion. The durability of BIW is mainly controlled by the strength of the spot weld joints [83]. Andreas Rupp et al done a theoretical approach for structural durability and the reliable design for optimization of spot welded components. Finite-Element post processor calculation procedure allows to determine the local stress and improve the life of the BIW structure [84].

Chon L.Tsai et al studied the control systems for the resistance spot welding. They have done a systematic approach for expansion-based control algorithm for spot welding, the inadequate welding conditions that causes nugget expulsion and current shunting [85].

Xin Sun et al addresses the modeling issues of resistance spot welds. He explained the techniques on simulation of weld process, weld property prediction and evaluation of weld engineering performance [86]. Won Wook Jung et al discussed about the accurate reason for the fatigue failure of the spot weld in the developing stage and another method for repair [87]. Gilvan Prada Rossi presented to compare two different methods of spot weld modeling through a correlation study, by considering the maximum force of the welded joint, between virtual and lab test results [88].

Shinichiro Yoda et al described a new method to predict the rupture of spot welds, which is suitable for vehicle crash simulation. He had
developed a new method to predict the rupture of spot welds which relates axial and shear forces and bending moment of spot weld that can cause stress around nugget. Rupture risk can also be estimated through this method [89].

Eric R. Pickering et al studied aluminum spot welding. When aluminum sheets are spot welded, electrode tip life is limited due to tip erosion and pickup of aluminum on the tip. They have examined the control variables in the spot welding process and offered an improved weld schedule to achieve desired weld properties [90].

The geometric integrity of a sheet metal assembly is a direct function of the spot weld positions and the spot weld count. The geometry of a sheet metal assembly can be controlled by a minimum of two spot welds and a maximum of three spot welds depending on the part parameters, Selvam G et al [91]. When an assembly is controlled by such a low count of spot welds, the quality of the spot welds is paramount to keep the geometric integrity intact.

Failure resistance of a spot weld can be improved by optimization of weld parameters such as weld current, weld time and electrode geometry, Nasir Z et al [92]. An automotive structure has a wide variety of combinations which require the process planner to tune the weld parameters for every weld station individually. The parameter setting, and weld coupon evaluation consumes a high process time. Commonization of parameters will provide a substantial improvement in this area [93]. Selvam G et al observes that one of the crucial aspects that impact the total automotive Body-in-White (BIW) proto build timeline is the parameter setting and fine-tuning time [94].

The tensile-shear strength of the weld is dependent on the thickness of the sheet combinations and the diameter of the nugget formed, Pouranvari M et al [95]. The change in the weld parameters will impact the developed weld nugget size, Shamsul J.B et al. [96]. Thus, by ensuring a target range of nugget diameter for a thickness combination, the weld parameters can be studied for optimization.
Different material grades can affect the spot weld quality and strength, Gedgeon S.A et al. [97]. As an automotive BIW is made of multiple material combinations, optimization of weld parameters will provide effective results only when the commonization of parameters is across multiple material combinations. Thakur A.G et al studied the impact of weld parameters on spot weld quality of galvanized steel. The weld parameters; weld current, weld time, electrode diameter and weld force were optimized using Taguchi experimentation process [98].

2.7 GAPS IDENTIFIED IN CONVENTIONAL PROCESS PLANNING

- The existing data sources indicate that there is no attention shown in appropriate spot allocation between the geometry and re-spot stations
- Percentage of spots and stations are having an inter-linkage. Reduction of geometry spots will reduce the number of geometry stations
- There is a scope to bridge the identified gap in BIW process planning to improve productivity

To the best of our knowledge, no previous work has been reported on “Appropriate spot allocation between the geometry and re-spot stations to improve productivity”.

And, it was noticed that less attention was given on “Improving productivity in body shop with geometry spots optimization and reduction of geometry stations” and hence this work has been carried out to bridge the gap.

2.8 SUMMARY

From the literature review, it is clearly observed that the spot weld accuracy, position of spot welds, sequencing of spot welding and the number of spots play an important role in body dimensional control. Different
research activities were carried out with various approaches to improve the dimensional accuracy and to optimize the processes. BIW geometry setting and process optimization is a very wide subject, where there are huge scopes for improving the unresolved issues and partially addressed issues.

In the latest research of Kristina et al, it has been identified that two weld spots are sufficient to set the geometry between any two assembled parts in any sub-assembly welding [36]. This was taken as the basis and further studies were conducted with the parts of different sizes and with different surface contacts.

Ali explained about the importance of productivity improvement in body shop by reducing transfer lead-time and process time. However, BIW geometry set and process optimization are a vast area and still lot of unanswered questions are there in front of us to resolve [50].

In this study both geometry set, and process optimization are integrated to obtain maximum productivity with an appropriate dimensional quality. As per the previous studies, the minimum number of spots required to set geometry between the two parts are “2”. Further investigation is done with the consideration of four major factors to investigate the applicability of implementing the optimized number of spots across body shops with different configurations. This problem is studied using Design of Experiments (DOE) method. Abbas and Kawther used Taguchi (L27OA) method for tableting process optimization with three controllable factors [99], there are four controllable factors used in our study.