Received: 18 January 2021 | Revised: 20 March 2021 | Accepted: 31 March 2021

DOI: 10.1002/amp2.10084

RESEARCH ARTICLE

JOURNAL OF ADVANCED MANUFACTURING AND PROCESSING WILEY

Optimization of the cycle time of robotics resistance spot welding for automotive applications

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Abstract

In the automobile manufacturing industry, resistance spot welding (RSW) is widely used, especially to build the car's body. The RSW is a standard and wide-ranging joining technique in several assembling ventures, showing a wide range of possibilities for a competent procedure. Robots are commonly used for spot welding in various industrial applications. After completing assembling design, interest increases to improve the designed processes, cost-reduction, environmental impact, and increase time productivity when all is said to be done. In this paper, the robot movement between two welding points, a path followed while spotting, gripping and payload-carrying activities, numbers of holds, moves, and a possibility to enhance interaction between four Robots were analyzed using an offline Robot simulation software "*DELMIA*-V5." The body shop assembly line of the SML ISUZU plant has four robots that perform about 209 welding spots in 532 s. The optimal model reduced the whole welding cycle time by 68 s, and after modification and proper sequencing, a12.7% reduction in cycle time was achieved. The offline Robot simulation software "*DELMIA*-V5" has good potential to produce optimal algorithms while saving precious time. It enables an organization to promote higher quality and to encourage meaningful creativity by reducing design flaws.

KEYWORDS

assembly line balancing, offline programming, program evaluation and review technique (PERT), resistance spot welding (RSW), robotic welding, simulation

1 | INTRODUCTION

Spot-welding assembly lines are extensively utilized in the automotive industries. Many robots are employed with spot welding to build the body of the vehicles. The major problems in an assembly line are allocating various operations to the robotic cell stations and reducing cycle time. These problems are directly linked with the cost of production, time, and carbon emissions, so the manufacturing units face pressure to optimize their assembling task.[1] The efforts were made to optimize scheduling and proper assignment to the assembly line.[2]

The challenges to optimize the workstation include locating the part, grasping the part, moving the part, placing the part within the assembly, manipulating parts, fastening, and other moves that need to be calibrated.[3] The benefits of concurrent engineering notions integrated into weld design and a methodology to evade welding infeasibility were developed based on computer-aided design and drafting (CAD) decision support system.[4] A procedure was developed that considered product analysis as well as robot cell configuration and applied the method in an inert metal gas or metal active gas processing four robot welding cells.[3] A modular and systems approach was used with multiple system layers such as process, system configuration, installation, variables, program, and simulation to assist robotic implementation.[5,6] An amended genetic and simulated annealing algorithm applied to the hull assembly line balancing. The minimization of several workstations, the static load balancing index, the dynamic load balancing index between workstations, and the multi-station-associated complexity were considered.[7] A methodological design process anticipated uniting finite element analysis and an instrument oriented to enlighten the design resolutions for production affluence.[7] Many other aspects of robotic use in production systems include coordination, scheduling, reusing process knowledge, and monitoring system control. The decrease in weight of vehicles was made conceivable by original plans and excellent solidarity materials to weight proportions, such as aluminum and composite materials.[8] The energy-saving scheme was reported in a robotic assembly line of automotive units. The techniques projected to control the robots' motion from the preceding operation point to the initial positions and reduce energy consumption by discharging the actuator brakes earlier.[9] The investigation of the efficiency of robotic spot welding was presented in automotive body shops, and it provides a chance for enhancing business performance of body shop.[10] A case study demonstrated an optimum design in an automotive assembly line while considering resource energy consumption, investment cost, availability and annual production volume, and machine utilization.[11] Some measures and techniques were portrayed for a robotic workplace to utilize robot technology for welding effectively, and presented strategies were tested in a welding shop.[12] A new methodology presented to optimize robot layout to diminish energy consumption and two robot work cells built within the *DELMIA* robotics environment reveals 20% saving of energy.[13] The robotic assembly line design was proposed for Brazil's automotive industry while considering dead time during a cycle, space constraints, task assignment restrictions, and parallelism possibilities.[14] The gantry machine tool's effective and efficient lightweight design presented and saves manufacturing cost.[15] The research roadmap was presented for robotization and management of specific knowledge to guide project managers, engineers and technicians.[16]

Over history, the process has resulted in different ways, such as forge welding, thermite welding, and more current arc welding innovations. Scientific developments over the 1800s have led with most transformative derivatives as resistance spot welding (RSW). RSW was believed to be first created by Elihu Thompson during a copper wiring trial in the second half of the 19th century. RSW is a fusion process based on the electrical resistance of two metals to produce thermal energy. A responsive confluence of temperature, pressure, and time results in molten metal between the sheets, which becomes the core of the weld recognized as the weld nugget when cooled.[17–19] Many manufacturers have implemented automation into their day-to-day operations. Robots have been aiding in vehicles' production with RSW. From a safety point of view, approximately half of producing robots is used for welding programs, with many being utilized in the automobile enterprise. The robotic welding grows protection in the workshops with the aid of getting rid of the human element from unsafe welding work, preserving workers faraway from fumes, chemicals, excessive heat, and noise, in addition to weld flash.[20,21] The evolving technologies in the automotive vehicle assembly plants were demonstrated considering assembly operations of handling and joining.[22] The RSW operation was optimized and modeled to manufacture car bodies.[23] The monitoring strategies for RSW were portrayed for process and weld quality. The limitations and benefits also presented for joining sheet metal industries.[24]

Today, about half of manufacturing robots are used for welding applications, with many being utilized in the automobile industry. These welders allow much higher protection in the workshops with the aid of eliminating the human issue from hazardous welding work, preserving people away from fumes, chemicals, severe warmness, and noise, as properly as weld flash. They additionally limit musculoskeletal stress from twisting, lifting, and different repetitive motions. These robots additionally resource in crash protection tests, preserving no longer solely the people out of harm's way, however additionally future consumers. Not solely have robotic welders improved security in factories, however they have additionally saved many automobile producers tens of millions of bucks by means of doubling, or even tripling, their manufacturing time by using extensively reducing labor costs. Robots additionally do no longer drop components or manage them in approaches that may want to be probably damaging, thus, lowering waste formerly induced with the aid of human error. These financial savings a long way outweigh the fee of any preservation and repairs that might also be required, and even the preliminary value in shopping for these machines can be overshadowed through the return on funding they provide. In particular, the automotive industry continues to use RSW as its main joining process, despite strong competition from the processes of beam welding, adhesive bonding, and mechanical joining. Major trends and developments in RSW are optimization of welding processes, investigating new high-performance robotic welding guns, deploying self-regulating process control, quality assurance, and developing hybrid and virtual welding processes.[25] The *DELMIA*-V5 robotics utilized to simulate the Kuka robot environment to avoid collisions, and enhance path planning, and physical dimensions while implementing in the real workstation.[26] A simulation-based method was proposed to reduce coordination cycle time losses in an automatic robot line balancing. It reduces robot weld loads and optimized robot coordination significantly.[27] The energy consumption and cycle time were optimized for the robotic assembly line, and robots were assigned at best-fit workstations to balance the assembly line.[28] An offline-line arrangement was presented using *DELMIA*-V5 robotics for edifice robotic arc welding workstation within the learning workshop context.[29] *DELMIA* allows manufacturers in any industry to define, plan, create, monitor virtually, and control all production processes. It provides a range of dedicated business applications coupled with an expertise-sharing, approach, and strategic planning landscape to capture and establish better manufacturing practices. *DELMIA* PLM technology helps producers communicate early in the design phase with plant operations and months before the final manufacturing commitment. Engineers, administrators, and customers can have a 3D real-world simulation and the potential to analyze “what-if scenarios,” adjust, automate shop floor processes, and recognize and remove expensive mistakes and design flaws. *DELMIA* now applies the PLM platform to smaller enterprises within the supply chain, allowing smaller companies to communicate and partner with larger suppliers effectively.[30]

Literature survey reveals that with some sequencing and elimination of a few activities, cycle time could be further reduced in a Robotic system. But the manual implementation of observed points would be dangerous or hazardous. There might be a chance of interference and clashing of two robots while working. Thus, an offline working method for simulation and analysis is a better choice. The study focuses on reducing work cell cycle time by simulating the model on offline Robotic software “*DELMIA*-V5.” The “*DELMIA*-V5” robotics offers a versatile, adaptable, and simple to-utilize solution for tooling definition, work cell design, robot programming, and work cell reproduction. With this software's help, the organization can reuse best practices, influence programming information, and computerize Robot programming's dreary work. A funding in a robotic spot welder will take the employee away from the risky area and put them at the back of the robotic as an operator. Underlining these facts, in this work, an effort has been made to implement *DELMIA*'s robotics solution in an automotive industry and to oversee its effectiveness in creating a 3D virtual manufacturing environment to simulate the modified production processes. Furthermore, the reduction in the total cycle time has also been calculated using an analytic and visual capacities implemented under *DELMIA* system.

2 | PROBLEM FORMULATION

The SML ISUZU plant (Ropar, India) has a RSW cell where four robots, make FANUC R-2000iC. Robots have a load capacity of 280 kg, which means each can bear their end-effector load up to 280 kg. There are two C gun and two X gun in the Robotic cell, which is handed over to each Robot diagonally. The truck cabin has 216 spots that are supposed to be welded. A robotic spot-welding process on an automotive chassis is shown in Figure 1. The JBM got a contract for designing a Robotic cell for ISUZU; the team suggested performing 160 spots on a respective truck cabin in “Robotic Body Shop Cell” while remaining 56 spots to be welded in “re-spot cell.” The automation system during Robotics spot welding is shown in Figure 2. The JBM team simulated the plant suggested a model in offline simulating software, namely “*DELMIA*-V5.” The cycle time generated was approximately 7 min 27 s (447 s). When all these things started implementing in the Ropar plant, ISUZU people asked them to add a few more spots to reduce manual work in the re-spotting section, thus enhancing productivity. Such activities, like floor re-spotting, roof header re-spotting, were added in Robotic tasks. The number of spots to be welded in the Robotic cell then increased to 200. The remaining 16 spots at door-floor sections have been shifted to the “re-spot cell” due to Panel material constraints. But here the problem got arrived. Incremented spotting has not been simulated for optimum time management.

Similarly, in initial tasks gapping and spacing between two activities were two much because of interdependence. Hence cycle time increased to 8 min 52 s (532 s) for 200 spots. By thorough observation standing in front of the Robotic cell and simulating the same cycle in offline programming software, it is ensured about there is an excellent chance of cycle time reduction by doing proper sequencing

FIGURE 1 Resistance spot welding process on automotive chassis

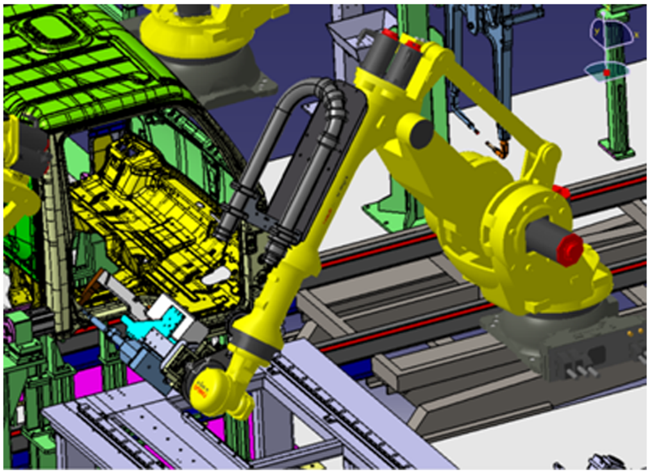


FIGURE 2 Automation during resistance spot welding

in the program evaluation and review technique (PERT) chart.

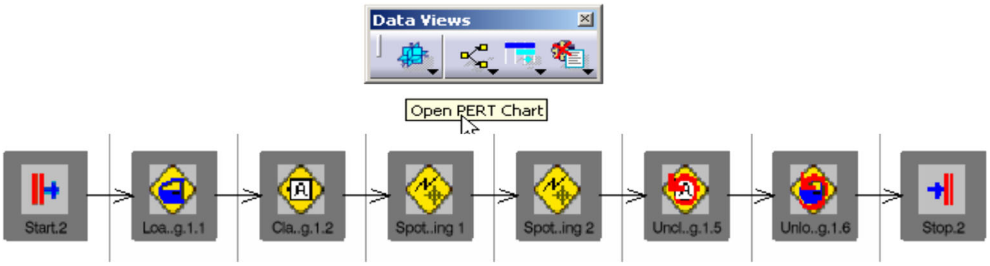
3 | EVOLUTIONARY APPROACH

To develop well planned, clash less and optimized model, a parallel process has been created with timing in offline simulation software "*DELMIA*-V5." One optimized cycle was developed by doing sequencing in the PERT chart, as shown in Figure 3, by reducing holding time, time of occurrence, and adding or eliminating a few tasks. The Robot motion planning algorithm in "*DELMIA*-V5" is shown in Figure 4 to design and motion planning of multi-robot assembly cells for the body in white spot welding. It consists of offline motion planning for a single robot, followed by offline collision check of two-robot paths, multi-robot cell design and offline motion planning, and the motion plan's end validation.

Following points were considered while optimizing cycle time virtually:

- *Reach and Feasibility*: It is checked whether a particular group of spots could be reached and performed by a specific robot or not. It helped to decrease the workload from a Robot, which is working a little excessively. After putting the roof by Robot-2, it goes home, picks a gun, performs Panel spotting of a roof with back panel, drops the Gun, and then put off the gripper to the home position. It is checked whether the same Panel spotting was in reach as well as feasible by Robot-1 and Robot-3 or not. It was found possible. So, it reduced the workload as well as the performance time of Robot-2.
- *Task Sequencing*: The downtime took for each task by each Robot was noted. Also noted, down hold time by each Robot at both times, that is, before and after lifting. The study was carried out to interfere and resequencing tasks in this empty period by fulfilling each job's required environmental conditions.
- *After Lifting Spot Adaption*: Activities that left working alone before lifting conditions were tried to adapt in after lifting conditions by checking the time of both activity and empty spaces, front panel re-spot was the activity performed by Robot-4, was adapted in after lifting status. It was performed once the side re-spotting of the snake member was done.

FIGURE 3 Robot welding task sequencing in program evaluation and review technique (PERT)



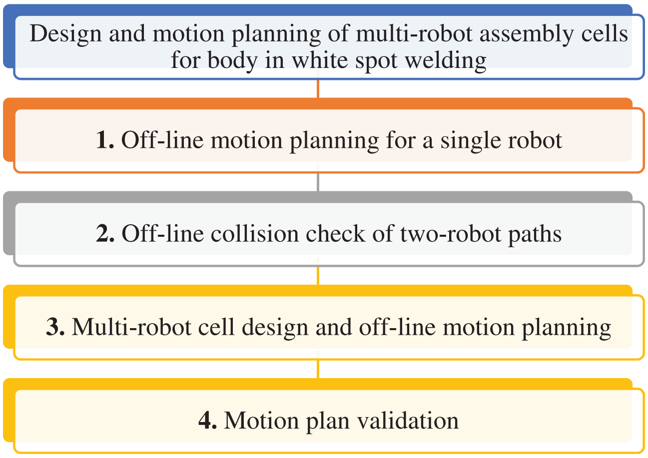


FIGURE 4 Robot motion planning algorithm in *DELMIA*-V5

- *Motion followed*: Joint motion is to be applied while non-spotting activities such as gripping or putting-off of any object, free movement non-carrying activities, payload-carrying tasks. It helps to get smooth and flawless motion. While "Linear Motion" is applied for spotting actions where the path is linear and well-directed. It gives us a very disciplined motion. Time taken by joint motion is a more comparatively linear motion. Thus, the whole simulation is a combination of both motions.
- *Limiting Conditions*: Each Robot is having six degrees of freedom. External seventh axis is added in the form of the end-effectors, maybe C gun, X gun, or any kind of gripper. It is taken care that rotation of joint-5 would not exceed more than 85%, and the rotation of the remaining axis not more than 88% as per norms. These are not critical limiting values, but the factor of safety was considered. "*DELMIA*-V5" user interface for four Robots under study is shown in Figure 5.

4 | SIMULATION EXPERIMENTS

4.1 | Simulation of Robot-1

There are 10 activities in the current working cycle, whose overall working time is 204 s out of 532 s. That means Robot-1 is a standing idle for the remaining 328 s. Through an observation, it has been found that Robot-1, amongst all four robots, has a maximum idle time. Further, Robot-2 and Robot-4 were waiting for Robot-1 to complete its task. It has made the two robots to finish their job and commanded Robot-1 to perform afterwards. Previously, the systems have shared a few functions from other robots with Robot-1. After doing Panel-spotting of the side panel, Robot-1 remains idle. Following this, X gun has been inserted through the side panel and made panel spotting the roof with a back panel. The robot's sequence task for automobile chassis spot-welding is starting from the back-pick operation to place in floor after the complete welding process. Similarly, at the end of the front panel re-spotting, it becomes free. Thus, for optimization inserted it through the side panel to perform Roof-Roof header re-spotting. The process and hold time comparison of Robot-1 are shown in Table 1.

4.1.1 | Simulation of Robot-2

There are 13 activities in the current working cycle, whose overall working time is 400 s out of 532 s. That means Robot-1 is standing idle for the remaining 132 s. After thorough observation, we found that Robot-2 is busy, but its sequence is such that at some moments, Robot-1 and Robot-2 were waiting for Robot-3 to place the roof at the dock. So, before performing side panel re-spots, commanded it to dock roof before and due to change in the sequence of Robot-3, a collision was taking place inside the panel region. Thus, new upgraded side re-spot activity just after door grippers start moving off. After docking of the roof, Robot-3 used to pick the Gun, used to perform Panel spotting, and removed the gripper. Previously shared this Panel-spotting task by Robot-1 and Robot-3. Thus, overall working time reduced. The process sequential changes in the operation of Robot-2are shown in Table 2.

4.1.2 | Simulation of Robot-3

There are 13 activities in the current working cycle, whose overall working time is 304 s out of 532 s. That

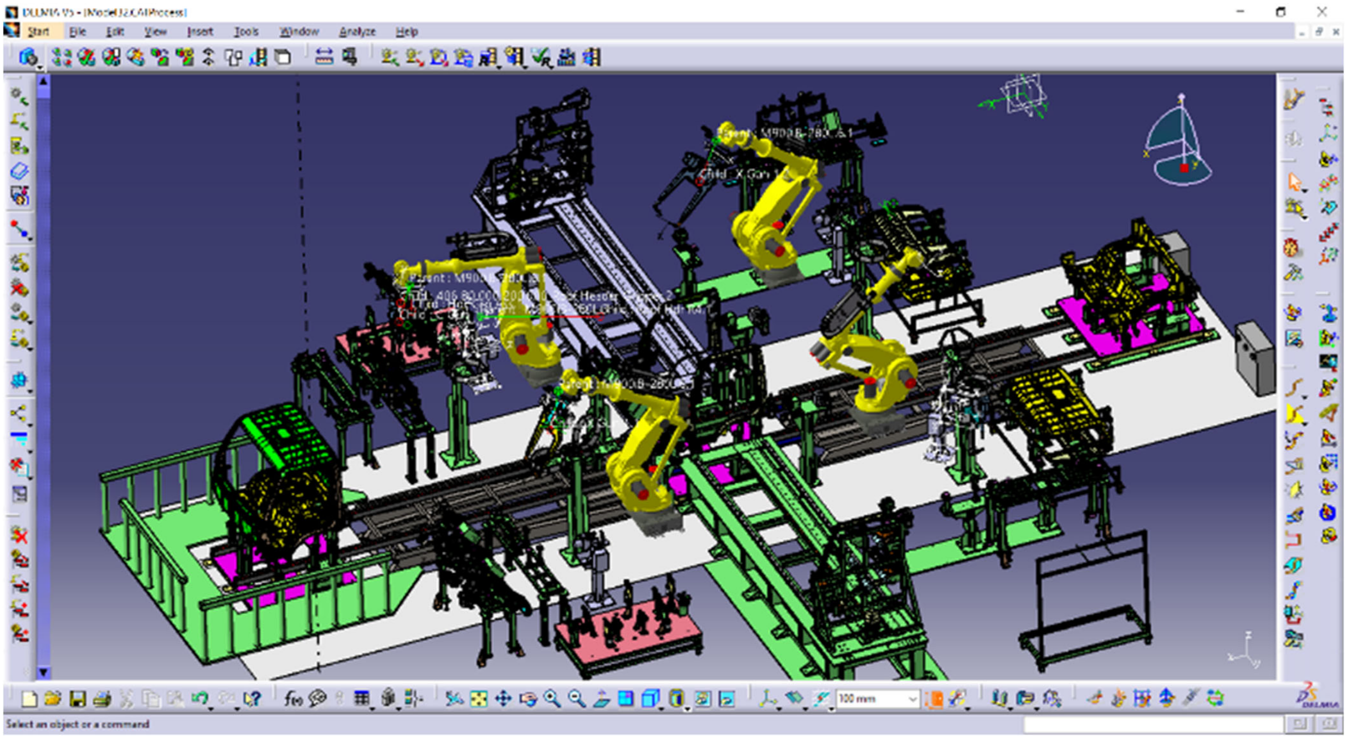


FIGURE 5 *DELMIA*-V5 user interface

TABLE 1 Sequence of Robot-1

Current sequence	Process time (s)	Hold time (s)	Optimized sequence	Process time (s)	Hold time (s)
Back pick	27	-	Back pick	27	-
Gun pick	06	-	Gun pick	06	-
Roof header	11	-	Roof header	11	-
Back panel	33	-	Back panel	33	52
Gun drop	12	35	Back trial	15	
Gripper drop	20		Gun drop	12	20
Gun pick	06	-	Gripper drop	20	
Roof re-spot	16	85	Gun pick	06	95
Back re-spot	16		Roof re-spot	16	
Front re-spot	30		Back re-spot	18	
		143	Front spot	30	
			Roof re half	22	56
Floor	25	65	Floor	25	
	Σ Process time = 204	Σ Hold time = 328		Σ Process time = 241	Σ Process time = 223

means Robot-1 is standing idle for the remaining 228 s. After thorough observation, Robot-3 is busy enough, but resequencing is needed to make the whole cycle compact. Thus, to place the front gripper first before doing side panel spotting as Robot-4 was idle at that time. Similarly, as discussed before, its shared Panel spotting of the back panel and re-spotting of the roof with Robot-1. It was getting tackled while performing a side spotting activity. Thus, their sequences changed from roof header re-spot to back panel re-spotting. The process sequential changes in the operation of Robot-3 are shown in Table 3.

TABLE 2 Sequence of Robot-2

Current sequence	Process time (s)	Hold time (s)	Optimized sequence	Process time (s)	Hold time (s)
Gun pick	06	25	Gun pick	06	29
Back panel	67		Back panel	67	
Side panel	37	16	Gun drop	08	
Gun drop	08		Gripper pick	30	48
Gripper pick	30		Gripper drop	17	
Gun pick	14		Gun pick	06	
Roof spot	25		Side panel	37	12
Gun drop	10		Side re-spot	46	
Gripper drop	34		Roof re-spot	36	
Gripper pick	06		Re-spot bottom	38	
Roof re-spot	36				
Re-spot bottom	38				
Side re-spot	46	48			
Floor re-spot	50	43	Floor re-spot	50	34
	Σ Process Time = 400	Σ Hold Time = 132		Σ Process Time = 340	Σ Process Time = 123

4.1.3 | Simulation of Robot-4

There are 10 activities in the current working cycle, whose overall working time is 367 s out of 532 s. That means Robot-1 is standing idle for the remaining 165 s. After a thorough observation found thatRobot-4 is also busy enough, it reduced its holding time due to cumulative response and support from the other three. The front panel brought by Robot-3 and roof by Robot-2 early as compared to working one helped Robot-4 to perform its task restlessly. Roof re-spot is the task that got shared by Robot-1, and Robot-3 made its work more manageable. The process sequential changes in the operation of Robot-4 are shown in Table 4.

Optimized sequence for all Robots; for Robot-1 is “1 - 2 - 3 - 4 - * - 5 - 6 - 7 - 8 - 9 10 - *,” Robot-2 “1 - 2 - 4 - 5 - # - # - # - 9 - 10 - 3 -13 - 11 - 12,” Robot-3 “1 - 2 - 4 - 5 - 6 - 3 - * -8 - 11- 12 - 13 - * - 9 - 8 - 7” and for Robot-4 “1 - 2 - 3 - 4 - 7 - 5 - 6 - 8 - 9 - 10 - #,” where “*” represents an added activity and “#” represents removed activity. The current sequencing of Robot-1 is “1 - 3 - 2 -4 - * - 6 - 8 - 7 - 9 - 9 10 - *,” Robot-2 “1 - 3 - 5 - 7 - # - # - # - 9 - 10 - 3 -13 - 11 - 12,” Robot-3 “1 - 2 - 4 - 6 - 8 - 9 - * - 11- 12 - 13 - * - 10 - 5 - 7” and for Robot-4 “1 - 2 - 3 - 5 - 7 - 4 - 9 - 6 - 8 - 10 - #.” Holding time for each Robot has been reduced due to proper sequencing. The processing time of Robot-2 is diminished by 59 s due to the removal of Back Panel activity. In comparison, the 40 s reduces the processing time of Robot-4 due to the elimination of front rewelding spot activity. But due to the addition of both events, as mentioned above, has been shared by Robot-1 and Robot-3, their operation time increased by 37 and 34 s, respectively refer to Figure 6. The time comparison of different robots is shown in Table 5, and sequential changes in Robot operations are shown in Table 6.

The robot movement between two welding points, a path followed while spotting, gripping and payload-carrying activities, number of holds moves, and the possibility to enhance interaction between four Robots were analyzed on offline Robot simulation software “*DELMIA*-V5.” The body shop assembly line has four Fanuc Robots that perform about 209 welding spots in 532 s. After modification and proper sequencing, a significant reduction in cycle time was observed. The algorithm was developed in offline simulation software in “*DELMIA*-V5” to develop well planned, clash less and optimized model. By doing sequencing in the PERT chart, reducing holding time and its time of occurrence, we developed one cycle by adding or eliminating few tasks. Overall cycle time was reduced by 68 s to 7 min 44 s (464 s). For Robot-1, sequence has been changed to “1 - 2 - 3 - 4 - * - 5 - 6 - 7 - 8 - 9 - 10 - *” where “*” represents added activity. So, after completion of the fourth task, that is, “Side body Panel spots,” rather than going for “Gripper off” activity it will wait for the roof to be docked by Robot-2 and then it will perform “Panel spotting of a roof” which was a task of Robot-2 initially. Similarly, after completion of “Front panel re-spotting,” rather than going to “home position,” it will do “Roof Re-spotting,” which was currently the task of

TABLE 3 Sequence of Robot-3

Current sequence	Process time (s)	Hold time (s)	Optimized sequence	Process time (s)	Hold time (s)
Gun pick	06	14	Gun pick	06	32
Roof header	30		Roof header	30	
Back panel	60		Gun drop	10	
Gun drop	10		Gripper pick	28	
Gripper pick	28		Gun pick	26	
Gun pick	06	118	Back panel	60	
Roof (29)	23		Back trial 1	18	06
Back re-spot	20		Roof re-spot	23	
Front re-spot	40		Gun drop	06	28
Roof re-spot	23		Gripper drop	18	
Gun drop	06		Gun pick	06	
Gripper drop	18		Roof re Half	16	
			Front re-spot	40	
		52	Back re-spot	20	
			Roof (29)	23	
					10
Gun pick	06				50
Floor	28		Floor	28	
	Σ Process time = 304	Σ Hold time = 228		Σ Process time = 338	Σ Process time = 126

TABLE 4 Sequence of Robot-4

Current sequence	Process time (s)	Hold time (s)	Optimized sequence	Process time (s)	Hold time (s)
Yo-Yo	14		Yo-Yo	14	16
Header drop	06	40	Header drop	06	
Gripper drop	12		Gripper drop	12	40
Gun pick	06	25	Gun pick	06	22
Side panel	32		Front top	22	
Roof spot	28	52	Side panel	32	
Front top	22		Roof spot	28	
Front panel	70	04	Front panel	70	
Side re-spot	60		Side re-spot	60	
Front re-spot	20	11	Front re-spot	20	36
Header R4	40				
Floor spot	57	33		57	
					33
	Σ Process time = 367	Σ Hold time = 165		Σ Process time = 327	Σ Process time = 137

Robot-4. Because of these changes, its performance time increased to 241 from 204 s and idle time reduced to 223 from 328 s. Thus, the developed algorithm saved overall 68 s successfully.

For Robot-2, sequence has been changed to "1 - 2 - 4 - 5 - # - # - # - 9 - 10 - 3 - 13 - 11 - 12." Where "#" represents removed activity. So, after placement of the roof into the dock, that is, Activity 5, it used to take the Gun,

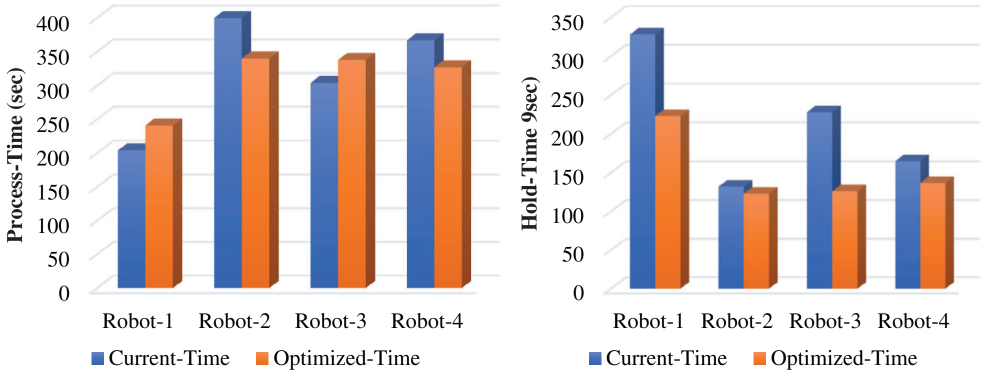


FIGURE 6 Process and hold time comparison of various robots during resistance spot welding

TABLE 5 Time comparison of different robots

Different robots	Activity	Current cycle	Optimized cycle	Time change	Time saved (s)
Robot-1	Process time (s)	204	241	−37	68
	Hold time (s)	328	223	105	
Robot-2	Process time (s)	400	341	59	68
	Hold time (s)	132	123	9	
Robot-3	Process time (s)	304	338	−34	68
	Hold time (s)	228	126	102	
Robot-4	Process time (s)	367	327	40	68
	Hold time (s)	165	137	28	

TABLE 6 Sequential changes in robot operations

Process	Robot-1	Robot-2	Robot-3	Robot-4
Change in Sequence	1 - 2 - 3 - 4 - * - 5 - 6 - 7 - 8 - 9 - 10 - * - 11 - 12	1 - 2 - 4 - 5 - # - # - # - 9 - 10 - 3 - 13 - 11 - 12	1 - 2 - 4 - 5 - 6 - 3 - * - 10 - 11 - 12 - 13 - * - 9 - 8 - 7	1 - 2 - 3 - 4 - 7 - 5 - 6 - 8 - 9 - 10 - #
Activity added in optimized	•5 •12	No	•7	No
Activity removed from current	No	•6 •7 •8	No	•11

complete the Panel spotting, and then used to remove the gripper. But now, the "Panel spotting," activity is being shared by Robot-1 and Robot-3. Thus, "Gun picks," "Panel spotting," "Gun drop" these three activities got removed from the list. There is some sort of sequencing in the middle of the play like there-spotting of side panel just after side grippers get off to prevent clashing with Robot-3. Because of these changes, its performance time reduced to 234 from 400 s and idle time was reduced to 123 from 132 s. Thus, saved overall 68 s successfully. For Robot-3, sequence has been changed to "1 - 2 - 4 - 5 - 6 - 3 - * -8 - 11- 12 - 13 - * - 9 - 8 - 7," where "*" represents added activity. After completing Activity 2, that is, "Roof header Panel spotting," It was supposed to go for "Side panel spotting." But to bring the front panel first, continue with your remaining task as Robot-4 was idle at that time. Previously shared some work of Robot-2, as said earlier. Thus, "Back panel spotting" activity of Robot-2 and "Roof header re-spotting" activity of Robot-4 is added. Because of these changes, its performance time increased to 338 from 304 s, and idle time reduced to 126 from 228 s. Thus, to save overall 68 s successfully. For Robot-4, sequence has been changed to "1 - 2 - 3 - 4 - 7 - 5 - 6 - 8 - 9 - 10 - #." Where "#" represents removed activity. So, after completion of Activity 4, that is, Gun pick, it performs "Front panel Panel-spotting" and then goes for "Side panel Panel-spotting" as Robot 3 brings the front panel the dock. In the end, before lifting the cabin, it used to perform "Roof header re-spotting" activity alone for 35 s. This activity got done by Robot-1 and Robot-3 earlier in the cycle. Hence this activity got removed. Because of these changes, its performance time reduced to 327 from 367 s, and idle time reduced to 137 from 165 s. Thus, the optimal algorithm saved production time overall 68 s successfully.

5 | CONCLUSIONS

Not solely that, however every other purpose because vehicle producers use robotic welders is their capacity to persistently meet enterprise expectations besides delays and inside time constraints. They produce accurate, notable welds with fewer errors and, thus, reduced accidents. Robots can additionally operate a myriad of jobs, such as welding, painting, finishing, and many others. Their programming enables maneuvering complicated duties as common tasks. With new enterprise requirements calling for lighter cars, these machines are capable to produce tighter welds that can solely be done by using robots. Robotic welders play a key position in the car enterprise through being able to produce new and advanced, excessive fantastic vehicles. As specs set with the aid of the enterprise turn out to be extra precise, these robots are capable to meet them quicker and greater efficiently. Semiautomatic welding, frequently exact for constrained portions of products, requires an operator to manually load the components into the fixture. A weld controller then ensures the welding, torch, and all components can meet the requested parameters. Once completed, the operator can endorse the completed assembly. In wholly automated system a "perfect welding" is crucial for good assembly.

DELMIA's robotics solution has solved this problem by providing a simple and powerful way to layout 3D virtual manufacturing environment and used it, efficiently, to simulate the modified production processes. With this modified production process, the commercial manufacturers can design, install, and ramp-up their robotic systems with confidence that they will perform as expected. Indeed, DELMIA, in the present work, went beyond programming and resulted in significant reduction in the cycle time of SML ISUZU plant. Furthermore, its analytic and visual capacity proved to be a good tool to integrate CAD and CAM, numerical output, graphical part description, simulation of machining sequence, and bottleneck identification. Further, accurate leveling and applying a simulating environment result in achieving the correct minimization of work cell cycle time. The updated sequence for all robots decreases the holding time for every robot, the holding time diminished by 32.01%, 6.82%, 44.74%, and 16.97% for Robot-1, Robot-2, Robot-3, and Robot-4, respectively. The optimal model reduced the whole cycle time by 68 s. The current cycle time is 532 s, which is reduced to 464 s by using an optimal algorithm. Some of the areas which can be examined in the future are dual resources that could be added at the gun docking position to reduce cycle time, thereby increasing productivity. Sequential changes in the 216 spotted cycle that is being done could be applied to the 150 spotted cycles, which is used in high rated production conditions. The speed and acceleration of both servo and hydraulic motor can be increased. It will bring the floor panel to the working position quite earlier than the actual. The simulation completed in "*DELMIA*-V5" software can reduce the cycle time of the spot-welding robotic cell. It can be forecasted that specific investigations should be made to identify the economic benefits of the RSW system in-terms of higher efficiency and reduction in the number of expensive failed attempts, reduce the prototyping cost, reduction in the machining and straightening costs, shortening the time-to-market, optimal use of the material and energy, and sustainability.

CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

AUTHOR CONTRIBUTIONS

Harish Kumar Banga: Conceptualization; data curation. **Parveen Kalra:** Conceptualization; formal analysis. **Raman Kumar:** Investigation. **Sunpreet Singh:** Methodology; project administration. **Catalin Pruncu:** Investigation; methodology; writing-review and editing.

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How to cite this article: Banga HK, Kalra P, Kumar R, Singh S, Pruncu CI. Optimization of the cycle time of robotics resistance spot welding for automotive applications. *J Adv Manuf Process*. 2021;e10084. https://doi.org/10.1002/amp2.10084