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Productivity and Plant Capacity Improvement of the Automobile Industry using different Soft Computing Technologies

Mayank Kumar Agrawal
Lecturer, Department of Mechanical Engineering
Department of Mechanical Engineering
Dayalbagh Educational Institute,
Agra, 282005, India

Dr. Ashok Yadav
Associate Professor, Department of Mechanical Engineering
Dayalbagh Educational Institute,
Agra, 282005, India

Prof. Ravi Shankar
Professor Department of Management Studies
Indian Institute of Technology Delhi,
New Delhi, 122010, India

Mr. Rishabh Singhal
Software Developer
Amazon,
Hyderabad, 500001, India

***Abstract*— This paper offers the findings of a study whose main goal was to examine the effects of productivity development strategies in the automotive sector. Robotic arm/manipulator route optimization in targeted areas aids in the elimination of non-value adding operations and increases productivity. In order to advance toward lean manufacturing and to improve operational efficiency, Kaizen tool is utilized. Finding bottleneck locations in robotic welding in the automobile sector is the main goal of this effort. Analysis of line stops and delays, reduction in downtime, and the development of various waste-reduction measures are the major goals. (Similar analysis can be done for automobile painting and assembly shops.) By applying the TSP (Traveling Salesman Problem), the Nearest Neighbor Heuristic, and the Clarke and Wright Algorithm, a significant decrease in travel time of the robotic arm leading to energy saving, increased productivity, and decreased vehicle waiting time can be achieved which will eventually lead to increase in market share.**

Keywords*— *Clarke and Wright Algorithm, Nearest Neighbor Heuristic, Productivity, Robotic arm/Manipulator.

I. INTRODUCTION (*Heading 1*)

Transportation has become life force in this century. It plays a major role in every important area of our life like education, business, security and improving quality of human life. Rapidly growing population of developing nations such as India, China and Brazil has made research and development in all aspects of transportation system highly imperative.

The Indian Automobile Industry is one of the largest, most diverse and least planned transport in the world. The 21st Century brought rapid growth to India; the passenger car industry has benefited most in the transportation sector. As of 2021, India is home to 256 million passenger vehicles, making India the fastest growing Automobile market in the world. According to the Society of Indian Automobile Manufacturers annual vehicle sales are projected to increase at a rate of 9 million per year by 2023. By 2050, the country is expected to have more than 611 million vehicles on the nation's road.

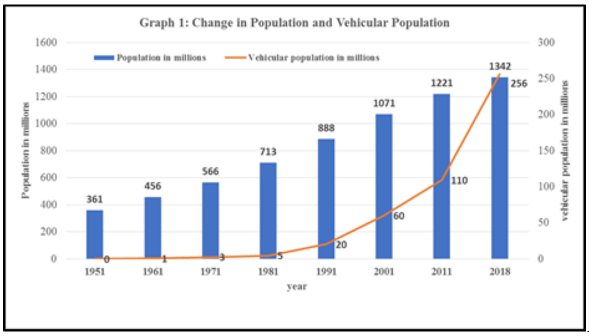

Fig.1: Showing the growth in Vehicle and Population sectors

The above graph [1]-[10] is showing the growth in population and vehicular population from 1951 to 2018. Rapid growth is seen after 1983, when Maruti started its production and after 1991 when international Original Equipment Manufacturers (OEMs) started to appear in the Indian market.

India's automobile sector, which produces four-wheeled vehicles, is confronted with a number of difficulties, including intense rivalry and rising competitive pressure [11]. The requirement for business improvement in all facets of production as a result of the rise in demand has led to the deployment of continuous improvement tools across all automotive-related businesses. In order to improve processes with a strong emphasis on cost-cutting, quality improvement, and productivity growth, kaizen is used as a method to eliminate non-value-added operations [12]. Tools for continuous improvement are desperately needed in modern industry to boost productivity. By recommending continuous development and further optimizing welding paths for the robot used in welding shops for spot welding operations in the four-wheeler industries, this study aims to investigate bottleneck locations. The Nearest Neighbor heuristic, the Clarke and Wright Algorithm and The Traveling Salesman Problem (TSP) are used to identify the most acceptable, feasible, and

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interference-free welding pathways for robotic arms and manipulators.

Path optimization for robotic arms (Fig.2) and manipulators is a technology that has a variety of uses. One of the locations is the welding shop, where the spot welding procedure is carried out by a manipulator or a robotic arm. A predetermined number of spots must be welded using the manipulator/robotic arm [13] in spot welding procedures, as indicated in figure 1. The manipulator/robotic arm is designed to weld at one location before moving to the next location until all of the locations are welded. However, no logic was added to the manipulator's programming to guarantee that it would go the smallest distance possible while doing so with the least amount of time. Time was lost as a result of the manipulator's/robotic arm's deviation from the shortest practical path in order to cover the necessary number of places.

The path used by the manipulator/robotic arm to weld all the places is repeated using a previous approach, as shown in figure 8(a) (on page no. 5). As soon as the flaws of this strategy became apparent, a mechanism for minimizing time waste during the spot welding process had to be established. This made it necessary for the manipulator/robotic arm's path to have the shortest distance and, consequently, the shortest time. To identify the path with the shortest distance between all the points (or dots), the Nearest Neighbor heuristic is utilized [14]

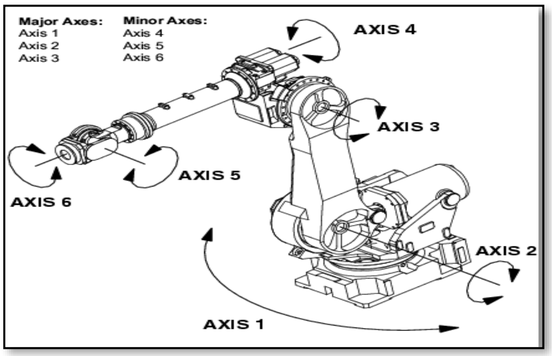

Fig.2: Robotic Arm or Manipulator (Make Fanuc)

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II. Literature Review

To meet increasing demand of market many automobile players are expanding their companies or focusing to improve productivity without capital investment.

Weld, Paint and vehicle assembly are the main workshops to manufacture a four wheeler. These may be bottleneck for different players. Various methods are applied to increase efficiency of an automatic welding workshop in which spot welding is done by robotic manipulators.

Approximately 8% of total energy in production is consumed in spot welding process of an automobile industry [15]. The process comprises of logging robot trajectories through software functions existing in the robots. The method is tested on KUKA robots in the laboratory at Chalmers University of Technology in Sweden and in the laboratories in the German companies KUKA Robotics GmbH and Daimler AG. The optimization results reduced up to 30% of energy consumption and up to 60% in peak power.

For instance, in a typical body shop, over 300 robots assemble roughly 200 to 400 parts using a total of 2500 to 4000 spot welds before they are dispatched to the paint shop [16]. An average of 180-kg-payload body shop robot consumes energy of about 8MWh in a year [17] and robots overall consume approximately 8% of the total electrical energy in production processes.

The problem of effective motion planning for industrial robots are seen at present for which trajectory of manipulator is optimized using the principle of interpolation in the configuration or Cartesian space [18].

Zengxi, P. et al., tackles the complexity of programming which is one of the major hurdles, preventing automation using industrial robots for small to medium enterprises (SMEs) [19]. The solution to such problem is a comprehensive review of the recent research progresses on the programming methods for industrial robots, including online programming, offline programming (OLP) [20], and programming using Augmented Reality (AR) techniques. Different online programming softwares are listed in the table below:

Table 1
Online Programming software package

	Software/ Ref	Company/Feature
Generic Robotics Software	Delmia (IGRIP, ENIVISION); Kineo, CENIT; [23]	Dassault Systems; VR
	Rob CAD (Emworkplace) [24][25]	Technomatix; VR
	Robomaster	Robomaster
	Robsim; [26]	Camelot
	Workspace 5	Wat Solutions
	Cosimir	Festo
Robotics Software from Robot Manufactures	RobotStudio	ABB: Most Popular
	MotoSim	Motoman
	KUKA-SIM, CAMrob;[27]	KUKA
	Roboguide	Fanuc
	Wincaps III	Denso
	D STUDIO	Staubli
	MELFA WORKS	Mitsubishi
	Pc-ROSET	Kawasaki
	AX on Desk	Nachi

Glorieux E. et al., discussed a methodology for collision free trajectory and coordination optimization of cyclic multi-robot systems, both velocity tuning and time delays are used to coordinate the robots that operate in close proximity and avoid collisions. This methodology can be demonstrated for productivity/smoothness optimization, and for energy conservation. It can also be verified for Multi-stage tandem sheet metal press line of an automobile industry [21].

The traditional manual path planning processes are less efficient, and cannot guarantee optimality. To obtain shortest collision free welding paths GA, PSO and improved GA-PSO algorithms are used which results in terms of no. of iteration, error, strong searching ability and practicality [22].

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Figure 3: Pictorial view of Multi robot spot welding process

III. METHODOLOGY

Welding is an essential part of manufacturing industry, and welding robots are widely used to decrease costs, improve quality and increase productivity. Existing simulation tools such as Rob cad, IGRIP or Catia are unable to solve the problem of optimal robot motion planning. Existing literature gives methods based on the *Rob cad* simulation model which are less feasible for real robotic work cell to give our proposal an insight. We have selected spot welding robots which are widely used in four wheeler manufacturing.

To find a reasonable path of spot welding robot we propose a MATLAB based program. We compare convergence rate of solution of the Clarke and Wright Algorithm with different evolutionary techniques.

Here we propose an approach in which we will optimize the trajectory of spot welding manipulator by using evolutionary techniques like the Nearest Neighbor heuristic, the Clarke and Wright Algorithm and GA etc. With this approach trajectory of robot can be optimized which will minimize the distance travelled by the robot and reduce energy consumption in manufacturing process.

Vehicle routing Problem: The Vehicle routing Problem has wide spread application backgrounds and this important theory optimizes value in combination with efficiency [23]. The idea of Vehicle routing problem to find the shortest tour path between a given number of cities, and each city can be visited only one time to achieve maximum efficiency in terms of distance, time and cost of trip. The feasibility of this solution is (n-1)! /2, when 'n' is the number of cities. If the number of cities increases, the feasibility of the solution increases as well formulating this problem requires the introduction of a decision variable x_{ij} which is given a value of 1.

If the salesman goes from i to j otherwise $x_{ij} = 0$, this is expressed mathematically by

$$\sum_{i=1}^{n} x_{ij} = 1 \quad i = 1, 2, \ldots n$$

(Because it is assumed that the salesman visits every city once)

$$\sum_{j=1}^{n} x_{ij} = 1 \quad i = 1, 2, \ldots n$$

(Because every city must be visited)

Where the objective function is:

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij}\, x_{ij} \quad = z$$

$$d_{ij} = distance\ from\ city\ i\ to\ j$$
$$x_{ij} = constaints$$

And constraint is:

$$\sum_{i=1}^{n} x_{ij} = 1\ \forall j$$

And

$$\sum_{j=1}^{n} x_{ij} = 1\ \forall i$$
$$x_{ij} + x_{ji} = 1 \quad i, j$$

Step 1: In this problem, total 20 spots are to be welded on inner door of a notch back.

Step 2: The distances between each of the spots are entered in the distance matrix as shown in table1.The distance matrix is a square matrix with 20 rows and 20 columns. The diagonal of the square matrix is a zero line, which results from the fact that the distance of each spot from itself is zero.1st row shows the distances of spot 1 from every other spot. For instance, the 2nd cell in the 1st row shows the distance of spot 1 from spot 2 (3.5cm in the present situation).Similarly, the 2nd row shows the distances of spot 2 from every other spot. If seen in a different way, the 1st column also shows the distances of spot 1 form every other spot. Similarly, the 2nd column shows the distances between spot 2 and every other spot. The data on the two sides of the zero-diagonal line is a mirror reflection of each other.

Step 3:-The software generates a list of all the possible paths and displays it in the solution summary area. It also shows the distance traversed by the manipulator/robotic arm corresponding to each path [24].

Step 4:-The most feasible /the 'best' near optimal path (row 8th as shown in figure 7) for the manipulator /robotic arm is implemented for spot welding operation as shown in figure 8(b).

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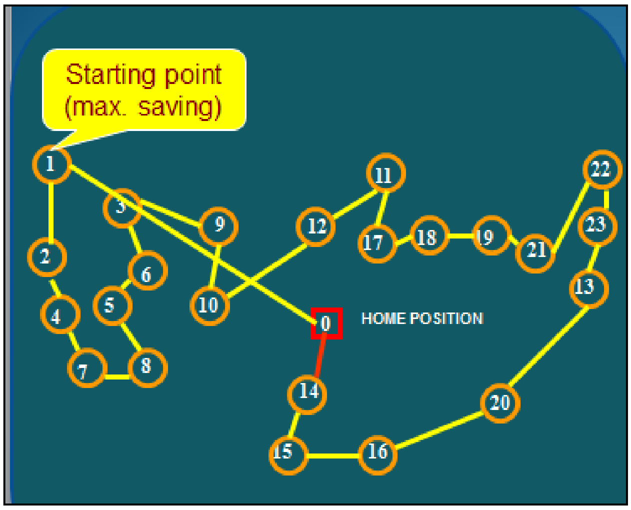


Fig. 4: The example path showed motion of Robotic arm/manipulator path

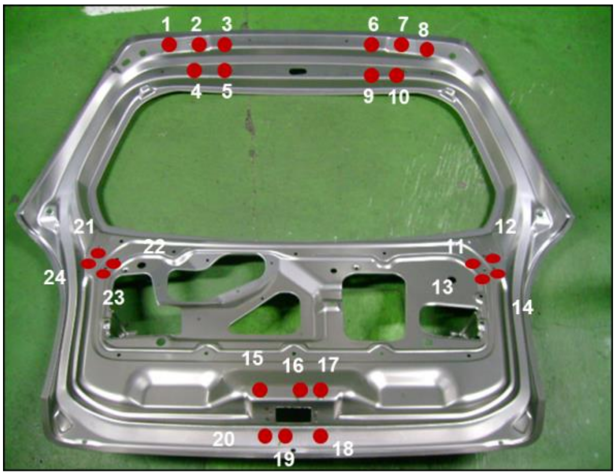


Fig. 5: Actual Spot Data for inner door

Table 2: Distance diagonal matrix for spots located inner door

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	**0**	3.5	27	55	62	67	69	74	78	16	15	14	60	63	65	32	56	71	128	103
2	3.5	**0**	25.5	53	59	66	67	71	74	19	17	16	57.5	59.5	60.5	29	56.5	71	128	103
3	27	25.5	**0**	29	35	40	43	50	56	42.5	40	38	39	42	44	38	73	89	139	89
4	55	53	29	**0**	7	12	14	25	33	70	68	66	23	27	30	58	96	108	152	79
5	62	59	35	7	**0**	6	9	20	31	76	74	72	24	28	31	63	102	111	159	79
6	67	66	40	12	6	**0**	4	19	29	81	79	77	27	30.5	33	69	110	119	162	79
7	69	67	43	14	9	4	**0**	16	26	85	83	81	25	28	30	70	110	120	162	77
8	74	71	50	25	20	19	16	**0**	10	90	88	86	18	20	21	67	105	114	155	62
9	78	74	56	33	31	29	26	10	**0**	92	90	88	19	17	17	66	105	110	150	53
10	16	19	42.5	70	76	81	85	90	92	**0**	5	9	73	76	77	37	49	64	122	109
11	15	17	40	68	74	79	83	88	90	5	**0**	4	72	75	77	39	54	69	125	110
12	14	16	38	66	72	77	81	86	88	9	4	**0**	74	76	79	42	56	72	130	111
13	60	57.5	39	23	24	27	25	18	19	73	72	74	**0**	5	8	48	88	97	137	57
14	63	59.5	42	27	28	30.5	28	20	17	76	75	76	5	**0**	3	50	89	96	133	52
15	65	60.5	44	30	31	33	30	21	17	77	77	79	8	3	**0**	51	8	97	131	49
16	32	29	38	58	63	69	70	67	66	37	39	42	48	50	51	**0**	41	51	102	74
17	56	56.5	73	96	102	110	110	105	105	49	54	56	88	89	8	41	**0**	16	79	97
18	71	71	89	108	111	119	120	114	110	64	69	72	97	96	97	51	16	**0**	55	97
19	128	128	139	152	159	162	162	155	150	122	125	130	137	133	131	102	79	55	**0**	111
20	103	103	89	79	79	79	77	62	53	109	110	111	57	52	49	74	97	97	111	**0**

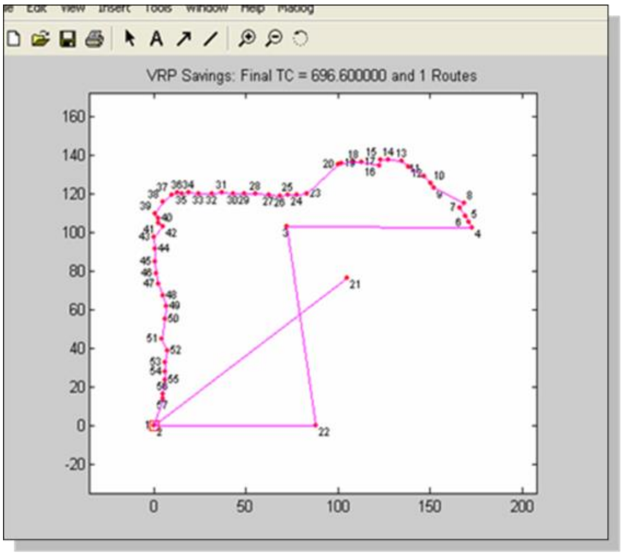
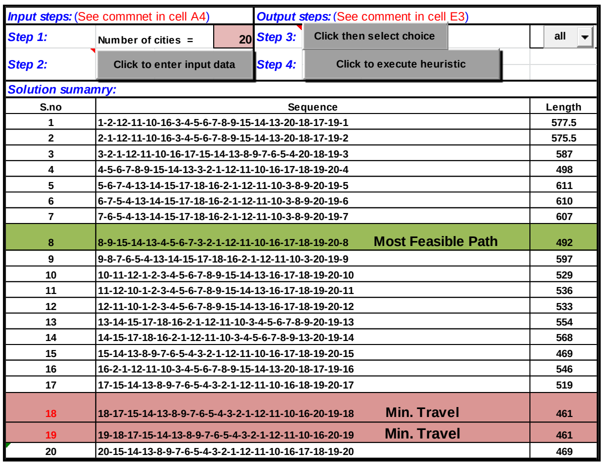


Fig. 6: Optimized Programme path



Input steps: (See commnet in cell A4) | Output steps: (See comment in cell E3)
Step 1: Number of cities = 20 | Step 3: Click then select choice | all
Step 2: Click to enter input data | Step 4: Click to execute heuristic
Solution sumamry:

S.no	Sequence	Length
1	1-2-12-11-10-16-3-4-5-6-7-8-9-15-14-13-20-18-17-19-1	577.5
2	2-1-12-11-10-16-3-4-5-6-7-8-9-15-14-13-20-18-17-19-2	575.5
3	3-2-1-12-11-10-16-17-15-14-13-8-9-7-6-5-4-20-18-19-3	587
4	4-5-6-7-8-9-15-14-13-3-2-1-12-11-10-16-17-18-19-20-4	498
5	5-6-7-4-13-14-15-17-18-16-2-1-12-11-10-3-8-9-20-19-5	611
6	6-7-5-4-13-14-15-17-18-16-2-1-12-11-10-3-8-9-20-19-6	610
7	7-6-5-4-13-14-15-17-18-16-2-1-12-11-10-3-8-9-20-19-7	607
8	8-9-15-14-13-4-5-6-7-3-2-1-12-11-10-16-17-18-19-20-8 Most Feasible Path	492
9	9-8-7-6-5-4-13-14-15-17-18-16-2-1-12-11-10-3-20-19-9	597
10	10-11-12-1-2-3-4-5-6-7-8-9-15-14-13-16-17-18-19-20-10	529
11	11-12-10-1-2-3-4-5-6-7-8-9-15-14-13-16-17-18-19-20-11	536
12	12-11-10-1-2-3-4-5-6-7-8-9-15-14-13-16-17-18-19-20-12	533
13	13-14-15-17-18-16-2-1-12-11-10-3-4-5-6-7-8-9-20-19-13	554
14	14-15-17-18-16-2-1-12-11-10-3-4-5-6-7-8-9-13-20-19-14	568
15	15-14-13-8-9-7-6-5-4-3-2-1-12-11-10-16-17-18-19-20-15	469
16	16-2-1-12-11-10-3-4-5-6-7-8-9-15-14-13-20-18-17-19-16	546
17	17-15-14-13-8-9-7-6-5-4-3-2-1-12-11-10-16-18-19-20-17	519
18	18-17-15-14-13-8-9-7-6-5-4-3-2-1-12-11-10-16-20-19-18 Min. Travel	461
19	19-18-17-15-14-13-8-9-7-6-5-4-3-2-1-12-11-10-16-20-19 Min. Travel	461
20	20-15-14-13-8-9-7-6-5-4-3-2-1-12-11-10-16-17-18-19-20	469

Fig.7: Screen Shot showing most feasible/best path starting from spot 8 (or dot 8) and completing at spot 20 in green color (S.No.8 and length 492), no collision between robots operation.

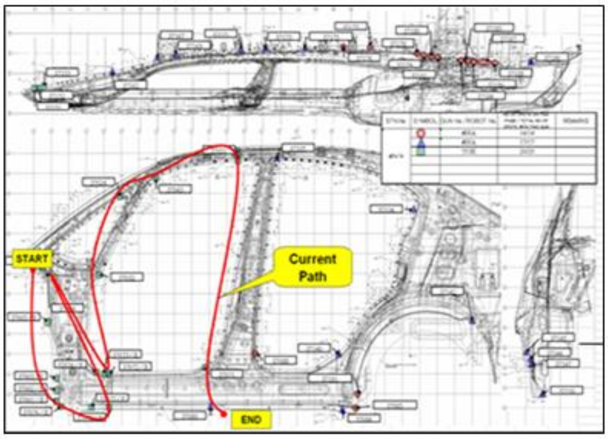


Fig 8(a): Robotic arm/manipulator path profile for inner door spot welding (without optimization)

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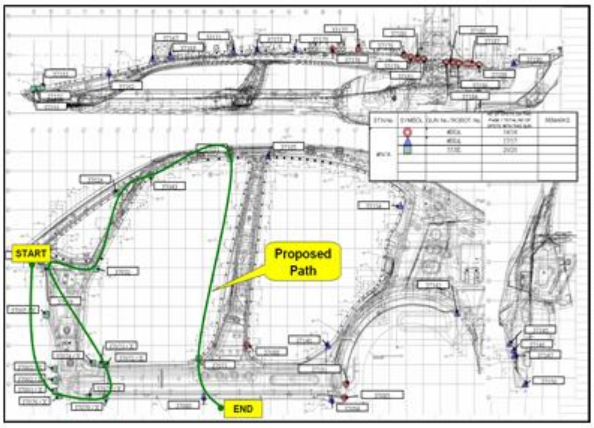

Fig 8(b): The most feasible optimal path (the path in which robots don't have chance of collision during operations)

IV. Result and Discussions

The welding paths of robots were studied in detail and a matrix for the paths was developed. The optimal and at the same time feasible path are selected for inner door spot welding operation. The developed path details are shown in Figure 7.

The Fig. 8 (b) shows the most feasible optimized improved path [25] of the manipulator/robotic arm (inner door spot welding of notch back car) and was observed significant reduction in tack time (as shown in table 4) without any collision between the robots during operations.

Table 3

Comparison of different Soft Computing Techniques Computational Time and Performance

Input Nodes		36	65	20
Nearest Neighbor Heuristic	Least Distance	317	679.2	461
	Computational Time (Sec)	0.978	4.032	0.325
OR tools	Least Distance	288	563.2	452
	Computational Time (Sec)	0.0189	0.1049	0.0029
Clarke and Wright Algorithm	Least Distance	279.5	484.2	452
	Computational Time (Sec)	0.6359	6.216	0.138
Remark	Least Distance by CW Algoritm	279.5	484.2	452
	Least Computational Time by OR Tools	0.0189	0.1049	0.0029

Table 4

Operation time saved after robotic arm/manipulators path optimization

After optimization of path			
Robot ID	Timing before optimization	Timing after optimization	Time saved
M/B#3	110 Sec	89 Sec	21 Sec

The shortest path was obtained by the Clarke and Wright Algorithm as shown in table 3. We therefore conclude the Clarke and Wright algorithm is better than other two soft computing techniques to find the optimized path. By implementing this new workable paths productivity is increased by 8%.

V. CONCLUSION

The study has highlighted the need of optimizing the welding path of robots. This will further make manufacturing economical and have competitive edge over the various players of manufacturing in the automobile field.

- To achieve enhanced productivity, companies need to be able to highlight the bottleneck areas and then apply appropriate tools and optimization techniques.
- Optimization of robotic arm/manipulator path in focused areas helped in eliminating non value adding activities and resulted in increased productivity.
- The increasing demand of industries can be met easily by enhancing productivity.

REFERANCES

[1] https://community.data.gov.in/composition-of-vehicle-population-in-india-from-1951-to-2015/
[2] https://en.wikipedia.org/wiki/2011_Census_of_India
[3] https://en.wikipedia.org/wiki/2001_Census_of_India
[4] https://en.wikipedia.org/wiki/1991_Census_of_India
[5] https://countryeconomy.com/demography/population/india?yar=1981
[6] https://countryeconomy.com/demography/population/india?year=1971
[7] https://en.wikipedia.org/wiki/1961_Census_of_India
[8] https://en.wikipedia.org/wiki/1951_Census_of_India
[9] https://timesofindia.indiatimes.com/auto/miscellaneous
[10] https://community.data.gov.in/category-wise-registered-motor-vehicles-in-india-during-1951-2011/
[11] Shanmugam, K. R. and S. N. Bhaduri (2002), "Size, Age and Firm Growth in the Indian Manufacturing Sector". Applied Economics Letters 9(9): pp. 607-613.
[12] International Labour Organisation, 'Introduction to Work Study', Universal Publishing Corporation, India, 1986, pp.192
[13] Ae-Hyoung Park,(2005), "Path Planning of Automatic Optical Inspection Machines for PCB Assembly Systems" IEEE International Symposium on Computational Intelligence in Robotic and Automation.
[14] Hassin, R.; Rubinstein, S. (2000), "Better approximations for max TSP", Information Processing Letters", 75 (4): 181–186.
[15] Sarmad Riazi, Oskar Wigström, Kristofer Bengtsson, and Bengt Lennartson, "Energy and Peak Power Optimization of Time-Bounded Robot Trajectories", IEEE transactions on automation science and engineering, Vol. 14, 2017.
[16] M. Todtermuschke, M. Findeisen, and A. Bauer, "Methodology for creation a reference trajectory for energetic comparability of industrial robots in body shop", Procedia CIRP, Vol. 23, pp. 122–126, 2014.
[17] D. Meike and L. Ribickis, "Energy efficient use of robotics in the automobile industry", in Proc. 15th Int. Conf. Adv. Robot. (ICAR), pp. 507–511, 2011.
[18] Pavol Božek, "Robot Path Optimization For Spot Welding Applications In Automotive Industry", ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) UDC/UDK 004.896:004.94]:621.791.763.
[19] Zengxi Pan, Joseph Polden, Nathan Larkin, Stephen Van Duin, and John Norrish, "Recent Progress on Programming Methods for Industrial Robots", ISR / ROBOTIK, 2010.
[20] Bottazzi, V.S., Fonseca, J.F.C., "Off-Line Robot Programming Framework", Joint International Conference on Autonomic and Autonomous Systems and Networking and Services, ICAS-ICNS 2005. Page(s):71 – 71, 2005.
[21] Emile Glorieux, Sarmad Riazi and Bengt Lennartson, "Productivity/Energy Optimization Of Trajectories And Coordination For Cyclic Multi-Robot Systems", Robotics And Computer–Integrated Manufacturing 49, pp. 152-161, 2018.
[22] Xuewu Wang, Yingpan Shi, Dongyan Ding and Xingsheng Gu, "Double Global Optimum Genetic Algorithm–Particle Swarm Optimization-Based Welding Robot Path Planning", ISSN: 0305-215X, 2015.
[23] Grotschel, M.,(1980), "Symmetric traveling salesman problem: Solution of a 120-city problem. Mathematical programming study", 12, pp. 61-77
[24] P. Mahakantee and K. Chamniprasart (2012), "Control of Robot Motion for the Shortest Path from Point to Point Through from Machine Vision", 2nd International Conference on Materials, Mechatronics and Automation Lecture Notes in Information Technology, Vol.15.
[25] Shanmugam, K. R. and S. N. Bhaduri (2002), "Size, Age and Firm Growth in the Indian Manufacturing.

BIOGRAPHIES

Mr. Mayank Agrawal is working as Lecturer in the Department of Mechanical Engineering, in D.E.I. Technical College, Dayalbagh, Agra since 2013. He did his B.Sc. in Engineering and M. Tech. from D.E.I. in 2010 and 2018, respectively. He was awarded the prestigious Founder's Medal for the Best Student among all undergraduate students and Director's Medal for securing highest marks in Comparative Study of Religion and Cultural Education in 2010. He represented the DEI at National level Inter-University Hindi Debate competition in A.M.U. (2009), Delhi University (2008) and National Co-Operative Society (2007) and won prizes for Best Team and Best Speaker. Through on-campus placement he was selected in Maruti Suzuki India Ltd, Punj Lloyd Ltd, and L&T. He joined Maruti Suzuki India Ltd in June, 2010 and worked there as an Assistant Manager for three years. During this period he worked in the Production Planning and Control department. He worked on productivity and capacity enhancement for mix model weld shop as a result of which his team was able to reduce the waiting time of Swift Desire in market. Now, he teaches Mechanics of Solid, Production Automation and Computer Integrated Manufacturing, Production Technology etc. and holds various responsible positions in the Institute.

Dr Ashok Yadav, PhD is Associate Professor in the Department of Mechanical Engineering, Faculty of Engineering, DEI with more than 20 years of teaching experience. He teaches Refrigeration and Air Conditioning, Heat Transfer, IC Engines, Automobile Engineering, Energy System Management, Applied Thermodynamics and Renewable Energy Sources like wind energy, solar energy, and geothermal thermal energy. His research interests include renewable energy, alternate renewab le fuels (Bio-diesels) for CI Engines, Life Cycle Analysis (LCA), Solar Energy and Energy Management. Presently, he is engaged in various projects in the area of Phage Change Materials (PCM), Bio-aerosol and Health, Development of Eco-friendly Grain Dryer, direct sub-surface water recharge system (ground water recharging), cooling/heating using Ground Source Heat Pump. He has authored more than 40 research papers which have been published in archival journals of high repute like Journal of Power and Energy, IMechE (London), National Journal, International and National conferences. He is also member of several professional bodies like Institution of Engineers India, IE(I) and Indian Society of Heating, Refrigeration and Air conditioning Engineers, ISHRAE. Presently, he is Chairman of Institution of Engineers (India), Agra Local Center.

Dr. Ravi Shankar is Professor of Operations and Supply Chain Management in the Department of Management Studies (DMS) Indian Institute of Technology (IIT) Delhi India. He is Fellow of prestigious Indian National Academy of Engineers (FNAE). His research citations exceed 33,175 with an H-index of 77 (February 2022). His areas of interest include Business Analytics & Optimization, Project Management, Sustainability, and Technology Management & Innovation. Hon. Minister Human Resource Development (Govt. of India) honoured Prof Ravi Shankar with "Outstanding Faculty Award" on March 20, 2018 in the domain of Business, Management and Accounting during 2015-17. This was organised by Career360: Faculty Research Award. The citation presented to him, puts on record that Prof. Ravi Shankar is "The Most Research Proficient Faculty of India for the Year 2018." On January 20, 2019, he received "Dr R. P. Mohanty Gold Medal for Outstanding Teacher Award" for the year 2018 by Indian Institute of Industrial Engineering (IIIE), Mumbai India. He was conferred the prestigious "Fellow of Indian National Academy of Engineers (FNAE)" in December 2017 in the Inter-disciplinary Engineering and Special Fields (Section X). With a rich industry and teaching experience of over 35 years, Prof. Shankar has provided consultancy to various Industries and Government Departments. His many completed funded projects include, major International funded projects from UKIERI British Council, European Union, and University of Connecticut USA. He has published over 300 research papers and co-authored 09 books, including four most popular text books in the area of Supply Chain Management, Operations Management, Management of Technology, and Strategic Management of Technology Innovation. His research papers have appeared in leading journals like Journal of Operations Management, European Journal of Operational Research, International Journal of Production Economics, Transportation Research Part E, Computer and Operations Research, Omega: An International Journal of Management Science, Decision Support System, International Journal of Production Research, Technological Forecasting and Social Change, Transportation Research Part A, Computer and Industrial Engineering, Supply Chain Management: An International Journal, Journal of Knowledge Management, Journal of Cleaner Production, Production Planning and Control, International Journal of Quality and Reliability Management, IEEE Transaction in System Man and Cybernetics (Part-C), etc. Recently, two of his co-authored research papers appeared in the top 15 papers published in International Journal of Production Research (2017) and adjusted for "Best Paper Award". He has trained over 5000 corporate professionals through online and class-room training programs in the area of Business Analytics & Optimization, Project Management, Supply Chain Management, Naval Operations Analysis (especially developed for Indian Navy Officers), Six Sigma - Green Belt, Supply Chain Excellence, Production & Operations Management, Advanced Program in Software Engineering & Management (APSEM), Enterprise Resource Planning, etc.

Rishabh Singhal is currently working as a software developer at Amazon. He graduated from Dayalbagh Educational Institute, Agra in 2021 and has a professional working experience of 1.5 years. He has a keen research interest in theoretical computer science, quantum information and quantum computing, combinatory and optimization. He has published papers in national and international conferences and journals.