COMPARATIVE APPROACH FOR WORK STUDY AND RTA (ROBOT TIME ANALYSIS) METHOD ON POWDER COATING LINE BASED ON MINIMIZATION OF COST

Gunvanta T. Dhanuskar*

Jayant P. Giri**

Dr.V.S.Tatwawadi***

S.G.Mahakalkar****

Abstract:

The aim of this research paper is to minimize the processes and production cost in a spray powder line. The coating operation is the bottleneck point in modular furniture industries. For minimize the wastage of the powder by avoiding overspray painting on the article and improved the quality of the coating by using work study methodology and RTA method. Both are widely used to produce articles as per customer's demands. The sequencing is an important factor in powder coating industries. For resolved the sequencing problem in favour of minimizing the total cost and keeping uniform usage of each part and cost model is presented. To get best alternative between work study and RTA method, a comparison is done, concerning sequencing problem. This investigation suggests best sequence of the process and method. It gives continued consumption of parts as well as reducing cycle time which helps for higher production and cost saving.

Keywords- work study; powder coating; robot time analysis; sequencing operation.

* M.Tech. (Production Engineering) Department of Mechanical Engineering, Y.CC.E, Nagpur, India.

** Assist. Professor, Department of Mechanical Engineering, Y.C.C.E., Nagpur, India.

*** Principal of Data Meghe Institute of Technology and Research, Wardha, India.

**** Associate Professor, Department of Mechanical Engineering, Y.C.C.E, Nagpur, India.

I. INTRODUCTION :

The powder coating operation are widely use in industries to performing painting operation on the different article as per customer's demands. The powder coating is by far the youngest of the surface finishing techniques in common use today. Powder coating is the technique of applying dry paint to a part. The final cured coating is the same as a wet paint. In normal wet painting such as house paints, the solids are in suspension in a liquid carrier, which must evaporate before the solid paint coating is produced. The coating operations are performed in spray booth by manually or using automation. As the global economy becomes more competitive, industrial production requires more automation along with process optimization and increasing of plant availability. But the initial cost of the automation is high. Work study is performed on the existing line for improve the sequence of the processes and increasing the production rate by making suitable changes in existing setup with small investment. The objectives of this research are as follows;

- The main objective of this project is to present the cost model and compare the performance of work study and RTA with respect to cost savings. Costs are included, cost of parts, holding cost of parts, line setup cost for each article, holding cost of finished goods, penalty cost for late delivery of finished goods.
- The second objective is to keep the constant consumption of each part in the line.

A. Work Study

Work study is a generic term for those techniques, particularly method study and work measurement, which are used in examination of human work in all its contexts, and which lead systematically to the investigation of all factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement. The two major techniques of work study is - Method study is the systematic recording and critical examination of existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs. Next one is Work measurement is the application of techniques designed to established the time for a qualified worker to carry out a specified job at a defined level of performance[24].

The basic procedure is a complete fundamental to the whole work study. The examination of the process follows the following sequence of phase in that order.

a) *Select* the work to be study.

b) *Record* all the facts relevant to the problem.

c) *Examine* the facts critically but impartially.

d) *Develop* the most practical, economic and effective method.

e) *Define* the new method so that it can be always being identified.

f) *Install* that new method as standard practice.

g) *Maintain* that standard practice by regular routine checks.

B. Robot Time Analysis

The amount of time required for the work cycle is an important consideration in the planning of the workcell. The cycle time determines the production rate for the job, which is the significant factor in the economic success of robot installation. In case of work performed by human operator, the time required to accomplish the cycle would be determined by one of several work measurement techniques. One of these work techniques is called MTM (for Methods Time Measurement). With MTM, the work cycle is divided into basic motion elements to construct the time for the total cycle.

The standard time values have been previously complied by studying similar elements and analyzing the factors that determine the time required to perform the element. An approach similar to MTM has been developed by Nof and Lechtman at Purdue University for analyzing the cycle times of robot work [28]. The method, called RTM (for Robot Time and Motion), is useful for estimating the amount of time required to accomplish a certain work cycle before setting up the work station and programming the robot. This would allow an applications engineer to compare alternative methods of programming a particular robot task. It could even be utilized as an aid in selecting the best robot for a given application by comparing the performance of the different candidates on given work cycle.

MODELLING OF KAWASAKI KF 121 ROBOT

Fig. 1 shows the typical sequence of phases involved in an electrostatic powder coating system. A dedicated overhead conveyor moves the workpieces. Only for large batches of workpieces an acceptable performance is achieved with rigid spray-painting systems. An automatic spray-painting machine with capacity to adjust itself to the shape of the workpieces is possible to make the system more flexible and more efficient to small batches. The main elements of a complete KF 121 Robot system are six degree of freedom robots actuated by AC servo motors carrying the spray guns, arranged in the way that one is facing the other with the conveyor in the middle, a sensor ring system using laser technology, and a PLC based control system with profibus to provide communications among the different modules. The sensor ring gives online a crude estimate of the object shape, more precisely an estimate of the parallelepiped envelope that entirely encloses the workpiece.

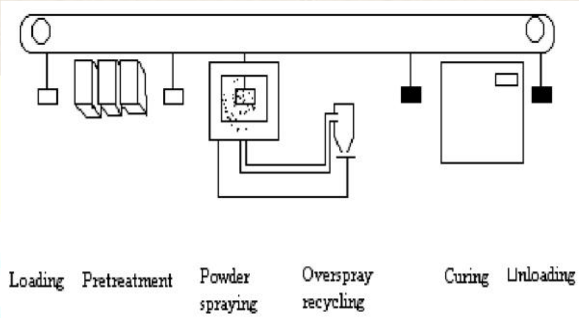

Fig. 1 Sequence of phases of a powder coating system.

The horizontal axis positions the guns in an appropriate distance from the workpieces and the vertical axis adjusts the vertical motion of the spray gun automatically to the piece height. The sensor ring is not lined up, it is before the robot actuation axes, allowing the anticipated estimation of the shape and the calculation of the spray-gun trajectory. In order to have appropriate coating trajectories, the machine should adapt itself online function of the conveyor velocity and workpiece dimensions, always having in view the guarantee of good quality of the painting. For that purpose a model of the process is an essential tool for the design of the KF 121 Robot machine. The required overall investment for the automation of the powder coating line is shown in table.

TABLE I

Investment	Cost (Rs)
1. Robot purchase cost (2)	80,00000
2. Engineering cost + Installation cost +Special tooling cost + Miscellaneous cost	10,00000

3. Total investment cost (1+2)	90,00000
4. Labor cost	967200
5. Maintenance cost	6000
6. Operating cost (4+5)	973200

II. PROBLEM DEFINITION:

In the modular furniture making industries, the powder coating line is the critical point. An operation, sequence of the coating and film thickness of the article is not defined. Because of this, powder consumption, power consumption, human effort and part per cost are more required. For minimized the problem, both method will be applied. RTA is equipped with overhead conveyor to deliver parts on coating the line, an electro-coating painting line which is broadly occupying robots. While in work study, coating and other operation performed by manually. Mostly, this work discussed for keeping constant parts consumption and minimum cost of production with selecting best method. But, in this study, it will be resolved the sequencing problem in favour of saving cost –production sequence is directly proportional to production cost, as sequence is controllable activity and proper sequencing provides continue consumption of each part and ultimately provides better cycle to fulfil the marketing demands, without backlog demand and holding cost.

III. ANALYSIS ON THE PROCESS BY USING WORK STUDY:

The recording is the step in the basic procedure, after selecting the work to be studied, is to record all the facts relating to the method. The success of the whole procedure depends on the accuracy with which the facts are recorded, because they will provide the basis of both the critical examination and the development of the improved method. For recording we are selected the seven different materials which is based on the;

- Large in shape and size.
- Critical in shape.
- For coating, article takes more time than standards.

- For coating, stop the conveyor for performing the operation.
- First article of the shifts.

The most commonly used of these recording techniques are charts and diagrams. There are several different types of standard charts available. For recording we are selecting the flow process chart. It is a process chart setting out the sequence of the flow of a product or a procedure by recording all events under review using the appropriate process chart symbols. The three types flow process charts, one of these man type flow process chart which records what the worker does. By using chart it will be find the operator utilization, working time and production rate.

IV. ROBOT TIME ANALYSIS METHODOLOGY:

The methodology of RTM is similar to MTM. There are ten general categories of robot work cycle elements. The categories can be collected into four major groups:

1) *Sensing Elements* - These are sensory activities performed by robots equipped with sensing capabilities.

2) *End Effecter Elements* - These elements relate to the action of the gripper or tool attached to the robot wrist as its end effectors.

3) *Delay Elements* - These are delay times resulting from waiting and processing conditions in the work cycle.

4) *Motion Elements* - These are manipulator movements, performed with or without load.

The robot work cycle must be divided into its corresponding elements, and each element is specified with its associated parameter such as distance, velocity, and so forth.

V. FACTORS TO BE CONSIDERED FOR RTA:

1) *Part Shape*- Complex part with recesses, curved surface & picture frames are challenge for the robot, whereas flat plates can be easily worked.

2) *Part Variety*- Output of robot depends upon the shape, size & similarity of products.

3) *Cycle Time*- Synchronization between robot speed, painting speed & product movement is essential.

4) *Capital & Operational Cost*- It is one time installation cost which eliminates the labor cost.

5) *Paint Saving – Repeatability*- In operations reduces accuracy, efficiency of manual work and so by using automation we can save paint.

6) *Conveyor*- Robot expects a part to be presented in a well defined position therefore a robot must know where the part is & how fast it is moving.

VI. CALCULATION OF RTA IN THE FORM RTM NOTATION WITH RESULTING TIMES FOR SEVEN MATERIALS:

By using third approach is "motion control", it can be applied to the group 1 elements involving robot motions. Motion control is concerned with the kinematic and dynamic analysis of the manipulator movement. It determines the element time values by considering the distances moved and the velocities to make the moves. It also considers acceleration and deceleration at the beginning and end of the moves. For example, if acceleration and deceleration are ignored for the movement, the time required to move the manipulator will be the distance (S) divided by the velocity (V). For some robot, the acceleration and deceleration times can be approximated closely by a constant value. In spray painting robot, tool (spray gun) is attached directly to the robot wrist and weight of the gun is 3 Pounds. The gun tip is maintained at a distance from approximately 10 inches to 2 inches from the object and powder is spread on the article upto 50 mm diameter.

TABLE II RTA notation and Parameters [28]

Element	Symbol	Element time, (s)	Parameters
1	R1	S/V+ 0.40 for S > V/2.5 0.40 for S < V/2.5	S= distance moved (ft) V= velocity (ft/s)
2	M1	For payload of less than 1.0 lb S/V+ 0.40 for S > V/2.5 0.40 for S < V/2.5 For payload between 1.0 lb and 5 lb	S= distance moved (ft) V= velocity (ft/s)

		S/V+ 0.60 for S > V/2.5 0.60 for S < V/2.5	
3	SE1	0.1V	V = previous velocity
4	GR1	0.1	Assumed to be independent of any parameters
5	RE	0.1	Assumed to be independent of any parameters
6	T	T	T = robot delay time
7	D	D	D = time process delay

Where,

R1– Is motion of manipulator from zero position to the object.

R2– Horizontal motion of robot arm.

R3– Vertical motion of robot arm.

M1– Motion of arm in vertical direction.

M2– Motion of arm in horizontal direction.

SE1–Bring the manipulator to rest immediately without waiting to null out joint errors.

VII. COST MODEL:

To calculate the different type of cost in work study and RTA, the cost model is developed. These costs are computed by using industrial data and by mathematical formulations. The comparative results are shown in below.

1) Production rate per shift

Production rate per shifts and other important details of the work study and RTA is given in the Table III and Table V; it should be calculated by using the chart details.

2) Average production cost per shift

The total direct cost and indirect cost for one shifts is find out by using chart data and overall industries data.

Total Direct Cost = Powder Cost + Fuel Cost + Power Cost + Labor Cost +Maintenance Cost

Then, Considered 10% as an indirect cost.

The total production cost of the one shifts are calculate by using total direct cost and indirect cost.

Total Production Cost = Total Direct Cost+ Total Indirect Cost

It is sufficient data to calculate the cost per product, time per piece; piece produced per min and productivity of the machine is shown in Table IV and Table VI. for work study and RTA method.

Cost of One Product = Total Production Cost / Total Production Unit

Time per Piece in Min = Shift Per Hr×60 / Production per Shift

Piece Produced per Min = 1/ Time per Piece

Productivity of the Machine = Productivity Unit / Machine Time

The RTA methodology will be applied on the powder coating processes, and then the cost model is prepared by comparing the work study cost model. The overall profit of RTA method for different cycle time is evaluated in Table VII

TABLE III
PRODUCTION PER SHIFT FOR WORK STUDY METHOD

Sr. No.	Product Name	Length (Cm)	Time taken to cross the door (S)	Activity 1	Activity 2	Operator working time (S) 1	Operator working time (S) 2	Waiting time (S) 1	Waiting time (S) 2	Total working time (S) 1	Total working time (S) 2	Total cycle time (S) (1+2)	Total number of part produced	Production per hour	Production per shift (7 hr)
1	10 CRCA long Plate	60	49	29	29	49.1	45.7	17.6	20.9	66.6	66.6	133.2	10	270	1890
2	8 Threseal Black Plate	48	45	33	33	40.2	38.7	22.4	24.0	62.6	62.6	125.2	8	230	1610
3	2 AL Plate	60	49	12	12	31.5	31.5	35.1	35.1	66.6	66.6	133.2	2	54	378
4	AL I Block	180	92	16	20	43.3	43.7	66.4	65.9	109.6	109.6	219.2	1	16	112
5	3 AL Triangular Black	50	46	23	23	33.8	30.1	29.9	33.5	63.6	63.6	127.2	3	85	595
6	AL Rectangular Box	25	38	12	12	30.7	27.5	24.9	28.1	55.6	55.6	111.2	1	32	224
7	AL Sieve Plate	120	71	14	14	44.5	45.8	44.1	42.8	88.6	88.6	177.2	1	20	140

TABLE IV
TOTAL DIRECT COST PER SHIFT FOR WORK METHOD

Article No.	Product produce in 1 min	Total surface area coated (M^2)	Total powder consume (Kg)	Powder cost (RS)	Fuel cost (RS)	Power consumption (Rs)	Labor cost (Rs)	Maintenance cost	Total direct cost (Rs)	Productivity of machine
1	4.5	85.05	8.51	1148.17	2280.85	15778	3750	685	23642.02	3.9
2	3.8	17.38	1.74	234.74	2280.85	15778	3750	685	22728.58	3.3
3	0.9	136.08	13.61	1837.08	2280.85	15778	3750	685	24330.93	0.78
4	0.27	120.96	12.09	1632.96	2280.85	15778	3750	685	24126.81	0.23
5	1.41	14.87	1.48	200.8	2280.85	15778	3750	685	22694.66	1.24
6	0.54	28	2.8	378	2280.85	15778	3750	685	22871.85	0.47
7	0.34	100.8	10.08	1360.8	2280.85	15778	3750	685	23854.65	0.29

TABLE V
PRODUCTION PER SHIFT FOR RTA METHOD

Sr. No	Product Name	Length (Cm)	Time taken to cross the door(S)	Activity 1	Activity 2	Robot working time (S) 1	Robot working time (S) 2	Waiting time (S) 1	Waiting time (S) 2	Total working time (S) 1	Total working time (S) 2	Total cycle time (S) (1+2)	Total number of part produced	Production per hour	Production per shift	Extra production per shift
1	10 CRCA long Plate	60	49	62	62	44.2	44.2	15	15	59.2	59.2	118.4	10	304	2432	542
2	8 Threseal Black Plate	48	45	53	53	25.6	25.6	15	15	40.6	40.6	81.2	8	355	2840	1230
3	2 AL Plate	60	49	63	63	49.5	49.5	15	15	64.5	64.5	129.02	2	56	448	70
4	AL I Block	180	92	32	32	20.3	20.3	15	15	35.3	35.3	69.36	1	52	416	304
5	3 AL Triangular Black	50	46	58	58	28.4	28.4	15	15	43.3	43.3	83.8	3	129	1032	437
6	AL Rectangular Box	25	38	18	18	11.1	11.1	15	15	26.1	26.1	53.1	1	68	544	320
7	AL Sieve Plate	120	71	62	62	53.5	53.5	15	15	68.5	68.5	137	1	26	208	68

TABLE VI
TOTAL DIRECT COST PER SHIFT FOR RTA METHOD

Article No.	Product produce in 1 min	Total surface area coated (M^2)	Total powder consume (Kg)	Powder cost (RS)	Fuel cost (RS)	Power consumption (Rs)	Labor cost (Rs)	Maintenance cost	Total direct cost (Rs)	Productivity of machine
1	5.06	109.44	10.94	1477.44	2280.85	17928	3100	702	25488.29	5.06
2	5.92	30.67	3.06	414.07	2280.85	17928	3100	702	24424.92	5.92
3	0.93	161.28	1.13	2177.28	2280.85	17928	3100	702	26188.13	0.93
4	0.87	449.28	44.93	6065.28	2280.85	17928	3100	702	30076.13	0.87
5	2.15	25.8	2.58	348.3	2280.85	17928	3100	702	24359.15	2.15
6	1.13	68	6.8	910	2280.85	17928	3100	702	24920.85	1.13
7	0.43	149.76	14.98	2021.76	2280.85	17928	3100	702	26032.61	0.43

TABLE VII
OVERALL PROFIT FOR DIFFERENT CYCLE TIME

Article. No.	Time per product (Min) Work study	Time per product (Min) RTA	% of savi-ng in time	Increa-se in output in %	Particulate Daily Emissions (Pound) Work study	Particulate Daily Emissions (Pound) RTA	VOC Emissions (Pound) Work study	VOC Emissions (Pound) RTA	Cost per part (Rs) Work study	Cost per part (Rs) RTA	Cost of extra product (Rs)	Extra income per day (Rs)	Indir-ect wages in day (10% - 50%) (Rs)	Profit (Rs)
1	0.22	0.19	13.6	12.44	2.65	4.5	0.38	0.64	12.50	10.48	6775	20325	2032.5	18292.5
2	0.26	0.16	38.4	55.78	0.77	0.92	0.11	0.13	14.11	8.6	17355.3	52065.9	5206.5	46859.3
3	1.11	1.07	3.60	3.33	6.6	7.2	0.94	1.02	64.36	58.45	4505.2	13515.6	1351.5	12164.0
4	3.70	1.15	68.9	222.22	6.6	6.55	0.94	0.93	215.4	72.29	65484.6	196453	19645	176808.
5	0.70	0.46	34.2	52.48	0.62	0.78	0.08	0.11	38.14	23.60	16667.2	50001.6	5000.1	45001.4
6	1.87	0.88	52.9	109.25	1.22	1.49	0.17	0.21	102.1	45.81	32672	98016	9801.6	88214.4
7	3	2.30	23.3	26.47	5.35	5.4	0.76	0.77	170.3	125.1	11586.5	34759.5	3475.9	31283.5

VIII. RESULT AND DISCUSSION:

The comparative result between the Work Study and RTA method by using the above data is represent in the graphical way for the different cycle time article. In Fig.2, the production rate of the RTA method is greater than the Work Study method.

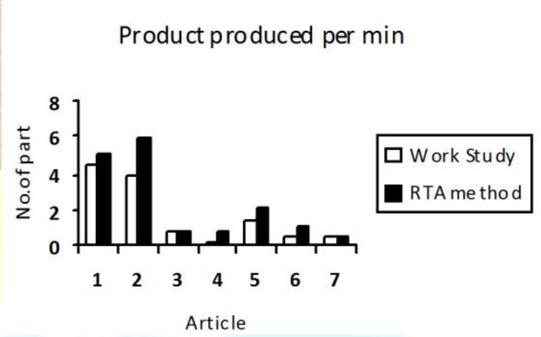

Fig. 2 Comparison between the Work Study and RTA method on product produced per min for different article.

The production cost per product of the RTA method is less than the Work Study method for different cycle time of the article is shown in Fig 3.

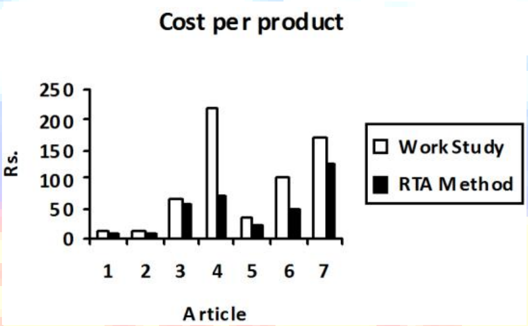

Fig. 3 Comparison between the Work Study and RTA method on cost per product for different.

The productivity of the machine is increases by using RTA method than the Work Study method is shown in Fig 4

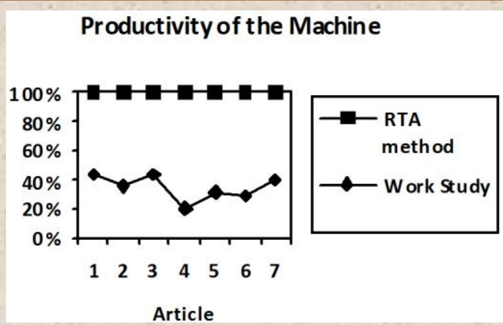

Fig. 4. Comparison between the Work Study and RTA method on productivity of the machine.

From the Figure 2, 3 and 4, it can be seen that, with a highly autonomous robotic system, the requirements for getting a profitable price of the robotic system are easier to achieve. This was attained because the operator was found to be free to do different tasks for about 60% of the total task duration. Therefore, the analysis was conducted as RTA system is best method for the cost minimization. The economy analysis of the RTA method is;

a) Payback Period

The payback period is the length of time required for the net accumulated cash flow to equal the initial investment in the project. Under the assumption that the net annual cash flow is equal from year to year, this notion can be reduced to the following formula [28];

$$\eta = IC/NACF$$

Where, η = the payback period

IC = the investment cost

NACF = the net annual cash flow

= anticipated revenue – operating cost

The investment cost will be returning in 0.5 year which is means that maximum scope in automation.

b) Rate of Return

ROI method determines the rate of return for the proposed project based on the estimated costs and revenues. This rate of return is then compared with the company's minimum attractive rate of return to decide whether investment is justified. The determination of the rate of return involves setting up an equivalent uniform annual cost equation is [28];

$$EUAC = -IC\ (A/P,\ i,\ SL) + Re - OC$$

EUAC sum on the left-hand side of the equation is made equal to zero. Then the values of the interest factors (and correspondingly, the interest rates) are found that make the right-hand side of the equation sum to zero. The equivalent uniform annual cost is 1.89. Looking through the interest factor tables for a match of the A/P factor for n = 1 years, we find the following value;

$$\text{For } i = 50\%,\ (A/P,\ 50\%,\ 1) = 1.5$$

Because, calculate value of (A/P, i, 1) = 1.89 is close to (A/P, 50%, 1) = 1.5.

So that the rate of return to be 50 percent. Therefore, the RTA method will be favor in saving of the cost and the collection of data occurred just after the modelling of the robot in the production line. The painting will be done on the same set of the article by the robot and the other with manual painting. A film thickness frequency of the automatic painting is better than the manual painting. In manual painting, the ideal film thickness is depends on the operator's ability and experience in positioning, orientating, and moving the spray-gun smoothly and around a certain constant speed. From this set of results we cannot conclude in what concerns the film thickness along the surface. For, a better consistency in film thickness, the automatic painting is required. However a tendency for overpainting and a greater number of too high thickness values occur in manual painting. An important benefit of the automatic painting is the possibility to make parameter adjustments with a gradual improvement of the painting quality and, at the same time, reducing costs. The knowledge of the process and the influence of its variables in the final result are made possible with the process automation.

IX. CONCLUSION:

This paper compared the work study and robot time analysis method on powder coating line by using the real industries data. The global aim is to develop an automatic spray painting machine that improves the quality of painting and at the same time leads to the reduction of the production, maintenance costs and constant consumption of the each part. In order to compete, a company should continue the RTA method of their production lines. The hazard operation and control the parameters, have become increasingly important to protect costly systems, ensure the safety of personnel and guarantee the quality of the production. Our proposed cost model demonstrates in favour of saving cost. Followings are the main contribution of the current research;

- It is also observed that the best sequence pattern and its job order, depends on production and demand quantity.
- The comparative study goes to favour in RTA method because it takes less time of the production.
- The standard methods is capitulate to continues consumption of parts and minimize the overall cost of the product.
- Maximum cycle time is also a factor for higher cost.

REFERENCES:

- Pesenti, R. and Ukovich, W., 2003, "Economic lot Scheduling on Multiple Production Lines with Resources Constraints", International Journal Production Economics, **81-82**, 469-481
- Ponnambalam, S.G., Aravindan, P., and Rao, M.S., 2003, "Genetic algorithms for Sequencing Problems in Mixed Model Assembly Lines", Computers and Industrial Engineering, **45**, 669-690.
- Choi, W., and Shin, H., 1997, "A Real-Time Sequence Control System for the level Production of theAutomobile Assembly Line., Computers and Industrial Engineering, **33**, 3-4.
- Chiang, S. Y., Kuo, C. T., and Meerkov, S. M., 1998, "Bottlenecks in Markovian Production Lines: A Systems Approach," IEEE Trans. Robot. Autom.,**14**, pp. 352–359.

- Chiang, S.-Y., Kuo, C.-T., and Meerkov, S. M., 2000, "DT-Bottlenecks in Serial Production Lines: Theory and Application," IEEE Trans. Rob. Autom.,**16**, pp. 567–580.
- Fozzard, G., Spragg, J., & Tyler, D., 1996, Simulation of flow lines in clothing manufacture: Part 1: model construction, International Journal of Clothing Science and Technology, **8**, pp. 17-27
- Vijay Manikrao Athawalea and Shankar Chakrabortyb 2011, A comparative study on the ranking performance of some multi-criteria decision-making methods for industrial robot selection. International Journal of Industrial Engineering Computations **2**, 831–850
- Karsak, E.E., & Ahiska, S.S. 2005. Practical common weight multi-criteria decision-making approach with an improved discriminating power for technology selection. International Journal of Production Research,**43**, 1537-1554.
- Cai, W. J., Hu, S. J., and Yuan, J., 1997, "A Variational Method of Robust Fixture Configuration Design for 3-D Workpieces," ASME J. Manuf. Sci. Eng., **119**, pp. 593–602.
- Potkonjak, V., G.S. Dordevic, D. Kostic, and M. Rasic. (2000). Dynamics of anthropomorphic painting robot: Quality analysis and cost reduction. In: Int. Journ. on Robotics and Autonomous Systems, **32**, 17-38.
- Rosenfeld Y. Shohet I. M. and Warszawski A, "Optimization Algorithms of Task-Planning for Construction Robots", International Journal of Cosiruction Information Technot. Vol. 2, No. 3, 1994, pp. 1-19.
- Nunes, U., A. Lourenço, V. Costa, V. Cavaleiro, A. Batista, and J. Figueiredo (2001). Industrial Powder Coating Systems: sensor-based spray trajectory control, In: Preprints of 6th IFAC Symposium on Cost Oriented Automation, Berlin, 109-114.
- A. N. Aljaw, A. S. Balamesh, T. D. Almatrafi and M. Akyurt, December 2002 "Symbolic Modeling Of Robotic Manipulators" the 6th Saudi engineering conference, KFUPM, **4**.
- C.F. Rose, P-P. J. Sloan and M.F. Cohen, 2001 "Artist-Directed Inverse Kinematics Using Radial Basis Function Interpolation" Eurographics,**20**, no. 3, pp. 1-12.

- M. Z. Al-Faiz, M. Z. Othman, and B. B. Al-Bahri, 2006 " An Algorithm to Solve the Inverse Kinematics Problem of a Robotic Manipulator Based on Rotation Vectors" 3rd IEEE-FCC, Bahrain.
- J. Denavit, R.S. Hartenberg; A Kinematic Notation for Lower Pair Mechanisms Based on Matrices, J. Appl. Mech. ASME, June 1955, pp. 215-221.
- Braglia, M., & Gabbrielli, R. 2000, Dimensional analysis for investment selection in industrial robots. International Journal of Production Research, **38**, 4843-4848.
- D. Whitney and D. M. Gorinevskii, 1972 "The mathematics of coordinated control of prosthetic arms and manipulators," ASME Journal of Dynamic Systems, Measurement and Control, **20**, no. 4, pp. 303–309.
- Terauchi, S., T. Miyajima, T. Miyamoto, K. Arai, and S. Takizawa, 1993. Development of an Exterior Wall Painting Robot Capable of Painting Walls with Indentations and Protrusions. Automation and Robotics in Construction X. 285-293.
- M. W. Walker and D. E. Orin, 1982, "Efficient dynamic computer simulation of robotic mechanisms," ASME Journal of Dynamic Systems, Measurement and Control, **104**, pp. 205–211.
- H. Zhang, J. Wang, G. Zhang, Z. Gan, Z. Pan, H. Cui, Z. Zhu., 2005, Machining with flexible manipulator: toward improving robotic machining performance. Proceedings of IEEE/ASME, July 24th – 28th, Monterey (California-USA), pp 1127-1132.
- Zhou, J., and Mourelatos, Z. P., 2008, "A Sequential Algorithm for Possibility-Based Design Optimization," ASME J. Mech. Des., **130**, p. 011001.
- Chang, Q., Ni, J., Bandyopadhyay, P., Biller, S., and Xiao, G., 2007, "Supervisory Factory Control Based on Real-Time Production Feedback," ASME J. Manuf. Sci. Eng., **129**, pp. 653–660.
- M. N. Pal, A. K. Chatterjee, "Introduction to Work Study,"1st ed. New Delhi: Oxford and IBH publication co. pvt.ltd, 1979, pp. 17–246.
- Ralph M. Barnes, Motion and Time Study Design and Measurement of Work, New York: Wiley Publication House.1980, pp. 35-50, 61-87,257-482.

- Denavit J., Hartenberg R.S. 1955. A Kinematic Notation for Lower-Pair Mechanisms Based on Matrices. J. App. Mech., **77**, pp 215-221.
- Zeleny, M. (2002). Multiple criteria decision making. New York: McGraw Hill.
- Pandit, S. M., and Wu, S., 1993, *Time Series and System Analysis With Applications*, Wiley, New York.
- Law, A. M. 2007. *Simulation Modeling and Analysis.* 4nd ed. McGraw-Hill.
- Sven Spieckermann, Kai Gutenschwager,Holger Heinze and Stefan, 2000, Simulation-based Optimization in the Automotive Industry – A Case Study on BodyShop Design, *SIMULATION*, **75/5**, 276-286
- Gupta, T. and S. Arasakesari. 1991. "Capacity Planning in Wood Products Industry Using Simulation." *Proceedings of the 1991 Winter Simulation Conference* (Phoenix, AZ, Dec. 8-11). IEEE. Picataway, N. J., 435-440.
- Coleman, T., Branch, M. A., and Grace, A., Optimization Toolbox User's Guide, *Matlab The Mathworks Inc.*, Version 2.