Extended Work: Empirical Correlation of Consistency and Time of Trajectory for Industrial Robotics

[a, b, c] **Hayder Zghair and** [c] **Ahad Ali**

[a] Engineering Department of Automated Manufacturing Systems
University of Baghdad
Main Campus, Aljadria St.
Baghdad, IQ 00964
hayder@kecbu.uobaghdad.edu.iq

[b] Industrial and Manufacturing Engineering Department
Kettering University
1700 University Ave.
Flint, MI 48504
hzghair@kettering.edu

[c] A. Leon Linton Department of Mechanical Engineering
Lawrence Tech University
21000 West Ten Mile Road
Southfield, MI 48075
aali@ltu.edu

Salem Lakrash
[c] A. Leon Linton Department of Mechanical Engineering
Lawrence Tech University
21000 West Ten Mile Road
Southfield, MI 48075
slakrash@ltu.edu

Abstract

This research is devoted to develop an empirical correlation mathematical based for consistency and time of a robotized industrial task simulating an automated manufacturing work-cell such as the robotic leaser cutting using an educational robotics test-cell. The correlation is to investigate contributions of the impact parameters on the performance of robotized work-cell. Processing time models the cycle time and quality of the task has been modeled in terms the consistency of cutline. A set of mathematical formulas have been used to simulate the consistency and cycle time in order to tackle the variability of proposed sources as pieces of time and dimensions that need to be processed in the loaded parts the work-cell; in addition the relationship that suggestively correlates the impacts. A set of experimental tests has been conducted responding to the predicted formulas for the cycle time and consistency. Experimentation factors that have been leveled from minimal to maximal values are selected based on the robot's computer operating system in terms of processing speed, motion properties, and termination types the default characters of the programming. Analysis the results shows that the correlation can be used to tradeoff the programming solutions objectively depending on the task design requirements. The contribution of this research work is to introduce a new depiction of optimizable factors of robotic computer programs that directly affect the performance criteria.

Keywords
Industrial robots, manufacturing, factors, responses, DOE analysis

1. Introduction

According to Feng there are many approach to gain the optimal cell design, one of them is multi-robot cell design. It means the selection and location of the resources, which, where and how many robots and tools will be used. Off-line motion planning optimizes the allocation of the welding points and connecting trajectories [1]. André Hengstebeck says the gap between technical capability and practical application of service robotics increased constantly within the last years, especially regarding small and medium-sized enterprises. By utilizing this approach, industrial operators will be considerably supported regarding the planning and implementation of automated and especially hybrid robot-assisted work systems [2]. Human–robot collaboration has been a significant research topic since the initial steps of robotics. The constant introduction of robots in industrial environments, the creation of new compliant robots and the sensors available nowadays in the market, cheaper and more accurate, makes it an even more interesting research subject and. Different approaches can be found for safe human–robot interaction, from pre-collision to post-collision approaches, using force sensors and or different vision systems and just to name few [3].There has become a common practice to conduct simulation based design of industrial robotic cells, where Mechatronic system model of an industrial robot is used to accurately predict robot performance characteristics like cycle time, critical component lifetime, and energy efficiency. However, current robot programming systems do not usually provide functionality for finding the optimal design of robotic cells. Robot cell designers therefore still face significant challenge to manually search in design space for achieving optimal robot cell design in consideration of productivity measured by the cycle time, lifetime, and energy efficiency. In addition, robot cell designers experience even more challenge to consider the trade-offs between cycle time and lifetime as well as cycle time and energy efficiency [3].
Industrial robot motion paths are designed using programmatic points in a three dimensional space. These points have specific values in six axis of motion. As the robot moves from point to point, there are several factors that have an impact on how the motion occurs. Factors such as motion speed and CNT % change how the robot moves in space as it executes a program. Using regression models analysis, the relationships between these factors and performance metrics for the robot's movements can be observed. Using the statistical significance of the relationships between these inputs and outputs, improvements can be made to motion path efficiency.
This research develops how the consistency and cycles of processing time are correlated. Performance of an industrial robot may be modified by adapting robot drive-train configuration parameters without any need of modification of hardware of the robot. Performance of a robotic system depends on placement of a task that the robot performs in the workspace of the robot [1]. In this study, two elements will be investigated. First, taste and state the correlation between cycle processing time and the trajectory consistency, using sadistic methods: NOVA analysis and DOE. Second, state the research hypothesis. A FANUC Robot LR Mate 200iB, R-J3iB controls and Handling Tool Software are used in this analysis. The robot has a payload at wrist of 5kg a reach of 700 mm. The robot motion cycle used is a laser application cycle processing a particular path then reverse trajectory to return to the original position. Fusaomi Nagata describes the development of a robotic CAM system for an articulated industrial robot RV1A from the view point of robotic servo controller. It is defined here that the CAM system includes an important function which allows an industrial robot to move along cutter location data (CL data) consisting of position and orientation components. In addition, the developed CAM system has a high applicability to other industrial robots whose servo systems are technically opened to end-users [4]. The industry which uses industrial robots, as automotive, has improved considerably the last years; therefore, it faces many challenges as flexibility, improves the productivity, and reduces the cost. In order to satisfy the costumers and get value in the production, the industry should manage several products on the same robotized assembly cell [5]. The introduction of robots in shop-floors allows sharing the different tasks of the production process between humans and machines, giving the chance to liberate human operators from repetitive and monotonous works to perform high added value operations [3].

FANUC Robot LR-Mate 200iB is a compact robot that can be used for a variety of applications. The robot is electric servo-driven and has an arm conformed by six axes and many different mounting capabilities. This robot has five modes; each one is for specific purposes like assembly, material handling, cleanroom, industrial washing and food handling along several others. The end arm depends on the final task [6]. The key elements of the FANUC Robot are 1) Mechanic unit: It is a series of mechanical links driven by servomotors 2) Teach Pad: the communication channel between the operator and the robot. 3) Controller: the principal computer which has a control panel. 4) Software: program, run and test the task. FANUC uses Handling Tool Software. The axes of the FANUC Robot are; J1: Base or Waist; J2: Shoulder; J3: Elbow, J4: Rotation of the arm; J5: Pitch of the wrist; J6: Rotation of the faceplate. Figure 1 illustrates the axes robotic system. The objective of this study is to analytically gain a more complete understanding of the relationship between a robot's motion path performance with regard to cycle time and consistency and the programmatic factors of motion speed and termination CNT %. The hypothesis to prove are the next: H_0: The consistency is independent of cycle time and the alternative is $H_{a:}$ The consistency is dependent of cycle time.

Analysis the trajectory motion is programmed that moves during the particular design process. The program content is then run at a variety of speeds and CNT percentages as follows: (1000 mm/s @ 0% CNT), (1000 mm/s @ 100% CNT), (2000 mm/s @ 0% CNT), and (2000 mm/s @ 100% CNT). This research paper arranged in the following manner that section 2 for the results and analysis and section 3 is to conclude the findings and record the recommendations for the future work.

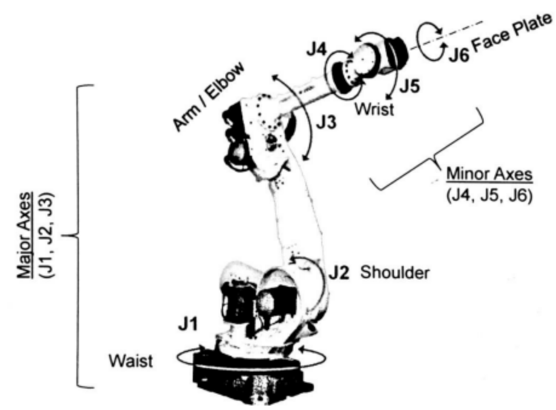

Figure 1: Major axes of leading the robotic system trajectory [6]

2. Programming Variables Analysis

In order, to understand the problem of the correlation between cycle time and consistency with other robot variables it should first be realized what variables that we are deciding to understand. Variables that affect the correlation investigation are three main parts of robot performance. The first being controller components. This being the software, operating system, and input/output hardware. The second is the arm manipulator joint and non-joint movements. Finally, the robotic cell cycle time. These three variables surely come together when effectively operating the robot in the ways that we want to run. We find that these 3 things are affected by user-defined variables within the coding process of the TP. The variables that we are looking at are terminations and speeds. Terminations are variables defined to affect a robot's accuracy during movement. While speed is how fast the robot moves within the given run task from start to finish. The way that describes speed and termination can be seen in the figure 2.

Figure 2: Programming variables of the trajectory analysis

Terminations are described on the TP as “CNT#” whereas speed is just seen as “#mm/sec”. As can be seen in Figure 2, there are codes defined on different lines. The first initial where it says J or L is the motion format. Motion formatting is giving the robot a motional direction based on the x, y, and z coordinate system. J stands for Joint where it moves to points in all three coordinates to move the robot body from point to point. L stands for Linear where it moves in the pathway of one point to another. The second column that says P stands for the position data format which describes the position data. The third column describes the feed rate of the code for the row given. This could be programmed for 1 to 100% for any feed rate programmed into the robot. Finally, the fourth column describes the positioning path that the robot will take depending on the motion format being either labeled as FINE or CNT. Defining the variables for motion programming can be resulted to solve the problem of cycle times and consistency through variables. This will benefit the way of defining the robot variables to create future programs and edit already existing ones.

3. Results and Analysis

In this study, two factors were considered, the speed of the arm (factor A) and the termination bath (factor B). The levels of interest for factor A (Speed) have been given 1000 mm/sec as a low level and 2000 mm/sec as a high level. Meanwhile, the levels of interest for factor B, have been given (CNT) 0% as a low level and 100% as a high level. The factors and its levels are shown in Table 1.

Table1: Factors and Levels for Design of Experiments

Factor	Name of Factor	Level
A	Speed of the arm	A1: 1000 mm/sec A2: 2000 mm/sec
B	Termination	B1: 0% B2: 100%

Using Minitab to create general factorial design with number of factors, factor names, number of levels and level values. The response is the cycle time and consistency. A snapshot of the design worksheet of 80 data point of the empirical test is as shown in Figure 2. There are two factors, each factor with two levels which is expressed by 2^2 full factorial DOE.

	StdOrder	RunOrder	PtType	Blocks	Speed	Termination	Consistency	Cycle Time
1	1	1	1	1	1000	0%	2.57	20.14
2	2	2	1	1	1000	100%	7.64	19.95
3	3	3	1	1	2000	0%	1.14	22.68
4	4	4	1	1	2000	100%	8.82	20.55
5	5	5	1	1	1000	0%	1.41	24.18
6	6	6	1	1	1000	100%	11.60	18.31
7	7	7	1	1	2000	0%	1.18	22.44
8	8	8	1	1	2000	100%	8.93	20.50
9	9	9	1	1	1000	0%	2.49	20.41
10	10	10	1	1	1000	100%	5.74	21.83
11	11	11	1	1	2000	0%	1.15	22.64
12	12	12	1	1	2000	100%	9.20	20.50
13	13	13	1	1	1000	0%	1.49	23.64
14	14	14	1	1	1000	100%	8.30	19.58
15	15	15	1	1	2000	0%	1.17	22.54
16	16	16	1	1	2000	100%	9.83	18.99
17	17	17	1	1	1000	0%	1.44	23.81
18	18	18	1	1	1000	100%	7.09	20.49
19	19	19	1	1	2000	0%	1.16	22.58
20	20	20	1	1	2000	100%	8.52	20.91

Figure 2: Variables design matrix

Plotting the main effects for the mode of speed; factor A, and termination; factor B, and its level are shown in Figure 3. It can be noticed that the center line indicates to the overall mean of cycle time which is 21.12 sec. that is illustrated in Table 2. Moreover, switching the mode of speed from 2000 mm/sec to 1000 mm/sec on average reduces the cycle time by 0.45 sec and switching the termination (CNT%) from 0% to 100% on average decreases the mean cycle time by 2.25 sec. as illustrated in Table 3. It can be seen that in each case the cycle time at speed 1000 is less than the cycle time at speed 2000 and also in each case speed at 1000 give us the best scores. Since the lines, her don't intersect we would say likely there is a little interaction.

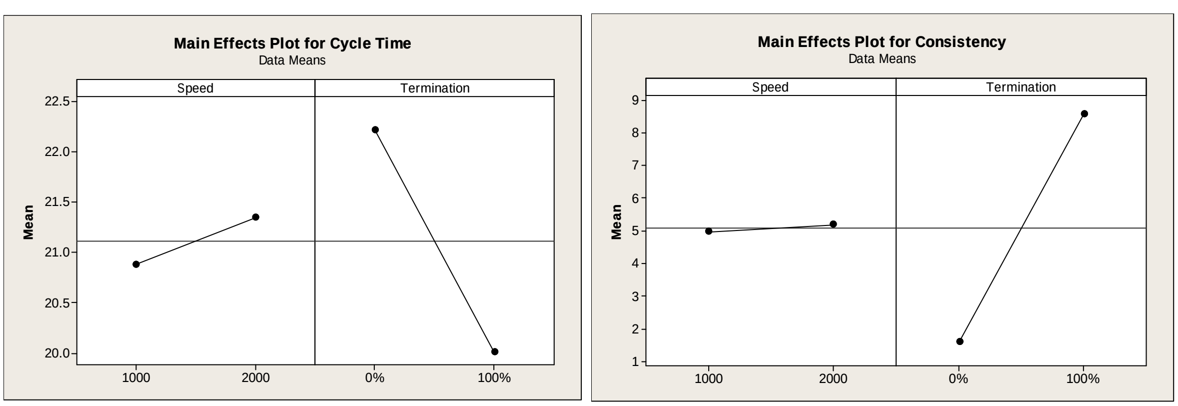

Figure 3: Effect direction plots of the variables

Table2: Variance statistical analysis of the cycle processing

		Factor B, Termination		
		0%	**100%**	**Mean**
Factor A, Speed	**1000 mm/sec**	21.89	19.88	20.89
	2000 mm/sec	22.53	20.16	21.34
	Mean	22.21	20.02	21.12

Table3: Variance statistical analysis of the trajectory consistency

		Factor B, Consistency		
		0%	**100%**	**Mean**
Factor B, Speed	**1000 mm/sec**	2.02	7.93	4.98
	2000 mm/sec	1.17	9.20	5.19
	Mean	1.60	8.57	5.08

In each case, the cycle time at speed 1000 is less than the cycle time at speed 2000 and also in each case speed at 1000 give us the best scores. Since the lines her don't intersect we would say likely there is a little interaction. The regression analyses of motion path consistency and cycle time have led to the conclusion that while motion speed may not have a statistically significant impact on either cycle time or consistency, CNT % has a very strong statistical impact. For each increase in CNT %, Cycle time decreases by a regressed coefficient factor of 8.1 while consistency also decreases but with a regressed coefficient factor of 4.3. This conclusion suggests that if a cycle time needs to be shortened, consideration for a discrepant ratio of approximately 2:1 in motion path consistency. To analyze the experiment, two statistics methods use that are the regression analysis for test the dependency hypotheses and ANOVA analysis for test the correlation. Basically, we did the program with the movement cycle jogging the robot and recording the key points. After it, we took lectures at the time and we calculated the consistency per each line of the motion cycle. At the end, we used Minitab to do both analysis DOE and ANOVA.

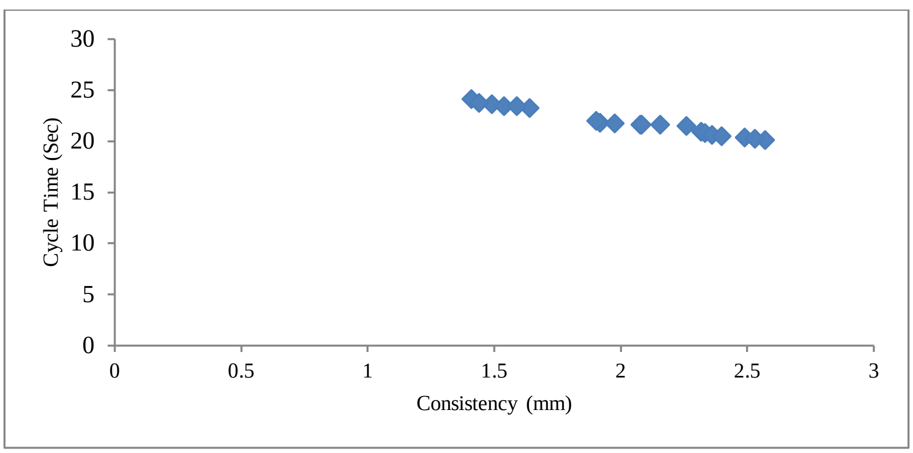

Figure 4: Empirical correlation of the consistency (Termination = 0, Speed = 1000)

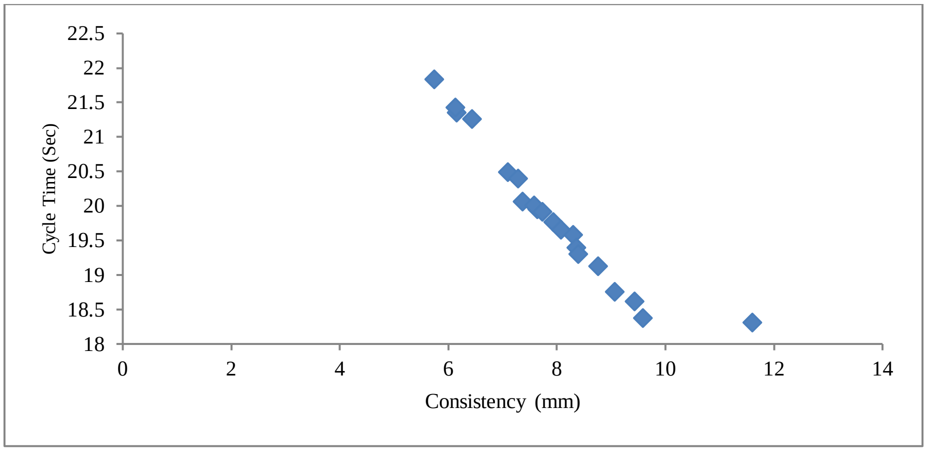

Figure 5: Empirical correlation of the consistency (Termination = 100, Speed = 1000)

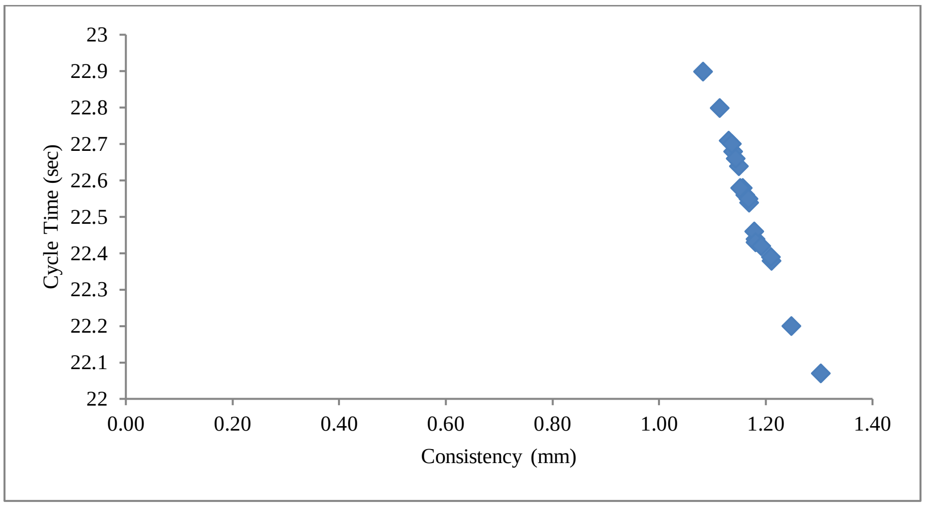

Figure 6: Empirical correlation of the consistency (Termination = 0, Speed = 2000)

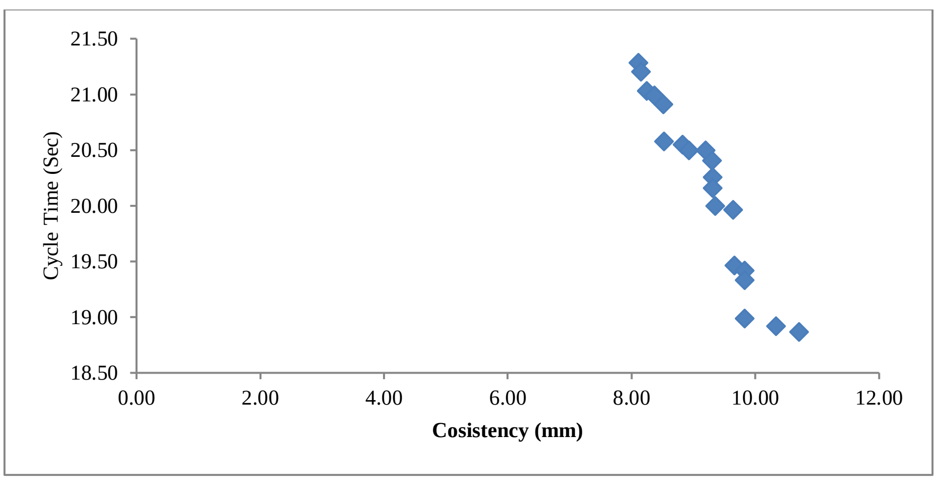

Figure 7: Empirical correlation of the consistency (Termination = 100, Speed = 2000)

4. Conclusion

As a future work, an approach to optimize the efficiency of the robot regarding final throughput and energy consumption is highly recommended. In automated industrial production, the efficiency of robotic motions directly affects both the final throughput and the energy consumption. Simulating and analyzing the robot trajectories depending on the cycle of processing time and energy consumption can be reduced.

- According to the DOE analysis, the termination is more significant and has more correlation than the speed, the optimal parameters are termination 100: Speed 2000 to get the major consistency get the smallest cycle time.
- The consistency and the cycle processing time are highly dependent of the variation of motion components.
- To build an effective program for the accuracy, manufacturing details are to be prepared relative the consistency movement of the tool.

Error issues that impact data is a combination of human and robotic error. Human in terms of hand measuring with no constitutes as a deviation, yet still developed a trend supporting the claim as such. Robot error because of the grip strength of the FANUC robot used. The gripper is not as tight as trying to hold object steady. This causes the tool to be pushed back or forward where the trajectory when process is not consistent and far away from the original path.

5. References

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Biographies

Hayder Zghair is a Faculty in the Department of Industrial and Manufacturing Engineering Department at Kettering University, Michigan, USA. Mr. Zghair earned B.Sc. in Production Engineering from University of Technology, Baghdad; and two M.Sc. degrees. The first Master has been earned in Production Engineering from University of Technology, Baghdad, Iraq. The second Master was in Manufacturing Systems Engineering from Lawrence Technological University, Michigan, USA. Currently, Mr. Zghair is PhD candidate in Manufacturing Systems Engineering at Lawrence Technological University, Michigan, USA. He has published journal and conference papers. Mr. Zghair has completed E-Learning project with UNISCO. His research interests include Flexible Automated Manufacturing, Robotics, Analytical Modeling & Simulation, and Optimization. He is member of ASEE, IEOM & IEU.

Ahad Ali is an Associate Professor, and Director of Bachelor of Science in Industrial Engineering and Master of Science in Industrial Engineering in the A. Leon Linton Department of Mechanical Engineering at the Lawrence Technological University, Michigan, USA. Dr. Ali is Director of Smart Manufacturing and Lean Systems Research Group. He earned B.S. in Mechanical Engineering from Khulna University of Engineering and Technology, Bangladesh, Masters in Systems and Engineering Management from Nanyang Technological University, Singapore and PhD in Industrial Engineering from University of Wisconsin-Milwaukee. He has published journal and conference papers. Dr Ali has completed research projects with Chrysler, Delphi, DTE Energy, Ford, GE Medical Systems, GM, Harley-Davidson, International Truck and Engine Corporation (Navistar), National Panasonic, New Center Stamping, Progressive Metal Manufacturing Company, Rockwell Automation, Whelan Co., and Whitlam Label Company. His research interests include manufacturing, simulation, and optimization, reliability, scheduling, manufacturing, and lean. He is member of ASEE, IIE, INFORMS, SME and IEEE.

Salem Lakrash is a Doctoral student in Manufacturing Systems Engineering at Lawrence Technological University, Michigan, USA. Mr. Lakrash obtained his B.Sc. in Petroleum Engineering from Bright Star University of Technology, Braiga, Libya. Mr. Lakrash earned his MSc. degree in Process Manufacturing Management from Teesside University, UK. His research interests include manufacturing, simulation, and optimization techniques.