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Comparison of Conventional Methods for Manufacturing Process Optimization

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Extended Abstract

Optimization of machining processes is essential to achieve high productivity and maintain product quality [1]. To accomplish this, certain variables are designated as Evaluation Variables (EVs) while others are selected as Control Variables (CVs). Experiments are conducted by varying the states of the CVs, and the corresponding values or states of the EVs are recorded. Subsequently, the relationships between CVs and EVs [2] are established using an appropriate data analysis method. These relationships help optimize the machining processes. In this regard, various methods, e.g., data visualization, denoted as M_1, calculation of mean and standard deviation, denoted as M_2, and analysis of variance (ANOVA), denoted by M_3, to name a few, have been used. In this study, these methods (M_1, M_2, and M_3) are used. The relevant datasets are collected from [3] for a manufacturing process called rotary ultrasonic machining for drilling precision holes in a workpiece made of Ti6A14V. The sets of CVs, EVs, and datasets are presented in Tables 1, 2, and 3, respectively. The results of the data analysis for M_1, M_2, and M_3 are displayed in Tables 4, 5, and 6. Tables 4 and 5 provide the optimal states of the corresponding CVs for each EV, while Table 6 presents the p-values (ANOVA) for each CV-EV combination. In some cases, the results are consistent across different data analysis methods, whereas in others, the outcomes vary depending on the method used. For instance, as shown in Tables 4 and 5, ultrasonic power (P) = 40% should be used instead of 20% to minimize FC. However, for OE, the optimal P differs: P = 20% in Table 4 and 40% in Table 5. On the other hand, ANOVA results from Table 6 show that the levels of P (20 and 40%) are indifferent to minimize for FC, TW, OE, and CE while S (refers to spindle speed) plays a significant role to minimize the above EVs except TW. In addition, f has no effect on EVs except FC.

Table 1: Setting of CVs.

CVs	Levels		
	1	2	3
Ultrasonic power (P, %)	20	40	
Feed rate (f, mm/min)	0.1	0.6	
Spindle speed (S, rpm)	2000	4000	6000
Tool diameter (D, mm)	3.97	5.9	8.9

Table 2: Setting of EVs.

EVs	Objective
Cutting Force (FC, N)	Minimization
Tool Wear (TW, mg)	
Overcut Error (OE, mm)	
Cylindrical Error (CE, mm)	

Table 3: Experimental Datasets (CV-EV-Centric Datasets).

Exp. No.	P [%]	f [mm/min]	S [rpm]	D [mm]	FC [N]	TW [mg]	OE [mm]	CE [mm]
1	20	0.1	2000	3.97	97.32	2.8	0.28	0.0463
2	20	0.1	2000	5.9	67.58	0.9	0.25	0.0251
3	20	0.1	2000	8.9	30.2	4.5	0.18	0.0152
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36	40	0.6	6000	8.9	69.55	24.5	0.19	0.0078

Table 4: Results of M_1.

CVs	Level	EVs			
		Objective: Minimization			
		FC [N]	TW [mg]	OE [mm]	CE [mm]
		Optimal State of CVs			
P [%]	20, 40	40	20	20	20
f [mm/min]	0.1, 0.6	0.1	0.1	0.6	0.1
S [rpm]	2000, 4000, 6000	6000	2000	6000	6000
D [mm]	3.97, 5.9, 8.9	5.9	3.97	8.9	8.9

Table 5: Results of M_2.

CVs	Level	EVs			
		Objective: Minimization			
		FC [N]	TW [mg]	OE [mm]	CE [mm]
		Optimal State of CVs			
P [%]	20, 40	40	20	40	20
f [mm/min]	0.1, 0.6	0.1	0.1	0.6	0.1
S [rpm]	2000, 4000, 6000	6000	2000	6000	6000
D [mm]	3.97, 5.9, 8.9	5.9	3.97	8.9	8.9

Table 6: Results of M_3.

CVs	Level	EVs			
		Objective: Minimization			
		FC [N]	TW [mg]	OE [mm]	CE [mm]
		p-value if $p < 0.05$ then CV is significant			
P [%]	20, 40	0.913	0.618	0.229	0.644
f [mm/min]	0.1, 0.6	0.001	0.127	0.239	0.178
S [rpm]	2000, 4000, 6000	0.014	0.268	0.006	0.001
D [mm]	3.97, 5.9, 8.9	0.169	0.195	0.459	0.016

In conclusion, the methods sometimes yield similar results, while at other times, they differ due to unique perspective, providing valuable insights into the CV-EV relationships. Therefore, integrating them into a holistic method might facilitate effective understanding and optimization of a process. Developing such a method will be a key focus of future research.

References

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