UTICAJ FAKTORA NA VRIJEME MONTAŽE PREMA ORTOGONALNOM NIZU $L_{16}(2^{15})$

IMPACT OF FACTORS ON ASSEMBLY TIME ACCORDING TO ORTHOGONAL ARRAY $L_{16}(2^{15})$

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REZIME

U datom primjeru Taguchijevog eksperimenta provedeno je istraživanje o uticaju faktora na brzinu montaže alata za precizno pritezanje vijaka. Nepotrebni gubitak vremena može biti štetan za proizvodne procese; stoga je ključno pravovremeno identificirati sve negativne faktore koji utiču na vrijeme. Proveden je Taguchijev eksperiment prema ortogonalnom nizu $L_{16}(2^{15})$. Date su preporuke za optimalne uslove montaže.

Professional paper

SUMMARY

In the given example of Taguchi's experiment, an investigation was conducted into the influence of factors on the assembly speed of the tool for precise bolt tightening. Unnecessary loss of time can be detrimental to production processes; therefore, it is crucial to promptly identify all negative factors that affect time. Taguchi's experiment was carried out according to the orthogonal array $L_{16}(2^{15})$. Recommendations for optimal assembly conditions were provided.

1. INTRODUCTION

The Taguchi quality concept focuses on minimizing variations in the manufacturing process to achieve stable and high product quality. Instead of correcting defects after production, this approach uses preventive optimization of key factors. By applying the Taguchi methodology and factorial design of experiments (DOE) in a real environment, processes can be analyzed and optimized with minimal costs. The results provide a better understanding of how different factors influence quality, enabling informed decisions to improve products, reduce costs, and increase customer satisfaction.

2. EXPERIMENTAL WORK

Research was conducted on the production line of a company that manufactures tools for precise bolt tightening. The experiment was carried out according to Taguchi's methodology using the orthogonal array $L_{16}(2^{15})$. The investigation involved examining the impact of five factors on the assembly time of the final product. Two levels of the given factors were considered. The measurement was performed using a time-measuring device, with time as the output data. The obtained average time is expressed in the form [min:s] as well as [s]. Each measurement was carried out five times to achieve the highest precision, with the experimental plan and the obtained measurement results presented in the following.

The factors are as follows:

T – use of assembly technology,
K – type of checklist,
S – shift,
P – presence of colleagues directly at the workplace,
R – variety of work tasks during the day.

Table 1. Factors and levels

Factors	Level 1	Level 2
T	YES	NO
K	10 questions	3 questions
S	1	2
P	YES	NO
R	DIFFERENT	SAME

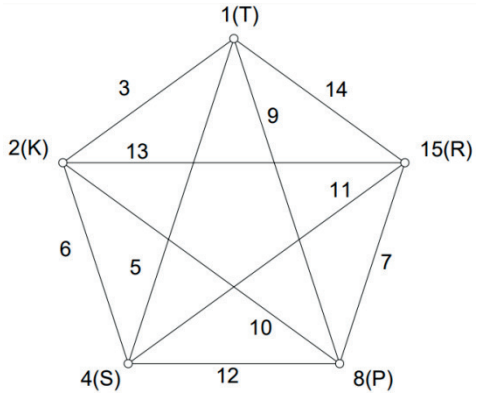

***Figure 1**. Linear graph for orthogonal array L_{16} (2^{15})*

3. RESULTS OF EXPERIMENTAL ANALYSIS

There are two approaches to factor influence analysis. The first approach is half-half and this approach is used when there is no significant difference between two adjacent factors.
The second approach is used when there is a more significant difference among the factors (for example, five factors have a considerably greater intensity of influence than the remaining factors; in that case, only those five factors are analyzed). A half-and-half approach was used.

3.1 TP Interaction

When the factor level is P=1 (presence of colleagues), it is evident that the assembly time decreases when switching from T=1 to T=2. When P=2 (absence of colleagues), the assembly time significantly decreases when switching from T=1 to T=2. The assembly technology considerably reduces the time, particularly when the operator works alone (P=2). When colleagues are present (P=1), the reduction in time is less pronounced.

Table 2. Experimental plan and measurement results

	FACTORS															MEASURED VALUES [t]						
	T	K	TK	S	TS	KS	PR	P	TP	KP	SR	SP	KR	TR	R	t1	t2	t3	t4	t5	Average [min:s]	Average [s]
T1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	37:50	39:30	32:00	37:40	31:30	35:42	2142
T2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	40:10	35:50	34:00	37:30	39:00	37:18	2238
T3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	33:30	36:20	35:30	36:20	37:20	35:48	2148
T4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	36:40	39:30	35:50	36:40	39:00	37:32	2252
T5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	37:30	30:00	35:20	37:00	38:30	35:40	2140
T6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	40:50	34:40	37:00	36:50	39:30	37:46	2266
T7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	39:30	35:50	39:20	39:00	32:50	37:18	2238
T8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	33:40	36:10	35:30	38:20	39:10	36:34	2194
T9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	33:50	35:20	28:50	30:30	32:20	32:10	1930
T10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	29:20	36:50	34:10	30:30	32:30	32:40	1960
T11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	33:30	31:10	34:00	35:30	36:00	34:02	2042
T12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	31:30	29:50	32:50	29:10	32:10	31:06	1866
T13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	35:00	32:50	37:20	35:50	36:30	35:30	2130
T14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	28:20	32:20	29:50	27:50	30:00	29:40	1780
T15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	34:40	38:50	34:00	36:30	32:10	35:14	2114
T16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	31:00	33:20	30:00	34:50	29:40	31:46	1906

Table 3. Effects table

	T	K	TK	S	TS	KS	PR	P	TP	KP	SR	SP	KR	TR	R
LEVEL 1 [s]	17618	16578	16710	16586	16714	16722	16630	16884	16180	16408	16820	16560	16624	16588	16936
LEVEL 2 [s]	15728	16768	16636	16760	16632	16624	16716	16462	17166	16938	16526	16786	16722	16758	16410
DELTA [s]	**1890**	**190**	74	174	82	98	86	**422**	**986**	**530**	**294**	**226**	98	170	**526**
DELTA [min:s]	**31:30**	**03:10**	01:14	02:54	01:22	01:38	01:26	**07:02**	**16:26**	**08:50**	**04:54**	**03:46**	01:38	02:50	**08:46**
RANK	**1**	**8**	15	9	14	12	13	**5**	**2**	**3**	**6**	**7**	11	10	**4**

Figure 2. *Response graphs of factors and interactions*

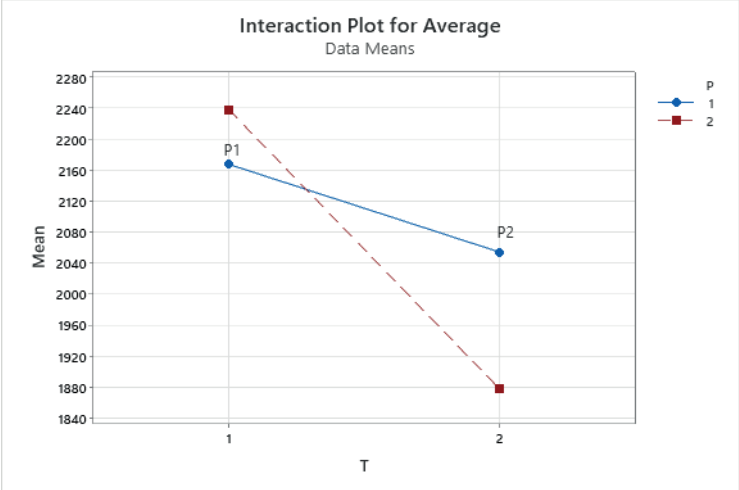

Figure 3. *TP Interaction*

$$\overline{T_1} * \overline{P_1} = \frac{2142 + 2148 + 2140 + 2238}{4} = 2167 \quad (1)$$

$$\overline{T_1} * \overline{P_2} = \frac{2238 + 2252 + 2266 + 2194}{4} = 2237.5 \quad (2)$$

$$\overline{T_2} * \overline{P_1} = \frac{1930 + 2042 + 2130 + 2114}{4} = 2054 \quad (3)$$

$$\overline{T_2} * \overline{P_2} = \frac{1960 + 1866 + 1780 + 1906}{4} = 1878 \quad (4)$$

3.2 KP Interaction

When P=1 (presence of colleagues), it is evident that transitioning from K=1 (detailed checklists) to K=2 (less detailed checklists) increases assembly time. When P=2 (absence of colleagues), transitioning from K=1 to K=2 decreases assembly time. The optimal choice of checklist depends on whether the operator is working independently or as part of a team.

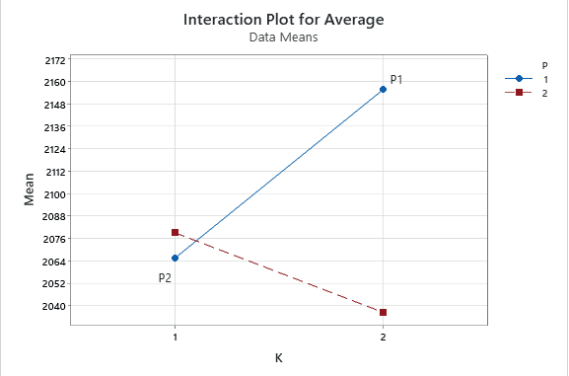

Figure 4. *KP Interaction*

$$\overline{K_1} * \overline{P_1} = \frac{2142+2148+1930+2242}{4} = 2065.5 \quad (5)$$

$$\overline{K_1} * \overline{P_2} = \frac{2238+2252+1960+1866}{4} = 2079 \quad (6)$$

$$\overline{K_2} * \overline{P_1} = \frac{2140+2238+2130+2114}{4} = 2155.5 \quad (7)$$

$$\overline{K_2} * \overline{P_2} = \frac{2266+2194+1780+1906}{4} = 2036.5 \quad (8)$$

3.3 Impact of R Factor

Figure 5 shows the direct impact of R factor (task diversity) on assembly time, where R=1 (different tasks) and R=2 (a single task). Focusing on one task throughout the entire day significantly reduces assembly time, which underscores the advantage of specialization.

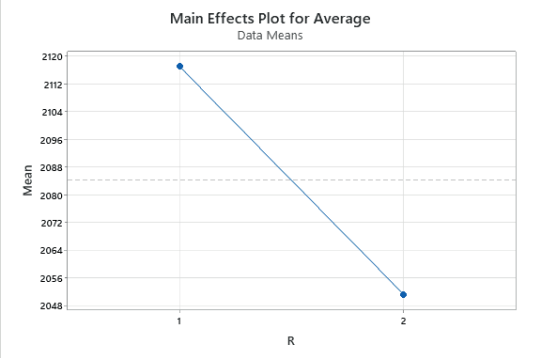

Figure 5. *The impact of the R factor*

3.4 Recommendations for Factor Level Selection

Table 4 displays the significance of the factors and interactions for the average assembly time. Half of the factors and interactions with higher delta values were considered in the experiment, while the other half, with lower delta values, have significantly less influence and were not included. The only factor that is not significant is the shift. Figure 2 also shows the impact of the shift on assembly time. The assembly time is slightly longer during the second shift, but this does not have a significant impact. The remaining four factors are significant, and the recommended levels are Level 2 for all four factors.

Table 3. Recommendations for Factor Level Selection

Factor	Label	Level	Significance
Using assembly technology	T	2	YES
Writing checklists	K	2	YES
Shift	S	1	NO
Presence of colleagues	P	2	YES

Variety of work tasks	R	2	YES

4. CONCLUSION

A series of factors considered to directly influence the assembly speed of the final product were analyzed. While it was possible to assume how these factors affect the production process, the research provided precise results regarding their impact. Based on the experimental results, process optimization can be achieved.
Considering all working conditions and the results of the experimental analysis, it is concluded that the following factor levels should be selected to achieve minimal assembly time:

Factor T – Level 2 – not using assembly technology,
Factor K – Level 2 – completing checklists with three questions,
Factor P – Level 2 – without the presence of colleagues directly at the workstation,
Factor R – Level 2 – the operator should work on the same task throughout the entire workday, and
Factor S – has no significant impact.

5. REFERENCES

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