

ACDA5021 – Systems Engineering

Taguchi Methods Analysis

Using the Taguchi Catapult Experiment to understand how noises and variations affect system performance, and to find optimum settings for design.

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Spring 2026

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Abstract

This report aims to either support or question the methods proposed by Japanese engineer Genich Taguchi, who proposed that carrying out experiments using the right number of combinations of possible noise and control variables would ultimately provide the designer with enough information to be able to accurately predict the output of the system under any combination of variables, minimising time and cost.

To tackle this problem, a catapult experiment was set up using a Statapult system using a combination of decided upon control factors. By carrying out firings and finding the two most significant variables, further firings were carried out to predict a theoretical projectile carry distance for a specified set of variable settings. A validation test of this theory found the theoretical answer to be correct to within a 1% tolerance, verifying the validity of Taguchi's methods in full.

Introduction to Taguchi Methods and Catapult Experiment

Genich Taguchi was a Japanese engineer and statistician who proposed a series of statistical innovations to improve product design quality, known as Taguchi Methods [1]. Among these contributions to systems engineering was a series of statistics driven experiment designs which used arrays to combine a series of factors involved in the design and engineering process that are inevitable in a real-world setting, such as changing the operator and small variations in production, but that within the experiment can be deliberately controlled to measure their effect on the final product – and ultimately be able to accurately predict the impact on a product of certain variations before they are physically tested. By analysing pairs of variables instead of every combination against

each other, it is possible to gather all the required data in a minimal number of trial runs, ultimately speeding up the process and reducing cost [1].

Among the most famous training aids to demonstrate the strength of the Taguchi methods is the catapult experiment. Using a Statapult catapult, as shown in Figure 1, deliberate adjustments are made to each individual firing to highlight the effects of each variation, and how variations together can cause large-scale variations in result. The aim of the experiment is to be able to gather the most information possible about the impact of noise whilst running the fewest possible iterations of the experiment. The array of results should then be able to predict the outcome of any combination of tested noises to a high degree of accuracy [1].

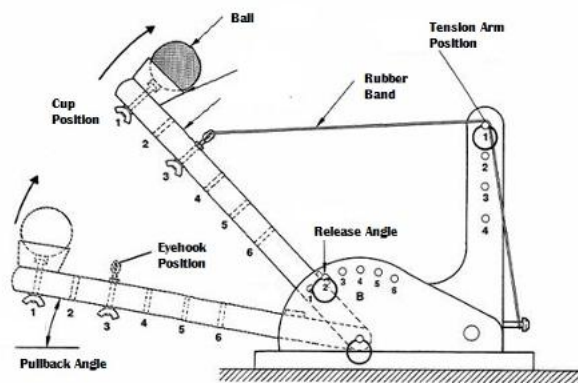


Figure 1: Statapult design showing all variations that can be made to the system. [2]

Objective

The aim of the experiment carried out in this report was to verify Taguchi's statistical methods using a Statapult catapult device to carry out a series of firings, each time adjusting a few variations to see the impact of the variations on the distance travelled by the ball.

In total, firings were carried out under eight different combinations of noise controls. By populating the results from each combination and finding relationships, it should be possible to find the two most influential variables. From here, further firings were to be carried out using the most consistent operator and the two variables in the same vein as before to find a predicted distance travelled at the midpoint of these variables. Finally, a validation firing was calculated to test this theory.

Methodology

Before starting the experiment, the key control factors for testing were identified. These factors were:

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- Band Front Position (Tension Arm Position on Figure 1)
- Band Anchor Position (Back Arm Position on Figure 1)
- Stop Position (Release Angle on Figure 1)
- Pullback Angle
- Operator

The band front position was altered between position 1 and position 3 (see Figure 1) for this experiment, and the band anchor position was altered between position 2 and position 4. The stop position was altered between positions 1 and 3 and the pullback angle was altered between 140 and 170 degrees from rest position.

Two operators were used, referred to as Operators A and B.

Using the array provided in Figure 2, making the adjustments as dictated, a series of firings were carried out.

Experiment	Array Populated						
	1	2	3	4	5	6	7
	Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator
Expt 1	1	2	1	1	140	1	A
Expt 2	1	2	1	3	170	2	B
Expt 3	1	4	2	1	140	2	B
Expt 4	1	4	2	3	170	1	A
Expt 5	3	2	2	1	170	1	B
Expt 6	3	2	2	3	140	2	A
Expt 7	3	4	1	1	170	2	A
Expt 8	3	4	1	3	140	1	B

Figure 2: Populated array with decided upon control factors along the top and combinations used for the eight initial experiments down the table.

In each firing, there was one operator, one retriever, one results taker, and three observers tasked with accurately measuring the distance travelled by the ball in firing. In each instance, the carried distance (distance travelled before first impact with the ground) was recorded.

Metre rules were placed along the ground to measure distance travelled, and firings were filmed to be reviewed to make sure that observed distances were accurate. Each individual experiment was carried out three times and averaged to account for uncontrolled variations.

Once this was completed, the two observed most influential factors, and most consistent operator, took part in four more firing experiments in the same manner as before, according to the array in Figure 3, which would be populated with combinations of the two most influential factors. The other factors remained at the level which allowed the most distance to be travelled.

	KF1	KF2		1	2	3	Ave
Firing 1			range				
Firng 2			range				
Firing 3			range				
Firng 4			range				

Figure 3: Array for second experiment set, to be populated upon observation of key control factors.

Results and Discussion

Figure 4 shows the raw data collected from the first eight firing experiments with averages taken, and figure 5 shows the averaged distances travelled by the projectile within the populated array from figure 2.

	Trial 1	Trial 2	Trial 3	Average
Experiment 1	83	76	87	82
Experiment 2	239	248	183	223.3333
Experiment 3	63	74	86	74.33333
Experiment 4	174	174	179	175.6667
Experiment 5	103	108	104	105
Experiment 6	43	43	30	38.66667
Experiment 7	78	74	79	77
Experiment 8	51	53	51	51.66667

Figure 4: Raw data obtained from eight firing experiments.

Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator	Variable. Range
1	2	1	1	140	1	A	82
1	2	1	3	170	2	B	223
1	4	2	1	140	2	B	74
1	4	2	3	170	1	A	176
3	2	2	1	170	1	B	105
3	2	2	3	140	2	A	39
3	4	1	1	170	2	A	77
3	4	1	3	140	1	B	52

Figure 5: Populated array from figure 2 with averaged results displayed.

From this raw data, examining the relationships and combinations from each firing, it was possible to create graphs showing the effect that each variation of the key noise factors had on overall distance travelled by the projectile. Figure 6 shows these graphs together.

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Figure 6: Graphs showing the impact of changing each individual control factor on the distance travelled by the projectile.

From analysing Figure 6, it could be seen that the two most impactful factors on the projectile during firing were the front position (tension arm position in figure 1) and the pull-back angle. These two factors were analysed further in the second part of the experiment. Although the difference between operators was small, Operator B was the most consistent and therefore was chosen as the operator for the second phase. All other variations were set and fixed at the higher level for this part of the experiment – stop position was held at position 3, and anchor position was held at position 2.

The array from figure 3 was then populated to create the array shown in figure 7, with the results found.

	KF1	KF2		1	2	3	Ave		
Firing 1	1	140	range	40	40	40	40	KF 1 :1	KF2 :1
Firing 2	3	140	range	25	25	23	24.33333	117.1667	32.16667
Firing 3	1	170	range	184	205	194	194.3333	KF 1 :2	KF2 :2
Firing 4	3	170	range	100	112	108	106.6667	65.5	150.5

Figure 7: Populated array of results from second phase of experiment.

Using the distances obtained from these experiments, it was calculated that, if the results were accurate, then a projectile fired at the midpoint of these variables would travel 91.3cm.

A final validation firing to test this hypothesis was carried out using tension arm position 2, at a pull back angle of 155 degrees. In this firing, the average distance travelled by the projectile was 92cm, an error of 0.7%, suggesting an accurate set of results.

The results obtained in this experiment directly support the theories proposed by Taguchi regarding using statistics to understand product output when affected by variations and noise, and the implications of failing to control noises.

The result obtained from the validation experiment being within 1% of the theoretical value further supports this idea.

Conclusion

In conclusion, the Taguchi catapult experiment provides a robust and easy-to-understand insight in to how statistics can drive decision-making in systems engineering, and reduce the cost and time required to produce accurate analysis.

By carrying out just eight trial runs, the orthogonal array system proposed by Taguchi analysed pairs of combinations to produce a clear visual representation of which two factors had the most impact on the projectile carry distance.

From running just four more firings varying these two most significant factors, it was possible to calculate a predicted distance for a midpoint set of variables to 0.7% error, demonstrating the validity of the process, and of Taguchi's methods.

If this experiment were to be repeated, it should be repeated with more controls identified to see if the number of identified possible variables affecting the system requires more combinations of variables to be tested, and to see if a relationship can be established between the number of trial runs required for a certain number of variables in order to ensure that any variation can be predicted accurately to within 1%.

References

- [1] S. Fraley, J. Zalewski, M. Oom and B. Terrien, "Design of Experiments via Taguchi Methods - Orthogonal Arrays," University of Michigan, Ann Arbor.
- [2] M. Bryant and A. Finch, "Statapult Model For Accuracy," College of William and Mary, Williamsburg, VA, 2014.