*International Journal of Engineering & Technology*, 7 (4.42) (2018) 52-55

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

*Research paper*

# Optimization of Laser Cutting Parameters on 700MC Steel Using Grey Relational Analysis

**Orajit Jaemsang[1]*, Parinya Kaweegitbundit[2], Niwat Mookam[3]**

[1]*Department of Industrial Engineering Technology*
[2]*Rajamangala University of Technology Rattanakosin*
[3]*Wang Klai Kang Won Campus, Huahin, Prachuapkhirikhan, Thailand*
**Corresponding author E-mail: orajit.pra@rmutr.ac.th*

## Abstract

This paper presents an investigation of the optimization of laser cutting parameters on 700MC steel. The cutting parameters investigated in this study are focused on Laser power, cutting speed, and gas pressure. Full factorial design (3k) is employed as the random run of the experimental. Grey relational analysis is used to determine the optimization of these parameters. The experimental results show that the optimal cutting condition for laser power, cutting speed and gas pressure is 2600W, 1500 mm/min and 0.06 bars, respectively. In addition, the experimental validation provided the surface roughness and kerf width is 3.870 µm and 0.696 mm respectively.

***Keywords***: *grey relational analysis; laser cutting; optimization parameter*

## 1. Introduction

Laser light or light amplification by stimulation emission of radiation is one of the thermal energy machining processes. Hence, Laser beam machining (LBM) is a process to cut materials. A high-energy laser beam is focused on a minimal region. The focused beam causes melting, vaporization or chemical degradation throughout the depth of material. The melted and transformed materials are removed with high pressure assist gas. LBM is widely used for complex parts in the manufacturing industries such as aerospace, electronics, civil structures, and automobiles because of a low cost, high precision, and productivity [1-2]. However, the several factors of LBM process that affect the quality characteristics (i.e. LBM variables, material property, and operating) [3]. Effect of key process parameters, such as laser power, cutting speed, and gas pressure, on surface roughness and kerf width have been studied [4-6].

It well know that various methods using to predict the optimization parameters (i.e. mathematical and statistical, or collection of both mathematical and statistical technique). The response surface methodology (RSM) is employed to establish the reliable mathematical relationships between the parameters and desired responses [7]. A full factorial design of experiment (DOE) is used to collect the necessary data for developing and validating the models [8], but that method has a large number of experiments. Taguchi experimental design method is applied to significantly reduce the number of experiments [9] but simultaneous optimization of these machining characteristics has not been reported in the full factorial design and Taguchi. Generally, Grey relational analysis base on Taguchi experimental design method is used for the optimization of multifactor experiments. Grey relational analysis is one of the efficient solutions to the uncertainty, multi-input and discrete data problems [10]. This method defined the optimization process as a decision making process in which decision goals are represented a maximum of the average grey relational grade. Grey relational analysis was applied to optimize the input parameters simultaneously considering multiple output variables [11].

The main purpose of this paper is to investigate optimization parameters of laser cutting on 700 MC steel. The investigate laser cutting parameters were laser power, cutting speed, and gas pressure. Grey relational analysis method to predict both the surface roughness and kerf response of laser cutting.

## 2. Materials and Procedures

The 700MC steel is a high yield structural steel supplied under the EN10149: Part2 specification. Due to the materials high yield (700Mpa min.) it can be used in a variety of load bearing applications. The steel as above which has 20x30x6 mm rectangular bar was used in this study. For the procedure, the experiments were carried out on the AMADA laser cutting machine model FO3015 for cutting workpieces. The full factorial design ($3^k$) was generated the experiments. The symbol k is a number of regulated parameters. This study carried out with three experimental parameters of laser cutting and three replicate levels of each factor conditions that showed in Table 1. Hence, eighty-one experiments were carried out.

In this study, the surface roughness and kerf response of laser cutting is investigated. For surface roughness testing, the Mahr surface roughness machine model MarSurf PSI was used. Also the kerf measuring, the JENCO optical microscope model V203410 was used throughout Edn-2 software. Finally, the optimal cutting parameters were evaluated by grey relational analysis.

**Table 1:** The Experimental Parameters and Levels on the Laser Process Cutting

| Parameters | Units | Levels | | |
|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 |
| Laser power | watts | 2600 | 2800 | 3000 |
| Cutting speed | mm/min | 1000 | 1500 | 2000 |
| Gas pressure | bar | 0.04 | 0.06 | 0.08 |

## 3. Results and discussion

Figure 1 and Figure 2 demonstrate laser cutting process and specimen workpiece, respectively. The details of experiments and normalization values are shown in Appendix A.


**Fig. 1:** Laser cutting process.

**Fig. 2:** The specimen workpiece throughout cutting process.

Grey relation analysis is used to optimize the turning operation with multiple performance characteristics. For the method, all initial experimental data were normalized in range between zero and one by (1) or (2). Equation (1) is used for responses that larger-better value. Other hand, (2) is used for responses that smaller-better value.

$$x_i^*(k)=\frac{x_i^{(0)}(k)\ \text{-}\ \min_{all(i)}x_i^{(0)}(k)}{\max_{all(i)}x_i^{(0)}(\mathrm{k})\ \text{-}\ \min_{all(i)}x_i^{(0)}(\mathrm{k})} \quad (1)$$

$$x_i^*(k)=\frac{\max_{all(i)}x_i^{(0)}(k)\ \text{-}\ x_i^{(0)}(k)}{\max_{all(i)}x_i^{(0)}(k)\ \text{-}\ \min_{all(i)}x_i^{(0)}(k)} \quad (2)$$

where $x_i^*(k)$ is the value of response $i^{th}$ of scenario $k$, $x_i^{(0)}(\mathrm{k})$ is initial value of response $i^{th}$ of scenario $k$, $\min_{all(i)}x_i^{(0)}(k)$ is the minimum initial value of scenario $k$ and $\max_{all(i)}x_i^{(0)}(k)$ is the maximum initial value of scenario $k$.
In this study, the response of surface roughness and kerf of laser cutting was the smaller-better response characteristic. Therefore, the normalized equation as (2) was used. The maximum and minimum experimental result was 0 and 1, respectively. The grey relational coefficient is calculated by (3). In this experiment, the distinguishing coefficient was set as 0.5 initially [12] that infer to coordinate the surface roughness and kerf of laser cutting.

$$\zeta_i(k)=\frac{\Delta_{min}+\zeta\Delta_{max}}{\Delta_{0i}(k)+\zeta\Delta_{max}} \quad (3)$$

Where $\zeta_i(k)$ is grey relational coefficient of response $i^{th}$ of scenario $k$ and $\zeta$ is distinguishing coefficient, $\zeta \in [0,1]$. $\Delta_{min}$, $\Delta_{max}$ and $\Delta_{0i}(k)$ can be calculated by (4), (5) and (6), respectively.

$$\Delta_{min}=\min_{\forall j\in i}\min_{\forall k}\left|x_0^*(k)\text{-}x_j^*(k)\right| \quad (4)$$

$$\Delta_{max}=\max_{\forall j\in i}\max_{\forall k}\left|x_0^*(k)\text{-}x_j^*(\mathrm{k})\right| \quad (5)$$

$$\Delta_{0i}(k)=\left|x_0^*(k)\text{-}x_i^*(k)\right| \quad (6)$$

Where $\Delta_{0i}(k)$ is different between ideal response $x_0^*(k)$ and experimental response $x_i^*(k)$.
The grey relational grade is calculated after grey relational coefficients completely carried out. This value can be calculated as (7).

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\zeta_i(k) \quad (7)$$

Where $\gamma_i$ is grey relational grade of response $i^{th}$. The results of grey relational coefficient and grey relational grade demonstrate in table 2.

**Table 2:** The Experimental Parameters and Levels on the Laser Process Cutting

| Run | Grey Relational Coefficient | | Grey Relational Grade |
|---|---|---|---|
| | Surface Roughness | Kerf | |
| 1 | 0.3333 | 0.4286 | 0.3810 |
| 2 | 0.3782 | 0.4925 | 0.4354 |
| 3 | 0.8158 | 0.3626 | 0.5892 |
| 4 | 0.7028 | 0.5410 | 0.6219 |
| 5 | 0.3362 | 0.3882 | 0.3622 |
| 6 | 0.3443 | 0.4521 | 0.3982 |
| 7 | 0.6246 | 0.4783 | 0.5514 |
| 8 | 0.4282 | 0.4648 | 0.4465 |
| 9 | 0.5168 | 1.0000 | 0.7584 |
| 10 | 0.6347 | 0.4400 | 0.5374 |
| 11 | 0.4236 | 0.4783 | 0.4509 |
| 12 | 0.5344 | 0.4521 | 0.4932 |
| 13 | 0.4776 | 0.5077 | 0.4926 |
| 14 | 0.3890 | 0.4400 | 0.4145 |
| 15 | 0.6066 | 0.5077 | 0.5571 |
| 16 | 0.4857 | 0.4074 | 0.4466 |
| 17 | 0.7872 | 0.3708 | 0.5790 |
| 18 | 0.3642 | 0.4648 | 0.4145 |
| 19 | 0.3369 | 0.3474 | 0.3421 |
| 20 | 0.4353 | 0.4521 | 0.4437 |
| 21 | 0.9236 | 0.6226 | 0.7731 |
| 22 | 0.5044 | 0.4177 | 0.4611 |
| 23 | 0.5344 | 0.4648 | 0.4996 |
| 24 | 0.4754 | 0.3793 | 0.4274 |
| 25 | 0.5601 | 0.4074 | 0.4838 |
| 26 | 0.3984 | 0.5077 | 0.4530 |
| 27 | 0.4224 | 0.4074 | 0.4149 |
| 28 | 0.5744 | 0.4521 | 0.5132 |
| 29 | 0.8179 | 0.3708 | 0.5944 |
| 30 | 0.5446 | 0.4074 | 0.4760 |
| 31 | 0.5973 | 0.5593 | 0.5783 |
| 32 | 0.7156 | 0.5593 | 0.6375 |
| 33 | 0.3398 | 0.4521 | 0.3959 |
| 34 | 0.3316 | 0.4400 | 0.3858 |
| Run | Grey Relational Coefficient | | Grey Relational Grade |
| | Surface Roughness | Kerf | |
| 35 | 0.5020 | 0.4521 | 0.4770 |
| 36 | 0.7322 | 0.3548 | 0.5435 |
| 37 | 0.6981 | 0.3793 | 0.5387 |
| 38 | 0.4575 | 0.5410 | 0.4992 |
| 39 | 0.5808 | 0.4925 | 0.5367 |
| 40 | 0.6874 | 0.3474 | 0.5174 |

| | | | |
|---|---|---|---|
| 41 | 0.4957 | 0.4783 | 0.4870 |
| 42 | 0.4972 | 0.4074 | 0.4523 |
| 43 | 0.6478 | 0.4925 | 0.5702 |
| 44 | 0.5797 | 0.3882 | 0.4840 |
| 45 | 0.5152 | 0.4177 | 0.4664 |
| 46 | 0.5819 | 0.5238 | 0.5528 |
| 47 | 0.5611 | 0.4925 | 0.5268 |
| 48 | 0.4471 | 0.5410 | 0.4940 |
| 49 | 0.7444 | 0.3333 | 0.5389 |
| 50 | 0.5985 | 0.4783 | 0.5384 |
| 50 | 0.7172 | 0.3976 | 0.5574 |
| 52 | 0.5185 | 0.5077 | 0.5131 |
| 53 | 0.5126 | 0.4648 | 0.4887 |
| 54 | 0.7172 | 0.4521 | 0.5846 |
| 55 | 0.5052 | 0.3976 | 0.4514 |
| 56 | 0.6019 | 0.4400 | 0.5210 |
| 57 | 0.8116 | 0.7333 | 0.7725 |
| 58 | 0.7091 | 0.5593 | 0.6342 |
| 59 | 0.9236 | 0.5593 | 0.7415 |
| 60 | 0.8201 | 0.4648 | 0.6424 |
| 61 | 0.7853 | 0.5789 | 0.6821 |
| 62 | 0.7643 | 0.5593 | 0.6618 |
| 63 | 0.7289 | 0.6735 | 0.7012 |
| 64 | 0.7587 | 0.5410 | 0.6499 |
| 65 | 0.7322 | 0.5593 | 0.6458 |
| 66 | 0.7972 | 0.5238 | 0.6605 |
| 67 | 0.7853 | 0.4783 | 0.6318 |
| 68 | 0.8605 | 0.5789 | 0.7197 |
| 69 | 0.8897 | 0.5789 | 0.7343 |
| 70 | 0.7189 | 0.6226 | 0.6707 |
| 71 | 0.8535 | 0.5789 | 0.7162 |
| 72 | 0.9076 | 0.7333 | 0.8205 |
| 73 | 0.9182 | 0.6226 | 0.7704 |
| 74 | 0.9264 | 0.6226 | 0.7745 |
| 75 | 1.0000 | 0.5593 | 0.7797 |
| 76 | 0.7624 | 0.5593 | 0.6609 |
| 77 | 0.9516 | 0.3976 | 0.6746 |
| 78 | 0.8581 | 0.5789 | 0.7185 |
| 79 | 0.9319 | 0.5410 | 0.7364 |
| 80 | 0.9813 | 0.5789 | 0.7801 |
| 81 | 0.9692 | 0.7333 | 0.8513 |

To optimize the laser cutting parameters by using grey relational analysis, the average grey relational grade of each level is investigated. For the method, the maximum average grey relational grade of each parameter was selected. Therefore, the optimal cutting parameters in this experiment are shown in Table 3. Consequently, the optimal parameters of laser cutting in this study were 2600W of laser power, 1500 mm/min cutting speed and 0.06 bar of gas pressure. The experimental validation provided the surface roughness was 3.870 μm and the kerf of laser cutting was 0.696 mm.

**Table 3:** Average Grey Relational Grade

| Parameters | Units | Levels | | |
|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 |
| Laser power | watts | 0.5894* | 0.5494 | 0.5641 |
| Cutting speed | mm/min | 0.5541 | 0.6043* | 0.5445 |
| Gas pressure | bar | 0.5514 | 0.5956* | 0.5560 |
| | | *Optimal values in this study | | |

## 4. Conclusion

The optimization of laser cutting parameters on 700MC steel using grey relational analysis was carried out in this experiment. The response parameters of laser cutting were laser power, cutting speed and gas pressure. As the results, the optimal parameter for each response as above was 2600W, 1500 mm/min and 0.06 bar, respectively. The experimental validation provided the surface roughness and the kerf of laser cutting were 3.870 $\mu$m and 0.696 mm, respectively. This study indicated that grey relational analysis approach was effectiveness to optimize a multiple performance characteristics. Furthermore, this approach can be applied to setting other machine functions.

## Acknowledgement

The authors would like to thank Rajamangala University of Technology Rattanakosin and Manufacturing and Testing for industry Academic Service Center for the research supporting.

## References

[1] Groover MP (2010), Fundamentals of modern manufacturing engineering material processes and system. 4th Edition, John Wiley & Sons, Inc.

[2] Sharma A & Yadava V (2018), Experimental analysis of Nd-YAG laser cutting of sheet materials – A review. Optics and Laser Technology, Vol. 98, pp.264–280.

[3] Dubey AK & Yadava V (2008), Laser beam machining—A review. *International Journal of Machine Tools and Manufacture*, 48(6), pp.609-628.

[4] Yilbas BS, Shaukat MM & Ashraf F (2017), Laser cutting of various materials: Kerf width size analysis and life cycle assessment of cutting process. *Optics and Laser Technology*, Vol.93, pp.67–73.

[5] Zhang Y & Lei J (2017), Prediction of laser cutting roughness in intelligent manufacturing mode based on ANFIS. *Procedia Engineering*, Vol.174, pp.82 – 89.

[6] Fua CH, Liu JF & Guo A (2015), Statistical characteristics of surface integrity by fiber laser cutting of Nitinol vascular stents. *Applied Surface Science*, Vol.353, pp.291-299.

[7] Deeying J, Asawarungsaengkul K & Chutima P (2018), Multi-objective optimization on laser solder jet bonding process in head gimbal assembly using the response surface methodology. *Optics and Laser Technology*, Vol.98, pp.158–168.

[8] Kais I, Abdullah A, Abdi H, Peng LC & Yassin AW (2018), Force and temperature modelling of bone milling using artificial neural networks. *Measurement*, Vol.116, pp.25-37.

[9] Ballantyne KN, Van Oorschot RA & Mitchell RJ (2008), Reduce optimization time and effort: Taguchi experimental design methods. *Forensic Science International, Genetics Supplement Series* Vol.1, pp.7–8.

[10] Anand G, Satyanarayana S & Manzoor HM (2017), Optimization of process parameters in EDM with magnetic field using grey relational analysis with taguchi technique. *Materials Today, Proceedings*, Vol.4, pp.7723–7730.

[11] Srirangan AK & Paulraj S (2016), Multi-response optimization of process parameters for TIG welding of Incoloy 800HT by Taguchi grey relational analysis. *International Journal Engineering Science and Technology*, Vol.19, No.2, pp.811-817.

[12] Sreenivasulu R & Srinivasa RC (2012), Application of grey relational analysis for surface roughness and roughness error in drilling of AL 6061 alloy. *International Journal of Lean Thinking*, Vol.3, No.2, pp.67-78.

**Appendix A:** Experimental Result Data

| Run | Laser power (W) | Cutting speed (mm/min) | Gas passer (bar) | Surface roughness (μm) | Kerf (mm) | Surface roughness [0-1] | Kerf [0-1] |
|---|---|---|---|---|---|---|---|
| 1 | 3,000 | 1,000 | 0.04 | 7.61 | 0.78 | 0.0000 | 0.3333 |
| 2 | 2,800 | 2,000 | 0.08 | 6.49 | 0.73 | 0.1781 | 0.4848 |
| 3 | 3,000 | 1,000 | 0.06 | 2.03 | 0.85 | 0.8871 | 0.1212 |
| 4 | 2,800 | 1,500 | 0.04 | 2.65 | 0.70 | 0.7886 | 0.5758 |
| 5 | 2,800 | 2,000 | 0.04 | 7.53 | 0.82 | 0.0127 | 0.2121 |
| 6 | 2,600 | 2,000 | 0.08 | 7.31 | 0.76 | 0.0477 | 0.3939 |
| 7 | 3,000 | 1,500 | 0.08 | 3.21 | 0.74 | 0.6995 | 0.4545 |
| 8 | 2,800 | 1,000 | 0.04 | 5.52 | 0.75 | 0.3323 | 0.4242 |
| 9 | 2,80 | 2,000 | 0.04 | 4.26 | 0.56 | 0.5326 | 1.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | | | | | | 0 |
| 10 | 2,800 | 1,000 | 0.04 | 3.13 | 0.77 | 0.7122 | 0.3636 |
| 11 | 3,000 | 1,000 | 0.08 | 5.60 | 0.74 | 0.3196 | 0.4545 |
| 12 | 2,800 | 1,500 | 0.06 | 4.06 | 0.76 | 0.5644 | 0.3939 |
| 13 | 2,800 | 1,000 | 0.08 | 4.76 | 0.72 | 0.4531 | 0.5152 |
| 14 | 2,600 | 2,000 | 0.08 | 6.26 | 0.77 | 0.2146 | 0.3636 |
| 15 | 2,600 | 2,000 | 0.06 | 3.36 | 0.72 | 0.6757 | 0.5152 |
| 16 | 2,600 | 2,000 | 0.04 | 4.65 | 0.80 | 0.4706 | 0.2727 |
| Run | Laser power (W) | Cutting speed (mm/min) | Gas passer (bar) | Surface roughness (µm) | Kerf (mm) | Surface roughness [0-1] | Kerf [0-1] |
| 17 | 2,800 | 2,000 | 0.08 | 2.17 | 0.84 | 0.8649 | 0.1515 |
| 18 | 2,800 | 1,000 | 0.06 | 6.81 | 0.75 | 0.1272 | 0.4242 |
| 19 | 3,000 | 1,500 | 0.04 | 7.51 | 0.87 | 0.0159 | 0.0606 |
| 20 | 2,600 | 2,000 | 0.04 | 5.40 | 0.76 | 0.3514 | 0.3939 |
| 21 | 3,000 | 1,500 | 0.06 | 1.58 | 0.66 | 0.9587 | 0.6970 |
| 22 | 3,000 | 1,500 | 0.04 | 4.41 | 0.79 | 0.5087 | 0.3030 |
| 23 | 2,600 | 1,000 | 0.06 | 4.06 | 0.75 | 0.5644 | 0.4242 |
| 24 | 3,000 | 2,000 | 0.08 | 4.79 | 0.83 | 0.4483 | 0.1818 |
| 25 | 2,800 | 1,000 | 0.08 | 3.79 | 0.80 | 0.6073 | 0.2727 |
| 26 | 2,600 | 1,000 | 0.08 | 6.07 | 0.72 | 0.2448 | 0.5152 |
| 27 | 2,800 | 2,000 | 0.06 | 5.62 | 0.80 | 0.3164 | 0.2727 |
| 28 | 2,800 | 1,000 | 0.06 | 3.65 | 0.76 | 0.6296 | 0.3939 |
| 29 | 2,800 | 1,500 | 0.04 | 2.02 | 0.84 | 0.8887 | 0.1515 |
| 30 | 2,600 | 2,000 | 0.04 | 3.95 | 0.80 | 0.5819 | 0.2727 |
| 31 | 2,600 | 1,500 | 0.04 | 3.44 | 0.69 | 0.6630 | 0.6061 |
| 32 | 2,800 | 1,500 | 0.04 | 2.57 | 0.69 | 0.8013 | 0.6061 |
| 33 | 2,600 | 1,000 | 0.04 | 7.43 | 0.76 | 0.0286 | 0.3939 |
| 34 | 3,000 | 2,000 | 0.04 | 7.66 | 0.77 | -0.0079 | 0.3636 |
| 35 | 3,000 | 1,500 | 0.08 | 4.44 | 0.76 | 0.5040 | 0.3939 |
| 36 | 2,600 | 1,500 | 0.08 | 2.47 | 0.86 | 0.8172 | 0.0909 |
| 37 | 3,000 | 2,000 | 0.06 | 2.68 | 0.83 | 0.7838 | 0.1818 |
| 38 | 3,000 | 2,000 | 0.08 | 5.05 | 0.70 | 0.4070 | 0.5758 |
| 39 | 3,000 | 1,000 | 0.06 | 3.59 | 0.73 | 0.6391 | 0.4848 |
| 40 | 2,800 | 2,000 | 0.08 | 2.75 | 0.87 | 0.7727 | 0.0606 |
| 41 | 2,800 | 1,000 | 0.08 | 4.52 | 0.74 | 0.4913 | 0.4545 |
| 42 | 2,800 | 1,500 | 0.08 | 4.50 | 0.80 | 0.4944 | 0.2727 |
| 43 | 2,600 | 1,500 | 0.04 | 3.03 | 0.73 | 0.7281 | 0.4848 |
| 44 | 2,600 | 1,000 | 0.06 | 3.60 | 0.82 | 0.6375 | 0.2121 |
| 45 | 2,800 | 2,000 | 0.06 | 4.28 | 0.79 | 0.5294 | 0.3030 |
| 46 | 3,000 | 1,000 | 0.04 | 3.58 | 0.71 | 0.6407 | 0.5455 |
| 47 | 3,000 | 2,000 | 0.04 | 3.78 | 0.73 | 0.6089 | 0.4848 |
| 48 | 2,600 | 2,000 | 0.06 | 5.21 | 0.70 | 0.3816 | 0.5758 |
| 49 | 3,000 | 1,500 | 0.08 | 2.40 | 0.89 | 0.8283 | 0.0000 |
| 50 | 2,800 | 1,500 | 0.08 | 3.43 | 0.74 | 0.6646 | 0.4545 |
| 51 | 2,600 | 1,000 | 0.06 | 2.56 | 0.81 | 0.8029 | 0.2424 |
| 52 | 2,800 | 2,000 | 0.04 | 4.24 | 0.72 | 0.5358 | 0.5152 |
| 53 | 3,000 | 1,000 | 0.04 | 4.31 | 0.75 | 0.5246 | 0.4242 |
| 54 | 2,800 | 1,500 | 0.06 | 2.56 | 0.76 | 0.8029 | 0.3939 |
| 55 | 3,000 | 1,000 | 0.06 | 4.40 | 0.81 | 0.5103 | 0.2424 |
| 56 | 3,000 | 1,500 | 0.06 | 3.40 | 0.77 | 0.6693 | 0.3636 |
| 57 | 2,600 | 1,500 | 0.04 | 2.05 | 0.62 | 0.8839 | 0.8182 |
| 58 | 2,600 | 1,000 | 0.04 | 2.61 | 0.69 | 0.7949 | 0.6061 |
| 59 | 2,600 | 2,000 | 0.06 | 1.58 | 0.69 | 0.9587 | 0.6061 |
| 60 | 2,800 | 1,500 | 0.08 | 2.01 | 0.75 | 0.8903 | 0.4242 |
| 61 | 3,000 | 1,000 | 0.08 | 2.18 | 0.68 | 0.8633 | 0.6364 |
| 62 | 2,600 | 1,500 | 0.06 | 2.29 | 0.69 | 0.8458 | 0.6061 |
| 63 | 3,000 | 1,000 | 0.08 | 2.49 | 0.64 | 0.8140 | 0.7576 |
| 64 | 2,600 | 1,000 | 0.08 | 2.32 | 0.70 | 0.8410 | 0.5758 |
| 65 | 2,600 | 1,500 | 0.06 | 2.47 | 0.69 | 0.8172 | 0.6061 |
| 66 | 2,600 | 1,500 | 0.08 | 2.12 | 0.71 | 0.8728 | 0.5455 |
| 67 | 3,000 | 2,000 | 0.06 | 2.18 | 0.74 | 0.8633 | 0.4545 |
| 68 | 2,600 | 1,500 | 0.08 | 1.83 | 0.68 | 0.9189 | 0.6364 |
| 69 | 2,800 | 2,000 | 0.06 | 1.71 | 0.68 | 0.9380 | 0.6364 |
| 70 | 2,600 | 2,000 | 0.08 | 2.55 | 0.66 | 0.8045 | 0.6970 |
| 71 | 2,800 | 1,000 | 0.04 | 1.86 | 0.68 | 0.9142 | 0.6364 |
| 72 | 2,600 | 1,500 | 0.06 | 1.64 | 0.62 | 0.9491 | 0.8182 |
| 73 | 3,000 | 2,000 | 0.08 | 1.60 | 0.66 | 0.9555 | 0.6970 |
| 74 | 2,600 | 1,000 | 0.08 | 1.57 | 0.66 | 0.9603 | 0.6970 |
| 75 | 3,000 | 1,500 | 0.06 | 1.32 | 0.69 | 1.0000 | 0.6061 |
| 76 | 2,800 | 1,500 | 0.06 | 2.30 | 0.69 | 0.8442 | 0.6061 |
| 77 | 3,000 | 1,500 | 0.04 | 1.48 | 0.81 | 0.9746 | 0.2424 |
| 78 | 3,000 | 2,000 | 0.04 | 1.84 | 0.68 | 0.9173 | 0.6364 |
| 79 | 2,800 | 1,000 | 0.06 | 1.55 | 0.70 | 0.9634 | 0.5758 |
| 80 | 3,000 | 2,000 | 0.06 | 1.38 | 0.68 | 0.9905 | 0.6364 |
| 81 | 2,600 | 1,000 | 0.04 | 1.42 | 0.62 | 0.9841 | 0.8182 |