

Math 558 – Design of Experiments  
Final Exam May 2023  
Exam Release Date: April 17, 2023 – Time: 9:00 am  
Due Date: April 20, 2023 – Time: 9:00 am



Last name: \_\_\_\_\_ First name: \_\_\_\_\_

Student No.: \_\_\_\_\_

Note: Please clearly write your name in the above spaces.

### Instructions

1. Either use the template to answer your questions or answer on a separate sheet of paper. If you answer on a separate sheet of paper, your answers must be ordered as follows: Question 1, Question 2, Question 3, Question 4, Question 5.  
Your answers must be listed in this order, even though you may have worked on them in a different order. Thus, for example if your first page contains the answer to Question 2 instead of Question 1 you will receive no marks for your answers.
2. Your exam must be submitted by any means to myCourses as a single pdf (handwritten or typed), no later than April 20 at 9:00 am.
3. Submit your exam on myCourses as if you are submitting an assignment.
4. You will be allowed multiple submissions until the deadline. We will grade the latest submission before the deadline.
5. Make sure that you receive an acknowledgment from myCourses that your submission has been received. **If you encounter a problem with your submission you must let me know immediately. It is too late to inform me once the deadline has passed.**
6. The exam has been prepared in such a way that if undertaken under normal conditions, it can be completed in 3 hours. **Due to potential issues with internet connectivity and other unforeseen technical issues, it is strongly recommended that you plan to submit your exam script well in advance of the deadline.**
7. You are permitted to use any resource you want. However, you are not allowed to collaborate with other students in the course.

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Question 1. [20 points]

Steel is normalized by heating above the critical temperature, soaking, and then air cooling. This process increases the strength of the steel, refines the grain, and homogenizes the structure. An experiment is performed to determine the effect of temperature and heat treatment on the strength of normalized steel. Two temperatures and three times are chosen for the experiment. The experiment is performed by heating the oven to a randomly selected temperature and inserting three specimens. After 10 minutes one specimen is removed, after 20 minutes the second specimen is removed, and after 30 minutes the final specimen is removed. Then the temperature is changed to the other level and the process is repeated. Four shifts are required to collect the data, which are shown below. Analyze the data and draw conclusions, assuming both factors are fixed. Attach R-output and R-codes.

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Shift	Time(min)	Temperature( $^{\circ}F$ )	
		1500	1600
1	10	63	89
	20	64	91
	30	61	62
2	10	50	80
	20	52	72
	30	59	69
3	10	48	73
	20	74	81
	30	71	69
4	10	54	88
	20	48	92
	30	59	64

Solution: Q1.  
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Question 2. [20 Points] An engineer is interested in the effects of cutting speed (A), tool geometry (B), and cutting angle (C) on the life (in hours) of a turning tool. Two levels of each factor are chosen, and three replicates of a  $2^3$  factorial design are run. The results are given in the table below.



Treatment Combinations	Replicates		
	I	II	III
1)	22	31	25
a	32	43	29
b	35	34	50
ab	55	47	46
c	44	45	38
ac	40	37	36
bc	60	50	54
abc	39	51	47

- Write down a regression model for predicting tool life and estimate the model parameters
- Estimate the factor effects. Which effects appear to be large?
- Based on the results from parts (a) and (b) write down the reduced model and estimate its parameters.

Note: Attach R-output and R-codes

Solution Q2.

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- Question 3. a. [12 Points] Three different washing solutions are being compared to study their effectiveness in reducing bacteria growth in five gallon milk containers. The analysis is done in a laboratory, and only three trials can be run on any day. Because days could represent a potential source of variability, the experimenter decides to use a randomized block design. Observations are taken for four days, and the data are as follows. Analyze the data from this experiment (use  $\alpha = 0.05$ ). Attach R-output and R-codes.



	Days			
	1	2	3	4
1	13	22	18	39
2	16	24	17	44
3	5	4	1	22

- b. [8 Points] Show that for a  $(t, b, r, k, \lambda)$  BIBD,

$$b \geq t + (r - k)$$

Where,  $t$  is the number of treatments,  $b$  is the number of blocks,  $r$  is the replication,  $k$  is the block size and  $\lambda$  is the concurrence of the pair  $(i, j)$  for all  $i$  and  $j$ .

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Solution Q3.

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- Question 4. a. [14 Points] Seven different hardwood concentrations are being studied to determine their effect on the strength of the paper produced. However, the pilot plant can only produce three runs each day. As days may differ, the analyst uses the balanced incomplete block design that follows. Analyze this experiment (use  $\alpha = 0.05$ ) ns. Attach R-output and R-codes.



Conc	Days						
	2	3	4	5	6	7	
1				120			117
2	120				119		
3	137	114					134
4		129	149				
5	145		150	143			
6		120		118	123		
7			133		130	127	

- b. [3 Points] Give the incidence matrix for the design given in part (a).  
 c. [3 Points] Give the concurrence matrix for the design given in part (a).

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Solution Q4.

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Question 5. a. [8 Points] Show that for a  $(t, b, r, k, \lambda)$  BIBD,

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$$r \geq k$$

and

$$\lambda(t-1) > k^2 - k$$

Where,  $t$  is the number of treatments,  $b$  is the number of blocks,  $r$  is the replication,  $k$  is the block size and  $\lambda$  is the concurrence of the pair  $(i, j)$  for all  $i$  and  $j$ .



- b. [6 Points] Which type of design that would be most appropriate for each of the following situations?
- (i) investigating a new drug which purports (claims) to reduce high blood pressure.
  - (ii) comparing four diets for piglets to see which gives the greatest weight gain in the first six weeks of life.
  - (iii) seeing whether either of the two proposed new drugs to help people give up smoking has any effect.
- c. [3 Points] You want to compare four treatments in blocks of two runs. Find a Balanced Incomplete Block Design for this experiment with six blocks. (You just have to give all the parameters of this BIBD)
- d. [3 Points] Verify that a BIBD with the parameters  $a = 8, r = 8, k = 4$ , and  $b = 16$  does not exist.

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Solution Q5.

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