1. **QUESTION 1** **30 pts**

A production control engineer wishes to study the factors that influence the breaking strength of metallic sheets. He designs an experiment wherein four machines and three robots are selected at random and a factorial experiment is performed using metallic sheets from the same production batch. The relevant data on breaking strength in certain standard units are given as follows.

	Machine			
Robot	**1**	**2**	**3**	**4**
1	112	113	111	113
	113	118	112	111
2	113	113	114	118
	115	114	112	117
3	119	115	117	123
	117	118	122	119

Analysis of Variance

Source	DF	SS	MS	F-Value
Machine		17.79		
Robot		147.25		
Machine*Robot		49.08		
Error		47.50		
Total		261.62		

(a) (6 points) Write the ANOVA model and the assumptions for the experiment.

(b) (8 points) Test whether there are interaction effects between machines and robots. Use $\alpha = 0.05$. State the null and alternative hypotheses, decision rule, and conclusion.

(c) (8 points) Test whether there are main effects due to the machines. Use $\alpha = 0.05$. State the null and alternative hypotheses, decision rule, and conclusion.

(d) (8 points) Determine point estimates of the variance components of the model.

2. **QUESTION 2** **30 pts**

Consider the experiment in question 1. Suppose that the robots were selected at random, but only four machines were available for the test.

(a) (6 points) Write the ANOVA model and the assumptions for the experiment.

(b) (8 points) Test whether there are interaction effects between machines and robots. Use $\alpha = 0.05$. State the null and alternative hypotheses, decision rule, and conclusion.

(c) (8 points) Test whether there are main effects due to the machines. Use $\alpha = 0.05$. State the null and alternative hypotheses, decision rule, and conclusion.

(d) (8 points) Provide a point estimate and the standard error of the following contrast among the four machine means:

$$\frac{1}{2}\left(\mu_{.1} + \mu_{.2}\right) - \frac{1}{2}\left(\mu_{.3} + \mu_{.4}\right)$$

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3. **QUESTION 3** **10 pts**

A production engineer studied the effects of machine model and operator on the output in a bottling plant. Three bottling machines were used, each a different model. Twelve operators were employed. Four operators were assigned to a machine and worked six-hour shifts each. Data on the number of cases produced by each machine and operator were collected for a week. The data that follow represent the number of cases produced per hour for each day during the week.

Machine i:	1				2				3			
Operator j:	1	2	3	4	1	2	3	4	1	2	3	4
Day $k = 1$:	65	68	56	45	74	69	52	73	69	63	81	67
$k = 2$:	58	62	65	56	81	76	56	78	83	70	72	79
$k = 3$:	63	75	58	54	76	80	62	83	74	72	73	73
$k = 4$:	57	64	70	48	80	78	58	75	78	68	76	77
$k = 5$:	66	70	64	60	68	73	51	76	80	75	70	71

The engineer needs your help to analyze his data.

(a) (5 points) Identify *all* factors in this experiment.

(b) (5 points) For each factor, indicate if it should be treated as fixed or random. Provide a reason for each case.

4. **QUESTION 4** **15 pts**

A marketing research consultant evaluated the effects of fee schedule (factor A), scope of work (factor B), and type of supervisory control (factor C) on the quality of work performed under contract by independent marketing research agencies. The factor levels in the study were as follows:

Factor			Factor Levels
A	Fee level	$i = 1$:	High
		$i = 2$:	Average
		$i = 3$:	Low
B	Scope	$j = 1$:	All contract work performed in house
		$j = 2$:	Some work subcontracted out
C	Supervision	$k = 1$:	Local supervisors
		$k = 2$:	Traveling supervisors only

The quality of work performed was measured by an index taking into account several characteristics of quality. Four agencies were chosen for each factor level combination and the quality of their work evaluated.

Provide an ANOVA table for this study listing all sources of variation and the corresponding degrees of freedom.

QUESTION 5 **15 pts**

A sociologist classified 45 faculty members by subject matter of course (factor A with 4 levels) and highest degree earned (factor B with 3 levels).

The first ANOVA table below is from a model including A and B main effects and AB interaction effects. The second one is from a model including B main effects and AB interaction effects but no A main effects.

Sequential sum of squares ANOVA table with A, B and AB terms.

Analysis of Variance

Source	DF	Seq SS
A		4.1676
B		8.3825
A*B		0.0444
Error		0.7180

Sequential sum of squares ANOVA table with only B and AB terms.

Analysis of Variance

Source	DF	Seq SS
B		6.5708
A*B		1.7911
Error		4.9506

Use the information in the two tables to compute the F test statistic for testing the hypotheses: H_0 : There is no main effect due to factor A versus H_a : There is a main effect due to factor A.