Assignment

RE 30003: Introduction to Quality – Spring 2025

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Total Marks: 120 *Due: [8:00 AM] April 16, 2025*

Submission Guidelines:

Submit a physical copy of your completed assignment in class on the due date. All work must be handwritten (no typed or printed submissions) except for Q(14) and Q(15) where you can attach printed pages of your codes and figures. Late submissions will not be accepted and will result in a grade of zero for the assignment.

1)	Two types of defects are observed in the production line of mechanical gaming keyboards. It is estimated that 3% of the keyboards have mechanical switch defects and 5% of the keyboards have RGB lighting defects. The occurrences of the two types of defects are assumed to be independent of each other. If a customer buys a gaming keyboard, what will be the probabilities for the following situations: a) Either a mechanical switch defect or an RGB lighting defect or both are found. b) Only a mechanical switch defect is found. c) Both types of defects are found. d) The keyboard is free of any defects. e) If an RGB defect is found, what are the chances of finding a mechanical switch defect?	**[5]**
2)	The navigation system and power system of an Unmanned Surface Vessel (USV) are made of several components in parallel. In the navigation system, 4 components are placed in parallel and the probability of such a component working is 0.8. In the power system, 2 components are placed in parallel and the probability of such a component working is 0.95. A parallel configuration guarantees that the system will work if at least one component is working. Assume that the components operate independently of each other. a) What is the probability of the navigation system functioning? b) What is the probability of the power system functioning? c) Power or navigation, which system is more reliable? What are their failing probabilities? d) If the power system or the navigation system or both fails, the USV fails to function. What is the probability of the USV functioning? e) If another component of working probability of 0.95 is added in parallel to the power system, how will it impact the failing probability of the USV?	**[5]**
3)	C-washers, also known as spring washers or split lock washers, are typically made of steel and are used to create a spring-like action between the fastener and the surface being fastened. They come in various sizes and thicknesses, but their weights are generally quite light compared to other types of washers. For certain space related applications, the specifications for the thickness of C-washers are 1.0 ± 0.05 mm. The specifications for the weight of these C-washers are 15.0 ± 0.15 gm. From process data, the distribution of the C-washer thickness is estimated to be normally distributed with a mean of 1.02 mm and a standard deviation of 0.02 mm. On the other hand, the distribution of the C-washer weight is estimated to be normally distributed with a mean of 14.9 gm and a standard deviation of 0.05 gm. The unit cost of rework is \$15 and the unit cost of scrap is \$8. A unit needs to be reworked when both of its quality characteristics are greater than their upper specification limits (USL), whereas, a unit is scrapped if one or both of its quality characteristics are less than the lower specification limit(s) (LSL). For a daily production of 1200 washers:	**[5]**

	a) What proportion of the C-washers is thickness conforming? b) What proportion of the C-washers is weight conforming? c) What is the expected total daily cost of rework and scrap due to thickness nonconformance? d) What is the expected total daily cost of rework and scrap due to weight nonconformance? e) What proportion of the C-washers is both thickness and weight conforming assuming that these events are independent?	
4)	A glass manufacturing company produces bottles with a target neck diameter of 30 mm. The upper specification limit (USL) is 30.05 mm, and the lower specification limit (LSL) is 29.95 mm. The process has a standard deviation of 0.015 mm, and the company produces 12,000 bottles per day. a) Calculate the sigma level at which the process is currently operating. b) Determine the corresponding defect rate in terms of defects per million opportunities (DPMO) and the expected number of defective bottles produced per day.	**[5]**
5)	a) Name three methods used for fitting a distribution to an observed dataset. b) Derive the linear expression for constructing a Weibull Probability Paper Plot. c) What is the relation between the Weibull parameters with the slope and intercept of the PPP linear expression? d) For n number of data points, $x_1, x_2, \ldots, x_n$, derive the expressions for the parameter estimates of the normal distribution using the maximum likelihood estimation (MLE) method. e) The breaking strength is a quality characteristic for electric cables. The breaking strength data of a cable type shows the sample mean to be 4010 kg and the sample standard deviation to be 38 kg. If it is assumed that the breaking strength is normally distributed, what will be the estimated parameter values of the normal PDF according to the MLE method?	**[5]**
6)	A company produces precision gears used in robotic arms for automated manufacturing. These gears must meet strict specifications for both thickness and weight to ensure smooth and efficient operation. The specification for gear thickness is 5.0 ± 0.03 mm, and the specification for weight is 50.0 ± 0.5 g. Based on recent quality control data, the thickness of the gears is normally distributed with a mean of 5.02 mm and a standard deviation of 0.015 mm. The weight of the gears follows a normal distribution with a mean of 49.8 g and a standard deviation of 0.2 g. The unit cost of rework is \$20, and the unit cost of scrap is \$10. For a daily production of 2,000 gears: a) What proportion of the gears meet the thickness specification? b) What proportion of the gears meet the weight specification? c) Using the assumption that the events of thickness and weight conformance are independent, calculate the expected total daily cost of rework and scrap. A unit should be reworked if both quality characteristics exceed their upper specification limits, and it should be scrapped if either quality characteristic is below its respective lower specification limit.	**[5]**
7)	The safe operation of an automobile is dependent on several subsystems (e.g., engine, transmission, braking mechanism) as well as the physical and mental condition of the driver. Construct an Ishikawa diagram for automobile accidents caused by subsystem failures and driver conditions. Use the following table to construct the diagram. The failure modes are sorted according to severity of occurrence.	**[10]**

Failure Modes	**Causes**	**Severity**
Engine failure	Overheated radiator	High
Transmission failure	Tire blows	High
Traffic environment	Poor weather	High
Driver’s mental condition	Emotionally disturbed	High
Driver’s physical condition	Visual disability	High
Driver’s physical condition	Tired/Fatigued	High

Engine failure	Low fluid levels	Moderate
Engine failure	Broken/cracked hose	Moderate
Transmission failure	Broken belt	Moderate
Braking failure	Failure of primary system	Moderate
Traffic environment	Congested traffic	Moderate
Driver's mental condition	Personal issues	Moderate
Driver's mental condition	No support from supervisor	Moderate
Driver's physical condition	Not skilled for safe driving	Moderate
Engine failure	Electrical shorting	Low
Transmission failure	Failure of mechanism	Low
Braking failure	Hydraulic failure	Low
Braking failure	Failure of secondary system	Low
Traffic environment	Road construction	Low

8) The safe operation of a manufacturing process is reliant on several subsystems (e.g., machinery, quality control, worker conditions) as well as the overall organizational environment. Construct a cause-and-effect diagram for incidents occurring in the manufacturing process caused by subsystem failures and worker conditions. Use the following table to guide your construction of the cause-and-effect diagram. The failure modes are sorted according to severity of occurrence. **[10]**

Failure Modes	**Causes**	**Severity**
Machine malfunction	Overheated motor	High
Quality control failure	Inadequate inspection	High
Worker's mental condition	Stressful work environment	High
Worker's physical condition	Fatigue	High
Machinery failure	Worn-out parts	Moderate
Machinery failure	Lack of maintenance	Moderate
Quality control failure	Insufficient training	Moderate
Worker's mental condition	Personal issues	Moderate
Quality control failure	Inconsistent procedures	Moderate
Worker's physical condition	Poor ergonomics	Moderate
Machine malfunction	Electrical failure	Low
Quality control failure	Data entry errors	Low
Worker's physical condition	Lack of safety gear	Low
Worker's mental condition	Lack of motivation	Low
Environmental factors	Poor ventilation	Low
Environmental factors	Noise pollution	Low

9) In deep-sea exploration, various components of remotely operated underwater vehicles (ROVs) are crucial for successful operations. These components, however, can develop defects due to extreme underwater conditions such as high pressure and low temperature. Two of the most commonly used materials in ROV components are High-Density Polyethylene (HDPE) and Titanium. HDPE components are lightweight but more prone to deformation, while titanium components are durable but costly to repair. A company involved in ROV manufacturing produces both types of components and has recorded defect data from the previous year along with the per unit cost of rectification, as shown in the table below. Construct pareto charts for HDPE and titanium components based on the defect rectification costs. Compare and discuss the results, focusing on which defects the management should prioritize for rectification for each component type. **[10]**

Defect Categories	Frequency		Unit Costs	
	HDPE	*Titanium*	*HDPE*	*Titanium*
Deformation under pressure	1200	200	$3	$25
Seal failure	1500	1000	$2	$15
Abrasion wear	400	300	$10	$12
Corrosion	600	800	$5	$20
Electrical shorting	50	100	$50	$80
Hydraulic system leaks	300	150	$20	$30
Sensor malfunction	900	500	$3	$4

10) Keycaps are the individual covers placed on top of the switches of a computer keyboard. They come in various types, each offering different materials, profiles, and designs. ABS (Acrylonitrile Butadiene Styrene) keycaps are one of the most common types found on standard keyboards. However, these keycaps are prone to wear over time with heavy use. PBT (Polybutylene Terephthalate) keycaps are known for their durability and resistance to wear and tear. They have a rougher texture compared to ABS keycaps, providing a more satisfying tactile feel while typing. In a company that manufactures both types of keycaps, the previous year's data show various types of defects and the associated per unit cost of rectifying these defects, which are presented in the table below. **[10]**

a) Construct pareto charts for ABS and PBT keycaps and compare the results.
b) The management has a combined yearly allocation of $14,000. Due to the popularity of PBT keycaps, the management decided to allocate 40% of the budget to ABS keycap rectification and the rest 60% to the PBT keycap rectification. Which defects should they tackle for different keycaps?

Defect Categories	Frequency		Unit Costs	
	ABS Keycaps	*PBT Keycaps*	*ABS Keycaps*	*PBT Keycaps*
Warpage instability	1000	800	$0.5	$1
Plastic overflowing	1400	880	$1.5	$2
Incomplete legends	100	120	$0.2	$0.3
Colour inconsistencies	230	310	$0.2	$0.2
Stem misalignment	80	15	$30	$100
Air bubbles	300	250	$10	$13
Surface imperfections	1350	870	$1	$1.5

11) Industrial filters play a critical role in numerous sectors, including manufacturing, automotive, pharmaceuticals, and food and beverage industries. These filters are designed to remove impurities, contaminants, or unwanted particles from various fluids, gases, or air streams, ensuring product quality, equipment protection, and environmental compliance. The length of industrial filters is a quality characteristic of interest because it directly affects filtration efficiency, flow rate, capacity, uniformity, and compatibility with equipment. For process monitoring, 40 samples each of size (i.e., sample/batch size) 5 are chosen from the process output. The data yield an average length of 110.0 mm, with the process standard deviation estimated to be 4.0 mm. **[10]**

a) Find the 3-sigma control limits and the warning limits for a control chart of the average length.
b) What is the probability of a Type I error in this control chart?
c) If the process mean shifts to 108 mm, what is the probability of detecting this shift by the first sample drawn after the shift?
d) If the process mean shifts to the same 108 mm, what is the probability of detecting this shift on the third sample drawn after the shift?

	e) What is the Average Running Length (ARL) for this shift in the process mean? f) The specifications for the filter length are 113.0 ± 12.0 mm. Find the Process Capability Ratio (PCR), C_p, for the process and comment on the ability of the process to meet the specifications.	
12)	In a precision manufacturing setup for optical lens components, both length and diameter must be maintained within specifications. The required length is between 49.5 mm and 50.5 mm, while the diameter must range from 24.5 mm to 25.5 mm. However, the data collected for quality monitoring is susceptible to measurement noise. The observed (noisy) sample averages are 50.1 mm for length and 25.2 mm for diameter, with observed sample standard deviations of 0.5 mm for length and 0.35 mm for diameter. An additive noise model can be applied for both length and diameter measurements, where the observed (noisy) data $\boldsymbol{Y} = \boldsymbol{X}+\boldsymbol{e}$, with $\boldsymbol{X}$ being the true (noise-free) value and $\boldsymbol{e}$ representing the measurement noise. In this case, $\boldsymbol{X}$ is normally distributed, while $\boldsymbol{e}$ is normally distributed with a zero mean and a variance of 0.01 mm^2 for both length and diameter of the optical lens components. Calculate the average process capability ratio (Cp) for both dimensions based on these specifications. Additionally, discuss how measurement noise may impact the accuracy of the calculated Cp values and whether they accurately reflect the process capability under these noisy conditions.	**[10]**
13)	Spacecraft fuel filters are essential components in space missions, ensuring that fuel supplied to the propulsion system is free from impurities that could hinder engine performance. These filters must be manufactured to precise specifications, as their length directly impacts flow rate, filtration efficiency, and compatibility with various engine components. The manufacturing process for these filters requires close monitoring. To assess process stability, 40 samples each of size 5 are drawn from the output. The sample data reveal an average filter length of 215.0 mm, with the process standard deviation estimated to be 3.0 mm. a) Calculate the 3-sigma control limits and warning limits for a control chart monitoring the average filter length. b) If the process mean shifts to 213 mm, determine the Average Running Length (ARL) for detecting this shift in the process mean. c) After the process mean shift to 213 mm, calculate the probability of both Type I and Type II errors for this control chart.	**[10]**
14)	The dataset *boiler.txt* contains temperature readings from eight configured burners on a boiler system. Each row represents a temperature snapshot across all eight burners (t1 to t8) at different time intervals, recorded over 25 observations. a) Load the *boiler* dataset and examine its structure, summary statistics, and any noticeable patterns or outliers. Plot the temperature readings for each burner (t1 to t8) across the 25 observations to get an initial visualization of the data trends. b) Create individual control charts for each burner's temperature readings (t1 to t8). Analyse and interpret the control charts to identify any burners with temperature readings outside the control limits. c) Describe any multivariate patterns or signals and assess whether the system is in statistical control. Assume the acceptable temperature range for each burner is between 470 and 550 degrees. Calculate the process capability indices for each burner's temperature readings.	**[10]**
15)	The dataset *pistonrings.txt* provides measurements of the inside diameter of piston rings manufactured for an automotive engine through a forging process. The data includes two phases: *Phase I*: Preliminary samples, considered 'in control,' to establish control limits. This phase includes 25 samples, each of size 5. *Phase II*: Additional samples collected after establishing control limits in Phase I. This phase includes 15 samples, each of size 5, to monitor the ongoing process stability.	**[10]**

	a) Load the *pistonrings* dataset and separate the data into Phase I (preliminary, trial=TRUE) and Phase II (monitoring, trial=FALSE). Calculate and display basic summary statistics for the diameters in each phase, such as mean and standard deviation, to compare overall process characteristics across phases. b) Create an X-bar and R control chart for the Phase I data to establish baseline control limits for the mean and range of piston ring diameters. Identify any points that fall outside the control limits in Phase I and interpret whether any adjustments might be necessary to bring the process fully under control. c) Apply the control limits derived from Phase I to the Phase II samples. Construct X-bar and R charts for Phase II to evaluate the ongoing stability of the forging process. Identify any out-of-control points in Phase II, discuss their significance, and propose possible reasons for any observed shifts or trends. d) Assess the process capability for the piston ring diameters, assuming a target diameter of 74 mm and a tolerance of ±0.030 mm. Calculate the Process Capability Index based on Phase I data. Comment on whether the process is capable of consistently producing piston rings within the specified tolerance, and discuss any adjustments needed if capability is insufficient.	