NCEES PE Industrial and Systems Practice Exam Solutions

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This document was complied during my preparation for the 2025 offering of the NCEES PE Industrial and Systems Exam and reflects the questions in the 2020 PE Industrial and Systems Practice Exam solutions and 2023 errata. The NCEES practice exam was the cornerstone for my first-time pass exam experience.

Additional useful resources were "Introduction to Industrial and Systems Engineering" by Robert Wayne Atkins as an excellent high-level overview, and the PE practice exam guide ordered from the IISE. Purchasing the NCESS practice exam and the above two texts ran approximately $200, making it relatively inexpensive compared to many other discipline's preparation courses.

These resources were more than sufficient to pass the exam with a comfortable margin of time (approximately 6 hours for completion) and with very few questions feeling unfamiliar. As far as prior background I did not take the FE in Industrial and Systems (I did Other Disciplines), nor did I major in Industrial and Systems engineering.

Question 1:

Mission Definition Clear articulation of the purpose and objectives of a project / organization. It sets the direction and provides a framework for decision making and resource allocation throughout the lifecycle of the project or organization.

Preliminary product design plans The initial phase of the development process where the basic concept of a product is translated into detailed plans and specifications.

Market Share The portion or percentage of total sales (volume or revenue) in a market captured by a particular company, product, or brand over a specified period.

Interoperability Requirements Specifications designed to ensure that products, systems, or software can work together (interoperate) without losing functionality or efficiency.

The correct answer is **d**.

Question 2:

Omitted

Question 3:

System Requirements Specification (SRS)

- Defines the detailed technical and functional requirements of the system.
- Captures system architecture, including hardware and software components, interactions, and constraints.
- Serves as a reference for system designers and developers.

Stakeholder Requirements Specification (StRS)

- Documents the needs, expectations, and constraints of stakeholders.
- Focuses on high-level business goals rather than technical details.
- Used as a foundation for developing system requirements.

System Element Requirements Specification (SERS)

- Defines requirements for individual system elements or components.
- Provides a detailed breakdown of how different system elements contribute to the overall system architecture.
- Helps guide the design and development of specific modules or subsystems.

Business Requirements Specification (BRS)

- Outlines the business objectives, scope, and high-level needs of the project.
- Focuses on why the system is needed rather than how it will be implemented.
- Used to align technical requirements with business goals.

The correct answer is **c**.

Question 4:
The bottleneck is the workstation that has the lowest hourly production rate.

The production rates are:

Workstation 1: $\frac{1\,unit}{10\,min} * \frac{60\,min}{1\,hr} * 2\,workers = 12\frac{units}{hr}$

Workstation 2: $\frac{1\,unit}{6\,min} * \frac{60\,min}{1\,hr} * 1\,worker = 10\frac{units}{hr}$

Workstation 3: $\frac{1\,unit}{16\,min} * \frac{60\,min}{1\,hr} * 3\,workers = 11.25\frac{units}{hr}$

Workstation 2 is the bottleneck.

Since the demand is $8\frac{units}{hr}$ and the capacity is $10\frac{units}{hr}$, then the utilization is $\frac{8\frac{units}{hr}}{10\frac{units}{hr}} = 0.8$, or 80%.

> The correct answer is **c**.

Question 5:

The four main test and evaluation methods recognized by the industry are:

a) **Analysis** – Evaluating a system or component using calculations, logical reasoning, or qualitative assessment.

b) **Demonstration** – Showing that a system or component functions as required under specific conditions.

c) **Inspection** – Examining a product or system to verify compliance with requirements.

f) **Test** – Conducting controlled experiments or trials to measure performance and compliance.

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d) **Modeling** and e) **Simulation** are often used in conjunction with test and evaluation but are typically considered supporting techniques rather than primary evaluation methods.

The correct answers are **a, b, c, f**.

Question 6:

The productivity measure for 2016 was: $\frac{X}{MP}$.

In 2017 the productivity measure was: $\frac{1.1672X}{(0.9277M)*(1.2273P)}$

We see that for 2017 the measure is $\frac{1.1672}{0.9277*1.2273} * \frac{X}{MP}$.

This is the measure for 2016 multiplied by the factor $\frac{1.1672}{0.9277*1.2273} = 1.0251$, which is a 2.51% increase.

The correct answer is **a**.

Question 7:

Omitted

Question 8 (Errata Replacement):

We have a difference of two ratios here. The first ratio $\frac{C_1}{C_2}$ has a positive coefficient, 5. Since we want to maximize the equation, this ratio should be as large as possible given the constraints. As both values are constrained to positive numbers all we need to do is maximize C_1 as it is in the numerator, and minimize C_2 as it is in the denominator. And so $C_1 = 12$ and $C_2 = 15$.

The second ratio $\frac{C_3}{C_4}$ has a negative coefficient, -3. To maximize the equation overall, this ratio should be as small as possible given if it cannot be made positive, otherwise if one of the values can take on a negative number we should work to maximize like in the first ratio. We see that C_4 is always negative and C_3 always positive and so we can turn this part of the equation positive. We then seek to maximize. For C_3 we need to maximize this number as it is in the numerator, and maximize C_4 as it is in the denominator and all possible values are negative. And so $C_3 = 412$ and $C_4 = 15 - 3$.

The maximized equation is then:

$$\boxed{Y = 5 \times \frac{12}{15} - 3 \times \frac{4}{-3} = 8}$$

Question 9:

A production facility organized around processes (also known as a process-focused or job shop layout) is typically used for low-volume, high-variety production. This setup is flexible but less efficient compared to product-focused layouts.

Generally in these environments products follow different routes depending on their specific needs and there often is substantial customization, which causes variability in workflow. As a result, work-in-process (WIP) inventory tends to be high, since jobs may wait in queues at different workstations depending on scheduling and machine availability.

The correct answer is **a**.

For the other options:

b) low WIP inventory – incorrect; WIP tends to be high due to variability and queuing.

c) low variable costs – incorrect; variable costs are typically higher due to customization and lower economies of scale.

d) high production throughput – incorrect; throughput is usually lower due to complexity and lower standardization.

Question 10:

Risk models tend to have two types of nodes, **decision nodes** (usually indicated by squares) are where the decision maker chooses an action, and **chance nodes** (circles) where the outcome is probabilistic.

The risk model here contains a single node A with all its children as chance nodes. We can calculate the expected value of node A by working our way down each branch and calculating the expected value of the branch. Then we take the sum of all the expected values of the branches.

For the upper branch, we have an outcome of \$ -1,000 with probability 1, which is descended from an outcome of \$5,000 with probability 0.25. The expected value of the top branch is:

$$-(1,000 \times 1 + 5,000) \times 0.25 = 1,000$$

We can think of this branch as a 'win-now, lose-later' scenario. For example, say that we are considering adopting a new technology that will save \$5,000 in administrative overhead in the short term, but ultimately the technology is not yet fully compatible and will require manual adjustments causing a cost of \$1,000 in extra labor.

We can calculate the remaining branches as follows:

Middle branch:

$$((-5,000 \times 0.5 + 1,000 \times 0.5) + 20,000) \times 0.3 = 5,400$$

Lower branch:

$$(-10,000) \times 0.45 = -4,500$$

The expected value for A is then:

$$1,000 + 5,400 - 4,500 = 1,900$$

> The correct answer is **c**.

Question 11:

The Beta Distribution Method is often used in Project Evaluation and Review Technique (PERT) to estimate the expected duration of some activity within a project network. The uncertainty in the time estimation is handled by using a function of three estimates:

$$Expected\ \ Time = \frac{O + 4M + P}{6}$$

Where O is Optimistic time, the shortest possible time (here it is labeled Minimum). M is the most likely time (Mode), and P is Pessimistic time, the longest time (Maximum).

We will build the activity network which contains the following activities and their expected time:

Activity	**Expected Time (days)**
B	$\frac{1+4\times3+5}{6} = 3$
C	$\frac{2+4\times3+5}{6} =\approx 3.17$
D	$\frac{1+4\times2+4}{6} \approx 2.17$
E	$\frac{3+4\times4+5}{6} = 4$

The **critical path** is the longest path, i.e, the one that has the largest expected time. The activity network has the following paths:

Activity	**Expected Time (days)**
C	3.17
$B \to D$	$3 + 2.17 = 5.17$
$B \to E$	$3 = 4 = 7$

So $B \to E$ is the critical path.

The variability can be estimated by calculating the standard deviation, defined as:

$$\sigma = \frac{P - O}{6}$$

Activity	**Expected Time (days)**	**Standard Deviation (days)**
B	$\frac{1+4\times3+5}{6} = 3$	$\frac{5-1}{6} \approx .67$
C	$\frac{2+4\times3+5}{6} =\approx 3.17$	$\frac{5-2}{6} = .50$
D	$\frac{1+4\times2+4}{6} \approx 2.17$	$\frac{4-1}{6} = .50$
E	$\frac{3+4\times4+5}{6} = 4$	$\frac{5-3}{6} \approx .33$

We can then estimate the probability of completing a project within a certain time frame by calculating a Z score and using the standard normal table.

Recall that a Z score is calculated using the following:

$$Z = \frac{x - \mu}{\sigma}$$

Here x is our project completion date, μ is the length of the critical path, and σ is the sum of the standard deviations along the critical path.

For example, the probability of completing the project within 10 days is:

$$Z = \frac{10 - 7}{.67 + .33} = 3$$

Using the standard normal table we have:

$$Pr(Z \leq 3) \approx 0.99865$$

So, there is a 99.865% chance the project will finish in 10 or fewer days.

Note that this answer is based on the assumption that the project duration is well approximated by the normal distribution.

Question 12:

An **Activity-based diagram** is one of the behavioral diagrams in the Unified Modeling Language (UML), used in software engineering and business process modeling. They are used to model the flow of control and actions within a system or process. Unlike Activity-on-Node diagrams, these are not concerned with time, but are interested in the system workflow in its entirety.

A **CPM Diagram** (Critical Path Method) is a network like the activity-based diagram but has activity durations and visually identifies the critical path (the longest path through the network that determines the total project time).

A **Gnatt chart** is a time-scaled bar chart with one row for each task. The horizontal rows show each task' start, duration, and overlap.

A **flowchart** is a process map using standard shapes: terminator (rounded rectangle) for Start/End, parallelogram for Input/Output, rectangle for Process, and diamond for Decision; arrows show flow.

An **Activity-on-Node (AON) diagram**, also known as a precedence diagram, is a project management tool used to visualize the schedule and dependencies of project tasks. Its primary goal is to map out the sequence of activities and determine the project's critical path. It does so through Nodes (boxes) that represents individual projects or tasks and Arrows (edges) that represent the logicial dependencies between activities, showing which tasks need to be completed before others begin.

A **work breakdown structure** is a hierarchical decomposition of project scope into deliverables and work packages. These are drawn as trees with the following approximate structure: Project → Phases → Deliverables → Tasks.

Question 13:

Recall that the following phases for the system life cycle are: (1) Concept Definition, (2) Needs / Requirements Analysis, (3) System (High-level) Design, (4) Design Integration (Detailed Design), (5) Implementation (Development), (6) System Testing and Validation, (7) Deployment (Installation / Production), (8) Operation and Maintenance, and (9) Disposal / Retirement.

Project risk is considered highest during the concept definition phase because:

- There is the most uncertainty at this early stage.
- Requirements, scope, budget, and technologies may not yet be fully defined.
- Decisions made here have a long-term impact, but this is the point with the least amount of information available.

As the system life cycle progresses and more information becomes available, risks are identified, analyzed, and mitigated, thereby reducing the overall project risk.

So, the highest risk occurs at the beginning of the system life cycle, which is concept definition.

Question 14:

Recall that value engineering is a method to improve the value of some product, process, service, etc. by systematically analyzing its functions. The goal of value engineering is to select the function(s) that achieve the lowest total cost without compromising quality, performance, or reliability.

Value is defined as the ratio of function to cost.

Value engineering seeks to reduce costs or improve quality.

Answers **a** and **d** are clearly negative value and so cannot be the answer.

In general, value engineering often simplifies processes resulting is better job design. This simplification can result in the elimination of unnecessary or hazardous steps which enhances safety.

The answer is **c**

Question 15:

Note that question 15 is subject to a revision in the 2023 errata. The errata does not adjust the solution to the updated problem.

We see the widget is located on the risk cube with an impact of **high** and a likelihood of **30%**. High impact corresponds to a cost of $50,000.

The standard risk contingency formula is:

$$Contingency\ \ Budget = Likelihood\ \times\ Cost\ \ Impact$$

Which gives us a budget of $0.3 \times \$50,000 = \$15,000$.

We could also calculate the *time* contingency budget in a similar manner:

$$0.3 \times 6\ weeks = 1.8\ weeks$$

So we should have a schedule buffer of approximately 2 weeks to account for the risk.

Question 16:

The three common concepts that systems engineering and project management share are:

c) Project planning: Both disciplines involve planning to define objectives, scope, timelines, resources, and the whatever activities needed to achieve the desired outcome(s). Project management plans the overall project, while systems engineering plans the technical approach and activities. Ultimately, both plans need to be integrated.

d) Risk management: Both systems engineering and project management have processes to identify, analyze, assess, mitigate, and monitor risks. Project management typically focuses on risks to project objectives (cost, schedule, scope), while systems engineering focuses on technical risks related to system performance, integration, and successful operation. The fundamental concept of proactively managing uncertainty is common to both.

g) Task definition: Both fields require breaking down complex work into smaller, manageable, and definable tasks. Project management relies on task definition for creating work breakdown structures, scheduling, and assigning responsibilities. Systems engineering defines tasks throughout the system lifecycle, from requirements development and design to integration and testing.

The answers are **c, d, g**.

Question 17:

Recall that Taylor's tool life equation is:

$$VT^n = C$$

where V is the cutting speed, T is the tool life, n is Taylor's exponent (given here as 0.4), and C is a constant (given as 300). Both n and C are dependent on the tool material.

Since the tool life is increased by 50% we know that $T_2 = 1.5T_1$.

Our goal is to find how much the cutting speed must be reduced. We can use Taylor's equation for both the initial and final conditions and equate them.

$$V_1 T_1^n = C = V_2 T_2^n$$

Substituting $T_2 = 1.5T_1$ gives us $V_1 = V_2(1.5)^n$.

We then solve for the ratio $\frac{V_2}{V_1}$:

$$\frac{V_2}{V_1} = \frac{1}{(1.5)^{0.4}} \approx 0.85$$

So the cutting speed is reduced by $(1 - 0.85) \times 100\% = 15\%$.

$\boxed{\text{The answer is } \mathbf{c}.}$

Question 18:

We first need to calculate the total cycle time needed to create one part c. The cycle time c is the total time needed for loading the part, then both rough cuts, the finish cut, and finally unloading the part.

The time for a single rough cut is $\frac{60cm+2\times5cm}{250\frac{mm}{min}\times\frac{10mm}{cm}} \approx 2.8min$

The time for a single finish cut is $\frac{60cm+2\times5cm}{175\frac{mm}{min}\times\frac{10mm}{cm}} \approx 4.0min$

So the cycle time is (converting the load and unload times to minutes).

$$c = 0.27min + 2.8min \times 2 + 4min + 0.13min \approx 10min$$

We now need to calculate the time available for a single machine over the course of a year.

$$h = 7.5\frac{hours}{shift} \times 2\frac{shifts}{day} \times \frac{days}{week} \times 48\frac{weeks}{year} = 3600\frac{hours}{year}$$

So the number of machines needed to meet the demand of 200,000 parts per year can be found using the relation

$$Number\ of\ machines = Demand \times \frac{cycle\ time}{available\ hours}$$

Which gives us

$$\frac{200,000\ parts}{year} \times \frac{\frac{10min}{60\frac{min}{hour}}}{3600\frac{hour}{year}} = 9.25 \approx 10\ machines$$

As there are ten machines, we will need at least five operators per shift. So 10 total operators.

The answer is **d**.

Question 19:

We will operate under the standard assumption that a higher rating is superior. The score for each location is:

$$
\begin{aligned}
\mathit{Location}\ 1 &= 0.40 \times 7 + 0.15 \times 8 + 0.25 \times 4 + 0.20 \times 6 = 5.2 \\
\mathit{Location}\ 2 &= 0.40 \times 8 + 0.15 \times 6 + 0.25 \times 9 + 0.20 \times 8 = 7.95 \\
\mathit{Location}\ 3 &= 0.40 \times 6 + 0.15 \times 8 + 0.25 \times 7 + 0.20 \times 7 = 6.75 \\
\mathit{Location}\ 4 &= 0.40 \times 9 + 0.15 \times 5 + 0.25 \times 7 + 0.20 \times 8 = 7.7
\end{aligned}
$$

The answer is **b**

Question 20:

We need to find the straight-line distance (Euclidean) and the Manhattan distance (rectilinear). These can be found on page 17 of the handbook.

The Euclidean distance is:

$$\sqrt{(5-12)^2 + (16-3)^2} \approx 14.77$$

The Manhattan distance is:

$$|5-12| + |16-3| = 20$$

Then the change in distance from Manhattan to Euclidean is:

$$\frac{20 - 14.77}{20} \approx 0.262$$

The answer is **b**

Question 21:

We cannot arrange the packages end to end as this would give us a total length of 48 in., overhanging our pallet.

Instead we can place one package perpendicular to another forming an L shape. This results in a total length of 18 in. + 24 in. = 42 in. (the exact maximum length). We can form an identical L with two more packages to make a rectangle.

The dead space within the rectangle is 6 in. $\times$ 6in., which is too small to fit another package, and so the maximum number is four.

The answer is **b**.

Question 22:

We need to calculate the total number of available hours.

Since the factory has an equivalent time of 49 weeks per year with full use of the 24 hour day, the total hours within the time span is simply:

$$Total\ Hours = 49\ Weeks\ \times \frac{7\ days}{week} \times \frac{24\ hours}{day} = 74,088\ hours.$$

We then adjust for maintenance:

$$Maintence\ Adjusted\ Hours = Total\ Hours \times 0.92 = 68,161\ hours$$

And operator absenteeism:

$$Total\ Available\ Hours = Maintenence\ Adjusted\ Hours \times 0.95 = 64,753\ hours$$

The answer is **b**.

Question 23:

Let us calculate an adjacency matrix for the departments A to E.

	A	B	C	D	E
A	-	1	1	0	1
B	1	-	0	1	1
C	1	0	-	0	1
D	0	1	0	-	1
E	1	1	1	1	-

We will assume that the flow between departments, denoted by k, is the same.

The maximum amount of flow between departments ($\sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}$) is if all are connected to each other. A flows to B, C, D, and E. B flows to A, C, D, and E, and so on. Note that flow occurs only between departments, not within. The maximum amount of flow is $4k + 3k + 2k + 1k = 10k$ (the sum here decreases as we are removing already counted pairs between departments).

The numerator for our normalized adjacency score is simply the sum of one of the diagonals (either lower or upper as the matrix is symmetric) of our adjacency matrix. Viewing the adjacencies this way automatically prevents multiple counts for the same flow. We have (going column-wise) $3k+2k+1k+1k = 7k$.

And so the normalized adjacency score is $\frac{7k}{10k} = 0.70$

The answer is **c**.

Question 24:

The total cost (TC) is the fixed cost (FC) plus the variable cost (VC) per unit multiplied by the number of units.

The answer is **d**.

Question 25:

In Systematic Layout Planning (SLP), the activity relationship chart is a tool used to record qualitative information about how desirable it is for different areas (including both production and nonproduction spaces) to be located near each other. SLP uses letter codes like A (Absolutely necessary), E (Especially important), I (Important), O (Ordinary closeness okay), U (Unimportant), and sometimes X (Undesirable). Ultimately, the goal of SLP is to help inform layout decisions before quantitative flow data is available.

For the other options:

A **space relationship diagram** is a visual diagram that results from the activity relationship chart.

A **flow diagram** is used to show actual movement of materials or people, often on a scaled layout.

A **from-to chart** is a quantitative tool used to show the amount of flow between areas.

The answer is **a**.

Question 26:

Material Handling Equipment		**Type**
Forklift truck	________________	Point to Point
Belt conveyor	________________	Limited Area
Electric overhead traveling crane	________________	Wide Area

Consider the equipment's range of movement.

A belt conveyor is fixed in terms of location, and so it's type must be **point to point**.

An overhead traveling crane allows some movement of the crane itself, but is restricted to the paths allowed by the fixed rails it is attached to, and so it is **limited area**.

A forklift truck has freedom to move across any location that it suitable for its tires, and so it is considered **wide area**.

Question 27:

The total of number units produced at station B is $\frac{5000}{0.91} \approx 5495$ units.

The input needed to produce these units is $2 \times \frac{5495}{0.93} \approx 11,816$ for station A and $3 \times \frac{5495}{0.97} \approx 16,993$.

And so the total raw input to machines A and C is $11,816 + 16,993 = 28,809$ units.

The answer is **d**

Note that scrap (or defect) rate is a loss, so to find the required input, you need to 'reverse' the effect of this loss. That means dividing by the yield (good rate), not multiplying by the bad rate.

If you know the output you want and the yield, you must divide to find the input: $Input = \frac{Output}{Yield}$

If you know the input and want to estimate the output, you multiply by the yield: $Output = Input \times Yield$

Question 28:

We can calculate the net present value by subtracting initial investment from the sum of the recurring revenue (with each year converted to present dollars). To generate the sum, we need to find the present value for each year with respect to the discount rate. Now the discount rate means the money loses value over time at that rate, we effectively need to undo the growth by dividing by the rate. Discounting uses compound interest (future money shrinks at the same compound rate it would have grown) and so we use the Single Payment Present Worth (P/F) to calculate the amount for each year. For project A the recurring revenue is:

$$Year_1 = \frac{\$12,000}{(1.12)} \approx \$10,714$$
$$Year_2 = \frac{\$12,000}{(1.12)^2} \approx \$9,566$$
$$Year_3 = \frac{\$12,000}{(1.12)^3} \approx \$8,541$$
$$Year_4 = \frac{\$12,000}{(1.12)^4} \approx \$7,626$$

And the net present value is:

$$-30,000 + \sum_{i=1}^{4} Year_i = 10,714 + 9,566 + 8,541 + 7,626 = 6,447$$

For project B the recurring revenue is:

$$Year_1 = \frac{\$16,000}{(1.12)} \approx \$14,286$$
$$Year_2 = \frac{\$16,000}{(1.12)^2} \approx \$12,755$$
$$Year_3 = \frac{\$16,000}{(1.12)^3} \approx \$11,388$$
$$Year_4 = \frac{\$16,000}{(1.12)^4} \approx \$10,168$$

$$-52,000 + \sum_{i=1}^{4} Year_i = 14,286 + 12,755 + 11,388 + 10,168 = -3,403$$

The answers are **a, c**

Question 29:

A unit load is a single item or a group of items that are packaged together and handled as one unit during storage or transport. To form a unit load, you need packaging or containment devices (like boxes or totes) and supporting platforms (like pallets).

For this question, options a, b, and d disqualify themselves as they contain equipment for handling the load.

- a) **AS/RS**, container, pallet

  AS/RS (Automated Storage and Retrieval System) is not part of the load, it is equipment for handling it.

- b) Container, **conveyor**, skid

  Conveyor is a material handling system, not part of the load.

- d) Container, **forklift**, tote

  Forklift is a handling device, not part of the load.

The answer is **c**

Question 30:

We need to first determine the availability for each machine. We were given total hours (144) and two reductions in these hours (Block time and Downtime). Availability can then be calculated by:

$$Availability = \frac{Total\ hours\ per\ week - Block\ Time - Downtime}{Total\ hours\ per\ week}$$

Calculating the values for each of the seven machines gives us:

$$X1 = \frac{144 - 5.9 - 9}{144} \approx 0.897$$
$$X2 = \frac{144 - 5.8 - 9}{144} \approx 0.897$$
$$Y1 = \frac{144 - 4.2 - 19}{144} \approx 0.839$$
$$Y2 = \frac{144 - 4.2 - 19}{144} \approx 0.839$$
$$Z1 = \frac{144 - 1 - 5.4}{144} \approx 0.956$$
$$Z2 = \frac{144 - 1 - 5.4}{144} \approx 0.956$$
$$Z3 = \frac{144 - 1 - 5.4}{144} \approx 0.956$$

The effective process rate for each machine is its availability multiplied by its process rate (jobs per hour).

$$X1 = 0.897 \times 3\frac{jobs}{hour} = 2.691\frac{jobs}{hour}$$
$$X2 = 0.897 \times 3\frac{jobs}{hour} = 2.691\frac{jobs}{hour}$$
$$Y1 = 0.839 \times 3\frac{jobs}{hour} = 2.517\frac{jobs}{hour}$$
$$Y2 = 0.839 \times 3\frac{jobs}{hour} = 2.517\frac{jobs}{hour}$$
$$Z1 = 0.956 \times 1.9\frac{jobs}{hour} = 1.8164\frac{jobs}{hour}$$
$$Z2 = 0.956 \times 1.9\frac{jobs}{hour} = 1.8164\frac{jobs}{hour}$$
$$Z3 = 0.956 \times 1.9\frac{jobs}{hour} = 1.8164\frac{jobs}{hour}$$

Finally, to calculate the effective process rate for each station, we only need to sum up the machine effective process rates at each station.

$$X_{EPR} = X1 + X2 = 2.691\frac{jobs}{hour} + 2.691\frac{jobs}{hour} = 5.382\frac{jobs}{hour}$$
$$Y_{EPR} = Y1 + Y2 = 2.517\frac{jobs}{hour} + 2.517\frac{jobs}{hour} = 5.034\frac{jobs}{hour}$$
$$Z_{EPR} = Z1 + Z2 = Z3 = 1.8164\frac{jobs}{hour} + 1.8164\frac{jobs}{hour} + 1.8164\frac{jobs}{hour} = 5.4492\frac{jobs}{hour}$$

The answer is **c**

Question 31:

We will assume the most efficient combination between single and dual cycles is chosen for each hour. A single cycle takes 1.5 minutes and a dual cycle takes 2.4 minutes.

For the first hour, we have twenty pallets in and out and so can just use 20 dual cycles for a total of $2.4\frac{min}{cycle} \times 20\ cycles = 48\ minutes$. The utilization for the first hour is then $\frac{48\ minutes}{60\ minutes} = 0.80$.

For the second hour, we have 15 pallets in and 15 pallets out, plus an additional 15 pallets out. We will handle the paired 15 in and out pallets with dual cycles for a total of $2.4\frac{min}{cycle} \times 20\ cycles = 36\ minutes$ and the remaining outbound pallets will use single cycles for a total of $1.5\frac{min}{cycle} \times 15\ cycles = 22.5\ minutes$. The total required minutes are $36+22.5 = 58.5$ and the utilization is $\frac{58.5\ minutes}{60\ minutes} = 0.975$.

The answer is **d**

Question 32:

Unfortunately, this question is vaguely worded. 'Most useful' is not well defined and the standard life cycle cost equation is as follows:

$$LCC = Acquisition\,Costs + Operating\,Costs + Maintenance\,Costs + Disposal\,Costs$$

The official solution errata gives the answers as **a**, **b**, **c**. Options **e** and **h** are not correct, **e** is a business cost not an equipment cost, and **h** is not a cost at all, it is a revenue.

However, **f** is a valid choice that would replace **a** and **b** in many situations, as common machines in manufacturing (lathes, mills, etc) are not bespoke but a standard model being produced. This value was actually included in the original answer, but was removed for some reason in the errata. **d** and **g** are operating costs, which is part of the life cycle cost equation. For heavy machinery or highly skilled labor, these can be substantial expenses.

Question 33:

Omitted

Question 34:
Product Layout (also called line layout) is used in mass production settings (e.g., automotive assembly) and suited to standardized products in large quantities. This maps best with high-volume and low-variety.

Process Layout (also called functional layout) is used for customized or varied products. The equipment is grouped by function, and flow is non-linear. This is ideal for job shops or low-volume, high-variety production.

Cellular Layout is where workstations are arranged in cells, with each focused on a product family. This provides a balance between flexibility and efficiency and is best for medium variety and volume (e.g., batch production).

Question 35:

a) This is the definition of **cross docking**.

b) This is the definition of **hub and spoke**.

c) This is the definition of **transshipment**.

d) As there is a time requirement, the least amount of storage is ideal. **Cross docking** is the best option.

e) Airport construction is expensive and as such is restricted to only the most convenient of locations. **Hub and spoke** allows airlines to be based out of a few number of major airports while still providing service to many destinations.

f) Containerized shipping requires multiple methods of shipping (transportation to core infrastructure like a port or rail terminal and subsequent offloading for transport to further destinations). **Transshipment** is the best option.

g) **Cross docking** inherently sorts and partitions goods to be sent to a final destination.

Question 36:

Economic Order Quantity (EOQ) is defined (page 35 of the handbook) as:

$$EOQ = \sqrt{\frac{2AD}{h}}$$

Where A is the cost to place one order, D is the number of units used per year (i.e., the annual demand), and h is the holding cost per unit per year.

Since the annual demand increases by 28%, our new EOQ is:

$$EOQ_{new} = \sqrt{\frac{2A(1.28D)}{h}}$$

All we need to do is factor the increase out of the equation:

$$EOQ_{new} = \sqrt{1.28}\sqrt{\frac{2AD}{h}} \approx 1.1314\sqrt{\frac{2AD}{h}} = 1.1314\ EOQ$$

Converting this to a percentage gives us $\approx 13.14\%$.

The answer is **b**

Question 37:

We need to find hours per product and can do so with a minimum of mistakes by using basic dimensional analysis.

$$\frac{hours}{product} = \frac{20\ days \times (\frac{7\ workers}{day} \times \frac{8\ hours}{day} + \frac{2\ workers}{day} \times \frac{4\ hours}{day})}{1600\ units} = \frac{1280\ hours}{1600\ units}$$

Which simplifies to $0.80\ \frac{hours}{unit}$.

The answer is **c**

Question 38:

This is another problem easily solved through dimensional analysis.

$$\frac{units}{day} = \frac{500\ units}{20\ days} + \frac{1,750\ units}{60\ days} + \frac{2,750}{60\ days} \approx 77.08\ \frac{units}{day}$$

As a partial unit is not defined, we round up to the nearest unit.

The answer is 78 $\frac{units}{day}$

Question 39:

The Beta Distribution Method (seen as the Project Evaluation Review Technique (PERT), page 7 in the handbook).

The expected cost is calculated by the formula:

$$\mu = \sum_{(ij)\in\, CP} \mu_{ij}$$

Where

$$\mu_{ij} = \frac{a_{ij} + 4b_{ij} + c_{ij}}{6}$$

a_{ij} is the optimistic estimate, b_{ij} is the most likely estimate, c_{ij} is the pessimistic cost, and CP is the critical path.

All we need to do is calculate the mean for each of the four items, and then sum them together.

$$\mu_{direct\_labor} = \frac{\$92 + 4 \times \$98 + \$110}{6} = \$99$$

$$\mu_{direct\_material} = \frac{\$62 + 4 \times \$69 + \$73}{6} = \$68.50$$

$$\mu_{indirect\_labor} = \frac{\$83 + 4 \times \$87 + \$93}{6} = \$87.33$$

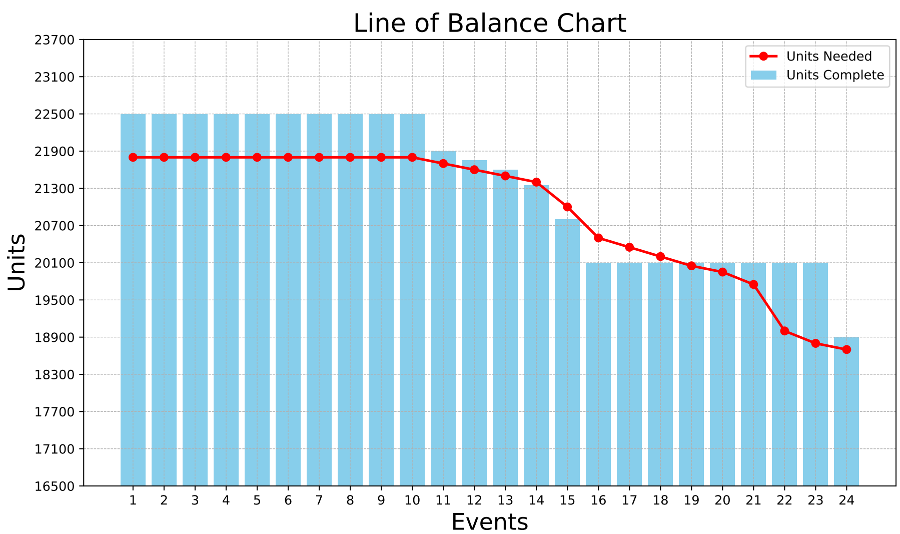
$$\mu_{fixed\_expenses} = \frac{\$57 + 4 \times \$62 + \$68}{6} = \$62.17$$

And so the expected cost is:

$$\mu = \$99 + \$68.50 + \$87.33 + \$62.17 = \$317\ million$$

The answer is **c**

Question 40:



Looking at the line of balance chart we see the first bottleneck appear at event 14. However, we were given specific wording to ignore the chart's data for events 1 to 15 (*If event numbers 16 through 23 ...*), and so event 16 is the first event that becomes the bottleneck.

The answer is **b**

Question 41:

Product turnover is defined as:

$$Product\ Turnover = \frac{Cost\ of\ Goods\ Sold}{Average\ Inventory}$$

Assuming the total investment inventory represents the average inventory (which is typical in contexts like this) the product turnover is $\frac{14.20}{1.69} \approx 8.402$.

The answer is **c**

Question 42:

We can find Johnson's rule on page 35 of the handbook. To begin, we need to find all of the individual machine times for each job.

Job	**Machine 1 Time**	**Machine 2 Time**
A	7	3
B	6	8
C	13	4
D	7	5

We then need to find the job with the shortest overall time across any machine. This is job A (3) and since it is at the second machine, it is scheduled last (otherwise it would be scheduled first if it was on the first machine).

Now we repeat the process. Job C now has the shortest time (4) and since it is on the second machine, it is scheduled second to last. Job D follows similarly and is now third to last. Job B is the only remaining job and is placed at the first position giving us B-D-C-A as the new order.
Drawing the new chart shows that the total job completion time is 33. And so the total job completion time reduction is:

$$\frac{38 - 33}{38} \approx 13.16\%$$

The answer is **a**

Question 43:

The formula for exponential smoothing (found in Section 3 - Operations Engineering page 19) is:

$$\hat{d}_t = \alpha d_{t-1} + (1-\alpha)\hat{d}_{t-1}$$

Where $\hat{d}_t$ is the forecasted demand for period t, d_t is the actual demand for period t, and $\alpha \in [0, 1]$ is the smoothing constant.

Through manipulation of the above formula, we can express the forecast for period t in terms of the forecast and error of the previous period $t-1$.

$$\begin{aligned}\hat{d}_t &= \alpha d_{t-1} + (1-\alpha)\hat{d}_{t-1}\\ &= \alpha d_{t-1} + \hat{d}_{t-1} - \alpha\hat{d}_{t-1}\\ &= \alpha(d_{t-1} - \hat{d}_{t-1}) + \hat{d}_{t-1}\end{aligned}$$

Now X is defined to be:

$$\begin{aligned}X &= \frac{\hat{d}_t}{d_{t-1} - \hat{d}_{t-1}}\\ &= \frac{\alpha(d_{t-1} - \hat{d}_{t-1}) + \hat{d}_{t-1}}{d_{t-1} - \hat{d}_{t-1}}\\ &= \frac{\hat{d}_{t-1}}{d_{t-1} - \hat{d}_{t-1}} + \alpha\end{aligned}$$

And by definition Y is:

$$Y = \frac{\hat{d}_{t-1}}{d_{t-1} - \hat{d}_{t-1}}$$

If α is known to be positive, then $X > Y$ is always true (which is the answer in the official solutions). However, this is not stated in the problem nor in the handbook (the handbook explicitly states $\alpha = 0$ is valid). While $\alpha = 0$ is largely vacuous (all new data would be ignored), we technically need information about α to decide.

Question 44:

We have a slotted ASRS aisle (Automated Storage and Retrieval System) and need to calculate the expected total travel time for a full cycle accounting for the weighted average over the item types.

Since the system can travel in both directions simultaneously, we are only concerned about the largest of the x and y values. Then, to travel to and back from the location this is simply twice the largest of the values.

The expected value can be found by using the percent of volume as the weight multiplied by twice the maximum value for the respective x, y coordinates (which here are both the same). This gives us:

$$Expected\ time = 0.6(2\times10)+0.3(2\times20)+0.1(2\times30) = 12+12+6 = 30\ seconds$$

The answer is **b**

Question 45:

Recall that profit is revenue + cost. Let x be the number of units sold. Then:

$$Profit = Px - Vx - F = Px - Vx - \$9,877$$

Since our required profit is \$1,832, we have:

$$\$1,832 = Px - Vx - \$9,877$$

And equivalently:

$$\$11,709 = Px - Vx$$

Since the profit increases by 13% we have:

$$1.13 \times (\$1,832) = Px - Vx - \$9,877$$

And equivalently:

$$\$11,974.16 = Px - Vx$$

The increase in profit is:

$$\frac{11,974.16 - 11,709}{11,709} \approx .0203$$

The answer is **a**

Question 46:

This question is filled with extraneous information. We need to find the pounds per cubic foot value given a pallet size in inches and a weight already in pounds. All we need to do is convert the cubic inches given to cubic feet and calculate the ratio:

$$48\ in. \times 40\ in. \times 45.5\ in. = 87,360\ in.^3$$

$$87,360\ in.^3 \times \frac{1\ ft^3}{1728\ in.^3} \approx 50.56\ ft^3$$

$$\frac{243.2\ lb}{50.56\ ft^3} \approx 4.81 \frac{lb}{ft^3}$$

Note that this question was the subject of a revision, previously it was ambiguous as to what was being double stacked for shipment, but a reasonable assumption would be the pallets (48 in. is generally the maximum height to be able to double stack pallets in a standard US semi-trailer). The question was clarified to make explicit that cases were being double stacked.

The answer is **a**

Question 47:

This problem is solved by simple substitution using the definitions given the problem statement.

$$ESF(t) = 1000 + 0.7[1072 - 1000] = 1050.4$$

The answer is **c**

Question 48:

Cross-docking is a logistics strategy designed to minimize storage time and handling. The primary goal is to transfer goods directly from inbound trucks to outbound trucks as quickly as possible. Therefore, items are typically held in a cross-docking facility for several hours at most, just long enough to be sorted and re-routed. This practice reduces storage costs and speeds up the delivery process and is commonly used with perishable goods.

The answer is **a**

Question 49:

We can calculate the piece cost (in dollars) by:

$$\frac{bid}{number\ of\ pieces} \times US\ dollar\ conversion\ rate$$

This gives us:

- $\frac{2000\ baht}{200\ pieces} \times \frac{\$1}{10\ baht} = \frac{\$1}{piece}$
- $\frac{2000\ rupees}{200\ pieces} \times \frac{\$1}{8\ rupees} = \frac{\$1.25}{piece}$
- $\frac{21850\ yen}{200\ pieces} \times \frac{\$1}{112.55\ yen} = \frac{\$0.97}{piece}$

With Sacramento Glow at $1 per panel, the lowest piece cost is Japan Glow.

The answer is **c**

Question 50:

Total cost is defined as:

$$Total\ Cost = Total\ Procurement\ Costs + Total\ Carrying\ Costs$$

The total procurement costs are simply the the procurement costs per order multiplied by the number of orders (5), which is \$75.

The total carrying costs are defined by the *average* inventory multiplied by its carrying cost. Given we have no information about the rate of consumption or replenishment, we will assume **uniform** consumption and **instantaneous** replenishment (which is standard in the Economic Order Quantity (EOQ) model). This results in inventory jumping from zero to 3000 instantly, and then dropping steadily over time. The cycle then repeats.

Given these assumptions the average is the average of starting value (0) plus the ending value (3000), which is 1500. We multiply this by the carrying cost per unit (0.25) and get \$375.

And so the total cost is $\$75 + \$375 = \$450$.

> The answer is **c**

Question 51:

We have the following equations:

$$A = 6B + 3C + 2D$$
$$B = C + 6D$$
$$C = 3D$$

So:

$$A = 6(C + 6D) + 3(3D) + 2D = 6(9D) + 11D = 65D \implies 25A = 1625D$$

Only one option has 1,625 units of D, but we can check our answer by calculating the needed units of C:

$$A = 6(C + 6D) + 3C + 2D = 9C + 38D \implies 25A = 225C + 950D$$

The answer is **a**

Question 52:

Note that this question is subject to errata regarding the answer d, but the official solution (b) remains erroneous.

Applying the log rules to both sides of the equation gives us:

$$log(y) = log(ab^x)$$

Using the log property $log(\alpha\beta) = log(\alpha) + log(\beta)$ we have:

$$log(y) = log(a) + log(b^x)$$

And using the log property $log(\alpha^\beta) = \beta\ log(\alpha)$ we have:

$$log(y) = log(a) + b\ log(x)$$

The answer is **c**

Question 53:

Time Study is a method of directly observing and timing a task to determine how long it takes to complete under normal working conditions.

- Requires continuous, close observation of individual workers.
- Impractical for 20 people across a large site.
- Not suited for estimating equipment uptime.

Predetermined Time Systems is a method that uses standardized time values for basic motions (like reach, grasp, move) to estimate task durations without direct observation.

- Involves using standard task time tables (like MTM, MOST).
- Requires task definitions and assumes repeatable motion.
- No inherent way to account for travel, delays, or tank status without direct modeling.

Work sampling is a statistical method that estimates the proportion of time spent on various activities by making random observations over time.

- Does not require continuous observation.
- Can simultaneously monitor multiple personnel and assets.
- Can be scaled to large numbers of people or areas.

Lean Six Sigma is a process improvement methodology that combines Lean (waste reduction) and Six Sigma (variation reduction) to enhance efficiency and quality. Learn Six Sigma is not used for data collection and is not efficient for direct time or uptime estimates.

Work sampling here is our best choice. We need to estimate time for both people and equipment across a wide area. It would likely be too burdensome to do full calculations of the time spent for every one of these actions (especially since the tanks do not have any electronic monitoring), and so a sampling method is ideal here.

The answer is **c**

Question 54:

We can expect to not have many emergencies, and so both frequency and sequence-of-use options are not reasonable. The emergency stop is its own distinct control, not part of a collection of similar controls and so function is not the principle. This leaves us with importance, the emergency stop button should be in a central, prominent location that is easy to access.

The answer is **b**

Question 55:

The following table has the different constants associated with the NIOSH Lifting Equation (found on page 48 of the handbook).

Table 1: NIOSH RWL Equation Components

Symbol	**Description**
LC	Load Constant (23 kg or 51 lb)
HM	Horizontal Multiplier (distance of hands from midpoint between ankles)
VM	Vertical Multiplier (height of hands at start of lift)
DM	Distance Multiplier (vertical travel distance of the lift)
AM	Asymmetry Multiplier (angle of torso twist from sagittal plane)
FM	Frequency Multiplier (lifts per minute and duration of task)
CM	Coupling Multiplier (quality of hand-to-object coupling)

The pallet positioning table can help with the HM as the rotation of the table can reduce reaching and twisting, effectively reducing how far the load is from the body. Since the table height can be raised, the DM and VM can be directly altered.

The answer is **a**

Question 56:

Processes 1 and 7 have a workload that exceeds the takt time (the maximum allowable time per unit to meet demand). As such, these need to be separated.

We can combine processes 2 and 3 as they are adjacent (and as such can be combined to begin with) and their summed loading is below the takt time. Processes 5 and 6 follow similarly.

The answer is **d**

Question 57:

Recall that a learning curve is an empirical relationship between output quantity and input quantity, where the quantities are most often time or cost. The standard formula used is:

$$Y = cX^{\frac{log(learning\ rate)}{log(2)}}$$

Where Y is the time or cost for the X-th unit, c is a constant that represents the time or cost for the first unit, X is the unit number, and the exponent $\frac{log(learning\ rate)}{log(2)}$ represents the rate of learning.

A learning curve is often described with a percentage (like in the question: 80% learning curve), which means every time total production doubles, the average time or cost per unit decreases **to** 80% (*not by*) of what it was before.

So the decrease in average time is:

$$Decrease = 1 - 0.80 = 0.20$$

The answer is **b**

Question 58:
In 1915, Frank and Lillian Gilbreth developed 17 motion study elements to analyze work motions. They called these elements '**Therbligs**'.

Ugoku is a Japanese word meaning 'to move'.

TMUs are time measurement units from Methods-Time Measurement (MTM).

Takt is from Takt time in lean manufacturing.

> The answer is **c**

Question 59:

Standard time is the final calculated time, which includes allowances (like rest, fatigue, delays):

$$Standard\,Time = Normal\ Time \times (1 + Allowance\ Factor)$$

Normal time is calculated by adjusting the observed time with a performance rating:

$$Normal\ Time = Observed\,Time \times Performance\ Rating$$

Shift allowances are predetermined or calculated based on work conditions or policies, and so are not directly measured.

Observed time is the actual time measured using a timing device while observing a worker perform a task.

The answer is **d**

Question 60:

We are given the sample size formula directly on page 81 of the handbook:

$$n = [\frac{z_{\alpha/2} \times \sigma}{\bar{x} - \mu}]^2 = [\frac{2.5758 \times 3 \ lbs}{0.5 \ lbs}]^2 \approx 238.85$$

Note that we are interested in estimated the true mean within 0.5 lbs, this is exactly what the denominator in the formula represents, the difference between the true mean and sample mean.

The answer is **d**

Question 61:

If the actual load exceeds the Recommended Weight Limit (RWL), the lifting task is not considered acceptable, regardless of how small the excess is. There is no formal "tolerance" in the NIOSH Lifting Equation because the equation is fundamentally risk based. RWL is the threshold for safe lifting for **most** healthy workers under defined conditions, there already exists some risk to begin with, incurring more is not acceptable.

The answer is **b**

Question 62:

In general, a slight recline is beneficial as it reduces stress on the lower back by opening up the hip angle.

The answer is **b**

Question 63:

Mistake-proofing has the goal of preventing defects by:

- Eliminating the possibility of error
- Detecting and correcting errors immediately
- Making it impossible or difficult to perform an incorrect action

Detection and reduction of error directly contributes to improved quality, and so options **a** and **b** are correct. The focus on making errors difficult to perform allows easier identification of problems when they occur by making them a more notable occurrence, and so option **c** is correct.

The answers are **a, b, c**

Question 64:

We need to find the 8 hour reference duration. Unfortunately the handbook does not have this value in the permissible noise exposure table (page 41). This value can be found instead in the OSHA 29 CFR 1910.95 Appendix A, which gives us the duration of 18.4.

The noise dose D can be calculated from the formula (page 40):

$$D = 100 \times (\frac{C}{T})$$

Where C is the actual time exposed at a noise level and T is the permitted time at the specified level.

We can then plug D into the time-weighted average formula to find the equivalent 8-hour exposure sound level (page 41).

$$TWA = 16.61 \times log_{10}(\frac{D}{100}) + 90 = 16.61 \times log_{10}(\frac{65.2}{100}) + 90 = 86.9$$

Without the OSHA reference, we could find a close enough answer by using interpolation of the permissible noise exposures table. We have a level of 80 dBA corresponding to a 32 hour duration, and a level of 85 dBA corresponding to a duration of 16 hours. Each decibel increase from 80 to 85 can then be viewed as a simple 3.2 hour decrease in duration, giving us a duration of 19.2 hours for 84 dBA. Using this value above gives us the 8-hour TWA noise dose as 86.1 dBA, which is fairly close to the true value.

The answer is **c**

Question 65:

We need to relate the length of the cut to the feed rate and rotational speed. This is given to us directly in the handbook for the equation of Turning Cutting Time (page 15).

The answer is **c**

Question 66:

Page 52 of the handbook has the DART rate formula:

$$IR = \frac{N \times 200,000}{T}$$

Where IR is the the DART incidence rate, N is the total number of incidents, and T is the total number of hours worked. We then have:

$$IR = \frac{4 \times 200,000}{56,800} \approx 14.08$$

The answer is **a**

Question 67:

MTM-1 is **Methods-Time Measurement**, a motion-time system used for the analysis and standardization of manual tasks. It's basic unit of measurement is the **Time Measurement Unit (TMU)** which is defined as 0.00001 hours (or 0.036 seconds).

For the other options:

- Therblig: A classification of basic motions used in time and motion studies but it is not actually a unit of time.
- Work-factor time: Refers to another motion-time system (the Work-Factor system) and is defined as 0.001 minute.
- Clo: Not actually a unit of time, but of thermal insulation.

The answer is **a**

Question 68:

We can approach this problem in two ways. The first being that options **b**, **c**, and **d** all *reduce* the recommended weight limit. This leaves **a** as the only remaining choice. Second, by looking at the multipliers, we see HM is at 0.50 which is less than the all other multipliers (and corresponds to what **a** is telling us), and so has the greatest room for increase (all the multipliers are bounded by 1).

The answer is **a**

Question 69:

The key is the emphasis of the word **actual**. We can find the definition for the capability ratios (options **b** and **c**) on page 56 of the handbook. Option **b** is defined to be the actual capability.

Intuitively, C_p measures how capable the process could be if it were perfectly centered between the specification limits. This is the theoretical best-case scenario. C_{pk} measures the actual capability and takes into account both spread and centering (mean shift). If the process mean is moving towards one limit then $C_{pk} < C_p$ which gives us an indication how close the process is to producing defects.

The answer is **b**

Question 70:

We see that there is a very high process capability (C_{pk}), which indicates that the process is extremely stable and well-centered. This process is producing parts well within spec at extremely low defect rates. This is confirmed by the lack of of rejected parts in the defective part area. With this level of process capability, defects will be extremely rare (see the table below for process capability values).

Cpk	**Sigma Level**	**% Within Spec**	**DPMO**
0.33	$\approx 1.0\sigma$	~68.27%	~317,300
0.67	$\approx 2.0\sigma$	~95.45%	~45,500
1.00	$\approx 3.0\sigma$	~99.73%	~2,700
1.33	$\approx 4.0\sigma$	~99.99%	~63
1.50	$\approx 4.5\sigma$	~99.99966%	~3.4
1.67	$\approx 5.0\sigma$	~99.99994%	~0.6
2.00	$\approx 6.0\sigma$	~99.9999998%	~0.002

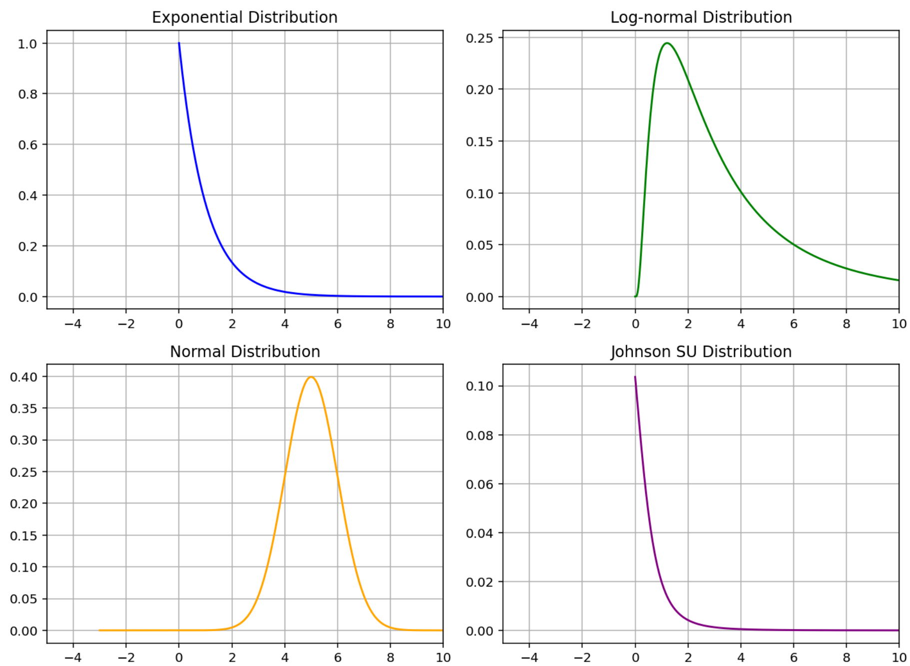
Additionally, by design there is no way to have a defective part be incorporated into a final product, so even if these components are part of a life-critical design, there is no risk of them causing a failure as they can never be used to begin with.

We also see that the backlog is caused by inspection and not production, and so the inspection is the process bottleneck. While adding another inspector or automating some of the inspection process would reduce the backlog, given the strength of the existing quality being delivered a strong choice is to just move the QC inspector be moved to somewhere where they are more needed. Studying the process further is likely overly cautious here due to the extremely strong quality associated with the process and the inherent safeguards against the incorporation of defective parts.

The answer is **c**

Question 71:

We can rule out the normal distribution immediately as it does not have a fixed lower boundary. Johnson is a family of distributions, and not a particular distribution. While it does include distributions that satisfy the question (one of which is actually the log-normal) this answer would be too clever given that we have two more straightforward choices. Both the exponential and log-normal distributions here are plausible choice here, however log-normal is less restrictive than the exponential distribution as it does not have the assumption of a constant rate of events (the *memoryless* property) and can model data that has a peak away from the lower boundary (see the figure below). Being able to model the peak away from the lower boundary gives the log-normal more flexibility as it is not constrained to a continuously decreasing function.



The answer is **a**

Question 72:

The key phrase here is *main objective*. While options **a** and **d** are often results from a well-implemented Six Sigma program, the fundamental goal is to decrease variability in a process.

The answer is **c**

Question 73:

To find the cell interval (also termed the *class width*) in a frequency distribution we use the following formula:

$$Cell\ Interval = \frac{Range}{Number\ of\ Cells}$$

Which for this question is:

$$Cell\ Interval = \frac{14.8 - 6.1}{10} = 0.87$$

Remember that the range is defined as $highest\ -\ lowest$. Option **d** is included as a confounder for reversing the subtraction.

The answer is **c**

Question 74:

Overall Equipment Effectiveness (OEE) is a performance indicator used in manufacturing to assess how effectively a machine or production line is utilized. It is calculated using the formula:

$$OEE = Availability \times Performance \times Quality$$

We are looking for attributes related to any of components of the formula.

Options **a**, **c**, **e**, and **f** are all forms of availability / performance. Option **b** directly mentions quality.

Human workload is not measured by OEE so option **d** is incorrect. OEE is applicable to both automated and manual systems, and automation itself is not measured and so option **g** is incorrect.

The answers are **a, b, c, e, f**

Question 75:

X-bar and R charts are classic control charts for variables data (e.g., length, diameter), which track the mean and range, respectively. Option **a** is correct.

Variables sampling plans typically require smaller sample sizes than attribute plans for the same level of confidence and discriminating power since variables provide more information (actual values), while attributes just give pass/fail. Option **b** is incorrect.

MIL-STD-105E (now sometimes replaced by ANSI/ASQ Z1.4) is a standard for attribute sampling and is common in acceptance sampling for lots of incoming materials. Option **c** is correct.

Options **d** and **e** and incorrect as the statements are reversed. Attribute data is usually modeled using a discrete distribution (like binomial or Poisson), while variables data are continuous and are modeling using continuous distributions (like the normal distribution).

> The answers are **a, c**

Question 76:

Lets add up the total number of each type of defect and compute their proportion of the overall total number of defects.

Defect Description (Code)	**Number of Defects**					**Total #**	**Total %**
	A	**B**	**C**	**D**	**E**		
Defective spot (111)	1	5		6		12	16.0
Nonconforming material (110)	9			2		11	14.7
Electrical failure (113)	7	2	4	3	1	17	22.7
Failed housing (115)		7				7	9.3
Film damage (120)	4	1				5	6.7
Failed dark spot (130)		3				3	4.0
Variable gain fails (145)	1	2	7		5	15	20.0
Blemish (201)	3					3	4.0
Arcs failures (301)	1			1		2	2.7
Total						75	100

We can see the largest number of total defects are electrical failure and then variable gain fails.

The answer is **d**

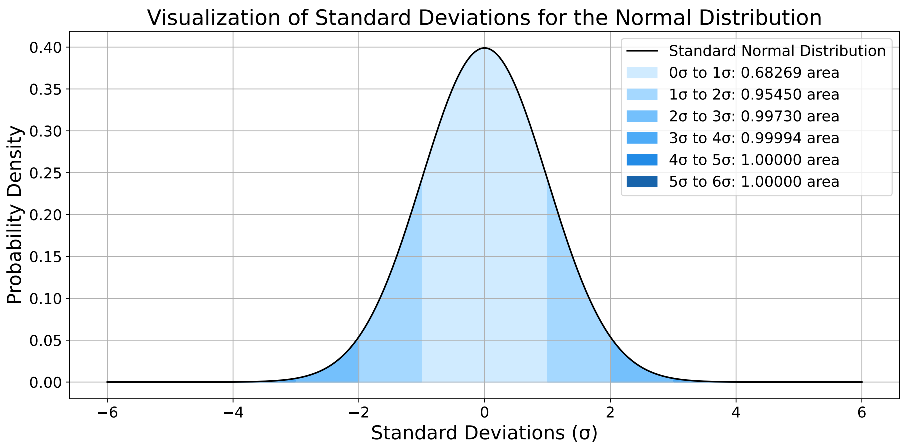
Question 77:

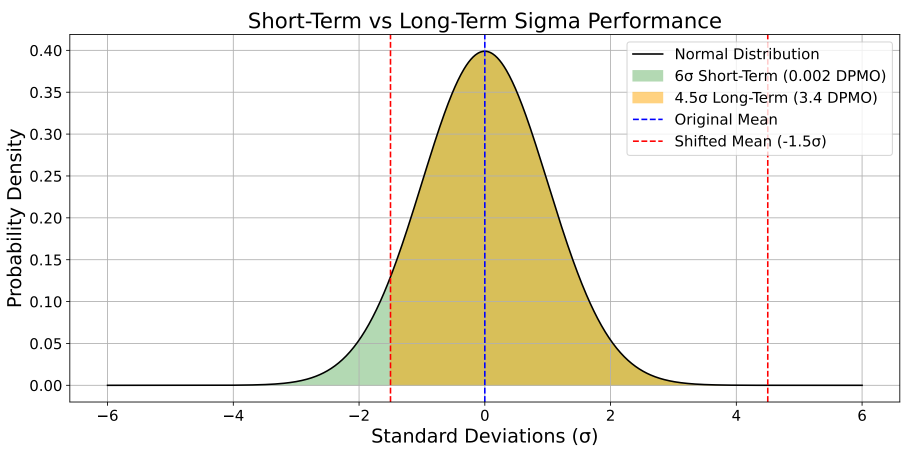
The theoretical defect rate at exactly six standard deviations is 0.002 per million or 2.0 per billion (see the table below). The process may be designed to operate at 6 sigma (so the specification limits are 6 standard deviations away from the mean) but the 1.5 sigma shift we incorporate is to adjust for the small but cumulative effects (like tool wear) that can cause the mean to drift over time. This leaves us with a worst-case scenario of 4.5 standard deviations away from the mean which amounts to 3.4 DPMO.

These values can be found by using the standard normal tables (Z tables).

Table 2: Defect Rates and Yield for Various Sigma Levels

Sigma Level (Z)	**Cumulative Area (–Z to Z)**	**Yield (%)**	**DPMO**
0.5	0.38292	38.29%	617,080
1.0	0.68269	68.27%	317,310
1.5	0.86639	86.64%	133,610
2.0	0.95450	95.45%	45,500
2.5	0.98758	98.76%	12,420
3.0	0.99730	99.73%	2,700
3.5	0.99953	99.95%	470
4.0	0.99994	99.9937%	63
4.5	0.9999966	99.99966%	3.4
5.0	0.9999994	99.99994%	0.6
5.5	0.99999997	99.999997%	0.03
6.0	0.999999998	99.9999998%	0.002
6.5	1.000000000	99.99999998%	0.00002
7.0	1.000000000	≈100.00%	≈0.0000001
7.5	1.000000000	≈100.00%	≈0.000000001





The answer is **b**

Question 78:

The quality spiral represents the idea that continuous improvement in quality through planning, design, production, inspection, and customer feedback, leads to increased customer satisfaction and competitive advantage. It illustrates how each step in the product or service lifecycle contributes to quality and requires ongoing enhancement. It is closely associated with total quality management (TQM) and continuous improvement philosophies like Kaizen and PDCA (Plan-Do-Check-Act).

The answer is **b**

Question 79:

On page 58 of the handbook we can find the equation for AOQ, but it is in terms of double sampling (and this problem is single sampling).

$$AOQ = \frac{[P_a^1(N - n_1) + P_a^2(N - n_1 - n_2)]p}{N}$$

Where P_a^1 is the probability of acceptance on the first sample, P_a^2 is the probability of acceptance on the second sample, p is the lot fraction defective, N is the lot size, n_1 is the first sample size, and n_2 is the second sample size.

As there is no second sample, the term associated with it is zero, and so the equation is reduced to the single sample version.

$$AOQ = \frac{P_a^1(N - n_1)p}{N}$$

We know the problem is single sample as there is no indication a second sample is taken and the AOQ values are directly tied to single points on the OC curve.

Give the OC data we have, we can interpolate the probability of acceptance for the percentage defect rate of 3.5% through a simple average of the probabilities of the 3% and 4% rates, which is $\frac{0.52+0.28}{2} = 0.40$. For 5% we are given the value directly.

Now we can use our AOQ equation to solve for the ratio of lot size to sample size (i.e how much larger the lot size is compared to the sample size). Rearranging the single sample equation gives us:

$$\frac{N}{n_1} = \frac{1}{1 - \frac{AOQ}{P_a^1 \times p}} \approx 9.868$$

Which is approximately an 886% increase.

> The answer is **d**

Question 79 (Errata Replacement):

We will still use the single sample AOQ equation from the original version of question 79:

$$AOQ = \frac{P_a^1(N - n_1)p}{N}$$

Our work here is much more straightforward; the only value that has not been given to us is P_a^1 is the probability of acceptance on the first sample (and only sample).

As acceptance sampling is without replacement, this introduces dependence, and so we need to use the hypergeometric distribution.

Now, the binomial distribution becomes a good substitute when the the ratio of the sample size to the lot size is small (around 10% is the common threshold). Our ratio here is $\frac{20}{120} \approx 17\%$ which is pushing the limits of the approximation. We will do both the hypergeometric calculation and the binomial and compare the two answers.

We can find the distributions on page 82 of the handbook. The hypergeometric distribution has the equation:

$$h(x; n, r, N) = \frac{\binom{r}{x}\binom{N-r}{n-x}}{\binom{N}{n}}$$

Where N is the lot size, r is the defectives in the lot, n is the sample size, and x is the number of defectives found in the sample. For an 18% defect rate we would expect $120 \times 0.18 = 21.6$ defectives in the lot. The hypergeometric distribution requires integer parameters and so we must round. We will be pessimistic and round up to 22 expected defects within the lot. Then:

$$P_a^1 = h(0; 20, 22, 120) + h(1; 20, 22, 120) = \frac{\binom{22}{0}\binom{120-22}{20-0}}{\binom{120}{20}} + \frac{\binom{22}{1}\binom{120-22}{20-1}}{\binom{120}{20}} \approx 0.076$$

Then

$$AOQ = \frac{0.076(120 - 20)0.18}{120} = 0.0114$$

The official solution errata uses the binomial approximation to the hypergeometric.

$$P_a^1 = b(0; 20, 0.18) + b(1; 20, 0.18) = \binom{20}{0}(0.18)^0(1-0.18)^{20-0} + \binom{20}{1}(0.18)^1(1-0.18)^{20-1} \approx 0.102$$

Then

$$AOQ = \frac{0.102(120 - 20)0.18}{120} = 0.0153$$

We can see that the proportional difference between the true value and the approximation is $\frac{0.0114-0.0153}{0.0114} \approx -0.34$, about 34% off.

Question 80 (Errata Replacement):

Recall that the *load factor* is how heavily the motor is being worked with respect to its maximum rated output (250hp). The % time the motor is used was referred to as the *utilization* in the original problem description and has been updated in the errata. *Efficiency* is how effectively the motor converts input power to output power.

The annual cost for each can be calculated as follows:

$$Cost_{new} = \frac{250\ hp}{0.92} \times 0.55 \times 8760\ hr \times 0.70 \times \frac{\$0.07}{kWh} \times \frac{1\ Kw}{1.341\ hp} + \$7,741.17 \approx \$55,580.63$$

$$Motor_{old} = \frac{250\ hp}{0.85} \times 0.55 \times 8760\ hr \times 0.75 \times \frac{\$0.07}{kWh} \times \frac{1\ Kw}{1.341\ hp} \approx \$55,477.69$$

The answer is **b**

Question 81:

The eight quality management principles in ISO 9000:2000 are:

1 Customer focus

2 Leadership

3 Involvement of people

4 Process approach

5 System approach to management

6 Continual improvement

7 Factual approach to decision-making

8 Mutually beneficial supplier relationships

The answers are **a, c, e**

Question 82:

This is a question filled with extraneous information. All we need to find is the expected number of failures, and to do so we need only the probability of failure and the number of chips to be tested. This is simply:

$$Expected\ number\ of\ failures = 0.12750 \times 1,800 = 229.5$$

The answer is **b**

Question 83:

Process T has an 80% yield with an output of 89,148 dies. As the output of process F is the sole input of process T, this means that the output of F must be $\frac{89{,}148}{.80} = 111,435$ dies.

We could also solve for the yield of F through the equation:

$$1,000 \times 230 \times 0.95 \times 0.85 \times 0.80 \times F \times 0.80 = 89,148 \implies F = 0.75$$

We can then list each step's output as:

$$\begin{aligned}
S_1 &: 1,000 \times 230 \times 0.95 = 218,500 \\
S_2 &: 218,500 \times 0.85 = 185,725 \\
P &: 185,725 \times 0.80 = 148,580 \\
F &: 148,580 \times 0.75 = 111,435 \\
T &: 111,435 \times 0.80 = 89,148
\end{aligned}$$

The answer is **b**

Question 84:

An **Ishikawa diagram** (also known as a fishbone or cause-and-effect diagram) is commonly used in root cause analysis to identify potential causes of a problem.

Failure modes, mechanisms, and effects analysis (FMMEA) is an extension of FMEA (Failure Modes and Effects Analysis) which is used to anticipate and analyze potential failure points. FEMA has the core components of:

- Failure Mode: The ways in which something might fail (e.g., a part cracks, software malfunctions).
- Effect: The consequences of a failure (e.g., customer dissatisfaction, system shutdown).
- Cause: The underlying reason for the failure (e.g., design flaw, poor material quality).

A Risk Priority Number (RPN) is calculated to prioritize which failure modes to address first using the equation:

$$RPN = S \times O \times D$$

Where Severity (S) is how serious the consequences are, Occurrence (O) is how likely the failure is to happen and Detection (D) is likely the failure is to be detected before it reaches the customer.

Fault tree analysis is a deductive method that uses logic diagrams to identify the root causes of system failures.

A Worker-machine chart is typically used in workplace studies and time-motion analysis, not for determining root causes of problems. It tracks the utilization of workers and machines over time.

The answer is **c**

Question 85:

Standard practice is to set the upper control limit at 3 times the standard deviation of the sample. Setting the control limits at 6σ is not reasonable, if the process is truly in statistical control then it would be extremely unlikely to notice a process shift with limits this generous.

The answer is **c**