Solutions Manual

for

Automation,
Production Systems, and
Computer Integrated Manufacturing

Third Edition

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Chapter 3
MANUFACTURING METRICS

REVIEW QUESTIONS

3.1 What is the cycle time in a manufacturing operation?

Answer: As defined in the text, the cycle time T_c is the time that one work unit spends being processed or assembled. It is the time between when one work unit begins processing (or assembly) and when the next unit begins.

3.2 What is a bottleneck station?

Answer: The bottleneck station is the slowest workstation in a production line, and therefore it limits the pace of the entire line.

3.3 What is production capacity?

Answer: As defined in the text, production capacity is the maximum rate of output that a production facility (or production line, work center, or group of work centers) is able to produce under a given set of assumed operating conditions.

3.4 How can plant capacity be increased or decreased in the short term?

Answer: As listed in the text, the two ways that plant capacity can be increased or decreased in the short term are (1) change the number of work shifts per week S_w or (2) change the number of hours worked per shift H_{sh}.

3.5 What is utilization in a manufacturing plant? Provide a definition.

Answer: Utilization is the amount of output of a production facility relative to its capacity. Expressing this as an equation, $U = Q/PC$, where U = utilization, Q = actual output quantity produced during the period of interest, and PC is the production capacity during the same period.

3.6 What is availability and how is it defined?

Answer: Availability is a reliability metric that indicates the proportion of time that a piece of equipment is up and working properly. It is defined as follows: $A = (MTBF - MTTR)/MTBF$, where A = availability, $MTBF$ = mean time between failures, and $MTTR$ = mean time to repair.

3.7 What is manufacturing lead time?

Answer: As defined in the text, manufacturing lead time is the total time required to process a given part or product through the plant, including any lost time due to delays, time spent in storage, reliability problems, and so on.

3.8 What is work-in-process?

Answer: As defined in the text, work-in-process (WIP) is the quantity of parts or products currently located in the factory that are either being processed or are between processing operations. WIP is inventory that is in the state of being transformed from raw material to finished product.

3.9 How are fixed costs distinguished from variable costs in manufacturing?

Answer: Fixed costs remain constant for any level of production output. Examples include the cost of the factory building and production equipment, insurance, and property taxes. Variable costs vary in proportion to the level of production output. As output increases, variable costs increase. Examples include direct labor, raw materials, and electric power to operate the production equipment.

3.10 Name five typical factory overhead expenses?

Answer: Table 3.1 in the text lists the following examples of factory overhead expenses: plant supervision, applicable taxes, factory depreciation, line foremen, insurance, equipment depreciation, maintenance, heat and air conditioning, fringe benefits, custodial services, light, material handling, security personnel, power for machinery, shipping and receiving, tool crib attendant, payroll services, and clerical support.

3.11 Name five typical corporate overhead expenses?

(b) $L_e = \frac{9(50)+5(120)+8(205)+9(110)+5(200)+8(115)+20(30)}{42} = \frac{6200}{42}$ = **147.6 m**

(c) $T_c = 1.0 + \frac{103.8}{40} + \frac{147.6}{40}$ = 7.26 min

$R_{dv} = \frac{60(0.90)}{7.26}$ = 7.44 del/hr per vehicle n_c = 42/7.44 = 5.65 → **6 vehicles**

10.3 In Example 10.2 in the text, suppose that the vehicles operate according to the following scheduling rule in order to minimize the distances the vehicles travel empty: vehicles delivering raw workparts from station 1 to stations 2, 3, and 4 must pick up finished parts at these respective stations for delivery to station 5. (a) Determine the empty travel distances associated with each delivery and develop a from-to Chart in the format of Table 10.5 in the text. (b) Suppose the AGVs travel at a speed of 50 m/min, and the traffic factor = 0.90. Assume reliability = 100%. As determined in Example 10.2, the delivery distance L_d = 103.8 m. Determine the value of L_e for the layout based on your table. (c) How many automated guided vehicles will be required to operate the system?

Solution: (a) Enumeration of empty trips:

Deliveries	Associated empty trips	Frequency	Empty distance
1 to 2	none		
2 to 5	5 to 1	9	30
1 to 3	none		
3 to 5	5 to 1	3	30
1 to 4	none		
3 to 4	none		
4 to 5	5 to 1	8	30

From-To chart:

To:	1	2	3	4	5
From: 1	0/0	-	-	-	-
2	-	0/0	-	-	-
3	-	-	0/0	-	-
4	-	-	-	0/0	-
5	20/30	-	-	-	0/0

(b) $L_e = \frac{20(30)}{42}$ = 14.3 m

(c) $T_c = 1.0 + \frac{103.8}{40} + \frac{14.3}{40}$ = 3.95 min

$R_{dv} = \frac{60(0.90)}{3.95}$ = 13.66 del/hr per vehicle n_c = 42/13.66 = 3.07 → **4 vehicles**

10.4 A planned fleet of forklift trucks has an average travel distance per delivery = 500 ft loaded and an average empty travel distance = 350 ft. The fleet must make a total of 60 deliveries per hour. Load and unload times are each 0.5 min and the speed of the vehicles = 300 ft/min. The traffic factor for the system = 0.85. Availability = 0.95, and worker efficiency = 90%. Determine (a) ideal cycle time per delivery, (b) the resulting average number of deliveries per hour that a forklift truck can make, and (c) how many trucks are required to accomplish the 60 deliveries per hour.

Solution: (a) T_c = 0.5 + 500/300 + 0.5 + 350/300 = 3.83 min/delivery

(b) Ideally, $R_{dv} = \frac{60}{3.83}$ = 15.66 deliveries/hr per truck

Accounting for traffic factor, availability, and worker efficiency,
R_{dv} = 15.66(0.85)(0.95)(0.90) = 11.39 deliveries/hr per truck

(c) n_c = 60/11.39 = 5.27 → **6 forklift trucks**

Chapter 16
AUTOMATED PRODUCTION LINES

REVIEW QUESTIONS

16.1 Name three of the four conditions under which automated production lines are appropriate.

Answer: The four conditions listed in the text are (1) high product demand, (2) stable product design, (3) long product life, and (4) multiple operations are required to produce the product.

16.2 What is an automated production line?

Answer: As defined in the text, an automated production line consists of multiple workstations that are automated and linked together by a work handling system that transfers parts from one station to the next.

16.3 What is a pallet fixture, as the term is used in the context of an automated production line?

Answer: As defined in the text, a pallet fixture is a workholding device that is designed to (1) fixture the part in a precise location relative to its base and (2) be moved, located, and accurately clamped in position at successive workstations by the transfer system.

16.4 What is a dial-indexing machine?

Answer: A dial-indexing machine is an automated system consisting of multiple workstations that process workparts attached to fixtures around the periphery of a circular worktable, and the table is indexed (rotated in fixed angular amounts) to position the parts at the stations.

16.5 Why are continuous work transport systems uncommon on automated production lines?

Answer: Continuous work transport systems are uncommon on automated lines due to the difficulty in providing accurate registration between the station workheads and the continuously moving parts.

16.6 Is a Geneva mechanism used to provide linear motion or rotary motion?

Answer: A Geneva mechanism provides rotary motion.

16.7 What is a storage buffer as the term is used for an automated production line?

Answer: As defined in the text, a storage buffer is a location in a production line where parts can be collected and temporarily stored before proceeding to subsequent (downstream) workstations.

16.8 Name three reasons for including a storage buffer in an automated production line?

Answer: The text lists the following five reasons: (1) to reduce the effect of station breakdowns, (2) to provide a bank of parts to supply the line, (3) to provide a place to put the output of the line, (4) to allow for curing time or other required delay associated with processing, and (5) to smooth cycle time variations.

16.9 What are the three basic control functions that must be accomplished to operate an automated production line?

Answer: The three basic control functions are (1) sequence control to coordinate the sequence of actions of the transfer system and associated workstations, (2) safety monitoring to ensure that the production line does not operate in an unsafe condition, and (3) quality control to monitor certain quality attributes of the workparts produced on the line.

16.10 Name some of the industrial applications of automated production lines.

Answer: Applications listed in the text include machining, sheet metal forming and cutting, spot welding of car bodies in final assembly plants, painting and plating operations, and assembly.

16.11 What is the difference between a unitized production line and a link line?

Answer: A unitized production line is an automated production line that consists of standard modules and is assembled in an appropriate configuration to satisfy the production requirements of the customer. A link line is a production line that consists of standard machine tools that are connected together by standard or special material handling devices.

Answer: Master black belts provide technical resources and serve as consultants and mentors for the black belts, who are the team leaders and project managers for a Six Sigma project. Master black belts are full-time positions, and they are selected for their teaching aptitudes, quantitative skills, and experience in Six Sigma.

20.20 What is a CTQ characteristic?

Answer: CTQ stands for critical to quality. CTQ characteristics are the features or elements of the process and its output that directly impact the customer's perception of quality. Typical CTQ characteristics include the reliability of a product or the timeliness of a service.

20.21 What is the measure step in DMAIC?

Answer: The measure step in DMAIC measures the process to assess its current performance. The measure step consists of (1) creating a data collection plan, (2) collecting the data, and (3) assessing the sigma level of the current process.

20.22 Why is defects per million (*DPM*) not necessarily the same as defects per million opportunities (*DPMO*)?

Answer: Defects per million (*DPM*) refers to the total number of defects per million parts, thus allowing that a given defective part may contain more than one type of defect. Defects per million opportunities (*DPMO*) also acknowledges this fact that there may be more than one type of defect that occurs in each unit and takes into account the complexity of the product or service so that entirely different types of products and services can be compared on the same sigma scale.

20.23 What is the analyze step in DMAIC?

Answer: The analyze step stands for analyzing the process and determining root causes for variations and defects. The analyze step consists of the following phases: (1) basic data analysis, (2) process analysis, and (3) root cause analysis.

20.24 What is root cause analysis?

Answer: Root cause analysis attempts to identify the significant factors that affect process performance. The situation can be depicted using the equation $y = f(x_1, x_2, . ., x_i, . . x_n)$, where y is some output variable of interest (e.g., some quality feature); and $x_1, x_2, . ., x_i, . . x_n$ are the independent variables in the process that may affect the output variable. The value of y is a function of the x_i values. In root cause analysis, an attempt is made to determine which x_i variables are most important and how they influence y. In all likelihood, there are more than one y variables of interest. For each y, there is likely to be a different set of x_i variables.

20.25 What is the improve step in DMAIC?

Answer: Improve the process by reducing variations and defects. The improve step consists of (1) generating alternative improvements, (2) analyzing and prioritizing alternative improvements, and (3) implementing the improvements.

20.26 What is the control step in DMAIC?

Answer: The control step refers to controlling the future process performance by institutionalizing the improvements. Control consists of the following actions: (1) develop a control plan, (2) transfer responsibility back to original owner, and (3) disband the Six Sigma team.

20.27 What is a robust design in Taguchi's quality engineering?

Answer: A robust design is one in which the function and performance of the product or process are relatively insensitive to variations that are difficult or impossible to control. In product design, robustness means that the product can maintain consistent performance with minimal disturbance due to variations in its operating environment. In process design, robustness means that the process continues to produce good product in spite of uncontrollable variations in its operating environment.

20.28 What is ISO 9000?

Answer: ISO 9000 is a set of international standards on quality developed by the International Organization for Standardization (ISO). It is not a standard for the products or services. Instead, ISO 9000 establishes standards for the systems and procedures used by a facility that affect the quality of the products and services produced by

Pr(reject) = (1 - p_1)(1 - q) = (1 - 0.9535)(1 - 0.14) = **0.040**
Nonconforming items:
Pr(accept) = (1 - p_2)q = (1 - 0.5714)(0.14) = **0.060**
Pr(reject) = p_2 q = (0.5714)(0.14) = **0.080**
Summary table:

	Conforming	Nonconforming	Total
Accept item	0.820	0.060	0.880
Reject item	0.040	0.080	0.120
Totals	0.860	0.140	1.000

21.4 An inspector's accuracy has been assessed as follows: p_1 = 0.94 and p_2 = 0.80. The inspector is given the task of inspecting a batch of 200 parts and sorting out the defects from good units. If the actual defect rate in the batch is q = 0.04, determine (a) the expected number of Type I and (b) Type II errors the inspector will make. (c) Also, what is the expected fraction defect rate that the inspector will report at the end of the inspection task?

Solution: (a) E(Type I error). Probability according to Table 21.3 in text is (1 - p_1)(1 - q)
(1 - p_1)(1 - q) = (1 - 0.94)(1 - 0.04) = (0.06)(0.96) = 0.0576
In 200 pc, E(number of Type I errors) = 0.0576(200) = **11.52 pc**

(b) E(Type II error). Probability according to Table 21.3 in text is (1 - p_2)q
(1 - p_2)q = (1 - 0.80)(0.04) = 0.2(0.04) = 0.008
In 200 pc, E(number of Type II errors) = 0.008(200) = **1.6 pc**

(c) E(number of defects reported).
Probability of rejection in Table 21.3 is 1 - p_1 - q(1 - p_1 - p_2)
1 - p_1 - q(1 - p_1 - p_2) = 1 - 0.94 - 0.04(1 - 0.94 - 0.80) = 0.06 - 0.04(-0.74) = 0.0896
In 200 pc, E(number of defects reported) = 0.0896(200) = 17.92 pc
Fraction defect rate reported = 17.92/200 = **0.0896**

21.5 An inspector must 100% inspect a production batch of 500 parts using a gaging method. If the actual fraction defect rate in the batch is q = 0.02, and the inspector's accuracy is given by p_1 = 0.96 and p_2 = 0.84, determine (a) the number of defects the inspector can be expected to report and (b) the expected number of Type I and Type II errors the inspector will make.

Solution: (a) Probability of rejection in Table 21.3 = 1 - p_1 - q(1 - p_1 - p_2)
E(q) = (1 - p_1 - q(1 - p_1 - p_2))Q = (1 - 0.96 - 0.02(1 - 0.96 - 0.84))(500)
= (0.04 - 0.02(-0.8))(500) = 0.056(500) = **28 pc**

(b) Probability of Type I errors according to Table 21.3 in text is (1 - p_1)(1 - q)
E(Type I errors) = (1 - p_1)(1 - q)Q = (1 - 0.96)(1 - 0.02)(500) = 0.04(0.98)(500) = **19.6 pc**

Probability of Type II errors according to Table 21.3 in text is (1 - p_2)q
E(Type II errors) = (1 - p_2)q Q = (1 - 0.84)(0.02)(500) = **1.6 pc**

Effect of Fraction Defect Rate

21.6 A batch of 10,000 raw work units is processed through 15 operations, each of which has a fraction defect rate of 0.03. How many defect-free units and how many defects are in the final batch?

Solution: $Q_f = Q_o(1 - q_i)^n = Q_o (1 - 0.03)^{15}$ = 10,000$(0.97)^{15}$ = 10,000(0.6333) = **6333 defect-free units**
D = 10,000 - 6333 = **3667 defects**

21.7 A silicon wafer has a total of 400 integrated circuits (ICs) at the beginning of its fabrication sequence. A total of 80 operations are used to complete the integrated circuits, each of which inflicts damages on 1.5% of the ICs. The damages compound, meaning that an IC that is already damaged has the same probability of being damaged by a subsequent process as a previously undamaged IC. How many defect-free ICs remain at the end of the fabrication sequence?

Solution: $Q_f = Q_o(1 - q_i)^n = Q_o (1 - 0.015)^{80}$ = 400$(0.985)^{80}$ = 400(0.2985) = **119 defect-free ICs**