AUTOMATED ASSEMBLY SYSTEMS

REVIEW QUESTIONS

1. Name three of the four conditions under which automated assembly technology should be considered.
2. What are the four automated assembly system configurations listed in the text?
3. What are the typical hardware components of a workstation parts delivery system?
4. What is a programmable parts feeder?
5. Name six typical products that are made by automated assembly.
6. Considering the assembly machine as a game of chance, what are the three possible events that might occur when the feed mechanism attempts to feed the next component to the assembly workhead at a given workstation in a multi-station system?
7. Name some of the important performance measures for an automated assembly system.
8. Why is the production rate inherently lower on a single-station assembly system than on a multi-station assembly system?
9. What are two reasons for the existence of partially automated production lines?
10. What are the effects of poor quality parts, as represented by the fraction defect rate, on the performance of an automated assembly system?
11. Why are storage buffers used on partially automated production lines?

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PROBLEMS

Multi-Station Assembly Systems

1. A dial indexing machine has six stations that perform assembly operations on a base part. The operations, element times, q and m values for components added are given in the table below (NA means q and m are not applicable to the operation). The indexing time for the dial table is 2 sec. When a jam occurs, it requires 1.5 min to release the jam and put the machine back in operation. Determine (a) production rate for the assembly machine, (b) yield of good product (final assemblies containing no defective components), and (c) proportion uptime of the system.

Station	Operation	Element time	q	m
1	Add part A	4 sec	0.015	0.6
2	Fasten part A	3 sec	NA	NA
3	Assemble part B	5 sec	0.01	0.8
4	Add part C	4 sec	0.02	1.0
5	Fasten part C	3 sec	NA	NA
6	Assemble part D	6 sec	0.01	0.5

2. An eight-station assembly machine has an ideal cycle time of 6 sec. The fraction defect rate at each of the 8 stations is $q = 0.015$ and a defect always jams the affected station. When a breakdown occurs, it takes 1 minute, on average, for the system to be put back into operation. Determine the production rate for the assembly machine, the yield of good product (final assemblies containing no defective components), and proportion uptime of the system.

3. Solve Problem 2 but assume that defects never jam the workstations. Other data are the same.

4. Solve Problem 2 but assume that $m = 0.6$ for all stations. Other data are the same.

5. A six-station automatic assembly line has an ideal cycle time of 12 sec. Downtime occurs for two reasons. First, mechanical and electrical failures cause line stops that occur with a frequency of once per 50 cycles. Average downtime for these causes is 3 min. Second, defective components also result in downtime. The fraction defect rate of each of the six components added to the base part at the six stations is 2%. The probability that a defective component will cause a station jam is 0.5 for all stations. Downtime per occurrence for defective parts is 2 min. Determine (a) yield of assemblies that are free of defective components, (b) proportion of assemblies that contain at least one defective component, (c) average production rate of good product, and (d) uptime efficiency.

6. An eight-station automatic assembly machine has an ideal cycle time of 10 sec. Downtime is caused by defective parts jamming at the individual assembly stations. The average downtime per occurrence is 3.0 min. The fraction defect rate is 1.0% and the probability that a defective part will jam at a given station is 0.6 for all stations. The cost to operate the assembly machine is $90.00 per hour and the cost of components being assembled is $.60 per unit assembly. Ignore other costs. Determine (a) yield of good assemblies, (b) average production rate of good assemblies, (c) proportion of assemblies with at least one defective component, and (d) unit cost of the assembled product.

7. An automated assembly machine has four workstations. The first station presents the base part, and the other three stations add parts to the base. The ideal cycle time for the machine is 3 sec, and the average downtime when a jam results from a defective part is 1.5 min. The fraction defective rates (q) and probabilities that a defective part will jam the station (m) are given in the table below. Quantities of 100,000 for each of the bases, brackets, pins, and retainers are used to stock the assembly line for operation. Determine (a) proportion of good product to total product coming off the line, (b) production rate of good product coming off the line, (c) total number of final assemblies produced, given the starting component quantities. Of the total, how many are good product, and how many are products that contain at least one defective component? (d) Of the number of defective assemblies determined in above part (c), how many will have defective base parts? How many will have defective brackets? How many will have defective pins? How many will have defective retainers?

Station	Part identification	q	m
1	Base	0.01	1.0
2	Bracket	0.02	1.0
3	Pin	0.03	1.0
4	Retainer	0.04	0.5

8. A six-station automatic assembly machine has an ideal cycle time of 6 sec. At stations 2 through 6, parts feeders deliver components to be assembled to a base part that is added at the first station. Each of stations 2 through 6 is identical and the five components are identical. That is, the completed product consists of the base part plus the five components. The base parts have zero defects, but the other components are defective at a rate q. When an attempt is made to assemble a defective component to the base part, the machine stops (m = 1.0). It takes an average of 2.0 min to make repairs and start the machine up after each stoppage. Since all components are identical, they are purchased from a supplier who can control the fraction defect rate very closely. However, the supplier charges a premium for better quality. The cost per component is determined by the following equation:

$$\text{Cost per component} = 0.1 + \frac{0.0012}{q}$$

where q = the fraction defect rate. Cost of the base part is 20 cents. Accordingly, the total cost of the base part and the five components is:

$$\text{Product material cost} = 0.70 + \frac{0.006}{q}$$

The cost to operate the automatic assembly machine is $150.00 per hour. The problem facing the production manager is this: As the component quality decreases (q increases), the downtime increases which drives production costs up. As the quality improves (q decreases), the material cost increases because of the price formula used by the supplier. To minimize total cost, the optimum value of q must be determined. Determine by analytical methods (rather than trial-and-error) the value of q that minimizes the total cost per assembly. Also, determine the associated cost per assembly and production rate. (Ignore other costs).

9. A six-station dial indexing machine is designed to perform four assembly operations at stations 2 through 5 after a base part has been manually loaded at station 1. Station 6 is the unload station. Each assembly operation involves the attachment of a component to the existing base. At each of the four assembly stations, a hopper-feeder is used to deliver components to a selector device that separates components that are improperly oriented and drops them back into the hopper. The system was designed with the operating parameters for stations 2 through 5 as given in the table below. It takes 2 sec to index the dial from one station position to the next. When a component jam occurs, it takes an average of 2 min to release the jam and restart the system. Line stops due to mechanical and electrical failures of the assembly machine are not significant and can be neglected. The foreman says the system was designed to produce at a certain hourly rate, which takes into account the jams resulting from defective components. However, the actual delivery of finished assemblies is far below that designed production rate. Analyze the problem and determine the following: (a) The designed average production rate that the foreman alluded to. (b) What is the proportion of assemblies coming off the system that contain one or more defective components? (c) What seems to be the problem that limits the assembly system from achieving the expected production rate? (d) What is the production rate that the system is actually achieving? State any assumptions that you make in determining your answer.

Station	Assembly time	Feed rate f	Selector θ	q	m
2	4 sec	32/min	0.25	0.01	1.0
3	7 sec	20/min	0.50	0.005	0.6
4	5 sec	20/min	0.20	0.02	1.0
5	3 sec	15/min	1.0	0.01	0.7

10. For Example 17.4 in the text, dealing with a single-station assembly system, suppose that the sequence of assembly elements were to be accomplished on a seven-station assembly system with synchronous parts transfer. Each element is performed at a separate station (stations 2 through 6) and the assembly time at each respective station is the same as the element time given in Example 17.4. Assume that the handling time is divided evenly (3.5 sec each) between a load station (station 1) and an unload station (station 7). The transfer time is 2 sec, and the average downtime per downtime occurrence is 2.0 min. Determine (a) production rate of all completed units, (b) yield, (c) production rate of good quality completed units, and (d) uptime efficiency.

Solution: (a) $T_c = 7 + 2 = 9.0$ sec = 0.15 min

Single Station Assembly Systems

11. A single-station assembly machine is to be considered as an alternative to the dial-indexing machine in Problem 17.4. Use the data given in the table for that problem to determine (a) production rate, (b) yield of good product (final assemblies containing no defective components), and (c) proportion uptime of the system. Handling time to load the base part and unload the finished assembly is 7 sec and the downtime averages 1.5 min every time a component jams. Why is the proportion uptime so much higher than in the case of the dial-indexing machine in Problem 17.4?

12. A single station robotic assembly system performs a series of five assembly elements, each of which adds a different component to a base part. Each element takes 4.5 sec. In addition, the handling time needed to move the base part into and out of position is 4 sec. For identification, the components, as well as the elements that assemble them, are numbered 1, 2, 3, 4, and 5. The fraction defect rate is 0.005 for all components, and the probability of a jam by a defective component is 0.7. Average downtime per occurrence = 2.5 min. Determine (a) production rate, (b) yield of good product in the output, (c) uptime efficiency, and (d) proportion of the output that contains a defective type 3 component.

13. A robotic assembly cell uses an industrial robot to perform a series of assembly operations. The base part and parts 2 and 3 are delivered by vibratory bowl feeders that use selectors to insure that only properly oriented parts are delivered to the robot for assembly. The robot cell performs the elements in the table below (also given are feeder rates, selector proportion θ, element times, fraction defect rate q, and probability of jam m, and, for the last element, the frequency of downtime incidents p). In addition to the times given in the table, the time required to unload the completed subassembly takes 4 sec. When a linestop occurs, it takes an average of 1.8 min to make repairs and restart the cell. Determine (a) yield of good product, (b) average production rate of good product, and (c) uptime efficiency for the cell? State any assumptions you must make about the operation of the cell in order to solve the problem.

Element	Feed rate f	Selector θ	Element	Time T_e	q	m	p
1	15 pc/min	0.30	Load base part	4 sec	0.01	0.6	
2	12 pc/min	0.25	Add part 2	3 sec	0.02	0.3	
3	25 pc/min	0.10	Add part 3	4 sec	0.03	0.8	
4			Fasten	3 sec			0.02

Partial Automation

14. A partially automated production line has a mixture of three mechanized and three manual workstations. There are a total of six stations, and the ideal cycle time of 1.0 min, which includes a transfer time of 6 sec. Data on the six stations are listed in the accompanying table. Cost of the transfer mechanism C_{at} = \$0.10/min, cost to run each automated station C_{as} = \$0.12/min, and labor cost to operate each manual station C_w = \$0.17/min. It has been proposed to substitute an automated station in place of station 5. The cost of this station is estimated at C_{as5} = \$0.25/min and its breakdown rate $p_5 = 0.02$, but its process time would be only 30 sec, thus reducing the overall cycle time of the line from 1.0 min to 36 sec. Average downtime per breakdown of the current line, as well as for the proposed configuration, is 3.5 min. Determine the following for the current line and the proposed line: (a) production rate, (b) proportion uptime, and (c) cost per unit. Assume the line operates without storage buffers, so when an automated station stops, the whole line stops, including the manual stations. Also, in computing costs, neglect material and tooling costs.

Station	Type	Process time	p_i
1	Manual	36 sec	0
2	Automatic	15 sec	0.01
3	Automatic	20 sec	0.02
4	Automatic	25 sec	0.01
5	Manual	54 sec	0
6	Manual	33 sec	0

15. Reconsider Problem 14 except that both the current line and the proposed line will have storage buffers before and after the manual stations. The storage buffers will be of sufficient capacity to allow these manual stations to operate independently of the automated portions of the line. Determine (a) production rate, (b) proportion uptime, and (c) cost per unit for the current line and the proposed line.

16. A manual assembly line has six stations. The assembly time at each manual station is 60 sec. Parts are transferred by hand from one station to the next, and the lack of discipline in this method adds 12 sec (T_r = 12 sec) to the cycle time. Hence, the current cycle time is 72 sec. The following two proposals have been made: (1) Install a mechanized transfer system to pace the line; and (2) automate one or more of the manual stations using robots that would perform the same tasks as humans only faster. The second proposal requires the mechanized transfer system of the first proposal and would result in a partially or fully automated assembly line. The transfer system would have a transfer time of 6 sec, thus reducing the cycle time on the manual line to 66 sec. Regarding the second proposal, all six stations are candidates for automation. Each automated station would have an assembly time of 30 sec. Thus if all six stations were automated the cycle time for the line would be 36 sec. There are differences in the quality of parts added at the stations; these data are given in the accompanying table for each station (q = fraction defect rate, m = probability that a defect will jam the station). Average downtime per station jam at the automated stations is 3.0 min. Assume that the manual stations do not experience line stops due to defective components. Cost data: C_{at} = \$0.10/min; C_w = \$0.20/min; and C_{as} = \$0.15/min. Determine if either or both of the proposals should be accepted. If the second proposal is accepted, how many stations

should be automated and which ones? Use cost per piece as the criterion of your decision. Assume for all cases considered that the line operates without storage buffers, so when an automated station stops, the whole line stops, including the manual stations.

Station	q_i	m_i	Station	q_i	m_i
1	0.005	1.0	4	0.020	1.0
2	0.010	1.0	5	0.025	1.0
3	0.015	1.0	6	0.030	1.0

17. Solve preceding Problem 16, except that the probability that a defective part will jam the automated station is $m = 0.5$ for all stations.