Sheet 6: AUTOMATED PRODUCTION LINES

REVIEW QUESTIONS

1. Name three of the four conditions under which automated production lines are appropriate.
2. What is an automated production line?
3. What is a pallet fixture, as the term is used in the context of an automated production line?
4. What is a dial-indexing machine?
5. Why are continuous work transport systems uncommon on automated production lines?
6. Is a Geneva mechanism used to provide linear motion or rotary motion?
7. What is a storage buffer as the term is used for an automated production line?
8. Name three reasons for including a storage buffer in an automated production line?
9. What are the three basic control functions that must be accomplished to operate an automated production line?
10. Name some of the industrial applications of automated production lines.
11. What is the difference between a unitized production line and a link line?
12. What are the three problem areas that must be considered in the analysis and design of an automated production line?
13. As the number of workstation on an automated production line increases, does line efficiency (a) decrease, (b) increase, or (c) remain unaffected?
14. What is starving on an automated production line?
15. In the operation of an automated production line with storage buffers, what does it mean if a buffer is nearly always empty or nearly always full?

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PROBLEMS

Transfer Mechanisms

1. A rotary worktable is driven by a Geneva mechanism with five slots. The driver rotates at 48 rev/min. Determine (a) the cycle time, (b) available process time, and (c) indexing time each cycle.
2. A Geneva with six slots is used to operate the worktable of a dial-indexing machine. The slowest workstation on the dial-indexing machine has an operation time of 2.5 sec, so the table must be in a dwell position for this length of time. (a) At what rotational speed must the driven member of the Geneva mechanism be turned to provide this dwell time? (b) What is the indexing time each cycle?
3. Solve the previous problem except that the Geneva has eight slots.

Automated Production Lines with No Internal Storage

4. A ten-station transfer machine has an ideal cycle time of 30 sec. The frequency of line stops is 0.075 stops per cycle. When a line stop occurs, the average downtime is 4.0 min. Determine (a) average production rate in pc/hr, (b) line efficiency, and (c) proportion downtime.
5. Cost elements associated with the operation of the ten-station transfer line in Problem 4 are as follows: raw workpart cost = $0.55/pc, line operating cost = $42.00/hr, and cost of disposable tooling = $0.27/pc. Compute the average cost of a workpiece produced.
6. In Problem 16.4, the line stop occurrences are due to random mechanical and electrical failures on the line. Suppose that in addition to these reasons for downtime, that the tools at each workstation on the line must be changed and/or reset every 150 cycles. This procedure takes a total of 12.0 min for all ten stations. Include this additional data to determine (a) average production rate in pc/hr, (b) line efficiency, and (c) proportion downtime.
7. The dial indexing machine of Problem 2 experiences a breakdown frequency of 0.06 stops/cycle. The average downtime per breakdown is 3.5 min. Determine (a) average production rate in pc/hr and (b) line efficiency.
8. In the operation of a certain 15-station transfer line, the ideal cycle time = 0.58 min. Breakdowns occur at a rate of once every 20 cycles, and the average downtime per breakdown is 9.2 min. The transfer line is located in a plant that works an 8-hr day, 5 days per week. Determine (a) line efficiency, and (b) how many parts will the transfer line produce in a week?
9. A 22-station in-line transfer machine has an ideal cycle time of 0.35 min. Station breakdowns occur with a probability of 0.01. Assume that station breakdowns are the only reason for line stops. Average downtime = 8.0 min per line stop. Determine (a) ideal production rate, (b) frequency of line stops, (c) average actual production rate, and (d) line efficiency.
10. A ten-station rotary indexing machine performs nine machining operations at nine workstations, and the tenth station is used for loading and unloading parts. The longest process time on the line is 1.30 min and the loading/unloading operation can be accomplished in less time than this. It takes 9.0 sec to index the machine between workstations. Stations break down with a frequency of 0.007, which is considered equal for all ten stations. When these stops occur, it takes an average of 10.0 min to diagnose the problem and make repairs. Determine (a) line efficiency and (b) average actual production rate.

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11. A transfer machine has six stations that function as follows:

Station	Operation	Process time	p_i
1	Load part	0.78 min	0
2	Drill three holes	1.25 min	0.02
3	Ream two holes	0.90 min	0.01
4	Tap two holes	0.85 min	0.04
5	Mill flats	1.32 min	0.01
6	Unload parts	0.45 min	0

12. In addition, transfer time = 0.18 min. Average downtime per occurrence = 8.0 min. A total of 20,000 parts must be processed through the transfer machine. Determine (a) proportion downtime, (b) average actual production rate, and (c) how many hours of operation are required to produce the 20,000 parts.

13. The cost to operate a certain 20-station transfer line is $72/hr. The line operates with an ideal cycle time of 0.85 min. Downtime occurrences happen on average once per 14 cycles. Average downtime per occurrence is 9.5 min. It is proposed that a new computer system and associated sensors be installed to monitor the line and diagnose downtime occurrences when they happen. It is anticipated that this new system will reduce downtime from its present value to 7.5 min. If the cost of purchasing and installing the new system is $15,000, how many units must the system produce in order for the savings to pay for the computer system?

14. A 23-station transfer line has been logged for 5 days (total time = 2400 min). During this time there were a total of 158 downtime occurrences on the line. The accompanying table identifies the type of downtime occurrence, how many occurrences of each type, and how much total time was lost for each type. The transfer line performs a sequence of machining operations, the longest of which takes 0.42 min. The transfer mechanism takes 0.08 min to index the parts from one station to the next each cycle. Assuming no parts removal when the line jams, determine the following based on the five-day observation period: (a) how many parts were produced, (b) downtime proportion, (c) production rate, and (d) frequency rate associated with the transfer mechanism failures.

Type of downtime	Number of occurrences	Total time lost
Associated with stations:		
Tool-related causes	104	520 min
Mechanical failures	21	189 min
Miscellaneous	7	84 min
Subtotal	132	793 min
Transfer mechanism	26	78 min
Totals	158	871 min

15. An eight-station rotary indexing machine performs the machining operations shown in the accompanying table, together with processing times and breakdown frequencies for each station. The transfer time for the machine is 0.15 min per cycle. A study of the system was undertaken, during which time 2000 parts were completed. It was determined in this study that when breakdowns occur, it takes an average of 7.0 min to make repairs and get the system operating again. For the study period, determine (a) average actual production rate, (b) line uptime efficiency, and (c) how many hours were required to produce the 2000 parts.

Station	Process	Process time	Breakdowns
1	Load part	0.50 min	0
2	Mill top	0.85 min	22
3	Mill sides	1.10 min	31
4	Drill two holes	0.60 min	47
5	Ream two holes	0.43 min	8
6	Drill six holes	0.92 min	58
7	Tap six holes	0.75 min	84
8	Unload part	0.40 min	0

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16. A 14-station transfer line has been logged for 2400 min to identify type of downtime occurrence, how many occurrences, and time lost. The results are presented in the table below. The ideal cycle time for the line is 0.50 min, including transfer time between stations. Determine (a) how many parts were produced during the 2400 min, (b) line uptime efficiency, (c) average actual production rate per hour, and (d) frequency p associated with transfer system failures.

Type of occurrence	Number	Time lost
Tool changes and failures	70	400 min
Station failures: (mechanical and electrical)	45	300 min
Transfer system failures	25	150 min

17. A transfer machine has a mean time between failures (*MTBF*) = 50 minutes and a mean time to repair (*MTTR*) = 9 minutes. If the ideal cycle rate = 1/min (when the machine is running), what is the average hourly production rate?

18. A part is to be produced on an automated transfer line. The total work content time to make the part is 36 minutes, and this work will be divided evenly amongst the workstations, so that the processing time at each station is $36/n$, where n = the number of stations. In addition, the time required to transfer parts between workstations is 6 seconds. Thus, the cycle time = $0.1 + 36/n$ minutes. In addition, it is known that the station breakdown frequency will be 0.005, and that the average downtime per breakdown = 8.0 minutes. (a) Given these data, determine the number of workstations that should be included in the line to maximize production rate. Also, what is the (b) production rate and (c) line efficiency for this number of stations?

Automated Production Lines with Storage Buffers

19. A 30-station transfer line has an ideal cycle time of 0.75 min, an average downtime of 6.0 min per line stop occurrence, and a station failure frequency of 0.01 for all stations. A proposal has been submitted to locate a storage buffer between stations 15 and 16 to improve line efficiency. Determine (a) the current line efficiency and production rate, and (b) the maximum possible line efficiency and production rate that would result from installing the storage buffer.

20. Given the data in Problem 18, solve the problem except that (a) the proposal is to divide the line into three stages, that is, with two storage buffers located between stations 10 and 11, and between stations 20 and 21, respectively; and (b) the proposal is to use an asynchronous line with large storage buffers between every pair of stations on the line; that is a total of 29 storage buffers.

21. In Problem 18, if the capacity of the proposed storage buffer is to be 20 parts, determine (a) line efficiency, and (b) production rate of the line. Assume that the downtime (T_d = 6.0 min) is a constant.

22. Solve Problem 20 but assume that the downtime (T_d = 6.0 min) follows the geometric repair distribution.

23. In the transfer line of Problems .20 and 22, suppose it is more technically feasible to locate the storage buffer between stations 11 and 12, rather than between stations 15 and 16. Determine (a) the maximum possible line efficiency and production rate that would result from installing the storage buffer, and (b) the line efficiency and production rate for a storage buffer with a capacity of 20 parts. Assume that downtime (T_d = 6.0 min) is a constant.

24. A proposed synchronous transfer line will have 20 stations and will operate with an ideal cycle time of 0.5 min. All stations are expected to have an equal probability of breakdown, p = 0.01. The average downtime per breakdown is expected to be 5.0. An option under consideration is to divide the line into two stages, each stage having 10 stations, with a buffer storage zone between the stages. It has been decided that the storage capacity should be 20 units. The cost to operate the line is $96.00/hr. Installing the storage buffer would increase the line operating cost by $12.00/hr. Ignoring material and tooling costs, determine (a) line efficiency, production rate, and unit cost for the one-stage configuration, and (b) line efficiency, production rate, and unit cost for the optional two-stage configuration.

25. A two-week study has been performed on a 12-station transfer line that is used to partially machine engine heads for a major automotive company. During the 80 hours of observation, the line was down a total of 42

hours, and a total of 1689 parts were completed. The accompanying table lists the machining operation performed at each station, the process times, and the downtime occurrences for each station. Transfer time between stations is 6 sec. To address the downtime problem, it has been proposed to divide the line into two stages, each consisting of six stations. The storage buffer between the stages would have a storage capacity of 20 parts. Determine (a) line efficiency and production rate of current one-stage configuration, and (b) line efficiency and production rate of proposed two-stage configuration. (c) Given that the line is to be divided into two stages, should each stage consist of six stations as proposed, or is there a better division of stations into stages? Support your answer.

Station	Operation	Process time	Downtime occurrences
1	Load part (manual)	0.50 min	0
2	Rough mill top	1.10 min	15
3	Finish mill top	1.25 min	18
4	Rough mill sides	0.75 min	23
5	Finish mill sides	1.05 min	31
6	Mill surfaces for drill	0.80 min	9
7	Drill two holes	0.75 min	22
8	Tap two holes	0.40 min	47
9	Drill three holes	1.10 min	30
10	Ream three holes	0.70 min	21
11	Tap three holes	0.45 min	30
12	Unload and inspect part (manual)	0.90 min	0
	Totals:	9.40 min	246

26. In Problem 24, the current line has an operating cost of \$66.00/hr. The starting workpart is a casting that costs \$4.50/pc. Disposable tooling costs \$1.25/pc. The proposed storage buffer will add \$6.00/hr to the operating cost of the line. Does the improvement in production rate justify this \$20 increase?

27. A 16-station transfer line can be divided into two stages by installing a storage buffer between stations 8 and 9. The probability of failure at any station is 0.01. The ideal cycle time is 1.0 min and the downtime per line stop is 10.0 min. These values are applicable for both the one-stage and two-stage configurations. The downtime should be a considered constant value. The cost of installing the storage buffer is a function of its capacity. This cost function is C_b = \$0.60b/hr = \$0.01b/min, where *b* = the buffer capacity. However, the buffer can only be constructed to store increments of 10 (in other words, *b* can take on values of 10, 20, 30, etc.). The cost to operate the line itself is \$120/hr. Ignore material and tooling costs. Based on cost per unit of product, determine the buffer capacity b that will minimize unit product cost.

28. The uptime efficiency of a 20 station automated production line is only 40%. The ideal cycle time is 48 sec, and the average downtime per line stop occurrence is 3.0 min. Assume the frequency of breakdowns for all stations is equal ($p_i = p$ for all stations) and that the downtime is constant. To improve uptime efficiency, it is proposed to install a storage buffer with a 15-part capacity for \$14,000. The present production cost is \$4.00 per unit, ignoring material and tooling costs. How many units would have to be produced in order for the \$14,000 investment to pay for itself?

29. An automated transfer line is divided into two stages with a storage buffer between them. Each stage consists of 9 stations. The ideal cycle time of each stage = 1.0 minute, and frequency of failure for each station is 0.01. The average downtime per stop is 8.0 minutes, and a constant downtime distribution should be assumed. Determine the required capacity of the storage buffer such that the improvement in line efficiency E compared to a zero buffer capacity would be 80% of the improvement yielded by a buffer with infinite capacity.

30. In Problem 17, suppose that a two-stage line were to be designed, with an equal number of stations in each stage. Work content time will be divided evenly between the two stages. The storage buffer between the stages will have a capacity = 3 T_d/T_c. Assume a constant repair distribution. (a) For this two-stage line, determine the number of workstations that should be included in each stage of the line to maximize production rate. (b) What is the production rate and line efficiency for this line configuration? (c) What is the buffer storage capacity?

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31. A 20-station transfer line presently operates with a line efficiency $E = 1/3$. The ideal cycle time = 1.0 min. The repair distribution is geometric with an average downtime per occurrence = 8 min, and each station has an equal probability of failure. It is possible to divide the line into two stages with 10 stations each, separating the stages by a storage buffer of capacity b. With the information given, determine the required value of b that will increase the efficiency from $E = 1/3$ to $E = 2/5$.