## Review Questions

3.1 What does sequential operations mean?

**Answer**: As defined in the text, sequential operations are a work system in which multiple processing steps are accomplished in order to complete a work unit, and the processing steps are performed sequentially (rather than simultaneously).

3.2 What is a precedence constraint in sequential operations?

**Answer**: A precedence constraint is a restriction on the order in which the sequence of operations must be performed. Certain operations must be accomplished before other operations can be started. The example given in the text is drilling and tapping. A hole must be drilled before it can be tapped.

3.3 What is the difference between pure sequential work flow and mixed sequential work flow?

**Answer:** Pure sequential means that all work units flow through the same exact sequence of workstations and operations. There is no variation in the processing sequence. Mixed sequential means that there are variations in the work flow for different work units. Different work units are processed through different stations.

3.4 Name and define the four types of part moves between workstations in sequential operations.

**Answer:** The four types of part moves identified in the text are: (1) in-sequence move, in which the work unit moves forward from the current operation to the neighboring operation immediately downstream; (2) bypassing move, which is a forward move beyond the neighboring workstation by two or more stations ahead of the current station; (3) backflow move, in which the work unit moves in the backward direction by one or more stations; and (4) repeat operation, in which the operation is repeated at the same workstation and the part does not move between stations.

3.5 What is a From-To chart?

**Answer:** A From-To chart is a tabular chart that is used to indicate various quantitative relationships between operations or workstations in a multi-station work system. Typical quantities displayed in a From-To chart include quantities between stations, flow rates of parts between stations, and distances between stations.

3.6 What is a bottleneck in sequential operations?

**Answer:** The bottleneck operation is the slowest operation in the sequence. It is the operation that ultimately limits the production rate of the sequence.

3.7 What do the terms *starving* and *blocking* mean in terms of sequential operations?

**Answer:** Blocking means that the production rate(s) of one or more upstream operations are limited by the rate of a downstream operation. The upstream operations are blocked by the slower rate of the downstream station. Starving means that the production rate(s) of one or more downstream operations are limited by the rate of an upstream operation (e.g., the


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bottleneck). The downstream operations can work no faster than the rate at which the bottleneck feeds work units to them.

3.8 What does the term *batch processing* mean?

**Answer**: As defined in the text, the term batch processing refers to the processing of work units in finite quantities or amounts.

3.9 What are some of the disadvantages of batch processing?

**Answer**: The disadvantages of batch processing include the following: (1) batch processing is discontinuous, which means there are periods in which the equipment is not producing; (2) delays occur between processing steps when batch processing is used in conjunction with sequential operations; (3) queues of work units form in front of operations, resulting in high work-in-process inventories; and (4) long lead times occur due to accumulation of work-in-process.

3.10 Given the disadvantages of batch production, what are the reasons why it is so widely used in industry?

**Answer**: The reasons given in the text are (1) work unit differences that require changeovers in processing equipment, (2) equipment limitations such as the capacity of equipment, and (3) material limitations, in which the material must be processed as a unit of material.

3.11 What are the two cost terms in the economic order quantity model?

**Answer**: The two cost terms in the economic order quantity model are (1) setup or changeover cost and (2) inventory holding cost.

3.12 Write the equation that describes the relationship between the starting quantity of work units $Q_o$, the completed quantity $Q$, and the fraction defect rate $q$ of the operation processing the work units.

**Answer**: The equation is $Q = Q_o(1 - q)$

3.13 What is a work cell?

**Answer**: As defined in the text, a work cell is a group of workstations dedicated to the processing of a range of work units within a given type.

3.14 What is a worker team?

**Answer:** A worker team is a collection of workers who are brought together to achieve a common objective or solve a common problem.

3.15 Define teamwork.

**Answer:** Teamwork refers to the cumulative efforts of the team members to achieve a result that is greater than the sum of their individual efforts. It requires the subordination of the members' individual goals in favor of the team's goals.

3.16 What is the difference between a work-unit team and a self-managed work team?

**Answer:** A work-unit team is one that consists of all the workers employed in a department or unit. It is basically an extension of the regular organizational structure,


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except that the management of the organization is attempting to instill a spirit of teamwork among the work-unit members. A self-managed work team operates like a separate business unit in the organization. It elects its own leaders, and plans and manages its own activities. Management provides the resources necessary for a self-managed team to operate, but the team basically runs itself.

3.17 What is cross-training and what is its value in a worker team?

**Answer:** Cross-training means workers become trained in more than one job in the work unit or cell. Although each individual brings unique knowledge, skills, and abilities to the team's activities, having more than one team member know each job mitigates problems of absences and allows for job rotations to increase work variety and employee satisfaction.

3.18 Name some examples of cross-functional teams.

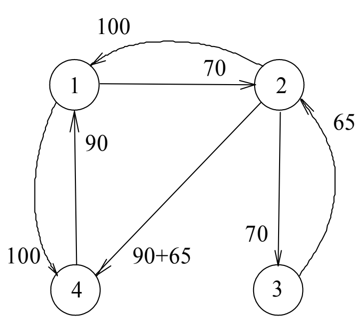
**Answer:** Examples given in the text are: (1) concurrent engineering teams, who work on product design projects; (2) task forces, which are usually assembled to deal with a significant organizational problem or exploit a commercial opportunity; and (3) crisis management teams, which are designed to cope with a crisis or disaster that occurs.

## Problems

### Workflow Structures

3.1 Four parts (A, B, C, and D) are processed through a sequence of four operations (1, 2, 3, and 4). Not all parts are processed in all operations. Part A, which has weekly quantities of 70 units, is processed through operations 1, 2, and 3 in that order. Part B, which has weekly quantities of 90 units, is processed through operations 2, 4, and 1 in that order. Part C, which has weekly quantities of 65 units, is processed through operations 3, 2, and 4 in that order. Finally, part D, which has weekly quantities of 100 units, is processed through operations 2, 1, and 4 in that order. (a) Draw the network diagram and (b) prepare the From-To table for this work system.

**Solution**: (a) Network diagram.




(b) From-to chart

| From\To | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | | 70 | 70 | 100 |
| 2 | 100 | | | 155 |
| 3 | | 65 | | |
| 4 | 90 | | | |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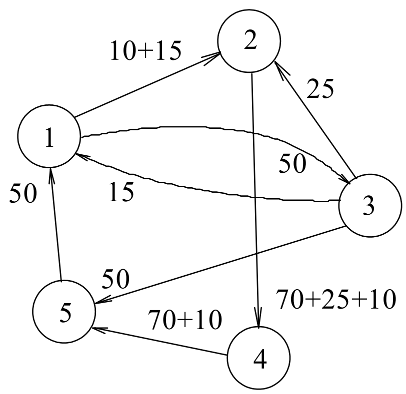
3.2 Five parts (A, B, C, D, and E) are processed through a sequence of five operations (1, 2, 3, 4, and 5). Not all parts are processed in all operations. Part A, which has daily quantities of 50 units, is processed through operations 1, 3, 5, and 1 in that order. Part B, which has daily quantities of 70 units, is processed through operations 2, 4, and 5 in that order. Part C, which has daily quantities of 25 units, is processed through operations 3, 2, and 4 in that order. Part D, which has daily quantities of 10 units, is processed through operations 1, 2, 4, and 5 in that order. Finally, part E, which has daily quantities of 15 units, is processed through operations 3, 1, and 2 in that order. (a) Draw the network diagram and (b) prepare the From-To table for this work system.

**Solution**: (a) Network diagram




(b) From-to chart

| From\To | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | | 25 | 50 | | |
| 2 | | | | 105 | |
| 3 | 15 | 25 | | | 50 |
| 4 | | | | | 80 |
| 5 | 50 | | | | |

## Bottleneck Operations

3.3 A factory produces cardboard boxes. The production sequence consists of three operations: (1) cutting, (2) indenting, and (3) printing. There are three automated machines in the factory, one for each operation. The machines are 100% reliable and the scrap rate in each operation is zero. In the cutting operation, large rolls of cardboard are fed into the cutting machine, which cuts the cardboard into blanks. Each large roll contains enough material for 4000 blanks. Production time = 0.03 min/blank during a production run, but it takes 25 min to change rolls and cutting dies between runs. In the indenting operation, indentation lines are pressed into the printed blanks that allow the blanks to later be bent into boxes. Indenting is performed at an average time of 2.5 sec. per blank. Batches from the previous cutting operation are subdivided into two smaller batches with different indenting lines, so that starting batch size in indenting = 2000 blanks. Time to change dies between batches on the indenting machine = 30 min. In printing, the blanks are printed with labels for a particular customer. Starting batch size in printing = 2000 blanks (these are the same batches as in indenting). Production rate = 30 blanks/min. Between batches, changeover of the printing plates is required, which takes 40 min. What is the maximum possible output of this factory



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during a 40-hour week, in printed and indented blanks/week. Assumptions: (i) steady state operation and (ii) there is work-in-process between operations 1 and 2 and between 2 and 3, so that blocking and starving of operations is negligible.

**Solution**: Operation 1: cutting: Batch time $T_B = 25 + 4000(0.03) = 145$ min
Production rate $R_p = 4000/145 = 27.58$ pc/min = 1655.2 pc/hr

Operation 2: indenting: $T_B = 30 + 2000(2.5/60) = 113.33$ min
$R_p = 2000/113.33 = 17.65$ pc/min = 1058.8 pc/hr

Operation 3: printing: $T_B = 40 + 2000/30 = 106.67$ min
$R_p = 2000/106.67 = 18.75$ pc/min = 1125 pc/hr

Bottleneck is Operation 2: indenting. The slowest operation sets the pace for the sequence.
Weekly plant production rate $R_p = 40(1058.8) = 42{,}353$ pc/wk

3.4 Solve the previous problem except that the reliability of the cutting machine is 80% (availability or uptime proportion = 80%), the reliability of the indenting machine = 95%, and the reliability of the printing machine = 85%. These reliability factors apply only when the machines are producing, not during setup or changeovers.

**Solution**: Operation 1: cutting: Batch time $T_B = 25 + 4000(0.03)/0.80 = 175$ min
Production rate $R_p = 4000/175 = 22.86$ pc/min = 1371.4 pc/hr

Operation 2: indenting: $T_B = 30 + 2000(2.5/60)/0.95 = 117.72$ min
$R_p = 2000/117.72 = 16.99$ pc/min = 1019.4 pc/hr

Operation 3: printing: $T_B = 40 + (2000/30)/0.85 = 118.43$ min
$R_p = 2000/118.43 = 16.89$ pc/min = 1013.2 pc/hr

Bottleneck is Operation 3: printing. The slowest operation sets the pace for the sequence.
Weekly plant production rate $R_p = 40(1013.2) = 40{,}530$ pc/wk

3.5 A factory produces one product. One unit of raw material is required for each unit of product. Two processes are required to produce the product, process 1, which feeds into process 2. A total of five identical machines are available in the plant that can be set up to perform either process. Once set up, each machine will be dedicated to perform that process. For each machine that is set up for process 1, production rate = 12 units per hour. For each machine that is set up for process 2, production rate = 18 units per hour. Both processes produce 100% good units (fraction defect rate = 0). A work-in-process buffer is provided between the two processes to avoid starving and blocking of machines. The factory operates 40 hours per week. (a) In order to maximize factory production, how many machines should be set up for process 1, and how many machines should be set up for process 2? (b) What is the factory's maximum possible weekly production rate of good product units?

**Solution**: (a) $R_{p1} = 12$ pc/hr, $R_{p2} = 18$ pc/hr
$n_1 = (18/12)n_2 = 1.5\ n_2$
$n_1 + n_2 = 1.5n_2 + n_2 = 2.5n_2 = 5$ machines total
$n_2 = 2$ machines, $n_1 = 5 - 2 = 3$ machines

(b) For the two operation sequence, $R_p = 2(18$ pc/hr$)(40$ hr/wk$) = 1440$ pc/wk
Check: $R_p = 3(12$ pc/hr$)(40$ hr/wk$) = 1440$ pc/wk


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3.6 A factory is dedicated to the production of one product. One unit of raw material is required for each unit of product. Two processes are required to produce the product, process 1, which feeds into process 2. A total of eight identical machines are available in the plant that can be set up to perform either process. Once set up, each machine will be dedicated to that process. For each machine that is set up for process 1, production rate = 10 units per hour. For each machine that is set up for process 2, production rate = 6 units per hour. Both processes produce 100% good units (fraction defect rate = 0). A work-in-process buffer is provided between the two processes to avoid starving and blocking of machines. The factory operates 40 hours per week. (a) In order to maximize factory production, how many machines should be set up for process 1, and how many machines should be set up for process 2? (b) What is the factory's maximum possible weekly production rate of good product units?

**Solution**: (a) $R_{p1}$ = 10 pc/hr, $R_{p2}$ = 6 pc/hr
$n_1 = (6/10)n_2 = 0.60\ n_2$
$n_1 + n_2 = 0.60n_2 + n_2 = 1.60n_2$ = 8 machines total
$n_2$ = 5 machines, $n_1 = 8 - 5 = 3$ machines

(b) For the two operation sequence, $R_p$ = 3(10 pc/hr)(40 hr/wk) = 1200 pc/wk

Check: $R_p$ = 5(6 pc/hr)(40 hr/wk) = 1200 pc/wk

3.7 There are 20 automatic turning machines in the lathe department. Batches of parts are machined in the department. Each batch consists of setup and run. Batch size = 100 parts. The standard time to set up a machine for each batch is 5.0 hours. Four setup workers perform the setups. They each work 40 hours per week. Once a machine is set up, it runs automatically, with no worker attention until the batch is completed. Cycle time to machine each part = 9.0 min; thus, it takes 15 hours of run time to produce a batch. Assume all machines are perfectly reliable. (a) What is the production output of the lathe department in 40 hours of operation per week? (b) How many machines are idle (not in use or being set up between production runs) on average at any moment?

**Solution**: (a) Compare machine output capacity and setup output capacity.
Machine capacity: Batch time $T_B$ = 5.0 + 100(9/60) = 20 hr/batch
In a 40 hr week, each machine produces 2 batches = 2(100) = 200 pc/wk
For 20 machines, $Q$ = 20(200) = 4000 pc/wk

Setup worker capacity: With $T_{su}$ = 5.0 hr, in 40 hr, each setup worker can set up 40/5 = 8 setups/wk. With 4 setup workers, number of setups = 4(8) = 32 setups = 32 batches
Output is limited by setup worker capacity to $Q$ = 32(100) = 3200 pc/wk

(b) Number of machines idle because of only 4 setup workers = (4000 – 3200)/4000
= 800/4000 = 0.20 = 20% of the 20 machines = 0.20(20) = 4 machines with no work.
In addition, with 4 setup workers doing setups, there will be 4 machines idle due to setups.
Thus, the total number of idle machines = 4 + 4 = 8 machines.

## Batch Processing and Economic Order Quantities

3.8 The annual demand for a certain item = 22,500 pc/yr. One unit of the product costs $35.00, and the holding cost rate = 15%/yr. Setup time to produce a batch = 3.25 hr. The cost of


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equipment downtime during setup plus associated labor = \$200/hr. Determine the economic order quantity and the total inventory cost for this case.

**Solution**: (a) $C_{su}$ = 200(3.25) = \$650, $C_h$ = 0.15(35) = \$5.25

$$EOQ = \sqrt{\frac{2(22{,}500)(650)}{5.25}} = 2360 \text{ pc}$$

(b) $TIC$ = (2360/2)(5.25) + (22,500/2360)(650) = 6195 + 6197 = \$12,392

3.9 A stamping plant supplies sheet metal parts to a final assembly plant in the automotive industry. Annual demand for a typical part = 150,000 pc. Average cost per piece = \$20; holding cost = 25%; changeover (setup) time for the presses = 5 hours; and cost of downtime for changing over a press = \$200/hr. Compute the economic batch size and the total annual inventory cost for the data.

**Solution**: (a) $C_{su}$ = 200(5) = \$1000, $C_h$ = 0.25(20) = \$5.00

$$EOQ = \sqrt{\frac{2(150{,}000)(1000)}{5.00}} = 7746 \text{ pc}$$

(b) $TIC$ = (7746 /2)(5.00) + (150,000/7746)(1,000) = 19,365 + 19,365 = \$38,730

3.10 Demand for a certain product is 25,000 units/yr. Unit cost = \$10.00. Holding cost rate = 30%/yr. Changeover (setup) time between products = 10.0 hr, and downtime cost during changeover = \$150/hr. Determine (a) economic order quantity, (b) total inventory costs, and (c) total inventory cost per year as a proportion of total production costs.

**Solution**: (a) $EOQ = \sqrt{\frac{2(25{,}000)(150x10)}{(0.30x10)}} = \sqrt{25{,}000{,}000} = 5000$ pc

(b) $TIC = \frac{3(5000)}{2} + \frac{1500(25{,}000)}{5000}$ = 7500 + 7500 = \$15,000/yr

(c) $TC = D_aC_p + TIC$ = 25,000(10) + 15,000 = \$265,000/yr
Proportion = 15,000/265,000 = 0.0566 = 5.66%

3.11 Last year, the annual demand for a certain piece of merchandise that is inventoried at a department store warehouse was 13,688 units. The annual demand is expected to increase 10 percent in the next year. One unit of the product costs \$8.75, and the selling price is \$19.95. The holding cost rate = 15%/yr. Cost to place an order for the merchandise is figured at \$65. Determine the economic order quantity and the total inventory cost for this case.

**Solution**: $D_a$ = 13,688(1 + 0.10) = 15,057 pc, $C_h$ = \$8.75(0.15) = \$1.3125

$$EOQ = \sqrt{\frac{2(15{,}057)(65)}{1.3125}} = 1221 \text{ pc}$$

(b) $TIC$ = (1221/2)(1.3125) + (15,057/1221)(65) = 801.28 + 801.56 = \$1602.84

3.12 A part is produced in batches of size = 3000 pieces. Annual demand = 60,000 pieces, and piece cost = \$5.00. Setup time to run a batch = 3.0 hr, cost of downtime on the affected equipment is figured at \$200/hr, and annual holding cost rate = 30%. What would the annual savings be if the product were produced in the economic order quantity?


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**Solution**: Currently at $Q$ = 3000, $TIC = \frac{0.30(5)(3000)}{2} + \frac{200(3)(60,000)}{3000}$

= 2250 + 12,000 = \$14,250/yr

$EOQ = \sqrt{\frac{2(60,000)(200\times 3)}{(0.30\times 5)}} = \sqrt{48,000,000}$ = 6928 pc

At $EOQ$ = 6928, $TIC = \frac{1.50(6,928)}{2} + \frac{600(60,000)}{6928}$ = 5196 + 5196.30 = \$10,392.30/yr

Savings = 14,250 – 10,392.30 = \$3857.70/yr

3.13 A certain machine tool is used to produce several components for one assembled product. To keep in-process inventories low, a batch size of 100 units is produced for each component. Demand for the product = 3000 units per year. Production downtime costs an estimated \$150/hr. All parts produced on the machine tool are approximately equal in value: \$9.00/unit. Holding cost rate = 30%/yr. In how many minutes must the changeover between batches be accomplished so that 100 units is the economic order quantity?

**Solution**: $EOQ = 100 = \sqrt{\frac{2(3000)(150T_{su})}{(0.30\times 9.00)}}$

$(100)^2 = \frac{2(3000)(150T_{su})}{2.70} = 333,333.33\ T_{su}$ $\qquad T_{su} = \frac{10,000}{333,333.33}$ = 0.03 hr = 1.8 min

3.14 Annual demand for a certain part = 10,000 units. At present the setup time on the machine tool that makes this part = 5.0 hr. Cost of downtime on this machine = \$200/hr. Annual holding cost per part = \$1.50. Determine (a) EOQ and (b) total inventory costs for this data. Also, determine (c) EOQ and (d) total inventory costs if the changeover time could be reduced to six minutes.

**Solution**: (a) $EOQ = \sqrt{\frac{2(10,000)(200\times 5)}{1.50}} = \sqrt{13,333,333}$ = 3641 pc

(b) $TIC = \frac{1.50(3,641)}{2} + \frac{1000(10,000)}{3641}$ = 2730.75 + 2746.50 = \$5477.25/yr

(c) If $T_{su}$ = 6.0 min = 0.1 hr, $EOQ = \sqrt{\frac{2(10,000)(200\times 0.1)}{1.50}} = \sqrt{266,667}$ = 516 pc

(d) $TIC = \frac{1.50(516)}{2} + \frac{200(0.1)(10,000)}{516}$ = 387 + 387.60 = \$774.60/yr

3.15 A variety of assembled products are made in batches on a manual assembly line. Every time a different product is produced, the line must be changed over which causes lost production time. The assembled product of interest here has an annual demand of 12,000 units. The changeover time to set up the line for this product is 6.0 hours. The company figures that the hourly rate for lost production time on the line due to changeovers is \$500/hr. Annual holding cost for the product is \$7.00 per product. The product is currently



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made in batches of 1000 units for shipment each month to the wholesale distributor. (a) Determine the total annual inventory cost for this product in batch sizes of 1000 units. (b) Determine the economic batch quantity for this product. (c) How often would shipments be made using this EOQ? (d) How much would the company save in annual inventory costs, if it produced batches equal to the EOQ rather than 1000 units?

**Solution**: (a) $C_{su} = 500(6.0) = \$3000$

At $Q = 1000$, $TIC = \dfrac{7.00(1000)}{2} + \dfrac{(3000)(12{,}000)}{1000} = 3500 + 36{,}000 = \$39{,}500/\text{yr}$

(b) $EOQ = \sqrt{\dfrac{2(12{,}000)(3000)}{7.00}} = \sqrt{10{,}285{,}714} = 3207$ pc

(c) Using this EOQ, number of batches per year = 12,000/3207 = 3.74
Cycle time per batch = 12/3.74 = 3.207 mo

(d) At $EOQ = 3{,}207$, $TIC = \dfrac{7.00(3207)}{2} + \dfrac{3000(12{,}000)}{3207} = 11{,}225.50 + 11{,}225.44$
= \$22,450.94/yr
The savings would be 39,500 – 22,451 = \$17,049

## Fraction Defect Rate

3.16 A starting batch of 5000 work units is processed through 8 sequential operations, each of which has a fraction defect rate of 3%. (a) How many good parts and (b) defects are in the final batch, and (c) what is the yield of the operation sequence?

**Solution**: (a) $Q_f = 5000(1 - 0.03)^8 = 5{,}000(0.97)^8 = 5{,}000(0.7837) = 3919$ pc

(b) $D_f = 5000(1 - 0.7838) = 1081$ defects

(c) $Y = 0.7837 = 78.37\%$

3.17 A starting batch of 10,000 parts is processed through 6 sequential operations. Operations 1 and 2 each have a fraction defect rate of 4%, operations 3, 4, and 5 each have a fraction defect rate of 6%, and operation 6 has a fraction defect rate of 10%. (a) How many good parts and (b) defects are in the final batch, and (c) what is the yield of the operation sequence?

**Solution**: (a) $Q_f = 10{,}000(1 - 0.04)^2(1 - 0.06)^3(1 - 0.10)$
$= 10{,}000(0.9216)(0.8306)(0.90) = 6889$ pc

(b) $D_f = 10{,}000 - 6889 = 3111$ defects

(c) $Y = 0.6889 = 68.9\%$

3.18 A total of 1000 good units must be produced by a sequence of 10 operations, each of which has fraction defect rate of 6%. (a) How many units must be in the starting batch in order to produce this required quantity? (b) What is the yield of the operation sequence?

**Solution**: (a) $Q_f = 1000 = Q_o(1 - 0.06)^{10} = Q_o(0.94)^{10} = Q_o(0.5386)$
$Q_o = 1000/0.5386 = 1857$ pc

(b) $Y = 0.5386 = 53.9\%$


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3.19 A starting batch of 20,000 work units is processed through 7 sequential operations. Operations 1, 2, and 3 each have a fraction defect rate of 5%, operations 4, 5, and 6 each have a fraction defect rate of 4%, and the fraction defect rate of operation 7 is unknown. If a final batch contains a total of 5,328 defects, determine the fraction defect rate of operation 7.

**Solution**: $Q_f$ = 20,000 – 5328 = 14,672 pc
$Y$ = 14,672/20,000 = 0.7336 = $(1 - 0.05)^3(1 - 0.04)^3(1 - q_7)$
0.7336 = (0.8574)(0.8847)$(1 - q_7)$ = (0.75855)$(1 - q_7)$
$(1 - q_7)$ = 0.7336/0.75855 = 0.9671
$q_7$ = 1 – 0.9671 = 0.0329

3.20 Three sequential operations are required for a certain automotive component. Operation 1 has a defect rate = 4%. Operation 2 has a defect rate = 5%. Operation 3 has a defect rate = 10%. Operations 2 and 3 can be performed on units that are already defective. If 25,000 starting parts are processed through the sequence, (a) how many units are expected to be defect-free, (b) how many units are expected to have exactly one defect, and (c) how many units are expected to have all three defects?

**Solution**: (a) Number of defect-free units = 25,000(1 – 0.04)(1 – 0.05)(1 – 0.10)
= 25,000(0.96)(0.95)(0.90) = 25,000(0.8208) = 20,520 pc

(b) Number of units with one defect
$D_1$ = 25,000(0.04)(1 – 0.05)(1 – 0.10) = 855 pc
$D_2$ = 25,000(1 – 0.04)(0.05)(1 – 0.10) = 1080 pc
$D_3$ = 25,000(1 – 0.04)(1 – 0.05)(0.10) = 2280 pc
$D_1 + D_2 + D_3$ = 4215 pc

(c) Number of units with all three defects $D_{123}$ = 25,000(0.04)(0.05)(0.10) = 5 pc

3.21 Solve Problem 3.3 except that there is a 10% scrap rate in printing (operation 3).

**Solution**: Operation 1: cutting: Batch time $T_B$ = 25 + 4000(0.03) = 145 min
Production rate $R_p$ = 4000/145 = 27.58 pc/min = 1655.2 pc/hr

Operation 2: indenting: $T_B$ = 30 + 2000(2.5/60) = 113.33 min
$R_p$ = 2000/113.33 = 17.65 pc/min = 1058.8 pc/hr

Operation 3: printing: $T_B$ = 40 + 2000/30 = 106.67 min
Although the batch time is less than for operation 2, operation 3 is limited by the slower input rate from operation 2. Thus, $R_p$ = 1058.8(1 – 0.10) = 952.9 pc/hr

Weekly plant production rate $R_p$ = 40(952.9) = 38,117 pc/wk

3.22 A starting batch of 10,000 workparts are processed through three sequential operations: 1 then 2 then 3. Operation 1 sometimes produces parts with defect type 1 at a rate = 5%. Operation 2 sometimes produces parts with defect type 2 at a rate = 8%. And operation 3 sometimes produces parts with defect type 3 at a rate = 10%. The defects occur randomly. If all 10,000 parts are processed through all three operations, (a) how many are expected to be defect free, (b) how many are expected to have all three defects, and (c) how many are expected to have exactly one defect?

**Solution**: (a) Number of defect-free units = 10,000(1 – 0.05)(1 – 0.08)(1 – 0.10)


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$= 10{,}000(0.95)(0.92)(0.90) = 10{,}000(0.7866) = 7866$ pc

(b) Number of units with all three defects $D_{123} = 10{,}000(0.05)(0.08)(0.10) = 4$ pc

(c) Number of units with one defect
$D_1 = 10{,}000(0.05)(1 - 0.08)(1 - 0.10) = 414$ pc
$D_2 = 10{,}000(1 - 0.05)(0.08)(1 - 0.10) = 684$ pc
$D_3 = 10{,}000(1 - 0.05)(1 - 0.08)(0.10) = 874$ pc
$D_1 + D_2 + D_3 = 1972$ pc

3.23 A factory is dedicated to the production of one product. One unit of raw material is required for each unit of product. Two processes are required to produce the product, process 1, which feeds into process 2. A total of eight identical machines are available in the plant that can be set up to perform either process. Once set up, each machine will be dedicated to the performance of that process. For each machine set up for process 1, production rate = 10 units per hour. For each machine set up for process 2, production rate = 6 units per hour. Process 1 produces only good units, but process 2 has a scrap rate of 20%. A work-in-process buffer is allowed between the two processes so that process 2 will not be starved for work. The factory operates 40 hours per week. (a) In order to maximize factory production, how many machines should be set up for process 1, and how many machines should be set up for process 2? (b) What is the factory's maximum possible weekly production rate of good product units? (c) How many starting units of raw material are needed each week to attain this production rate?

**Solution**: (a) and (b) $R_{p1} = 10$ pc/hr, $R_{p2} = 6(1 - 0.20) = 4.8$ pc/hr
$n_1 = (4.8/10)n_2 = 0.48\ n_2$
$n_1 + n_2 = 0.48n_2 + n_2 = 1.48n_2 = 8$ machines total
$n_2 = 5.4$ machines, $n_1 = 8 - 5.4 = 2.6$ machines
Since the number of each type must be an integer, compare the following two cases:
Case 1: $n_1 = 3$ and $n_2 = 5$
$R_p = \text{Min}\{R_{p1} = 3(10\text{ pc/hr})(40\text{ hr/wk}) = 1200, R_{p2} = 5(4.8\text{ pc/hr})(40\text{ hr/wk}) = 960\} = 960$
Case 2: $n_1 = 2$ and $n_2 = 6$
$R_p = \text{Min}\{R_{p1} = 2(10\text{ pc/hr})(40\text{ hr/wk}) = 800, R_{p2} = 6(4.8\text{ pc/hr})(40\text{ hr/wk}) = 1152\} = 800$
Case 1 achieves a higher output rate: $n_1 = 3$, $n_2 = 5$, and $R_p = 960$ pc/wk

(b) $Q_o = 960/(1 - 0.20) = 1200$ starting units of raw material

3.24 Two sheet metal parts, A and B, are produced separately, each requiring two press-working operations. Part A is routed through operations 1 and 2, and part B is routed through operations 3 and 4. The two parts are then joined in a welding step (operation 5), and the assembly is routed to an electroplating operation (operation 6). The six operations have the following fraction defect rates: $q_1 = 0.05$, $q_2 = 0.15$, $q_3 = 0.10$, $q_4 = 0.20$, $q_5 = 0.13$, $q_6 = 0.08$. If the desired final quantity of assemblies is 100,000 units, how many starting units of parts A and B will be required? There is no inspection or separation of defective units until after the final process, so defective units and good units are processed together through all production processes.


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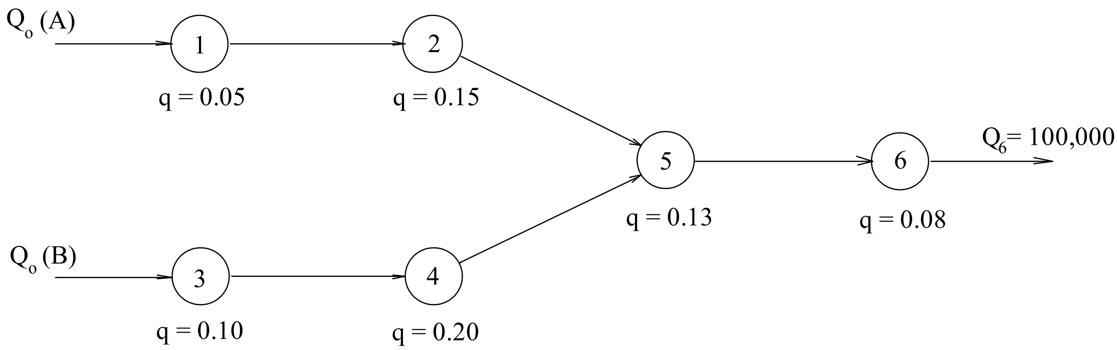
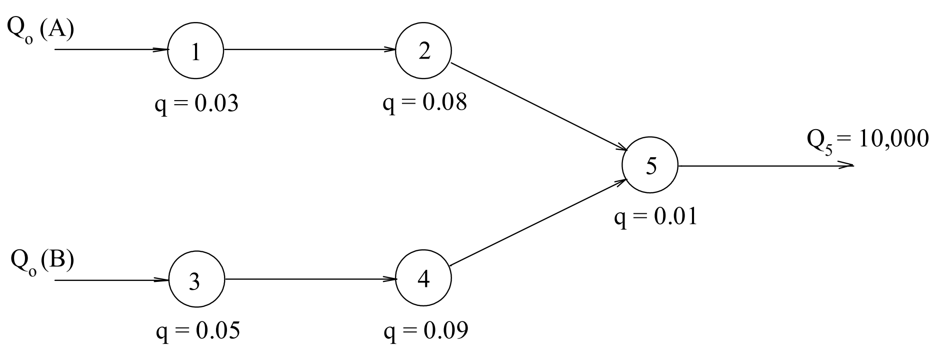
**Solution**: Required: output of $Q_6$ = 100,000 pc




$Q_6 = Q_5(1 - 0.08)$, $Q_5$ = 100,000/(0.92) = 108,696 pc
With $q_5$ = 0.13, input to $Q_5$ = 108,696/(1 – 0.13) = 124,938 pc
Starting quantity $Q_o$(A) = $Q_o$(B) = 124,938/{(1-0.05)(1-0.15)(1-0.10)(1-0.20)}
= 124,938/0.5814 = 214,891 pc of A and 214,891 pc of B

3.25 Two subassemblies, A and B, are processed separately, each requiring two finishing operations. A is routed through operations 1 and 2, and B is routed through operations 3 and 4. The two subassemblies are then joined in an assembly operation (operation 5). The five operations have the following fraction defect rates: $q_1$ = 0.03, $q_2$ = 0.08, $q_3$ = 0.05, $q_4$ = 0.09, $q_5$ = 0.01. If the desired final quantity of completed assemblies is 10,000 units, how many starting units of A and B will be required? There is no inspection or separation of defective units until after the final operation, so defective units and good units are processed together through all processing and assembly steps.

**Solution**: Required: output of $Q_5$ = 10,000 pc




With $q_5$ = 0.01, input to $Q_5$ = 10,000/(1 – 0.01) = 10,101 pc
Starting quantity $Q_o$(A) = $Q_o$(B) = 10,101/{(1-0.03)(1-0.08)(1-0.05)(1-0.09)}
= 10,101/0.7715 = 13,093 pc of A and 13,093 pc of B

## Work Cells and Worker Teams

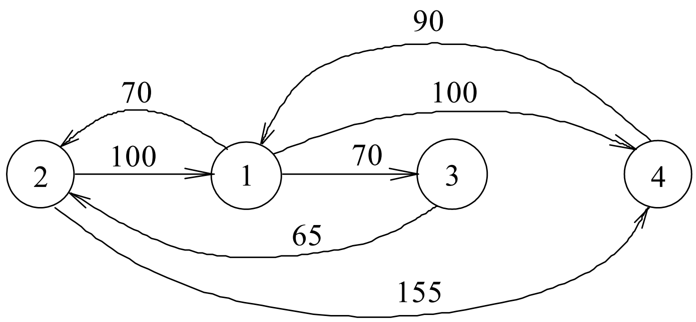
3.26 For Problem 3.1, (a) use the Hollier algorithm to determine the most logical in-line sequence of workstations in the work system, and (b) compute the percentage of in-sequence moves, backflow moves, and by-passing moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | | 70 | 70 | 100 | 240 | 1.263 |
| 2 | 100 | | | 155 | 255 | 1.889 |
| 3 | | 65 | | | 65 | 0.929 |
| 4 | 90 | | | | 90 | 0.353 |
| "To" sums | 190 | 135 | 70 | 255 | 650 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 2 – 1 – 3 – 4



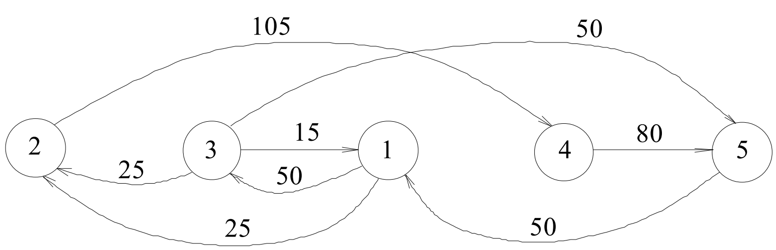

(b) % in-sequence moves = (100 + 70)/650 = 0.2615 = 26.15%
% backflow moves = (70 + 90 + 65)/650 = 0.3462 = 34.62%
% by-passing moves = (100 + 155)/650 = 0.3923 = 39.23%

3.27 For Problem 3.2, (a) use the Hollier method to find the most logical in-line sequence of workstations in the work system, and (b) compute the percentage of in-sequence moves, backflow moves, and by-passing moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | 5 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|---|
| 1 | | 25 | 50 | | | 75 | 1.15 |
| 2 | | | | 105 | | 105 | 2.1 |
| 3 | 15 | 25 | | | 50 | 90 | 1.8 |
| 4 | | | | | 80 | 80 | 0.762 |
| 5 | 50 | | | | | 50 | 0.385 |
| "To" sums | 54 | 50 | 50 | 105 | 130 | 400 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 2 – 3 – 1 – 4 – 5




(b) % in-sequence moves = (15 + 80)/400 = 0.2375 = 23.75%
% backflow moves = (25 + 50 + 25 + 50)/400 = 0.375 = 37.5%
% by-passing moves = (100 + 155)/400 = 0.3875 = 38.75%

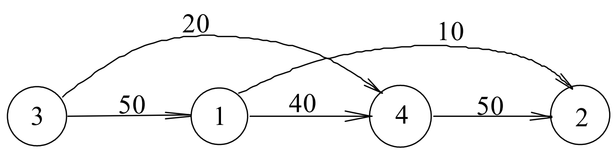
3.28 Four workstations (1, 2, 3, and 4) used to produce a family of similar parts are to be arranged into an in-line layout. The daily flow of parts between workstations is as follows: 10 parts from stations 1 to 2, 40 parts from stations 1 to 4, 50 parts from stations 3 to 1, 20 parts from stations 3 to 4, and 50 parts from stations 4 to 2. (a) Use the Hollier algorithm described to determine the most logical sequence of stations in the work system. (b) Draw the network diagram for the system. (c) Compute the percentage of in-sequence moves, by-passing moves, and backflow moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|
| 1 | | 10 | | 40 | 50 | 1.0 |
| 2 | | | | | 0 | 0 |
| 3 | 50 | | | 20 | 70 | ∞ |
| 4 | | 50 | | | 50 | 0.83 |
| "To" sums | 50 | 60 | 0 | 60 | 170 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 3 – 1 – 4 – 2

(b) Network diagram




(c) % in-sequence moves = (50 + 40 + 50)/170 = 0.824 = 82.4%
% by-passing moves = (20 + 10)/170 = 0.176 = 17.6%
% backflow moves = 0 = 0%

3.29 Four workstations (1, 2, 3, and 4) are used to produce similar parts. The stations are to be arranged into a work cell with an in-line layout. The daily flow of parts between workstations is as follows: 15 parts from stations 2 to 4, 60 parts from stations 3 to 2, 35 parts from stations 2 to 1, 20 parts from stations 4 to 3, and 30 parts from stations 4 to 2. (a) Use the Hollier algorithm to determine the most logical sequence of stations in the work system. (b) Draw the network diagram for the system. (c) Compute the percentage of in-sequence moves, by-passing moves, and backflow moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|
| 1 | | | | | 0 | 0 |
| 2 | 35 | | | 15 | 50 | 0.555 |
| 3 | | 60 | | | 60 | 3.0 |
| 4 | | 30 | 20 | | 50 | 3.33 |
| "To" sums | 35 | 90 | 20 | 15 | 160 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 4 – 3 – 2 – 1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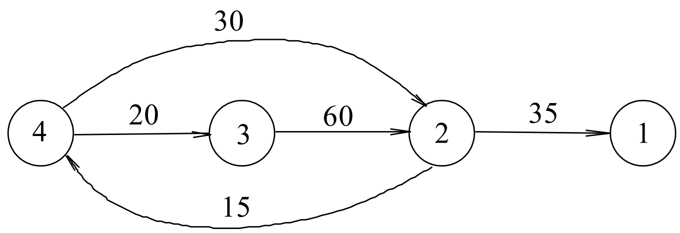
(b) Network diagram




(c) % in-sequence moves = (20 + 60 + 35)/160 = 0.719 = 71.9%
% by-passing moves = (30)/160 = 0.188 = 18.8%
% backflow moves = 15/160 = 0.094 = 9.4%

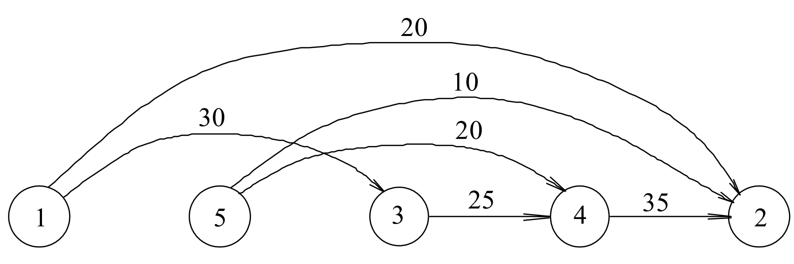
3.30 Five workstations (1, 2, 3, 4, and 5) that produce about ten similar parts must be arranged into an in-line layout. The daily flow of parts between workstations is as follows: 20 parts from stations 1 to 2, 30 parts from stations 1 to 3, 25 parts from stations 3 to 4, 20 parts from stations 5 to 4, 10 parts from 5 to 2, and 35 parts from stations 4 to 2. (a) Use the Hollier algorithm to determine the most logical sequence of stations in the work system. (b) Draw the network diagram for the system. (c) Compute the percentage of in-sequence moves, by-passing moves, and backflow moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | 5 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|---|
| 1 | | 20 | 30 | | | 50 | ∞ |
| 2 | | | | | | 0 | 0 |
| 3 | | | | 25 | | 25 | 0.833 |
| 4 | | 35 | | | | 35 | 0.777 |
| 5 | | 10 | | 20 | | 30 | ∞ |
| "To" sums | 0 | 65 | 30 | 45 | 0 | 140 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 1 – 5 – 3 – 4 – 2

(b) Network diagram.




(c) % in-sequence moves = (25 + 35)/140 = 0.429 = 42.9%
% by-passing moves = (10 + 20 + 30 + 20)/140 = 0.571 = 57.1%
% backflow moves = 0

3.31 Five workstations (1, 2, 3, 4, and 5) that produce about ten similar parts must be arranged into an in-line layout. The daily flow of parts between workstations is as follows: 40 parts from stations 5 to 2, 35 parts from stations 5 to 3, 20 parts from stations 3 to 1, 25 parts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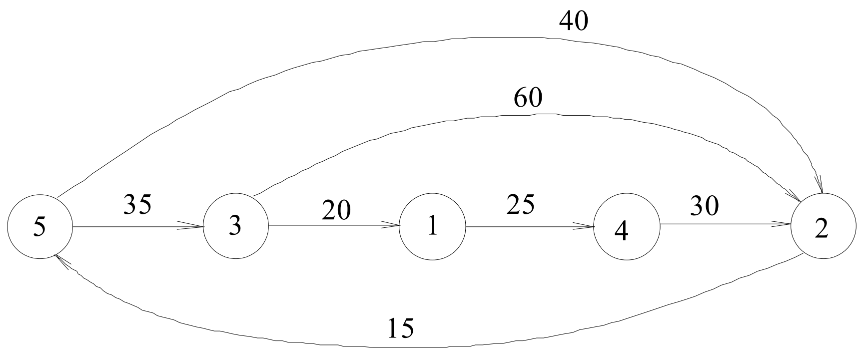
from stations 1 to 4, 60 parts from 3 to 2, 15 parts from stations 2 to 5, and 30 parts from stations 4 to 2. (a) Use the Hollier algorithm described to determine the most logical sequence of stations in the work system. (b) Draw the network diagram for the system. (c) Compute the percentage of in-sequence moves, by-passing moves, and backflow moves for the sequence.

**Solution**: (a) Hollier Method

| From\To | 1 | 2 | 3 | 4 | 5 | "From" sums | From/To ratio |
|---|---|---|---|---|---|---|---|
| 1 | | | | 25 | | 25 | 1.25 |
| 2 | | | | | 15 | 15 | 0.115 |
| 3 | 20 | 60 | | | | 80 | 2.29 |
| 4 | | 30 | | | | 30 | 1.2 |
| 5 | | 40 | 35 | | | 75 | 5.0 |
| "To" sums | 20 | 130 | 35 | 25 | 15 | 225 | |

Arranging operations in descending order of From/To ratio, we have the following sequence: 5 – 3 – 1 – 4 – 2

(b) Network diagram.




(c) % in-sequence moves = (35 + 20 + 25 + 30)/225= 0.489 = 48.9%
% backflow moves = (40 + 60)/225= 0.444 = 44.4%
% by-passing moves = 15/225 = 0.067 = 6.7%

3.32 A team approach is to be used in an assembly cell; each team will consist of $w$ workers, all working together to assemble the same product. The total work content time per product is $T_{wc}$ and so the cycle time $T_c$ to complete a unit is ideally $T_{wc}$ divided by $w$. However, congestion occurs as the number of workers in the cell increases; the workers get in each other's way, and this degrades the cycle time. Thus, a better model of cycle time is: $T_c = T_{wc}/w + wF_cT_{wc}$, where $T_c$ = production cycle time, min; $F_c$ = the congestion factor (a constant of proportionality); and other terms are defined above. If $T_{wc}$ = 45 min and $F_c$ = 0.02, and it is desired to maximize the production rate of the cell, determine (a) the optimum number of workers $w$ and (b) the corresponding production rate. The number of workers must be an integer.

**Solution**: $T_c = T_{wc}/w + wF_cT_{wc} = 45/w + 0.02(45)w = 45/w + 0.9w$
To maximize production rate, minimize $T_c$
$dT_c/dw = -45/w^2 + 0.9 = 0$
$45/w^2 = 0.9$

$w^2 = 45/0.9 = 50$
$w = \sqrt{50} = 7.07$ rounded down to 7 workers
Check: Try $w = 7$ workers: $T_c = 45/7 + 0.9(7) = 12.73$ min
$R_p = 60/12.73 = 4.71$ units/hr
Try $w = 8$ workers: $T_c = 45/8 + 0.9(8) = 12.83$ min
$R_p = 60/12.83 = 4.68$ units/hr
Use a work team of 7 workers to maximize production rate.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