Review Questions

4.1 What is a manual assembly line?

Answer: A manual assembly line is a work system consisting of multiple workers who are organized to produce a single product or a limited range of products for which demand is high. The assembly workers perform various tasks at workstations that are physically located along the line-of-flow of the product as it is being made.

4.2 What are the factors that favor the use of manual assembly lines?

Answer: Factors favoring the use of manual assembly lines include the following: (1) Demand for the product is high or medium. (2) The products made on the line are identical or similar. (3) The total work required to assemble the product can be divided into small work elements. and (4) It is technologically impossible or economically infeasible to automate the assembly operations.

4.3 What are the reasons why manual assembly lines are so productive compared to alternative methods of assembly?

Answer: The reasons given in the text are: (1) Specialization of labor, which asserts that when a large job is divided into small tasks and each task is assigned to one worker, the worker becomes highly proficient at performing the single task. (2) Interchangeable parts, which means that each component is manufactured to sufficiently close tolerances that any part of a certain type can be selected at random for assembly with its mating component. (3) Work flow, which means that each work unit should flow steadily along the line and travel minimum distances between stations. (4) Line pacing, in which workers on an assembly line are required to complete their assigned tasks on each product unit within a certain cycle time, which paces the line to maintain a specified production rate.

4.4 What does the term *manning level* mean in the context of a manual assembly line?

Answer: Manning level refers to the number of workers assigned to a workstation. When the term is allied to a given workstation, it is the number of workers at that station. When applied to the entire line, it is the average number of workers per station.

4.5 What are utility workers on a manual assembly line?

Answer: Utility workers are workers who are assigned to the line but not to specific workstations; instead they are responsible for functions such as (1) helping workers who fall behind, (2) relieving workers for personal breaks, and (3) maintenance and repair duties.

4.6 What is *starving* on a manual assembly line?

Answer: Starving occurs when an assembly operator has completed his or her assigned task on the current work unit, but the next unit has not yet arrived at the station. The worker is thus starved for work.

Answer: Blocking means that the operator has completed the assigned task on the current work unit but cannot pass the unit to the downstream station because that worker is not yet ready to receive it. The operator is therefore blocked from working.

4.8 What are the three major categories of work transport in mechanized production lines?

Answer: The three major categories are (1) continuous transport, in which the work units move along the line at a constant velocity, (2) synchronous transport, in which the movement of work units is intermittent (stop-and-go) and all work units are moved at the same moment, and (3) asynchronous transport, in which the movement of work units is intermittent but the movements are independent of each other.

4.9 What are the two types of line that can be designed to cope with product variety? What is the difference between them?

Answer: The two types are (1) batch model lines, in which the products are produced in batches and line changeover time is required between batches, and (2) mixed model lines, in which different models are made on the same line by workstations that are designed to cope with the model variations, so no downtime between models is experienced.

4.10 What does *work content time* mean?

Answer: The work content time is the sum of the times of all work elements that must be performed to make one unit of the product. It represents the total amount of work that is accomplished by the assembly line on one product unit.

4.11 What are repositioning losses as they are explained in the text?

Answer: Repositioning losses on a production line occur because some time is required each cycle to reposition the worker, or the work unit, or both.

4.12 What is the line balancing problem in the design of a manual assembly line?

Answer: The line balancing problem is the problem of allocating work elements to workers on the line so that all workers have an equal workload and production cycle time requirements of the line are met.

4.13 What is a minimum rational work element in the context of manual assembly lines?

Answer: A minimum rational work element is a work element that has a specific limited objective, such as adding a component to the base part, joining two components, or performing some other small portion of the total work content. It cannot be subdivided without loss of practicality.

4.14 What is a precedence constraint in the context of manual assembly lines?

Answer: Precedence constraints are technological requirements of the assembly work elements that limit the sequence in which they can be performed.

4.15 What are the three types of efficiency that must be considered in designing and operating a manual assembly line?

or the worker or both, and (3) balance efficiency, which results from the inability to perfectly balance the station workloads on the line.

4.16 What does *tolerance time* mean?

Answer: Tolerance time is the amount of time a work unit spends inside the boundaries of the workstation. It is the length of the station divided by the conveyor velocity.

4.17 Name the three line balancing algorithms described in the text.

Answer: The three line balancing algorithms described in the text are (1) largest candidate rule, (2) Kilbridge and Wester method, and (3) ranked positional weights method.

4.18 What are some of the methods by which assembly line balancing efficiency can be improved that are outside the scope of the line balancing algorithms?

Answer: The methods indicated in the text include (1) methods analysis on some of the tasks, (2) utility workers to relieve congestion at overloaded stations, (3) preassembly of components, (4) storage buffers between stations, and (5) parallel workstations.

Problems

Manual Assembly Lines

4.1 Determine (a) the required hourly production rate and (b) the cycle time for a manual assembly line that will be used to produce a product with a work content time of 75 min and an annual demand of 150,000 units, if the plant operates 50 wk/yr, 5 days/wk, and 8 hr/day. It is anticipated that the line efficiency will be 94%.

Solution: (a) R_p = 150,000/2,000 = 75 units/hr

(b) T_c = 60(0.94)/75 = 0.752 min

4.2 A manual assembly line has 25 workstations and the manning level is 1.0. The work content time to assemble the product is 29.5 min. Production rate of the line is 40 units/hr. The proportion uptime is 96% and the repositioning time is 9 sec. Determine the balance delay on the line.

Solution: T_c = 60(0.96)/40 = 1.44 min
T_s = 1.44 – 0.15 = 1.29 min
E_b = 29.5/25(1.29) = 0.915, d = 1 – 0.915 = 0.085 = 8.5%

4.3 A manual assembly line is being planned for an assembled product whose work content time = 47.2 min. The line will be operated 2000 hr/yr. The annual demand anticipated for the product is 100,000 units. Based on previous assembly lines used by the company, the proportion of uptime on the line is expected to be 94%, the line balancing efficiency will be 92%, and the repositioning time lost each cycle will be 6 sec. The line will be designed with 1 worker/station. Determine (a) the required hourly production rate of the line, (b) the cycle time, (c) the ideal minimum number of workers required, and (d) the actual number of workers required based on the efficiencies given.

Solution: (a) R_p = 100,000/2,000 = 50 units/hr

(b) T_c = 60(0.94)/50 = 1.128 min

(c) w^* = Min Int ≥ 47.2/1.128 = 41.84 rounded up to 42 workers

(d) T_s = 1.128 – 0.10 = 1.028 min
w = Min Int ≥ 47.2/1.028(0.92) = 49.9 rounded up to 50 workers

4.4 A manual assembly line is being planned for an assembled product whose annual demand is expected to be 175,000 units/yr. The line will be operated two shifts (4000 hr/yr). Work content time of the product is 53.7 min. For planning purposes, the following line parameter values will be used: uptime efficiency = 96%, balancing efficiency = 94%, and repositioning time = 8 sec. Determine (a) the required hourly production rate of the line, (b) the cycle time, and (c) the ideal minimum number of workers required, and (d) the actual number of workers required based on the efficiencies given.

Solution: (a) R_p = 175,000/4,000 = 43.75 units/hr

(b) T_c = 60(0.96)/43.75 = 1.3166 min

(c) w^* = Min Int ≥ 53.7/1.3166 = 40.79 rounded up to 41 workers

(d) T_s = 1.3166 – 0.1333 = 1.1832 min
w = Min Int ≥ 53.7/1.1832(0.94) = 48.3 rounded up to 49 workers

4.5 The required production rate for a certain product is 45 units/hr. Its work content time is 71.5 min. The production line for this product includes 5 automated workstations. Because the automated stations are not entirely reliable, the overall line efficiency is expected to be only 88%. All of the other stations will have one worker each. It is anticipated that 6% of each cycle will be lost due to worker repositioning. Balance delay is expected to be 7%. Determine (a) cycle time, (b) number of workers, (c) number of workstations, (d) average manning level on the line, including the automated stations, and (e) labor efficiency on the line.

Solution: (a) $T_c = 60(0.88)/45 = 1.1733$ min

(b) $T_r = 0.06T_c$, therefore, $T_s = 0.94T_c$ and $E_r = 0.94$
$E_b = 1 - d = 1 - 0.07 = 0.93$
w = Min Int $\geq 71.5/1.1733(0.94)(0.93) = 69.7$ rounded up to 70 workers

(c) $n = 70 + 5 = 75$ workstations

(d) $M = 70/75 = 0.933$

(e) Labor efficiency = $EE_rE_b = (0.88)(0.94)(0.93) = 0.769 = 76.9\%$

4.6 A manual assembly line is being designed for a product whose annual demand is 100,000 units. The line will operate 50 wk/yr, 5 shifts/wk, and 8 hr/shift. Work units will be attached to a continuously moving conveyor. Work content time is 42.0 min. Assume line efficiency is 0.95, balancing efficiency is 0.93 or slightly less, repositioning time is 6 sec, and manning level is 1.4. Determine (a) average hourly production rate to meet demand and (b) number of workers required. (c) If each station on the line is 3 m long, what is the total length of the assembly line?

Solution: (a) $R_p = 100{,}000/50(5)(8) = 100{,}000/2{,}000 = 50$ units/hr

(b) $T_c = 60(0.95)/50 = 1.14$ min
$T_s = 1.14 - 0.10 = 1.04$ min
w = Min Int $\geq 42.0/1.04(0.93) = 43.4$ rounded up to 44 workers

(c) $n = w/M = 44/1.4 = 31.43 = 32$ workstations
$L = 32(3) = 96$ m

4.7 The work content for a product assembled on a manual production line is 48 min. The work is transported using a continuous overhead conveyor that operates at a speed of 5 ft/min. There are 24 workstations on the line, one-third of which have two workers; the remaining stations each have one worker. Repositioning time per worker is 9 sec, and uptime efficiency of the line is 95%. (a) What is the maximum possible hourly production rate if the line is assumed to be perfectly balanced? (b) If the actual production rate is only 92% of the maximum possible rate determined in part (a), what is the balance delay on the line? (c) If the line is designed so that the tolerance time is 1.3 times the cycle time, what is the total length of the production line? (d) What is the elapsed time a product spends on the line?

Solution: (a) $w = 8(2) + 16(1) = 32$ workers
$w = T_{wc}/T_sE_b$. Rearranging, $T_s = T_{wc}/wE_b$
If the line is assumed to be perfectly balanced, then $E_b = 1.0$
Therefore, $T_s = 48.0/32(1.0) = 1.5$ min
$T_c = T_s + T_r = 1.5 + 0.15 = 1.65$ min
$R_p = E/T_c = 0.95/1.65 = 0.5757$ units/min = 34.54 units/hr

(b) Actual $R_p = 0.92(34.54) = 31.78$ units/hr
$T_p = 60/31.78 = 1.888$ min
$T_c = 0.95(1.888) = 1.794$ min
$T_s = 1.794 - 0.15 = 1.644$ min
$E_b = 48.0/32(1.644) = 0.913$
$d = 1 - E_b = 1 - 0.913 = 0.087 = 8.7\%$

(c) $T_t = 1.3\ T_c = 1.3(1.794) = 2.332$ min
Station length $L_s = v_cT_t = 5(2.332) = 11.66$ ft
$L = nL_s = 24(11.66) = 279.8$ ft

(d) Elapsed time $ET = nT_t = 24(2.332) = 55.96$ min
Alternative calculation: $ET = L/v_c = 279.8/5 = 55.96$ min

4.8 A manual assembly line must be designed for a product with annual demand of 150,000 units. The line will operate 50 wks/year, 10 shifts/wk, and 7.5 hr/shift. Work units will be attached to a continuously moving conveyor. Work content time is 58.0 min. Assume line efficiency is 0.95, balancing efficiency is 0.93, and repositioning time is 8 sec. Determine (a) hourly production rate to meet demand, and (b) number of workers required.

Solution: (a) $R_p = 150{,}000/50(10)(7.5) = 150{,}000/3{,}750 = 40$ units/hr

(b) $T_c = E/R_p = 60(0.95)/40 = 1.425$ min
$T_s = T_c - T_r = 1.425 - 8/60 = 1.292$ min
$w = T_{wc}/T_sE_b = 58.0/1.2917(0.93) = 48.3$ rounded up to 49 workers
Actual E_b after rounding up: $E_b = 58.0/49(1.2917) = 0.9164$

4.9 The total work content for a product assembled on a manual production line is 33.0 min, and the production rate of the line must be 47 units/hr. Work units are attached to a moving conveyor whose speed is 7.5 ft/min. Repositioning time per worker is 6 sec, and uptime efficiency of the line is 94%. Owing to imperfect line balancing, the number of workers needed on the line must be two more workers than the number required for perfect balance. Assume the manning level is 1.6. (a) How many workers are required on the line? (b) How many workstations will be in the line? (c) What is the balance delay for this line? (d) If the workstations are arranged in a line, and the length of each station is 11 ft, what is the tolerance time in each station? (e) What is the elapsed time a work unit spends on the line?

Solution: (a) $T_c = E/R_p = 0.94/47 = 0.02$ hr = 1.2 min
$T_s = T_c - T_r = 1.20 - 0.1 = 1.10$ min
For perfect balance, $E_b = 1.0$
$w = T_{wc}/T_sE_b = 33.0/1.1(1.0) = 30$ workers if line is perfectly balanced. Actual number of workers is two more than for perfect balance. Therefore, $w = 30 + 2 = 32$ workers

(b) $n = w/M = 32/1.6 = 20$ workstations

(c) $E_b = 33.0/32(1.1) = 0.9375$
Balance delay $d = 1 - 0.9375 = 0.0625 = 6.25\%$

(d) $T_t = L_s/v_c = 11/7.5 = 1.467$ min

(e) Elapsed time $ET = 20(1.467) = 29.33$ min

4.10 The production rate for a certain assembled product is 45 units/hr. The total assembly work content time is 33 min of direct manual labor. The line operates at 95% uptime. Ten workstations have two workers on opposite sides of the line so that both sides of the product can be worked on simultaneously. The remaining stations have one worker. Repositioning time lost by each worker is 10 sec/cycle. It is known that the number of workers on the line is three more than the number required for perfect balance. Determine (a) number of workers, (b) number of workstations, (c) the balance delay, and (d) manning level.

Solution: (a) $T_c = 60(0.95)/45 = 1.2667$ min
$T_s = T_c - T_r = 1.2667 - 10/60 = 1.10$ min
For perfect balance, $E_b = 1.0$
$w = T_{wc}/T_sE_b = 33.0/1.1(1.0) = 30$ workers if line is perfectly balanced. Actual number of workers is three more than for perfect balance. Therefore, $w = 30 + 3 = 33$ workers

(b) Given that 10 stations have 2 workers (total 20 workers), so the remaining 13 stations have 1 worker each.
$n = 10 + 13 = 23$ stations

(c) $E_b = 33.0/33(1.1) = 0.909$
Balance delay $d = 1 - 0.909 = 0.091 = 9.1\%$

(d) $M = 33/23 = 1.435$

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4.11 A powered overhead conveyor is used to carry washing machine base parts along a manual assembly line. The spacing between base parts is 2.5 m and the speed of the conveyor is 1.2 m/min. The length of each workstation is 3.1 m. The line has 30 stations and 42

workers. Determine (a) cycle time, (b) feed rate, (c) tolerance time, and (d) elapsed time a washing machine base part spends on the line.

Solution: (a) $T_c = s_p/v_c = 2.5/1.2 = 2.083$ min

(b) Feed rate of parts $f_p = v_c/s_p = 1.2/2.5 = 0.48$ units/min (also $f_p = 1/T_c = 1/2.083$)

(c) $T_t = L_s/v_c = 3.1/1.2 = 2.583$ min/station

(d) Elapsed time $ET = nT_t = 30(2.583) = 77.5$ min

4.12 An automobile final assembly plant is being planned for an annual production of 150,000 cars. The plant will operate one shift, 250 days per year, but the duration of the shift (hr/shift) is to be determined. The plant will be divided into three departments: (1) body shop, (2) paint shop, and (c) general assembly. The body shop welds the car bodies, and the paint shop coats the welded car bodies. Both of these departments are highly automated. The general assembly department has no automation, but a moving conveyor is used to transport the cars through the manual workstations. A total of 14.0 hours of direct labor (work content time) are accomplished in general assembly. Based on previous lines installed by the company, it is anticipated that the following design parameters will apply to the general assembly department: line efficiency = 95%, balance efficiency = 94%, repositioning time = 0.10 min, and manning level = 2.5. If the plant must produce 60 cars per hour, determine the following for the general assembly department: (a) number of hours the shift must operate, (b) number of workers required, and (c) number of workstations.

Solution: (a) $R_p = D_a/250H_{sh}$. Rearranging, $H_{sh} = D_a/250R_p = 150,000/250(60) = 10.0$ hr

(b) $T_c = 60E/R_p = 60(0.95)/60 = 0.95$ min
$T_s = T_c - T_r = 0.95 - 0.10 = 0.85$ min
w = Min Int $\geq 14.0(60)/0.85(0.94) = 1051.3$ rounded up to 1052 workers

(c) $n = w/M = 1052/2.5 = 421$ workstations

4.13 In the previous problem, each workstation in the general assembly department will be 6.0 m long, and the tolerance time will be equal to the cycle time. Determine (a) speed of the moving conveyor, (b) center-to-center spacing of car bodies on the line, (c) total length of the line in general assembly, and (d) elapsed time a work unit spends in the department.

Solution: (a) $T_c = 60E/R_p = 60(0.95)/60 = 0.95$ min from previous problem
$T_t = T_c = 0.95$ min
$v_c = L_s/T_t = 6.0/0.95 = 6.316$ m/min

(b) Center-to-center spacing between cars $s_p = v_c T_c = 6.316(0.95) = 6.0$ m

(c) $n = 421$ stations from previous problem
Length of assembly line $L = 421(6.0) = 2{,}526$ m

(d) Elapsed time $ET = L/v_c = 2526/6.316 = 399.9$ min
Alternative calculation: $ET = nT_t = 421(0.95) = 399.9$ min

4.14 Production rate for a certain assembled product is 48 units/hr. The assembly work content time is 36.3 min of direct labor. Twelve of the workstations have two workers on opposite

sides of the product, and the remaining stations have one worker each. Repositioning time lost per cycle is 0.10 min. The uptime efficiency of the line is 96%. It is known that the number of workers on the line is three more than the number required for perfect balance. Determine (a) number of workers, (b) number of workstations, (c) balance efficiency, (d) average manning level, and (e) overall labor efficiency on the line.

Solution: (a) $T_c = 60(0.96)/48 = 1.2$ min, $T_s = 1.2 - 0.1 = 1.1$ min
For perfect balance, w = Min Int $\geq 36.3/1.1(1.0) = 33$ workers. Actual number of workers is three more than for perfect balance. Therefore, $w = 33 + 3 = 36$ workers

(b) Given that 12 stations have 2 workers (total 24 workers), so the remaining 12 stations have 1 worker each.
$n = 12 + 12 = 24$ stations

(c) $E_b = 36.3/36(1.1) = 0.9167 = 91.67\%$

(d) $M = 36/24 = 1.5$

(e) Labor efficiency = $EE_rE_b = 0.96(1.1/1.2)(0.9167) = 0.8067 = 80.67\%$

4.15 The work content time for an appliance product on a manual production line = 90.4 min. The required production rate is 45 units/hr. Work units are attached to a moving overhead conveyor whose speed is 2.5 m/min. Repositioning time per cycle is 9 sec, uptime efficiency is 96%, and manning level is 1.4. Because of imperfect line balancing, the number of workers needed on the line will be 5% more than the number required for perfect balance. The workstations are arranged in one long straight line, and the length of each station is 3.6 m. Determine (a) balance efficiency, (b) total length of the line, and (c) elapsed time a unit spends on the line.

Solution: (a) $T_c = 60(0.96)/45 = 1.28$ min, $T_s = 1.28 - 0.15 = 1.13$ min
For perfect balance, $E_b = 1.0$, and w = Min Int $\geq 90.4/1.13(1.0) = 80$ workers
Actual number of workers is 5% more than for perfect balance
Therefore, $w = 80(1.05) = 84$ workers
$E_b = 90.4/84(1.13) = 0.952 = 95.2\%$

(b) $n = w/M = 84/1.4 = 60$ workstations
Line length $L = nL_s = 60(3.6) = 216$ m

(c) Elapsed time $ET = L/v_c = 216/2.5 = 86.4$ min

Assembly Line Balancing

4.16 The letters in the table below represent work elements in an assembly precedence diagram. (a) Construct the precedence diagram and (b) determine the total work content time. (c) Use the largest candidate rule to assign work elements to stations using a service time (T_s) of 1.5 min, and (d) compute the balance delay for your solution.

Work element or tasks	A	B	C	D	E	F	G	H	I	J
Time (min)	0.5	0.3	0.8	1.1	0.6	0.2	0.7	1.0	0.9	0.4
Preceding	-	A	A	A	B, C	D	E	F	F	G, H, I

4.18 Solve the previous problem but use the ranked positional weights method in part (c).

Solution: (a) and (b) Same as in Problem 4.16

(c) Ranked positional weights(RPW) method using T_s = 1.5 min

RPW	Element	T_e	Predecessor
6.5	A	0.5	-
3.6	D	1.1	A
2.5	C	0.8	A
2.5	F	0.2	D
2.0	B	0.3	A
1.7	E	0.6	B, C
1.4	H	1.0	F
1.3	I	0.9	F
1.1	G	0.7	E
0.4	J	0.4	G, H, I

Station	Element	T_e	ΣT_e
1	A	0.5	
	C	0.8	1.3
2	D	1.1	
	F	0.2	1.3
3	B	0.3	
	E	0.6	0.9
4	H	1.0	1.0
5	I	0.9	0.9
6	G	0.7	
	J	0.4	1.1
			6.5

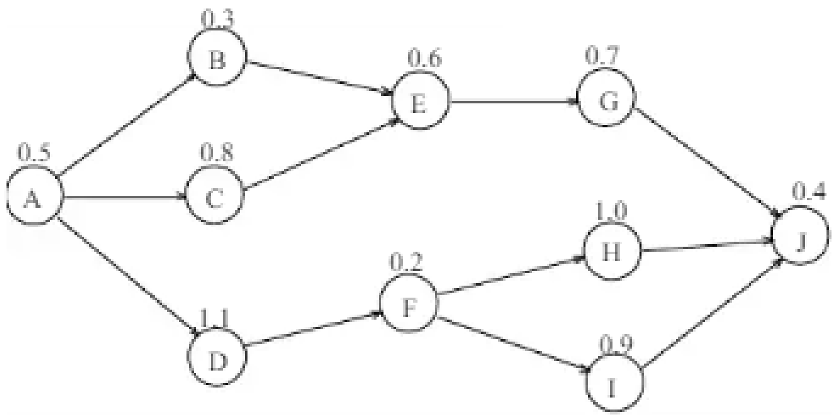
(d) Balance delay if T_s = 1.5, d = (6(1.5) – 6.5)/6(1.5) = 0.278 = 27.8%
However, if we use T_s = 1.3 min (highest ΣT_e at stations 1 and 2), d = (6(1.3) – 6.5)/6(1.3) = 0.167 = 16.7%

4.19 The table below defines the precedence relationships and element times for a new assembled product. (a) Construct the precedence diagram for this job. (b) If the ideal cycle time is 1.1 min and the repositioning time is 0.1 min, what is the theoretical minimum number of workstations required to minimize the balance delay under the assumption that there will be one worker per station? (c) Using largest candidate rule, assign work elements to stations. (d) Compute the balance delay for your solution.

Work element	T_e (min)	Immediate predecessors	Work element	T_e (min)	Immediate predecessors
1	0.5	-	6	0.6	3
2	0.3	1	7	0.4	4,5
3	0.8	1	8	0.5	3,5
4	0.2	2	9	0.3	7,8
5	0.1	2	10	0.6	6,9

Solution: (a) Precedence diagram.

Solution: (a) Precedence diagram.



(b) $T_{wc} = 0.5 + 0.3 + 0.8 + 0.2 + 0.1 + 0.6 + 0.4 + 0.5 + 0.3 + 0.6 = 4.3$ min
$w^* = \text{Min Int} \geq T_{wc}/T_c = 4.3/1.1 = 3.9$ rounded up to 4 workers and 4 workstations

(c) Largest candidate rule using $T_s = 1.0$ min

Element	T_e	Predecessor
3	0.8	1
6	0.6	3
10	0.6	6, 9
1	0.5	-
8	0.5	3, 5
7	0.4	4, 5
2	0.3	1
9	0.3	7, 8
4	0.2	2
5	0.1	2

Station	Element	T_e	ΣT_e
1	1	0.5	
	2	0.3	
	4	0.2	1.0
2	3	0.8	
	5	0.1	0.9
3	6	0.6	
	7	0.4	1.0
4	8	0.5	
	9	0.3	0.8
5	10	0.6	0.6
			4.3

(d) Balance delay $d = (5(1.0) - 4.3)/5(1.0) = 0.14 = 14\%$

4.20 Solve the previous problem but use the Kilbridge and Wester method in part (c).

Solution: (a) and (b) Same answers as in Problem 4.19

c) Kilbridge & Wester method using $T_s = 1.0$ min

Column	Element	T_e	Predecessor
I	1	0.5	-
II	3	0.8	1
	2	0.3	1
III	6	0.6	3
	4	0.2	2
	5	0.1	2
IV	8	0.5	3, 5
	7	0.4	4, 5
V	9	0.3	7, 8
VI	10	0.6	6, 9

Station	Element	T_e	ΣT_e
1	1	0.5	
	2	0.3	
	4	0.2	1.0
2	3	0.8	
	5	0.1	0.9
3	6	0.6	
	7	0.4	1.0
4	8	0.5	
	9	0.3	0.8
5	10	0.6	0.6
			4.3

(d) Balance delay $d = (5(1.0) - 4.3)/5(1.0) = 0.14 = 14\%$

4.21 Solve the previous problem but use the ranked positional weights method in part (c).

Solution: (a) and (b) Same answers as in Problem 4.19

(c) Ranked positional weights(RPW) method using $T_s = 1.0$ min

RPW	Element	T_e	Predecessor
4.3	1	0.5	-
2.8	3	0.8	1
2.4	2	0.3	1
1.9	5	0.1	2
1.5	4	0.2	2
1.4	8	0.5	3, 5
1.3	7	0.4	4, 5
1.2	6	0.6	3
0.9	9	0.3	7, 8

Station	Element	T_e	ΣT_e
1	1	0.5	
	2	0.3	
	5	0.1	0.9
2	3	0.8	
	4	0.2	1.0
3	8	0.5	
	7	0.4	0.9
4	6	0.6	
	9	0.3	0.9

0.6	10	0.6	6, 9

5	10	0.6	0.6
			4.3

(d) Balance delay $d = (5(1.0) - 4.3)/5(1.0) = 0.14 = 14\%$

4.22 The table below lists the work elements (in minutes) to be performed on an assembly line and the precedence requirements that must be satisfied. Annual demand for the product will be 60,000 units. The line will operate one shift (2000 hr/yr). Expected line efficiency (proportion uptime) is 95%. Repositioning time per cycle is 6 sec. Manning level is 1.0 for all stations. The products will be moved through the line by conveyor at a speed of 4 ft/min. All stations are of equal length, which is 10 ft. Determine (a) theoretical minimum number of workers, (b) actual number of workers, based on previous experience with similar lines in which the highest possible balance efficiency is 93%, (c) tolerance time, and (d) elapsed time a product spends on the line from when it is first launched at the front of the first station until it is finally removed after the last station. (e) Construct the precedence diagram and (f) solve the line balancing problem using the Kilbridge and Wester method.

Work element	1	2	3	4	5	6	7	8	9	10	11	12	13
Time (minutes)	0.5	0.3	0.8	1.1	0.6	0.2	0.7	1.0	1.2	0.4	0.9	0.1	1.3
Preceded by	-	-	1	1,2	2	3	4	5	5	6	7	8,9	10,11,12

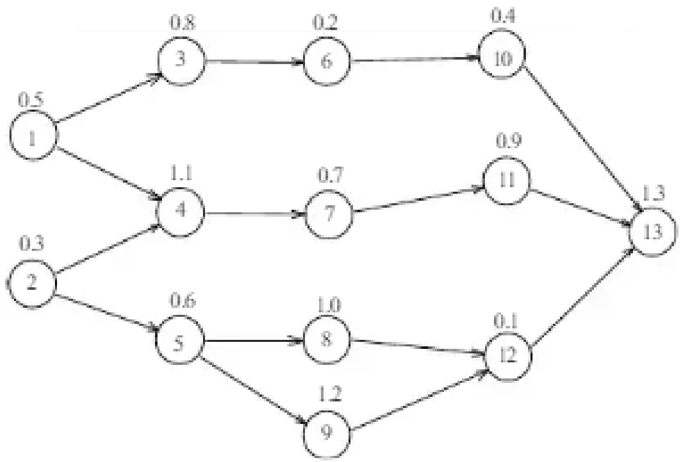
Solution: (a) $R_p = 60{,}000/2{,}000 = 30$ units/hr
$T_c = 60(0.95)/30 = 1.9$ min
$T_{wc} = 0.5 + 0.3 + 0.8 + 1.1 + 0.6 + 0.2 + 0.7 + 1.0 + 1.2 + 0.4 + 0.9 + 0.1 + 1.3 = 9.1$ min
$w^* = \text{Min Int} \geq 9.1/1.9 = 4.79$ rounded up to 5 workers

(b) $T_s = 1.9 - 0.1 = 1.8$ min
Given that $E_b = 0.93$, actual number of workers $w = \text{Min Int} \geq 9.1/1.8(0.93) = 5.44$ rounded up to 6 workers. With manning level $M = 1$, $n = 6$ stations.

(c) $T_t = L_s/v_c = 10/4 = 2.5$ min

(d) Elapsed time $ET = nT_t = 6(2.5) = 15.0$ min

(e) Precedence diagram.



(f) Kilbridge & Wester method using T_s = 1.8 min

Column	Element	T_e	Predecessor
I	1	0.5	-
	2	0.3	-
II	3	0.8	1
	4	1.1	1, 2
	5	0.6	2
III	6	0.2	3
	7	0.7	4
	8	1.0	5
	9	1.2	5
IV	10	0.4	6
	11	0.9	7

Station	Element	T_e	ΣT_e
1	1	0.5	
	2	0.3	
	3	0.8	
	6	0.2	1.8
2	4	1.1	
	5	0.6	1.7
3	7	0.7	
	8	1.0	1.7
4	9	1.2	
	10	0.4	
	12	0.1	1.7

	12	0.1	8, 9	5	11	0.9	0.9
V	13	1.3	10, 11, 12	6	13	1.3	1.3
							9.1

Actual balancing efficiency E_b = 9.1/6(1.8) = 0.843 = 84.3%

4.23 A manual assembly line is being planned to produce a small consumer appliance. The work elements, element times, and precedence constraints are indicated in the table below. The workers will work for 420 min/shift and must produce 350 units/day. A mechanized conveyor, moving at a speed of 1.4 m/min will transport work units through stations. Manning level is 1.0, and repositioning time is 0.1 min. Because worker service time at each station is variable, it has been decided to use a tolerance time that is 1.5 times the cycle time. (a) Determine the ideal minimum number of workers. (b) Use the largest candidate rule to solve the line balancing problem. (c) For your line balancing solution, compute the balancing efficiency. Determine (d) spacing between work units on the line and (e) required length of each workstation to satisfy the specifications of the line.

Work element	T_e (min)	Immediate predecessors	Work element	T_e (min)	Immediate predecessors
1	0.4	-	8	0.15	4
2	0.5	1	9	0.41	5
3	0.2	1	10	0.2	6, 7
4	0.6	-	11	0.3	8
5	0.25	2	12	0.33	9, 10
6	0.3	3	13	0.4	11
7	0.37	4	14	0.62	12, 13

Solution: (a) T_c = 420 min/350 units = 1.2 min/unit
T_{wc} = 0.4 + 0.5 + 0.2 + 0.6 + 0.25 + 0.3 + 0.37 + 0.15 + 0.41 + 0.2 + 0.3 + 0.33 + 0.4 + 0.62 = 5.03 min
w^* = Min Int ≥ 5.03/1.2 = 4.19 rounded up to 5 workers

(b) Largest candidate rule using T_s = 1.2 – 0.1 = 1.1 min

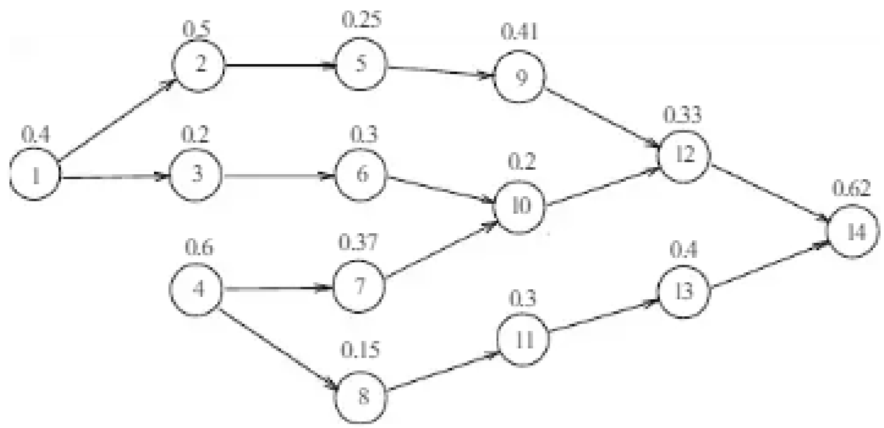
Element	T_e	Predecessor
14	0.62	12, 13
4	0.6	-
2	0.5	1
9	0.41	5

Station	Element	T_e	ΣT_e
1	4	0.6	
	1	0.4	1.0
2	2	0.5	
	9	0.41	

1	0.4	-
13	0.4	11
7	0.37	4
12	0.33	9, 10
6	0.3	3
11	0.3	8
5	0.25	2
3	0.2	1
10	0.2	6, 7
8	0.15	4

	8	0.15	1.06
3	7	0.37	
	11	0.3	
	5	0.25	0.92
4	13	0.4	
	3	0.2	
	6	0.3	
	10	0.2	1.1
5	12	0.33	
	14	0.62	0.95
			5.03

Precedence diagram.



(c) Balance efficiency E_b = 5.03/5(1.1) = 0.915 = 91.5%

(d) $s_p = v_c T_c$ = (1.4 m/min)(1.2 min) = 1.68 m/unit

(e) $T_t = 1.5 T_c$ = 1.5(1.2) = 1.8 min

$L_s = v_c T_t$ = (1.4 m/min)(1.8 min) = 2.52 m/station

4.24 Solve the previous problem but use the Kilbridge and Wester method in part (b).

Solution: (a), (d), and (e) Same answers as in Problem 4.23

(b) Kilbridge & Wester method using $T_s = 1.2 - 0.1 = 1.1$ min

Column	Element	T_e	Predecessor	Station	Element	T_e	ΣT_e
I	4	0.6	-	1	4	0.6	
	1	0.4	-		1	0.4	1.0
II	2	0.5	1	2	2	0.5	
	7	0.37	4		7	0.37	
	3	0.2	1		3	0.2	1.07
	8	0.15	4	3	8	0.15	
III	6	0.3	3		6	0.3	
	11	0.3	8		11	0.3	
	5	0.25	2		5	0.25	1.0
IV	9	0.41	5	4	9	0.41	
	13	0.4	11		13	0.4	
	10	0.2	6, 7		10	0.2	1.01
V	12	0.33	9, 10	5	12	0.33	
VI	14	0.62	12, 13		14	0.62	0.95
							5.03

(c) Balance efficiency using $T_s = 1.07$ from station 2, $E_b = 5.03/5(1.07) = 0.94 = 94\%$

4.25 Solve the previous problem but use the ranked positional weights method in part (b).

Solution: (a), (d), and (e) Same answers as in Problem 4.23

(b) Ranked positional weights method using $T_s = 1.2 - 0.1 = 1.1$ min

RPW	Element	T_e	Predecessor
3.21	1	0.4	-
2.97	4	0.6	-
2.11	2	0.5	1
1.65	3	0.2	1
1.61	5	0.25	2
1.52	7	0.37	4
1.47	8	0.15	4
1.45	6	0.3	3
1.36	9	0.41	5
1.32	11	0.3	8
1.15	10	0.2	6, 7
1.02	13	0.4	11
0.95	12	0.33	9, 10
0.62	14	0.62	12, 13

Station	Element	T_e	ΣT_e
1	1	0.4	
	4	0.6	1.0
2	2	0.5	
	3	0.2	
	5	0.25	
	8	0.15	1.1
3	7	0.37	
	6	0.3	
	9	0.41	1.08
4	11	0.3	
	10	0.2	
	13	0.4	0.9
5	12	0.33	
	14	0.62	0.95
			5.03

(c) Balance efficiency using $T_s = 1.1$, $E_b = 5.03/5(1.1) = 0.915 = 91.5\%$