ISYE 4803-REV: Advanced Manufacturing Systems

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Midterm Exam I

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Name: SOLUTIONS

Answer the following questions (**8 points each**):

1. What are the basic mechanisms that can be used by a company in its effort to increase its responsiveness to the experienced demand?

Traditionally, companies have tried to guard against unexpected fluctuations /surges to the experienced demand by maintaining safety stock and /or extra production capacity (i.e., a "material buffer" or a "capacity buffer").

But these days, the effective deployment of modern IT platforms enable the companies to improve the monitoring, communication and control capabilities of their operations so that they can enhance their responsiveness to the experienced demand without deploying (high levels of) the aforementioned buffers.

Furthermore, additional attributes like various aspects of operational flexibility, modularity and standardization, the development of richer and better (denser) integrated supply chain networks, etc., help modern companies attain high responsiveness to longer-term trends and shifts in their experienced demand for their various products.

2. What is the **main** feature of the U-shaped layout that makes it very attractive for contemporary sequential workflows?

The main feature is the high proximity that it establishes among the various workstations of the underlying production line which further implies

* better supervision
* better communication
* increased resource sharing
* etc.

3. Explain in a few words the rationale behind the Ranked Positional Weights (RPW) heuristic for the Assembly Line Balancing problem.

The RPW heuristic first tries to establish an ordered list for the various tasks supported by the line that will respect the imposed precedence constraints among these tasks. Ranking all these tasks in a decreasing order of their PWs provides this list.

With this list available, the second stage of this heuristic tries to define the necessary workstations of the line using essentially an adaptation of a heuristic for the "bin packing" problem. Each workstation is treated as a "bin" with packing capacity the cycle time c that corresponds to the target throughput of the line. Starting with the first workstation, workstations are built one at a time, by adding to them tasks from the head of the aforementioned list as long as the total proc. time of the tasks allocated to these workstations remains less than or equal to c.

4. In the assembly line balancing problem, the processing times t_i that are required for the various tasks T_i are treated as deterministic quantities. Provide some justification(s) for this approach.

This is justified as follows:

First, the simplicity of the tasks involved, together with the highly repetitive nature of these tasks in the eventual operation of the line, imply that the inherent variability in the corresponding proc. times is quite low. This is even more true for tasks that are executed in a fully automated/mechanized manner.

Furthermore, assuming a bell-shaped curve for the corresponding distributions, the t_i values that are used for each task might not be the corresponding mean, but a higher percentile that increases the probability that the task will be completed within its allocated time.

Finally, as seen in all the provided examples on the ALB problem, usually each workstation ends up with some idle time, and this idle time provides an additional "time buffer" for accommodating the variability in the proc. times of the tasks assigned to this workstation.

5. Explain the reason why an M/M/1 queueing station with $\rho = 1$ is unstable.

$\rho = 1$ implies a 100% utilization for the server of this workstation.

But an M/M/1 queueing station experiences variability in, both, its arrival process and ~~the~~ the service times, and therefore, a server utilization of 100% is not possible.

Problem 1 (30 points): An assembly process consists of six atomic tasks. The processing times for these tasks and the precedence constraints among them are reported in the following table:

Task	Proc. Time (secs)	Imm. Predecessors
a	10	-
b	25	-
c	12	a
d	13	c, b
e	30	-
f	20	d, e

i. (5 pts) What is the highest possible throughput that can be attained by any synchronous transfer line that supports the execution of these tasks? Please, provide your response in parts per hour.

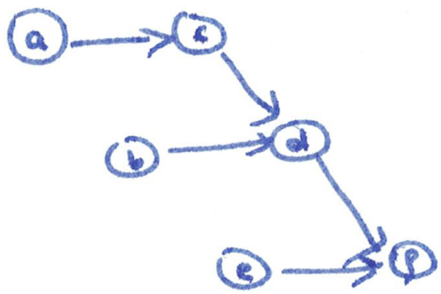
ii. (5 pts) Express the precedence constraints for the various tasks of this assembly line through a precedence graph.

iii. (15 pts) Use the Ranked Positional Weight heuristic presented in class in order to come up with an efficient design for this assembly line that will support a production rate of 100 parts per hour.

iv. (5 pts) Provide a lower bound for the number of workstations that are necessary for the line designed in part (iii) above. What is implied by this lower bound for the optimality of the design that you obtained in part (iii) above?

(i) Since tasks are indivisible and the highest proc. time is 30 secs, the smallest possible cycle time $\underline{c}$ is 30 secs. This implies a maximal throughput $\overline{TH} = 1/\underline{c} = \frac{1}{30\,sec} \times 3600\,sec/hr$ $= 120\ hr^{-1}$!

(ii)



(iii) Using the precedence graph of part (ii) and the provided proc. times for the various tasks, we get the following PWs:

Task i	Succ (i)	PW_i
a	$\{a, c, d, f\}$	55
b	$\{b, d, f\}$	58
c	$\{c, d, f\}$	45
d	$\{d, f\}$	33
e	$\{e, f\}$	50
f	$\{f\}$	20

Also,

$c = \frac{1}{TH} = \frac{1}{100}\, hr \times 3600\, s$

$= 36 sec$

The corresponding task list is: $\langle b, a, e, c, d, f \rangle$ and working as described in the response of Question 3 of this exam, we obtain the following line:

WS1	WS2	WS3	WS4
b, a	e	c, d	f
~~36~~	~~36~~	~~36~~	~~36~~
~~11~~	6	~~21~~	16
1		11	

(iv) This lower bound is

$$\left\lceil \frac{\sum_i t_i}{c} \right\rceil = \left\lceil \frac{110}{36} \right\rceil = \lceil 3.056 \rceil = 4$$

Hence, according to the above computation, the line obtained in part (iii) utilizes the minimum possible number of workstations. It is also interesting to notice that, assuming that the first three workstations were utilized 100%, the fourth workstation is needed only for, that's 6% of its available capacity; hence, we should expect significant idleness at some of the line workstations.

Finally, another line with a little better "balancing" (i.e., allocation of the experienced idleness across the line workstations) is as follows:

WS1	WS2	WS3	WS4
$\boxed{b}$	$\boxed{e}$	$\boxed{a, c}$	$\boxed{d, f}$
~~36~~	~~36~~	~~36~~	~~36~~
11	6	~~26~~	~~27~~
		14	3

Problem 2 (30 points): Consider a single-server queueing station that processes two types of jobs. Jobs from each job type arrive according to a Poisson process with corresponding rates $\lambda_1 = 5hr^{-1}$ and $\lambda_2 = 4hr^{-1}$, and they join a single queue of jobs waiting to be processed by the station servers according to a FCFS policy.

Processing times at the station server are exponentially distributed with rate $\mu = 10hr^{-1}$ for both job types.

Please, answer the following questions:

i. (5 pts) Argue that the considered queueing station is stable.

ii. (5 pts) What is the throughput of this station with respect to each job type?

iii. (5 pts) What is the utilization of the server of this station with respect to each job type?

iv. (5 pts) What is the probability that a job waiting in the queue of this station is type 1?

v. (5 pts) Argue that the considered queueing station can be modeled as an M/M/1 queue, and define the parameters of this model.

vi. (5 pts) What is the cycle time of a job that goes through this queueing station?

(i) The average workload per time unit that arrives at this workstation for each job type are as follows:

Job type 1: $\rho_1 = \lambda_1/\mu = \frac{5\,hr^{-1}}{10\,hr^{-1}} = \frac{5}{10}$

Job type 2: $\rho_2 = \lambda_2/\mu = \frac{4\,hr^{-1}}{10\,hr^{-1}} = \frac{4}{10}$

The combined workload arriving per time unit is

$$\rho = \rho_1 + \rho_2 = \frac{5}{10} + \frac{4}{10} = \frac{9}{10} < 1$$

Hence, the station is stable.

(ii) $TH_1 = \lambda_1 = 5\ hr^{-1}$

$TH_2 = \lambda_2 = 4\ hr^{-1}$

(iii) from the computation in part (i):

$u_1 = \rho_1 = \frac{5}{10} = 0.5$

$u_2 = \rho_2 = \frac{4}{10} = 0.4$

(iv) $p = \lambda_1 / \lambda_1 + \lambda_2 = \frac{5}{5+4} = \frac{5}{9}$

(v) Since the two arriving streams of jobs are Poisson, assuming that they are also independent, the total arriving stream is Poisson with rate $\lambda = \lambda_1 + \lambda_2 = 5\ hr^{-1} + 4\ hr^{-1} = 9\ hr^{-1}$.

Furthermore, since all these jobs join a common queue on a FCFS basis, and both job types have the same distribution for their proc. times (exp. with rate $\mu = 10\ hr^{-1}$) we can think of the processing of this combined stream as an M/M/1 queueing station with parameters $\lambda = 9\ hr^{-1}$ and $\mu = 10\ hr^{-1}$.

(vi) Thinking along the lines of part (v) above, and since we have already established the stability of this workstation, we have that

$$CT = \frac{t}{1-\rho} = \frac{1/10 \text{ hr}}{1 - 9/10} = 1 \text{ hr.}$$