

NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY
SORS 4105

FACULTY OF APPLIED SCIENCES

DEPARTMENT OF STATISTICS AND OPERATIONS RESEARCH

SORS 4105: CASE STUDIES IN OPERATIONS RESEARCH

DECEMBER 2024: EXAMINATION

Time : 3 hours

Candidates should attempt any **FOUR** questions from this question paper (25 marks each).

SECTION A

Answer any **FOUR** questions in this paper [25 Marks each]

A1. Never dull. That is how you would describe your job at the centralized records and benefits administration center for Cutting Edge, a large company manufacturing computers and computer peripherals. Since opening the facility six months ago, you and Mark Lawrence, the Director of Human Resources, have endured one long roller coaster ride. Receiving the go-ahead from corporate headquarters to establish the centralized records and benefits administration center was definitely an up. Getting caught in the crossfire of angry customers (all employees of Cutting Edge) because of demand overload for the records and benefits call center was definitely a down. Accurately forecasting the demand for the call center provided another up.

And today you are faced with another down. Mark approaches your desk with a not altogether attractive frown on his face.

He begins complaining immediately, "I just don't understand. The forecasting job you did for us two months ago really allowed us to understand the weekly demand for the center, but we still have not been able to get a grasp on the staffing problem. We used both historical data and your forecasts to calculate the average weekly demand for the call center. We transformed this average weekly demand into average hourly demand by dividing the weekly demand by the number of hours in the workweek. We then staffed the center to meet this average hourly demand by taking into account the

average number of calls a representative is able to handle per hour.

But something is horribly wrong. Operational data records show that over thirty percent of the customers wait over four minutes for a representative to answer the call! Customers are still sending me numerous complaints, and executives from corporate headquarters are still breathing down my neck! I need help!"

You calm Mark down and explain to him that you think you know the problem: the number of calls received in a certain hour can be much greater (or much less) than the average because of the stochastic nature of the demand. In addition, the number of calls a representative is able to handle per hour can be much less (or much greater) than the average depending upon the types of calls received.

You then tell him to have no fear, you have the problem under control. You have been reading about the successful application of queueing theory to the operation of call centers, and you decide that the queueing models you learned in school will help you determine the appropriate staffing level.

- (a) You ask Mark to describe the demand and service rate. He tells you that calls are randomly received by the call center and that the center receives an average of 70 calls per hour. The computer system installed to answer and hold the calls is so advanced that its capacity far exceeds the demand. Because the nature of a call is random, the time required to process a call is random, where the time frequently is small but occasionally can be much longer. On average, however, representatives can handle 6 calls per hour. Which queueing model seems appropriate for this situation? Given that slightly more than 35 percent of customers wait over 4 minutes before a representative answers the call, use this model to estimate how many representatives Mark currently employs. [9]
- (b) Mark tells you that he will not be satisfied unless 95 percent of the customers wait only 1 minute or less for a representative to answer the call. Given this customer service level and the average arrival rates and service rates from part (a), how many representatives should Mark employ? [8]
- (c) Each representative receives an annual salary of \$30,000, and Mark tells you that he simply does not have the resources available to hire the number of representatives required to achieve the customer service level desired in part (b). He asks you to perform sensitivity analysis. How many representatives would he need to employ to ensure that 80 percent of customers wait 1 minute or less? How many would he need to employ to ensure that 95 percent of customers wait 90 seconds or less? How would you recommend Mark choose a customer service level? Would the decision criteria be different if Mark's call center were to serve external customers (not connected to the company) instead of internal customers (employees)? [8]

A2. Reep Construction recently won a contract for the excavation and site preparation of a new rest area on the Pennsylvania Turnpike. In preparing his bid for the job, Bob Reep, founder and President of Reep Construction, estimated that it would take four months to perform the work and that 10, 12, 14, and 8 trucks would be needed in months 1 through 4, respectively. The firm currently has 20 trucks of the type needed to perform the work on the new project. These trucks were obtained last year when Bob signed a long-term lease with Penn State Leasing. Although most of these trucks are currently being used on existing jobs, Bob estimates that one truck will be available for use on the new project in month 1, two trucks will be available in month 2, three trucks will be available in month 3, and one truck will be available in month 4. Thus, to complete the project, Bob will have to lease additional trucks. The long-term leasing contract with Penn State has a monthly cost of \$600 per truck. Reep Construction pays its truck drivers \$20 an hour, and daily fuel costs are approximately \$100 per truck. All maintenance costs are paid by Penn State Leasing. For planning purposes, Bob estimates that each truck used on the new project will be operating eight hours a day, five days a week for approximately four weeks each month. Bob does not believe that current business conditions justify committing the firm to additional long-term leases. In discussing the short-term leasing possibilities with Penn State Leasing, Bob learned that he can obtain short-term leases of 1–4 months. Short-term leases differ from long-term leases in that the short-term leasing plans include the cost of both a truck and a driver. Maintenance costs for short-term leases also are paid by Penn State Leasing.

The following costs for each of the four months cover the lease of a truck and driver:

Length of Lease	Cost per Month (\$)
1	4000
2	3700
3	3225
4	3040

Bob Reep would like to acquire a lease that would minimize the cost of meeting the monthly trucking requirements for his new project, but he also takes great pride in the fact that his company has never laid off employees. Bob is committed to maintaining his no-layoff policy; that is, he will use his own drivers even if costs are higher. Perform an analysis of Reep Construction's leasing problem and prepare a report for Bob Reep that summarizes your findings. Be sure to include information on and analysis of the following items:

- (a) The optimal leasing plan. [9]
- (b) The costs associated with the optimal leasing plan. [8]
- (c) The cost for Reep Construction to maintain its current policy of no layoffs. [8]

A3. A pharmaceutical manufacturing company, entered the pharmaceutical market 12 years ago with the introduction of six new drugs. Five of the six drugs were simply permutations of existing drugs and therefore did not sell very heavily. The sixth drug, however,

addressed hypertension and was a huge success. Since the company had a patent on the hypertension drug, it experienced no competition, and profits from the hypertension drug alone kept the company in business. During the past 12 years, the company continued a moderate amount of research and development, but it never stumbled upon a drug as successful as the hypertension drug. One reason is that the company never had the motivation to invest heavily in innovative research and development. The company was depending on the profit generated by its hypertension drug and did not feel the need to commit significant resources to finding new drug breakthroughs. Now the company is beginning to fear the pressure of competition. The patent for the hypertension drug expires in 5 years, and the company knows that once the patent expires, generic drug manufacturing companies will swarm into the market like vultures. Historical trends show that generic drugs decreased sales of branded drugs by 75 percent. The company is therefore looking to invest significant amounts of money in research and development this year to begin the search for a new breakthrough drug that will offer the company the same success as the hypertension drug. The company believes that if the company begins extensive research and development now, the probability of finding a successful drug shortly after the expiration of the hypertension patent will be high. As head of research and development at the company, you are responsible for choosing potential projects and assigning project directors to lead each of the projects. After researching the needs of the market, analysing the shortcomings of current drugs, and interviewing numerous scientists concerning the promising areas of medical research, you have decided that your department will pursue five separate projects, which are listed below:

- Project Up is to develop an antidepressant that does not cause serious mood swings.
- Project Stable is to develop a drug that addresses manic-depression.
- Project Choice is to develop a less intrusive birth control method for women.
- Project Hope is to develop a vaccine to prevent HIV infection.
- Project Release is to develop a more effective drug to lower blood pressure.

For each of the five projects, you are only able to specify the medical ailment the research should address; since you do not know what compounds will exist and be effective without research. You also have five senior scientists to lead the five projects. You know that scientists are very temperamental people and will work well only if they are challenged and motivated by the project. To ensure that the senior scientists are assigned to projects they find motivating; you have established a bidding system for the projects. You have given each of the five scientists 1000 bid points. They assign bids to each project, giving a higher number of bid points to projects they most prefer to lead. Table 2 provides the bids from the five individual senior scientists for the five individual projects:

- (a) Use the Hungarian method to obtain a solution that maximise the references of the scientists. [12]
- (b) Assuming Dr. Zuner is no longer available for the project, Use any method to find the new assignment combinations that will maximise the bids. [13]

Table 1: Bids put by scientists on projects

Project	Dr Kvaal	Dr Zuner	Dr Tsai	Dr Mickey	Dr Rollins
Project Up	100	0	100	267	100
Project Stable	400	200	100	153	33
Project Choice	200	800	100	99	33
Project Hope	200	0	100	451	34
Project Release	100	0	600	30	800

A4. Sandstone and Waters Ltd. Specialise in cleaning the outside walls of old buildings in the heart of the big cities. They obtained a prestige contract for cleaning 17 buildings of historic interest in a famous London street. The basic requirements are labour and equipment. The labour force can be considered to specific number of men as, due to the nature of work, all the men employed can be used on any job involved in the cleaning process. The equipment consists of units of labour, each with a compressor and a water pump feeding a number of hand-held units. Limitations on distance of hand-held units from the compressor and pump are taken into consideration before bidding for the work. This particular contract, whilst giving the company the maximum publicity, was nevertheless a straightforward series of cleaning jobs that warranted no special approach except to complete them on time and to make profit. There were, however a series of constraints laid down by the organization letting out the work. These were: (1) The whole project was to be completed in 26 weeks, (2) Due to localized priorities, police traffic details, insurance and a variety of other factors the contractors were to be controlled by priorities as follows:

- (a) Building numbers 1 and 3 must be cleaned at the same time, but building number 4 cannot be started until building 1 and 3 are both completed.
- (b) Number 7, 9, 11, 13 and 15 must be cleaned in that order.
- (c) Numbers 4, 6 and 8 must be cleaned in that order.
- (d) Number 14 must be cleaned after number 16 has been finished and before number 7 is started.
- (e) Number 12 must follow number 10 and number 13 must follow number 11, but the two pairs must be cleaned during the same period.
- (f) The whole contract must start with number 2 and then numbers 3, 16 and 17 will follow all starting on completion of number 2. Number 1 can be started as soon as 17 is completed.
- (g) Number 5 cannot be started before number 3 is completed and number 7 cannot be started until number 5 is finished.
- (h) Number 8 must be completed before number 11 can be started.

In view of the limitations imposed by the availability of labour and equipment within the company, the contract manager drew up a plant and labour schedule in Table 2 as follows: Overheads costs on the whole contract are \$330 per week, labour costs are \$120 per week and plant costs are \$200 per week.

Table 2: Scheduling plan for Sandstone and Waters

Building No.	No. of Men	No. of plant units	Time (weeks)
1	3	2	4
2	4	4	6
3	3	1	2
4	2	2	2
5	5	4	7
6	3	4	6
7	2	2	1
8	3	2	2
9	3	3	1
10	4	1	3
11	2	3	2
12	3	3	4
13	2	1	1
14	4	3	4
15	3	2	2
16	2	2	1

(a) Draw the network diagram for the above problem. [12]

(b) Calculate the critical paths and the minimum total cost that can be used to complete the project. [13]

A5. Alabama Atlantic is a lumber company that has three sources of wood and five markets to be supplied. The annual availability of wood at sources 1, 2, and 3 is 15, 20, and 15 million board feet, respectively. The amount that can be sold annually at markets 1, 2, 3, 4, and 5 is 11, 12, 9, 10, and 8 million board feet, respectively.

In the past the company has shipped the wood by train. However, because shipping costs have been increasing, the alternative of using ships to make some of the deliveries is being investigated. This alternative would require the company to invest in some ships. Except for these investment costs, the shipping costs in thousands of dollars per million board feet by rail and by water (when feasible) would be the following for each route:

Considering the expected useful life of the ships and the time value of money, the equivalent uniform annual cost of these investments is one-tenth the amount given in the table. The objective is to determine the overall shipping plan that minimizes the total equivalent uniform annual cost (including shipping costs).

You are the head of the OR team that has been assigned the task of determining this shipping plan for each of the following three options.

Table 3: Cost of transportation by rail and by ship

Source	Unit Cost by Rail (\$1 000's) Market					Unit Cost by Ship (\$1 000's) Market				
	1	2	3	4	5	1	2	3	4	5
1	61	72	45	55	66	31	38	24	-	35
2	69	78	60	49	56	36	43	28	24	31
3	59	66	63	61	47	-	33	36	32	26

Table 4: Capital investment for ships

Source	Investment for Ships (\$1,000's) 242021 Market				
	1	2	3	4	5
1	275	303	238	-	285
2	293	318	270	250	265
3	-	283	275	268	240

Option 1: Continue shipping exclusively by rail.

Option 2: Switch to shipping exclusively by water (except where only rail is feasible).

Option 3: Ship by either rail or water, depending on which is less expensive for the particular route.

- (a) Present your results for each option. Compare. [12]
- (b) Finally, consider the fact that these results are based on current shipping and investment costs, so that the decision on the option to adopt now should take into account management's projection of how these costs are likely to change in the future. For each option, describe a scenario of future cost changes that would justify adopting that option now. [13]

A6. California Children's Hospital has been receiving numerous customer complaints because of its confusing, decentralized appointment and registration process. When customers want to make appointments or register child patients, they must contact the clinic or department they plan to visit. Several problems exist with this current strategy. Parents do not always know the most appropriate clinic or department they must visit to address their children's ailments. They therefore spend a significant amount of time on the phone being transferred from clinic to clinic until they reach the most appropriate clinic for their needs. The hospital also does not publish the phone numbers of all clinic and departments, and parents must therefore invest a large amount of time in detective work to track down the correct phone number. Finally, the various clinics and departments do not communicate with each other. For example, when a doctor schedules a referral with a colleague located in another department or clinic, that department or clinic almost never receives word of the referral. The parent must contact the correct department or clinic and provide the needed referral information.

In efforts to reengineer and improve its appointment and registration process, the children's hospital has decided to centralize the process by establishing one call center devoted exclusively to appointments and registration. The hospital is currently in the middle of the planning stages for the call center. Lenny Davis, the hospital manager, plans to operate the call center from 7 A.M. to 9 P.M. during the weekdays.

Several months ago, the hospital hired an ambitious management consulting firm, Creative Chaos Consultants, to forecast the number of calls the call center would receive each hour of the day. Since all appointment and registration-related calls would be received by the call center, the consultants decided that they could forecast the calls at the call center by totaling the number of appointment and registration-related calls received by all clinics and departments. The team members visited all the clinics and departments, where they diligently recorded every call relating to appointments and registration. They then totaled these calls and altered the totals to account for calls missed during data collection. They also altered totals to account for repeat calls that occurred when the same parent called the hospital many times because of the confusion surrounding the decentralized process. Creative Chaos Consultants determined the average number of calls the call center should expect during each hour of a weekday. The following table provides the forecasts.

Table 5: Average number of calls per hour

Workshift	Average Number of Calls
7 A.M.–9 A.M.	40 calls per hour
9 A.M.–11 A.M.	85 calls per hour
11 A.M.–1 P.M.	70 calls per hour
1 P.M.–3 P.M.	95 calls per hour
3 P.M.–5 P.M.	80 calls per hour
5 P.M.–7 P.M.	35 calls per hour
7 P.M.–9 P.M.	10 calls per hour

After the consultants submitted these forecasts, Lenny became interested in the percentage of calls from Spanish speakers since the hospital services many Spanish patients. Lenny knows that he has to hire some operators who speak Spanish to handle these calls. The consultants performed further data collection and determined that on average, 20 percent of the calls were from Spanish speakers.

Given these call forecasts, Lenny must now decide how to staff the call center during each 2 hour shift of a weekday. During the forecasting project, Creative Chaos Consultants closely observed the operators working at the individual clinics and departments and determined the number of calls operators process per hour. The consultants informed Lenny that an operator is able to process an average of six calls per hour. Lenny also knows that he has both full-time and part-time workers available to staff the call center. A full-time employee works 8 hours per day, but because of paperwork that must also be completed, the employee spends only 4 hours per day on the phone. To balance the schedule, the employee alternates the 2-hour shifts between

answering phones and completing paperwork. Full-time employees can start their day either by answering phones or by completing paperwork on the first shift. The full-time employees speak either Spanish or English, but none of them are bilingual. Both Spanish-speaking and English-speaking employees are paid \$10 per hour for work before 5 P.M. and \$12 per hour for work after 5 P.M. The full-time employees can begin work at the beginning of the 7 A.M. to 9 A.M. shift, 9 A.M. to 11 A.M. shift, 11 A.M. to 1 P.M. shift, or 1 P.M. to 3 P.M. shift. The part-time employees work for 4 hours, only answer calls, and only speak English. They can start work at the beginning of the 3 P.M. to 5 P.M. shift or the 5 P.M. to 7 P.M. shift, and like the full-time employees, they are paid \$10 per hour for work before 5 P.M. and \$12 per hour for work after 5 P.M.

For the following analysis consider only the labor cost for the time employees spend answering phones. The cost for paperwork time is charged to other cost centers.

- (a) How many Spanish-speaking operators and how many English-speaking operators does the hospital need to staff the call center during each 2-hour shift of the day in order to answer all calls? Please provide an integer number since half a human operator makes no sense. [9]
- (b) Lenny needs to determine how many full-time employees who speak Spanish, full-time employees who speak English, and part-time employees he should hire to begin on each shift. Creative Chaos Consultants advise him that linear programming can be used to do this in such a way as to minimize operating costs while answering all calls. Formulate a linear programming model of this problem. [10]
- (c) Obtain an optimal solution for the linear programming model formulated in part (b) to guide Lenny's decision. [6]

END OF QUESTION PAPER