Faculty of Computing and Informatics (FCI)
Multimedia University
Cyberjaya

CMA6134 – Computational Methods

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Coding Assignment

Car Wash Queue Simulator

Lecture Section

TC4L / TC5L

Submitted to:

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INTRODUCTION

This study shows a FreeMat-developed queue simulation model. FreeMat is a dependable and fast tool for creating queue simulation models due to its extensive mathematics and simulation capabilities. Two random number generator algorithms are used by the queue simulator which are default rand, and Linear Congruential Generator (LCG).

To begin the simulation, user must locate the directory in FreeMat to the folder where all the related files located. In command line processor, user need to type 'carwash()' as the main function which will initiate the simulation.

During simulation process, user will be asked to insert 2 values, which are type of rng and number of cars, after user insert all the values, all the probability and random number will be automated by generator.

At the end of the simulation, the system will show all the related table and informations such as tables, event logs, simulation evaluation, and etc.

These are the two types of Random Number Generator used: -

1) Default Rand:
- Using predefined function such as rand() to generate the value between 0 to 1.

2) Linear Congruential Generator (LCG):
- Linear Congruential Generator (LCG) implemented in the given code snippet generates pseudo-random numbers when 'rng_type' is set to 1. Using predefined function such as rand() to generate the value between 0 to 1. the number then will be multiplied with modulus to scales up the number, creating a large random number to be used as seed.

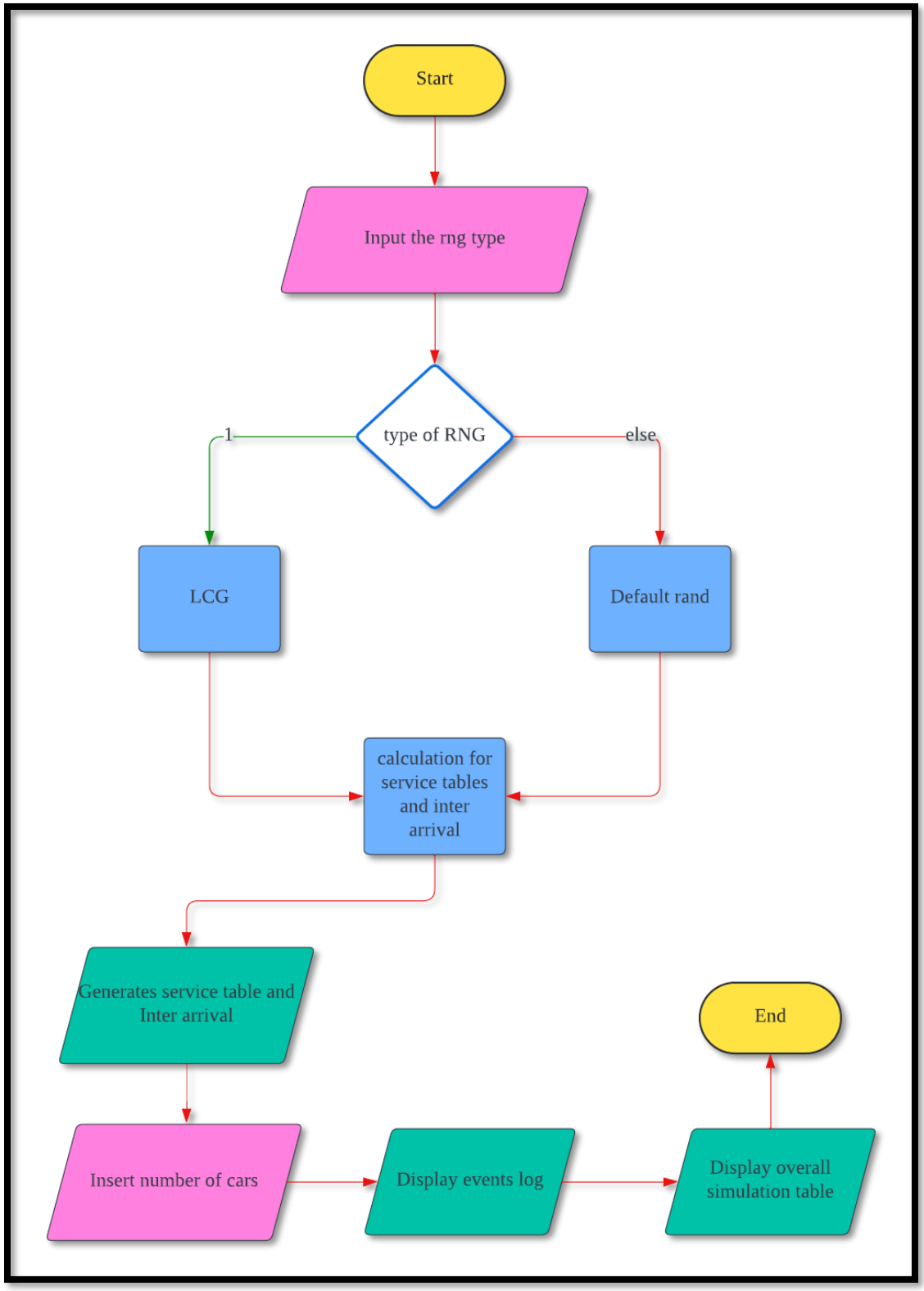
- The LCG formula used is:

$$X_n = (aX_{n-1} + c)(mod\, m)$$

where the constants:

a = 23 (multiplier)
c = 1 (increment)
m = 100 (modulus)

FLOWCHARTS


Start
Input the rng type
type of RNG
1
else
LCG
Default rand
calculation for service tables and inter arrival
Generates service table and Inter arrival
Insert number of cars
Display events log
Display overall simulation table
End

IMPLEMENTATION

Core Files:

- carwash.m

```
function carwash()

    rng_type = input('Choose RNG type (1 for LCG, 2 for default rand): '); %asks user for rng_type
    fprintf('\n');

    %===== Prepare Service Table #1 (contain pdf, cdf, range of RN)
    service_times1 = [1, 3, 5, 7]; %set service times of wash bay 1 as 1, 3, 5 and 7

    pdf_S1(1:4) = 0.25; %assign all pdf =0.25
    cdf_S1(1)=pdf_S1(1);
    range_S1(1) = cdf_S1(1)*100;
    for i=2:4
        cdf_S1(i) = cdf_S1(i-1) + pdf_S1(i);
        range_S1(i) = cdf_S1(i)*100;
    end

    %===== Prepare Service Table #2 (contain pdf, cdf, range of RN)
    service_times2 = [2, 4, 6, 8]; %set service times of wash bay 2 as 2, 4, 6 and 8

    pdf_S2(1:4) = 0.25; %assign all pdf =0.25
    cdf_S2(1)=pdf_S2(1);
    range_S2(1) = cdf_S2(1)*100;
    for i=2:4
        cdf_S2(i) = cdf_S2(i-1) + pdf_S2(i);
        range_S2(i) = cdf_S2(i)*100;
    end

    %===== Prepare Service Table #3 (contain pdf, cdf, range of RN)
    service_times3 = [5, 10, 15, 20]; %set service times of wash bay 3 as 5, 10, 15 and 20

    pdf_S3(1:4) = 0.25; %assign all pdf =0.25
    cdf_S3(1)=pdf_S3(1);
    range_S3(1) = cdf_S3(1)*100;
    for i=2:4
        cdf_S3(i) = cdf_S3(i-1) + pdf_S3(i);
        range_S3(i) = cdf_S3(i)*100;
    end

    %===== Prepare Inter-arrival Table (contain pdf, cdf, range of RN)
    pdf_inter_arr(1:5) = 0.2; %assign all prob dist equal = 0.2
    pdf_inter_arr(2) = 0.4;
    pdf_inter_arr(3) = 0.1;
    pdf_inter_arr(4) = 0.1;
    cdf_inter_arr(1) = pdf_inter_arr(1);
    range_inter_arr(1) = cdf_inter_arr(1)*100;
    for i=2:5
        cdf_inter_arr(i)=cdf_inter_arr(i-1) + pdf_inter_arr(i);
        range_inter_arr(i) = cdf_inter_arr(i)*100;
    end

```

```
%===== Prepare Service Types Table (contain pdf, cdf, range of RN)
pdf_service_types = [0.4, 0.3, 0.3]; %assign probability(pdf) for service types

cdf_service_types = cumsum(pdf_service_types);
cdf_service_types = cdf_service_types / max(cdf_service_types); %normalize CDF to range [0

range_service_types = cdf_service_types * 100;

%-- PRINT Service Time Table 1
fprintf('Table: Service Time for Wash Bay 1\n');
print_serviceTimeTable(service_times1, pdf_S1,cdf_S1, range_S1);

%-- PRINT Service Time Table 2
fprintf('Table: Service Time for Wash Bay 2\n');
print_serviceTimeTable(service_times2, pdf_S2,cdf_S2, range_S2);

%-- PRINT Service Time Table 3
fprintf('Table: Service Time for Wash Bay 3\n');
print_serviceTimeTable(service_times3, pdf_S3,cdf_S3, range_S3);

%-- PRINT Inter Arrival Table
print_interArrTable(pdf_inter_arr,cdf_inter_arr, range_inter_arr);

%-- PRINT Service Type Table
print_serviceTypeTable(pdf_service_types, cdf_service_types, range_service_types)


num_cars = input('Enter the number of cars: '); %asks user for num_cars
fprintf('\n');

%===== RN for Inter Arrival Customers =====
inter_arr_RN = generate_RN(rng_type, num_cars-1);

%===== RN for Service Time Customers =====
serviceTime_RN = generate_RN(rng_type, num_cars);

%===== RN for Service Type Customers =====
serviceType_RN = generate_RN(rng_type, num_cars);

fprintf('Random Numbers for Inter-Arrival Time: ');
disp(inter_arr_RN);

fprintf('Random Numbers for Service Time : ');
disp(serviceTime_RN);

fprintf('Random Numbers for Service Types : ');
disp(serviceType_RN);

%===== Queue rule: how assign ncustomers to k_stations') =====
queue(rng_type, range_inter_arr, inter_arr_RN, num_cars, serviceTime_RN, serviceType_RN)
```

The `carwash.m` simulates the operation of a car wash with three wash bays by generating random numbers for car arrival and service times using either a Linear Congruential Generator (LCG) or the default random number generator. It will process and output tables for service times and inter-arrival times based on predefined probability distributions. The user inputs the number of cars to be simulated, and the function generates and displays random numbers for inter-arrival and service times. Finally, it calls `queue.m` function to manage the assignment of cars to wash bays based on the generated random numbers.

- queue.m:

```
function queue(rng_type, range_inter_arr, inter_arr_RN, num_cars, serviceTime_RN, serviceType_RN)

    %initialize variables
    arrival_times = zeros(num_cars, 1);
    service_types = zeros(num_cars, 1);
    inter_arrival_times = zeros(num_cars, 1);
    service_times = zeros(num_cars, 3);

    %assign inter-arrival times
    inter_arrival_times = generate_inter_arrival_times(range_inter_arr, inter_arr_RN, num_cars);

    %generate random numbers for service types
    for i = 1:num_cars
        rn = serviceType_RN(i);
        service_types(i) = generate_service_type(rn);
    end

    %calculate arrival times
    arrival_times(1) = inter_arrival_times(1);

    for i = 2:num_cars
        arrival_times(i) = arrival_times(i-1) + inter_arrival_times(i);
    end

    %initialize variables
    wash_bay = zeros(3, 1);  %tracks end time for each wash bay
    start_times = zeros(num_cars, 3);
    end_times = zeros(num_cars, 3);

    %simulate the car wash process
    for i = 1:num_cars
        [temp, bay] = min(wash_bay);

        rn = serviceTime_RN(i);
        service_time = generate_service_time(rn, bay);
        start_time = max(arrival_times(i), wash_bay(bay));
        end_time = start_time + service_time;
        wash_bay(bay) = end_time;

        %print events
        fprintf('Arrival of car %d at minute %d\n', i, arrival_times(i));

        if start_time > arrival_times(i)
            fprintf('Car %d waiting in queue\n', i);
        end

        fprintf('Service for car %d started at minute %d at wash bay %d\n', i, start_time, bay);
        fprintf('Car %d departed at minute %d from wash bay %d\n', i, end_time, bay);
        fprintf('\n')

        %store the simulation data
        service_times(i, bay) = service_time;
        start_times(i, bay) = start_time;
        end_times(i, bay) = end_time;
    end

    %generate the overall simulation table
    print_simulationTable(inter_arr_RN, num_cars, inter_arrival_times, arrival_times, service_types)

    %generate the wash bay specific tables
    print_washbayTable(service_RN, num_cars, start_times, end_times, arrival_times, wash_bay, service_times)

    %evaluate the results of the simulation
    evaluate_results(num_cars, start_times, end_times, arrival_times, wash_bay, service_times, inter_arrival_times)
end
```

The `queue.m` function simulates the management and assignment of cars to wash bays in a car wash system. It initializes variables for tracking arrival times, service types, inter-arrival times, and service times. It generates random numbers to determine these times and service types using either a Linear Congruential Generator (LCG) or the default `rand` function based on user choice in carwash.m. The function calculates arrival times, assigns cars to the first available wash bay, and prints relevant events such as arrivals, queue waiting, service start, and departure times. It generates overall and bay-specific simulation tables and evaluates the simulation results, assessing metrics like wait times and bay utilization.

Data Generation Files:

- generate_RN.m

```
function rn = generate_RN(rng_type, num_cars)

    %LCG parameters
    modulus = 100;
    multiplier = 23;
    increment = 1;
    seed = rand() * modulus;  %initial seed using default rand()

    if rng_type == 1
        rn = zeros(1, num_cars);

        for i = 1:num_cars
            seed = mod(multiplier * seed + increment, modulus);   %LCG formula
            rn(i) = floor(1 + (modulus - 1) * (seed / modulus));
        end

    else
        rn = floor(1 + (100 - 1) * rand(1, num_cars));
    end

end

```

This file will take the number of cars and rng type to generate random number ’rn’ based on user selection. If the number of rng type is one then it will proceed with generating random number using LCG method, otherwise default rand() will be used instead. Once random number 'rn' is generated, all the other generation files will use these ’rn’ obtain the rest of the values.

- generate_inter_arrival_times.m

```
function inter_arrival_times = generate_inter_arrival_times(range_inter_arr, inter_arr_RN, num_cars)
    nIntArr = length(range_inter_arr);
    inter_arrival_times = zeros(num_cars, 1);
    inter_arrival_times(1) = 0;  % For the 1st customer, there is no inter-arrival time

    for i = 1:num_cars-1
        if inter_arr_RN(i) <= range_inter_arr(1)
            inter_arrival_times(i+1) = 1;  % When t=1
        else
            for j = 2:nIntArr
                if inter_arr_RN(i) > range_inter_arr(j-1) && inter_arr_RN(i) <= range_inter_arr(j)
                    inter_arrival_times(i+1) = j;
                    break;
                end
            end
        end
    end
end

```

This file will generate inter arrival times for each cars using random number obtained. For the 1st car, there will be no inter arrival time.

- generate_service_type.m

```
function type = generate_service_type(rn)
    if rn < 40
        type = 1;
    elseif rn < 70
        type = 2;
    else
        type = 3;
    end
end
```

This file will generate 3 different service types based on random number ‘rn’ obtained.

- generate_service_time.m

```
function time = generate_service_time(rn, bay)
    switch bay
        case 1
            if rn < 25
                time = 1;
            elseif rn < 50
                time = 3;
            elseif rn < 75
                time = 5;
            else
                time = 7;
            end
        case 2
            if rn < 25
                time = 2;
            elseif rn < 50
                time = 4;
            elseif rn < 75
                time = 6;
            else
                time = 8;
            end
        case 3
            if rn < 25
                time = 5;
            elseif rn < 50
                time = 10;
            elseif rn < 75
                time = 15;
            else
                time = 20;
            end
    end
end
```

Same as the other generation files, this file will utilise random number ‘rn’ to generate the service time for each cars. By utilising the switch case for different number of wash bay, different 3 times for each bay can be generated.

Result Presentation Files:

These files will print out all the tables such as service time, inter arrival, service types, washbay, simulation and results evaluation based on Data Generation files.

- print_serviceTimeTable.m

```
function print_serviceTimeTable(service_times, prob, cdf, range)

    n=size(prob,2);

    fprintf('-------------------------------------------------------------------\n');
    fprintf('|  Service Time |    Probability    |    CDF    |      Range       |\n');
    fprintf('-------------------------------------------------------------------\n');

    for t=(1:n)
        if t==1
            fprintf('|     %-2d        |       %.3f      |    %.3f   |      1-%d    \n',service_times(t), prob(t), cdf(t), range(t));
        else
            fprintf('|     %-2d        |       %.3f      |    %.3f   |      %d-%d     \n',service_times(t), prob(t), cdf(t), range(t-1)+1, range(t));
        end
    end
    fprintf('-------------------------------------------------------------------\n\n');
```

- print_interArrTable.m

```
function print_interArrTable(prob , cdf, range)

    n=size(prob,2);

    fprintf('Table: Inter-Arrival Time\n');
    fprintf('-----------------------------------------------------------------------------------\n');
    fprintf('|     Inter-arrival Time     |  Probability,pdf |    CDF    |      Range       |\n');
    fprintf('-----------------------------------------------------------------------------------\n');

    for t=1:n
        if t==1
            fprintf('|             %-2d             |       %.3f      |    %.3f   |      1-%d     \n',t, prob(t), cdf(t), range(t));
        else
            fprintf('|             %-2d             |       %.3f      |    %.3f   |      %d-%d    \n',t, prob(t), cdf(t), range(t-1)+1, range(t));
        end
    end
    fprintf('-----------------------------------------------------------------------------------\n\n');
```

- print_serviceTypeTable

```
function print_serviceTypeTable(prob, cdf, range)

    n=size(prob,2);

    fprintf('-------------------------------------------------------------------\n');
    fprintf('|  Car Wash Service |    Probability    |    CDF    |      Range       |\n');
    fprintf('-------------------------------------------------------------------\n');

    for t = 1:length(prob)
        if t==1
            fprintf('|     Type %d        |       %.3f      |    %.3f   |      1-%d    \n',t, prob(t), cdf(t), range(t));
        else
            fprintf('|     Type %d        |       %.3f      |    %.3f   |      %d-%d     \n',t, prob(t), cdf(t), range(t-1)+1, range(t));
        end
    end
    fprintf('-------------------------------------------------------------------\n\n');
```

- print_simulationTable.m

```m
function print_simulationTable(inter_arr_RN, num_cars, inter_arrival_times, arrival_times, service_types)

    fprintf('\nOverall Simulation Table:\n');
    fprintf('-------------------------------------------------------------------------------\n');
    fprintf('| Car | RN for Inter-arrival time | Inter-arrival time | Arrival time | Service type |\n');
    fprintf('-------------------------------------------------------------------------------\n');
    fprintf('| 1   |            -              |          %-7d   |      %-6d  |      %d \n', inter_arrival_times(1), arrival_times(1), service_types(1));

    for i = 2:num_cars
        fprintf('| %-2d  |           %-14d |          %-7d   |      %-6d  |      %-12d \n', i, inter_arr_RN(i-1), inter_arrival_times(i), arrival_times(i), service_types(i));
    end

    fprintf('-------------------------------------------------------------------------------\n');
```

- print_washbayTable.m

```m
function print_washbayTable(serviceTime_RN, num_cars, start_times, end_times, arrival_times, wash_bay, service_times)

    for bay = 1:3
        time_begin = 0;
        time_end = 0;

        fprintf('\nWash bay %d:\n', bay);
        fprintf('-------------------------------------------------------------------------------------------------------------------------\n');
        fprintf('| Car | RN for service time | Service time | Time service begins | Time service ends | Waiting time | Time spent in system |\n');
        fprintf('-------------------------------------------------------------------------------------------------------------------------\n');
        for i = 1:num_cars
            if service_times(i, bay) > 0
                waiting_time = end_times(i, bay) - arrival_times(i);
                time_spent = start_times(i, bay) - arrival_times(i);
                rn = serviceTime_RN(i);
                time_end = time_begin + service_times(i, bay);

                fprintf('|  %-2d |        %-6d       |       %-5d  |         %-6d      |       %-6d      |      %-4d    |           %-6d     \n', i, rn, service_times(i, bay),
                                                                                                                                    time_begin, time_end, waiting_time, time_spent);

                time_begin = time_begin + end_times(i, bay)+ 1;
            end
        end
        fprintf('-------------------------------------------------------------------------------------------------------------------------\n');
    end
```

- evaluate_results.m

```m
function evaluate_results(num_cars, start_times, end_times, arrival_times, wash_bay, service_times, inter_arrival_times)

    %initialize arrays to store results
    waiting_times = zeros(num_cars, 1);
    time_spent_in_system = zeros(num_cars, 1);
    avg_service_time = zeros(1, 3);

    for i = 1:num_cars
        bay = find(service_times(i, :) > 0, 1);
        waiting_times(i) = end_times(i, bay) - arrival_times(i);
        time_spent_in_system(i) = start_times(i, bay) - arrival_times(i);
    end

    %calculate average service time per wash bay
    for bay = 1:3
        service_times_bay = service_times(:, bay);
        avg_service_time(bay) = mean(service_times_bay(service_times_bay > 0));
    end

    %calculate other evaluation results
    avg_waiting_time = mean(waiting_times);
    avg_inter_arrival_time = mean(inter_arrival_times);
    avg_arrival_time = mean(arrival_times);
    avg_time_spent = mean(time_spent_in_system);
    prob_wait_in_queue = sum(time_spent_in_system > 0) / num_cars;

    %print evaluation results
    fprintf('\nEvaluation of Simulation Results:\n');
    fprintf('Average waiting time: %.2f minutes\n', avg_waiting_time);
    fprintf('Average inter-arrival time: %.2f minutes\n', avg_inter_arrival_time);
    fprintf('Average arrival time: %.2f minutes\n', avg_arrival_time);
    fprintf('Average time spent in system: %.2f minutes\n', avg_time_spent);
    fprintf('Probability of waiting in queue: %.2f\n', prob_wait_in_queue);
    fprintf('Average service time per wash bay:\n');

    for bay = 1:3
        fprintf('  Wash bay %d: %.2f minutes\n', bay, avg_service_time(bay));
    end

end
```

The ‘evaluate_results.m’ file will evaluate the simulation results. It will calculate the average times, waiting times and total time spent in the system. It will also print out all the data calculated.

OUTPUT

1) Output using LCG

```
--> carwash()
Choose RNG type (1 for LCG, 2 for default rand): 1

Table: Service Time for Wash Bay 1
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      1        |       0.250       |    0.250  |      1-25        |
|      3        |       0.250       |    0.500  |      26-50       |
|      5        |       0.250       |    0.750  |      51-75       |
|      7        |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Service Time for Wash Bay 2
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      2        |       0.250       |    0.250  |      1-25        |
|      4        |       0.250       |    0.500  |      26-50       |
|      6        |       0.250       |    0.750  |      51-75       |
|      8        |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Service Time for Wash Bay 3
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      5        |       0.250       |    0.250  |      1-25        |
|      10       |       0.250       |    0.500  |      26-50       |
|      15       |       0.250       |    0.750  |      51-75       |
|      20       |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Inter-Arrival Time
-----------------------------------------------------------------------------------
|     Inter-arrival Time     |  Probability,pdf |    CDF    |      Range       |
-----------------------------------------------------------------------------------
|             1              |       0.200      |    0.200  |      1-20        |
|             2              |       0.400      |    0.600  |      21-60       |
|             3              |       0.100      |    0.700  |      61-70       |
|             4              |       0.100      |    0.800  |      71-80       |
|             5              |       0.200      |    1.000  |      81-100      |
-----------------------------------------------------------------------------------


-------------------------------------------------------------------
|  Car Wash Service |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|     Type 1        |       0.400       |    0.400  |      1-40        |
|     Type 2        |       0.300       |    0.700  |      41-70       |
|     Type 3        |       0.300       |    1.000  |      71-100      |
-------------------------------------------------------------------
```

```
Enter the number of cars: 10

Random Numbers for Inter-Arrival Time:  25 81 67 52  5 96 12 66 22

Random Numbers for Service Time :   2 25 66 25 61 15 38 62 25 59

Random Numbers for Service Types :  87 10 22  2 46 50 48 93 59 53

Arrival of car 1 at minute 0
Service for car 1 started at minute 0 at wash bay 1
Car 1 departed at minute 1 from wash bay 1

Arrival of car 2 at minute 2
Service for car 2 started at minute 2 at wash bay 2
Car 2 departed at minute 6 from wash bay 2

Arrival of car 3 at minute 7
Service for car 3 started at minute 7 at wash bay 3
Car 3 departed at minute 22 from wash bay 3

Arrival of car 4 at minute 10
Service for car 4 started at minute 10 at wash bay 1
Car 4 departed at minute 13 from wash bay 1

Arrival of car 5 at minute 12
Service for car 5 started at minute 12 at wash bay 2
Car 5 departed at minute 18 from wash bay 2

Arrival of car 6 at minute 13
Service for car 6 started at minute 13 at wash bay 1
Car 6 departed at minute 14 from wash bay 1

Arrival of car 7 at minute 18
Service for car 7 started at minute 18 at wash bay 1
Car 7 departed at minute 21 from wash bay 1

Arrival of car 8 at minute 19
Service for car 8 started at minute 19 at wash bay 2
Car 8 departed at minute 25 from wash bay 2

Arrival of car 9 at minute 22
Service for car 9 started at minute 22 at wash bay 1
Car 9 departed at minute 25 from wash bay 1

Arrival of car 10 at minute 24
Service for car 10 started at minute 24 at wash bay 3
Car 10 departed at minute 39 from wash bay 3
```

Overall Simulation Table:

Car	RN for Inter-arrival time	Inter-arrival time	Arrival time	Service type
1	-	0	0	3
2	25	2	2	1
3	81	5	7	1
4	67	3	10	1
5	52	2	12	2
6	5	1	13	2
7	96	5	18	2
8	12	1	19	3
9	66	3	22	2
10	22	2	24	2

Wash bay 1:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
1	2	1	0	1	1	0
4	25	3	2	5	3	0
6	15	1	16	17	1	0
7	38	3	31	34	3	0
9	25	3	53	56	3	0

Wash bay 2:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
2	25	4	0	4	4	0
5	61	6	7	13	6	0
8	62	6	26	32	6	0

Wash bay 3:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
3	66	15	0	15	15	0
10	59	15	23	38	15	0

Evaluation of Simulation Results:
Average waiting time: 5.70 minutes
Average inter-arrival time: 2.40 minutes
Average arrival time: 12.70 minutes
Average time spent in system: 0.00 minutes
Probability of waiting in queue: 0.00
Average service time per wash bay:
  Wash bay 1: 2.20 minutes
  Wash bay 2: 5.33 minutes
  Wash bay 3: 15.00 minutes

2) Output using default rand()

```
--> carwash()
Choose RNG type (1 for LCG, 2 for default rand): 2

Table: Service Time for Wash Bay 1
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      1        |       0.250       |    0.250  |      1-25        |
|      3        |       0.250       |    0.500  |      26-50       |
|      5        |       0.250       |    0.750  |      51-75       |
|      7        |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Service Time for Wash Bay 2
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      2        |       0.250       |    0.250  |      1-25        |
|      4        |       0.250       |    0.500  |      26-50       |
|      6        |       0.250       |    0.750  |      51-75       |
|      8        |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Service Time for Wash Bay 3
-------------------------------------------------------------------
|  Service Time |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      5        |       0.250       |    0.250  |      1-25        |
|      10       |       0.250       |    0.500  |      26-50       |
|      15       |       0.250       |    0.750  |      51-75       |
|      20       |       0.250       |    1.000  |      76-100      |
-------------------------------------------------------------------

Table: Inter-Arrival Time
-------------------------------------------------------------------------------
|     Inter-arrival Time     |  Probability,pdf |    CDF    |      Range       |
-------------------------------------------------------------------------------
|             1              |       0.200      |    0.200  |      1-20        |
|             2              |       0.400      |    0.600  |      21-60       |
|             3              |       0.100      |    0.700  |      61-70       |
|             4              |       0.100      |    0.800  |      71-80       |
|             5              |       0.200      |    1.000  |      81-100      |
-------------------------------------------------------------------------------

-------------------------------------------------------------------
|  Car Wash Service |    Probability    |    CDF    |      Range       |
-------------------------------------------------------------------
|      Type 1       |       0.400       |    0.400  |      1-40        |
|      Type 2       |       0.300       |    0.700  |      41-70       |
|      Type 3       |       0.300       |    1.000  |      71-100      |
-------------------------------------------------------------------
```

```
Enter the number of cars: 10

Random Numbers for Inter-Arrival Time:  18 39 95 74 23 77 16 65 27

Random Numbers for Service Time :  72 25 74 38 76 98  5  4 94 49

Random Numbers for Service Types :  44 91 65 33 52 13 99 54  9 46

Arrival of car 1 at minute 0
Service for car 1 started at minute 0 at wash bay 1
Car 1 departed at minute 5 from wash bay 1

Arrival of car 2 at minute 1
Service for car 2 started at minute 1 at wash bay 2
Car 2 departed at minute 5 from wash bay 2

Arrival of car 3 at minute 3
Service for car 3 started at minute 3 at wash bay 3
Car 3 departed at minute 18 from wash bay 3

Arrival of car 4 at minute 8
Service for car 4 started at minute 8 at wash bay 1
Car 4 departed at minute 11 from wash bay 1

Arrival of car 5 at minute 12
Service for car 5 started at minute 12 at wash bay 2
Car 5 departed at minute 20 from wash bay 2

Arrival of car 6 at minute 14
Service for car 6 started at minute 14 at wash bay 1
Car 6 departed at minute 21 from wash bay 1

Arrival of car 7 at minute 18
Service for car 7 started at minute 18 at wash bay 3
Car 7 departed at minute 23 from wash bay 3

Arrival of car 8 at minute 19
Car 8 waiting in queue
Service for car 8 started at minute 20 at wash bay 2
Car 8 departed at minute 22 from wash bay 2

Arrival of car 9 at minute 22
Service for car 9 started at minute 22 at wash bay 1
Car 9 departed at minute 29 from wash bay 1

Arrival of car 10 at minute 24
Service for car 10 started at minute 24 at wash bay 2
Car 10 departed at minute 28 from wash bay 2
```

Overall Simulation Table:

Car	RN for Inter-arrival time	Inter-arrival time	Arrival time	Service type
1	-	0	0	2
2	18	1	1	3
3	39	2	3	2
4	95	5	8	1
5	74	4	12	2
6	23	2	14	1
7	77	4	18	3
8	16	1	19	2
9	65	3	22	1
10	27	2	24	2

Wash bay 1:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
1	72	5	0	5	5	0
4	38	3	6	9	3	0
6	98	7	18	25	7	0
9	94	7	40	47	7	0

Wash bay 2:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
2	25	4	0	4	4	0
5	76	8	6	14	8	0
8	4	2	27	29	3	1
10	49	4	50	54	4	0

Wash bay 3:

Car	RN for service time	Service time	Time service begins	Time service ends	Waiting time	Time spent in system
3	74	15	0	15	15	0
7	5	5	19	24	5	0

Evaluation of Simulation Results:
Average waiting time: 6.10 minutes
Average inter-arrival time: 2.40 minutes
Average arrival time: 12.10 minutes
Average time spent in system: 0.10 minutes
Probability of waiting in queue: 0.10
Average service time per wash bay:
  Wash bay 1: 5.50 minutes
  Wash bay 2: 4.50 minutes
  Wash bay 3: 10.00 minutes