A User's Guide to

RAQS:

Rapid Analysis of Queueing Systems

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INTRODUCTION

This tutorial is meant to give an introduction to RAQS (Rapid Analysis of Queueing Systems), a software developed at the Center for Computer Integrated Manufacturing, Oklahoma State University, Stillwater, OK. RAQS is a Windows based application software that combines several different queueing models into an integrated environment. All of the algorithms in RAQS are based upon the two-moment framework i.e. the algorithms are capable of dealing with general distributions, and require only the first two moments of these distributions. It is assumed that the user has prior knowledge of queueing network theory and has all the necessary information to build and solve a model.

RAQS operates in 3 modes, Basic, Intermediate, and Advanced.

- In the Basic mode, the user can build and solve single class open and closed queueing network models with FCFS multiserver nodes, unlimited waiting room, reliable servers, and probabilistic routing between nodes.

- In the Intermediate mode, the user can build and solve multiple-class open and closed network models. The customer routing in these models is class specific, deterministic, and service times are class specific at a node. Also, this mode adds the unreliable server feature to all models.

- In the Advanced mode (still under development), finite buffer tandem networks are the only models available at present.

At this point we would like to stress the fact that this software is still undergoing revisions, enhancements, and testing. Step by step instructions on the use of this software follow.
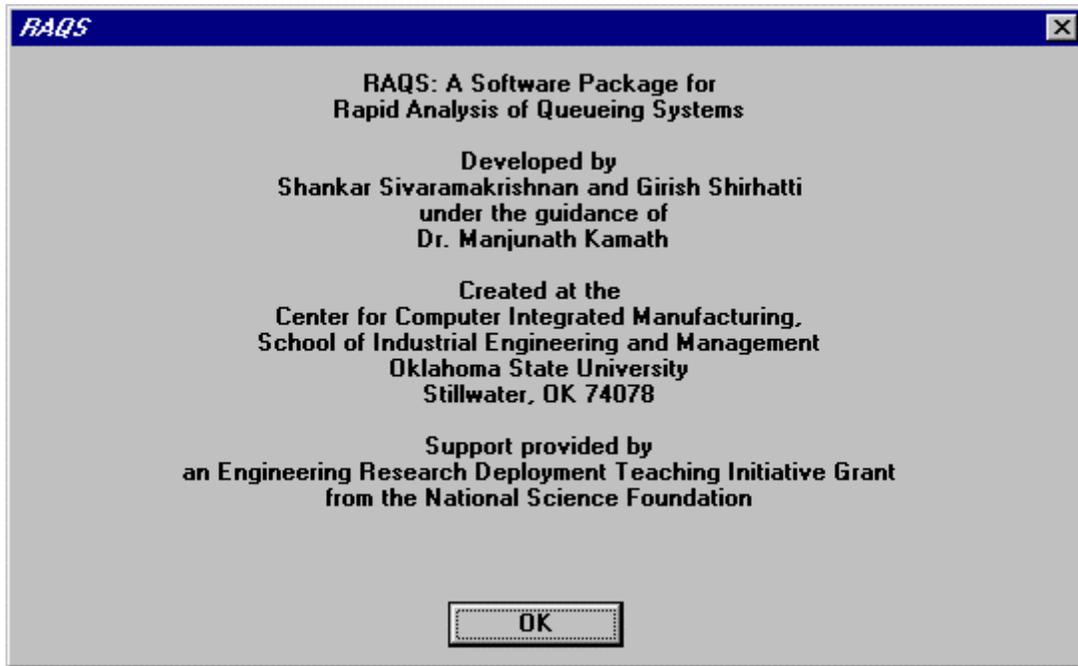

Before running RAQS ...

In the C:\WINDOWS\SYSTEM directory, you will need to have the GRID.VBX file. This file is in the disk/directory that contains RAQS.EXE.
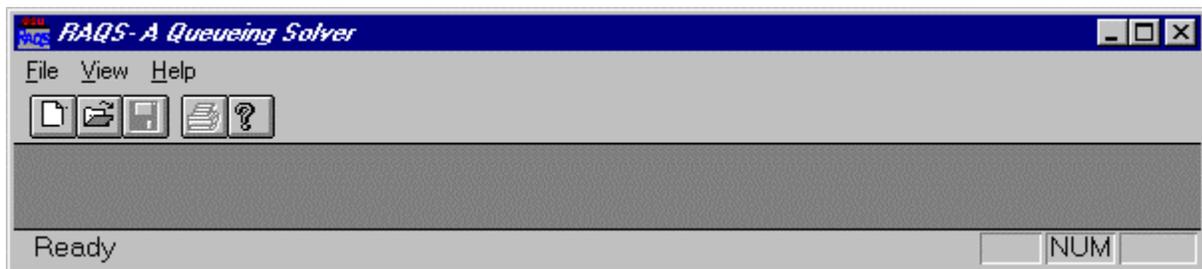

INSTRUCTIONS

Open the RAQS application, either from the Windows File Manager or by double clicking on the icon that is created when you put RAQS.EXE in the Windows Program Manager.

You will see a screen that looks like this:

Click OK and continue. The application workspace comes up:

When the application workspace comes up, only the File option is enabled. The options in the File menu are basically the standard Windows File options. You can open an existing model (file), start a new model (file), save a model (file), print model input or output, etc. There are four standard buttons on the toolbar that correspond to these functions. At this point, if the user wishes to open an existing model file, they would choose the File-Open Model option and select a model file to open. The Input screen of that model will come up. The procedure to build the various types of new models is described in the following sections.

BUILDING A NEW MODEL

1. Choose the File-New Model option, either from the File menu or the File-New Model button or the keyboard shortcut. The following screen will come up.
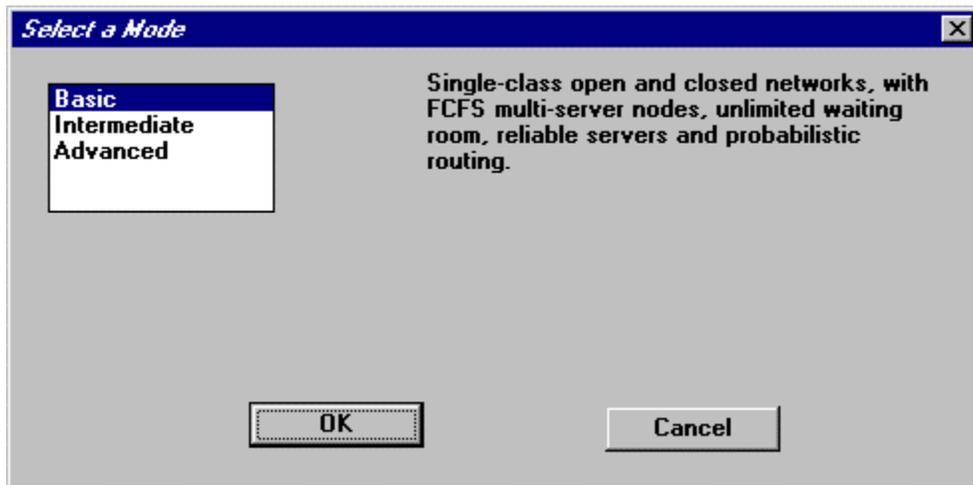
Each of these options is accompanied by comments about what the user can do in each mode. These mention what kind of models can be solved in each mode.

BUILDING A BASIC MODEL (OPEN NETWORK)

The model built in this demonstration is included in Appendix A, titled Basic Open Network Example.

1. Choose Basic from the 'Select a Mode' dialog box and click OK. You will see the following dialog box:
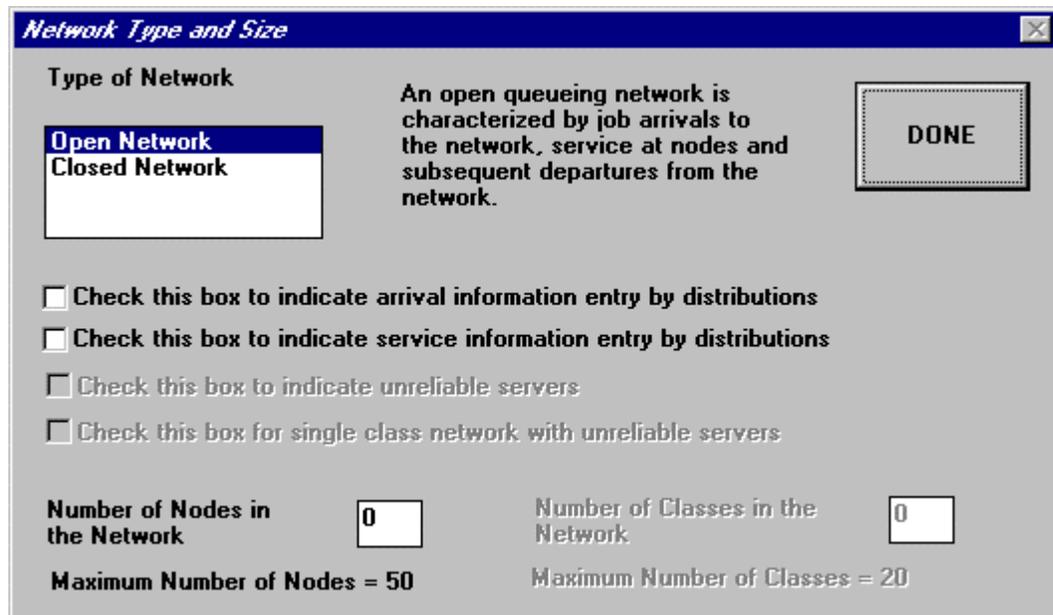
Since models built in the Basic mode cannot have multiple classes or unreliable servers, you will see that those options are disabled. Highlight the Open Network option, enter the number of nodes in the network in the input box at the bottom of the dialog box and click Done.   There is the option of entering both the arrival and the service information by distributions. Do not check these boxes for the current example.

2. You are again returned to the application workspace. The steps that are described below can be done in any order. The following is representative.

Choose the following string of menu options to enter the arrival rates : Edit - Basic Mode - Single Class Arrival Information. The following dialog box comes up. The information that is displayed in the dialog box when it first comes up is the default arrival information.
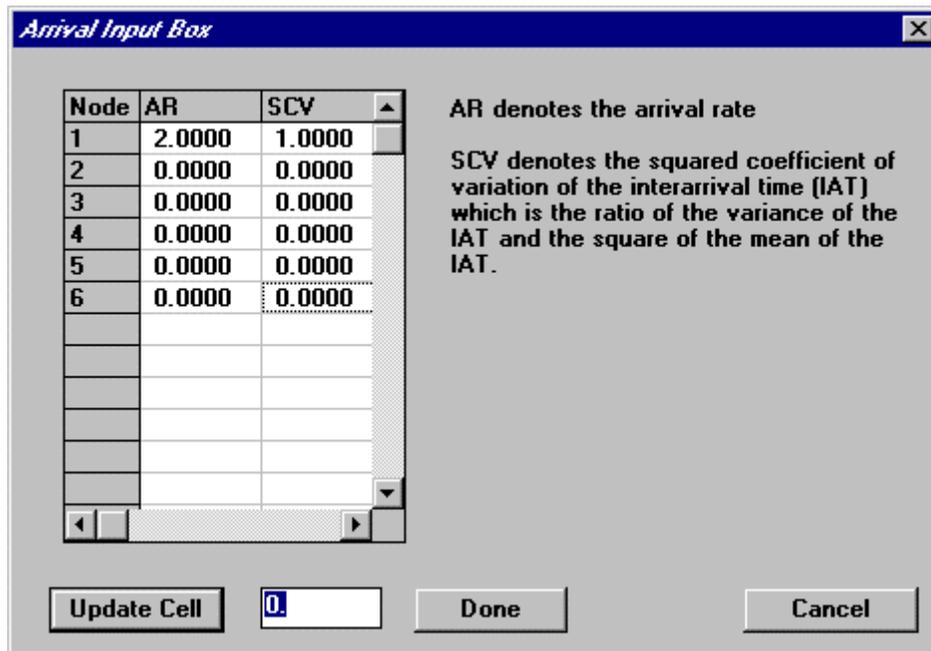
Here, enter the *external* arrival rate and the squared coefficient of variation of the *inter-arrival time* at each of the 6 nodes in the example. It is not required that each node have an external arrival process. However, at least one node should have an external arrival process. Click on any of the cells in the grid to enter the information for that cell. Information can, however, be entered only in the input box at the bottom of the dialog box. Each entry *must* be followed by a click of the Update button or enter for the information to be updated. Once all the information has been entered, click the Done button.

3. To enter service information, choose Edit - Basic Mode -Single Class Service Information from the menu structure. The following dialog box comes up:
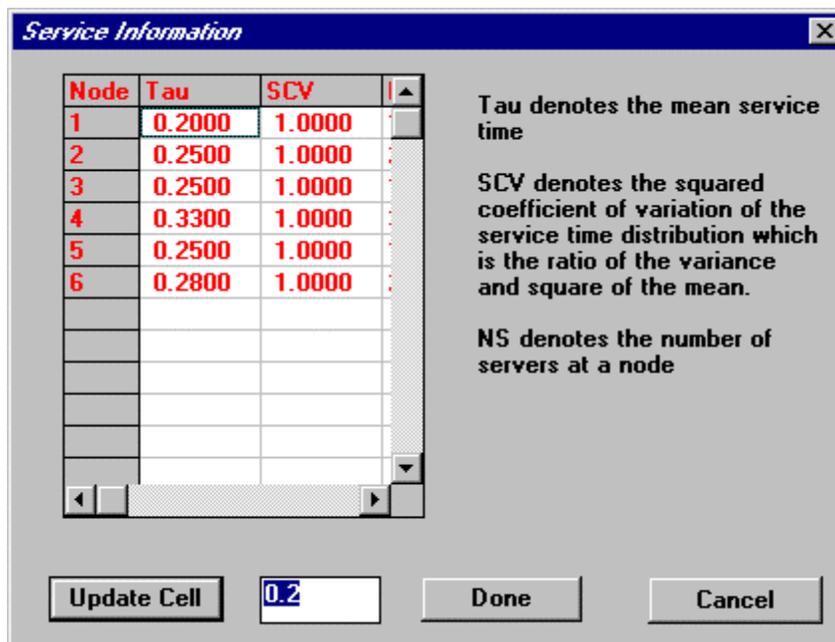
Here, tau denotes the mean service time at each node, SCV is the squared coefficient of variation of the service time, and NS is the number of servers at each node. Enter this information in the same manner as described for the Arrival information (by Updating every entry). The information that is displayed in the dialog box when it first comes up is the default service information. After entering the information, click on the Done button.

To enter the routing matrix, choose Edit - Basic Mode - Routing Matrix option from the menu structure. The following dialog box comes up:

Here, enter the probabilities of customers going from one node to another, using the same general technique (Updating each entry) as before. Once this is done, click on the Done button. The model entry is now complete. At this point, it is a good idea to save the model by choosing the File-Save Model option.

Several consistency and validity checks have been incorporated to avoid incorrect or incomplete model entry. This concludes the section on building a Basic Open Network model. For executing this model, refer to the section on execution and results.

BUILDING A BASIC MODEL (CLOSED NETWORK)

The model built in this demonstration is included in Appendix A, titled Basic Closed Network Example.

From the Select a Mode dialog box, choose the Basic Mode and click OK. The Network Type and Size dialog box will come up. Here, select Closed Network and enter the number of nodes and click Done.
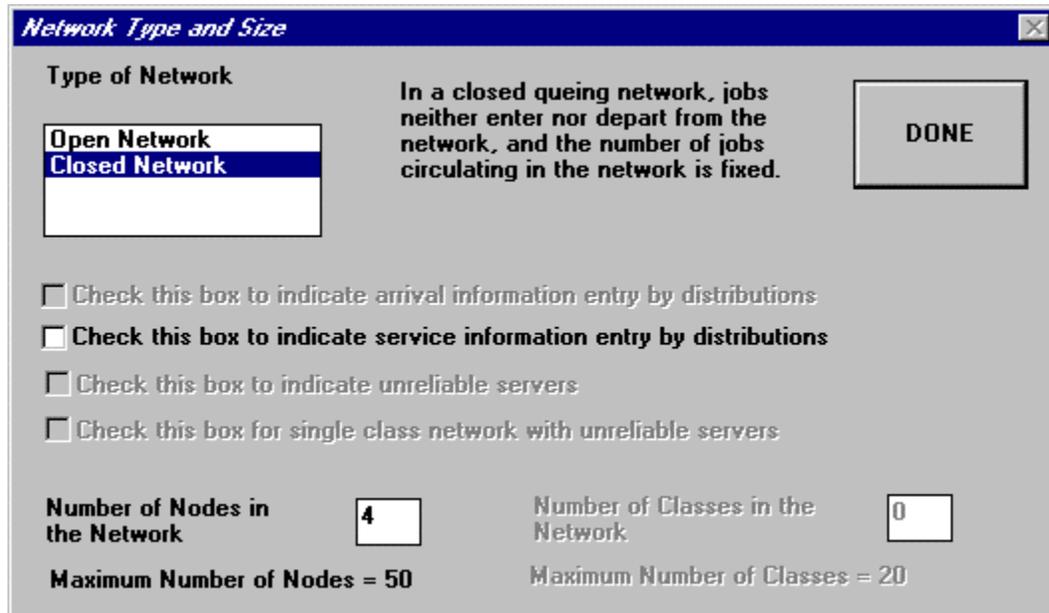
To enter number of customers, choose Edit - Basic Mode - Number of Customers from the menu structure. The following dialog box comes up:
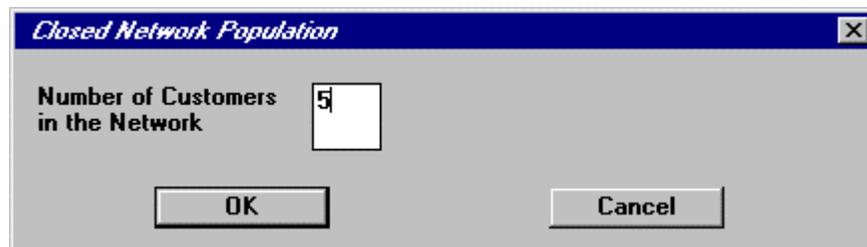
Here, enter the number of customers in the network and click OK.

3. To enter service information, choose Edit - Basic Mode - Single Class Service Information from the menu structure. The following dialog box comes up:

Service Information

Node	Tau	SCV	
1	0.2500	1.0000	
2	0.3300	1.0000	
3	0.2800	1.0000	
4	0.4000	1.0000	

Tau denotes the mean service time

SCV denotes the squared coefficient of variation of the service time distribution which is the ratio of the variance and square of the mean.

NS denotes the number of servers at a node
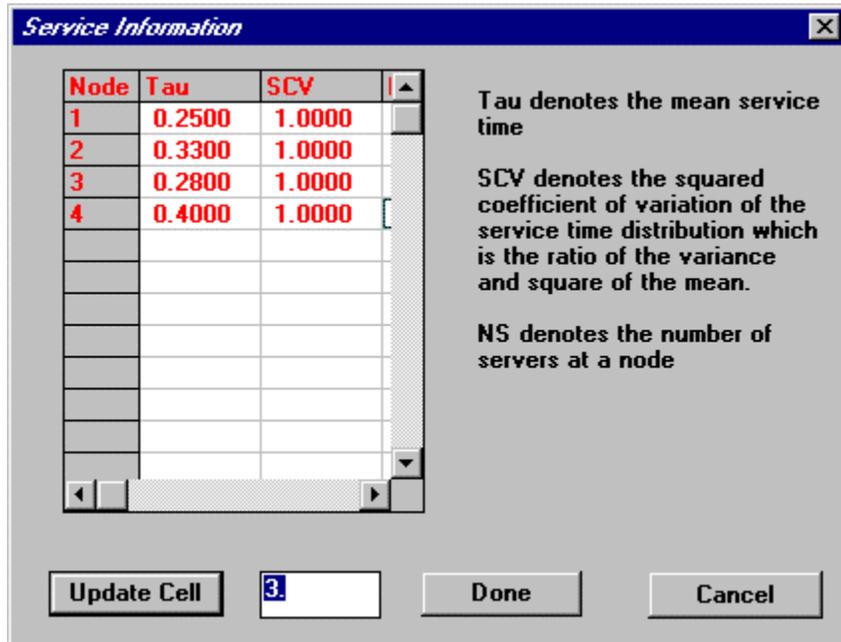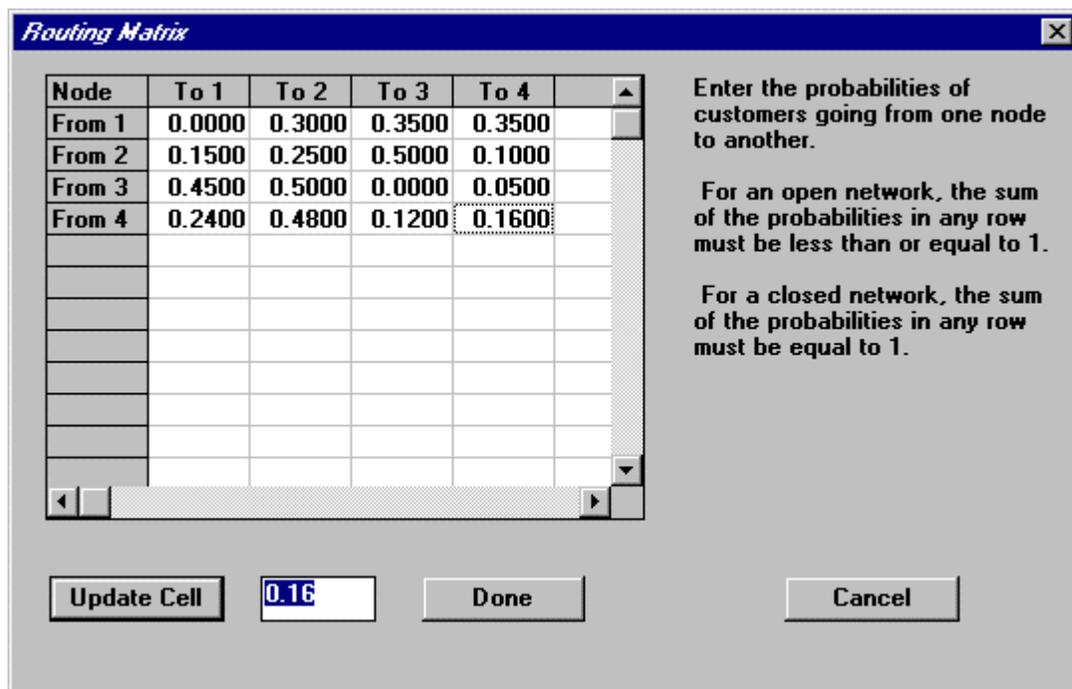
[Update Cell] [3.] [Done] [Cancel]

Here, enter the service information in the same fashion as that for the Open Network, clicking on the Update button after each entry. After all the entries have been made, click on the Done button.

4. To enter routing information, choose Edit - Basic Mode - Routing Matrix from the menu structure. The following dialog box comes up:

Routing Matrix

Node	To 1	To 2	To 3	To 4	
From 1	0.0000	0.3000	0.3500	0.3500	
From 2	0.1500	0.2500	0.5000	0.1000	
From 3	0.4500	0.5000	0.0000	0.0500	
From 4	0.2400	0.4800	0.1200	0.1600	

Enter the probabilities of customers going from one node to another.

For an open network, the sum of the probabilities in any row must be less than or equal to 1.

For a closed network, the sum of the probabilities in any row must be equal to 1.

[Update Cell] [0.16] [Done] [Cancel]

In this dialog box, enter the probability of a customer going from one node to another, Updating each entry. After all entries have been made, click on the Done button.

This concludes the input for the Basic Closed Network Model and the input information is displayed in the application workspace. Again, you would be well advised to save your model at this point.

BUILDING A MULTIPLE CLASS OPEN NETWORK MODEL (RELIABLE SERVERS)

The example chosen to demonstrate the building of this model is presented in Appendix A and is titled Multiple Class Open Network with Reliable Servers Example.

1. In the Select A Mode dialog box, choose Intermediate Mode and click OK.

2. The Network Type and Size dialog box will come up. Select Open Network, enter the number of nodes and number of classes.

Leave the Unreliable Servers box unchecked to indicate that all servers are reliable. Click on the Done button.

3. To enter reliable server information, choose Edit Intermediate Mode - Node Info - reliable server information from the menu structure. The following dialog box comes up:

Here, enter the number of servers at each node, Updating each entry before going to the next. After all the entries have been made, click on the Done button.

4. To enter the Arrival Information, choose Edit - Intermediate Mode - Arrival Information.

Class Arrival Information and Number of Node Visits

Class	AR	SCV	NO
1	1.0000	0.2500	5
2	1.5000	0.3300	6
3	2.3000	0.5000	4
4	1.7000	0.2500	3
5	1.6000	0.5000	6
6	0.6700	0.3300	2
7	1.0000	0.3300	5

AR denotes the mean arrival rate.

SCV denotes the squared coefficient of variation of the inter-arrival time, which is the ratio of the variance and the square of the mean.

NO denotes the number of operations for this class.

Update Cell — 5. — Done — Cancel

Enter the external arrival rate, the squared coefficient of variation of inter-arrival time, and the number of nodes visited by each class, updating each entry before going to the next. After all the entries have been made, click on the Done button.

5. To enter the Class routing information, choose the Edit-Intermediate Class - Routing Information menu from the menu structure. A message box telling you that you will be required to enter the routing information for each class sequentially comes up. If you choose 'Yes' in this box, now comes a series of dialog boxes where you enter Class specific information i.e. the route followed by each class, and the service time parameters of the class at each node it visits. You will have to enter information in as many dialog boxes as there are classes. What is shown below is a sample dialog box for Class 1:

Class Specific Information

Please enter Class 1 information

Visit	Node	Tau	SCV
1	1	0.5000	0.2500
2	5	0.4000	0.3300
3	4	0.7500	0.5000
4	3	0.4600	0.2300
5	2	0.1600	0.2500

Tau denotes the mean service time.

SCV denotes the squared coefficient of variation which is the ratio of the variance and the square of the mean.

Node is the node number of this visit

| Update Cell | 0.25 | Done | Cancel |

Once you have finished entering the class specific information for all the classes, the input for this model is complete. It is advised that the model be saved now.

BUILDING A MULTIPLE CLASS OPEN NETWORK (UNRELIABLE SERVERS)

The example chosen to demonstrate the building of this model is presented in Appendix A titled Multiple Class Open Network with Unreliable Servers Example.

All the steps in the building of this model are identical to that of building a multiple class open network with reliable servers, except Steps 2 and 3 which are described below.

2. In the Network Type and Size dialog box, apart from selecting Open Network and entering the number of nodes and classes, check the Unreliable Servers box to indicate that the servers are not reliable. Click Done.

3. To enter the unreliable server information, choose Edit - Intermediate Mode - Unreliable server information (Multiple Class).

Unreliable Server Information

Node	NS	U	D	DSCV
1	10	500.0000	5.0000	0.2500
2	6	460.0000	3.0000	0.3300
3	9	540.0000	6.0000	0.5000
4	12	600.0000	10.0000	0.2500
5	8	380.0000	2.0000	0.3300

NS denotes the number of parallel servers at a node.

U denotes the mean up time.

D denotes the mean down time.

DSCV denotes the squared coefficient of variation of down time, which is the ratio of the variance and the square of the mean.

[Update Cell]   10.   [Done]   [Cancel]

In this dialog box, enter the number of servers at each node and the reliability information for servers at each node. The information required is the mean up time and the mean and squared coefficient of variation of down time. This information is to be entered as before, Updating each entry before going to the next. The squared coefficient of variation of up time is not required by the algorithm.

All the other steps in the building of this model are the same as those for building a multiple class open network model with reliable servers.

BUILDING A MULTIPLE CLASS CLOSED NETWORK (Reliable servers)

The example used to demonstrate the building of this model is presented in Appendix A and is titled Multiple Class Closed Network with Reliable Servers Example.

1. In the Select A Mode dialog box, choose Intermediate Mode and click OK.

2. The Network Type, Size and Number of Classes dialog box will come up. Select Closed Network, enter the number of nodes and number of classes.

Network Type and Size

Type of Network

Open Network
Closed Network

In a closed queing network, jobs neither enter nor depart from the network, and the number of jobs circulating in the network is fixed.

DONE

☐ Check this box to indicate arrival information entry by distributions
☑ Check this box to indicate service information entry by distributions
☐ Check this box to indicate unreliable servers
☐ Check this box for single class network with unreliable servers

Number of Nodes in the Network `5`

Maximum Number of Nodes = 50

Number of Classes in the Network `3`

Maximum Number of Classes = 20

Leave the Unreliable Servers box unchecked to indicate that all servers are reliable. Click on the Done button.

3. To enter reliable server information, choose Edit - Intermediate Mode - Node Information - reliable server information from the menu structure. The following dialog box comes up:

Server/Buffer Information at a Node

Number of Parallel Servers at each Node

Node	N.S.
1	4
2	3
3	1
4	1
5	2

N.S. denotes the Number of servers at a node

`4`

Update Cell   **Done**   **Cancel**

Here, enter the number of servers at each node, Updating each entry before going to the next. After all the entries have been made, click on the Done button.

4. To enter the number of customers and node visits for each class, choose Edit - Intermediate Mode - Number of Customers. The following box comes up:

Enter the number of customers in each class, and the number of nodes visited by each class, updating each entry before going to the next. After all the entries have been made, click on the Done button.

5. To enter the Class routing information, choose the Edit-Intermediate Class - Routing Information menu from the menu structure. A message box telling you that you will be required to enter the routing information for each class sequentially comes up. If you choose 'Yes' in this box, now comes a series of dialog boxes where you enter Class specific information i.e. the route followed by each class, and the service time parameters of the class at each node it visits. You will have to enter information in as many dialog boxes as there are classes. What is shown below is a sample dialog box for Class 1:

Service Information by Distribution ☒

Please enter Class 1 information

Visit	Node	DT	Param	Param	Param	Param
1	1	U	5.0000	15.0000		
2	2	H	2	0.5000	0.1000	0.500
3	3	R	2	0.1330		
4	1	U	5.0000	10.0000		

Enter the distribution code under DT. Enter
E for Exponential,
R for Erlang,
U for Uniform, and
H for Hyperexponential.

 Enter the parameter(s) for each distribution
in the box(es) besides the distribution code.

>>Exponential - Service rate.

>>Erlang - Number of stages, rate at stage.

>>Uniform - Lower and upper limits.

>>Hyperexponential - Number of stages,
'probability and rate pair' for each stage.

[Update Cell]   [1]   [Done]   [Cancel]

Once you have finished entering the class specific information for all the classes, the input for this model is complete. It is advised that the model be saved now.

BUILDING AN OPEN TANDEM NETWORK WITH FINITE BUFFERS (ADVANCED MODE)

At present, the user can solve only an open tandem network with finite buffers in the advanced mode. The following procedure describes the method of entering the data for an open tandem line with finite buffers.

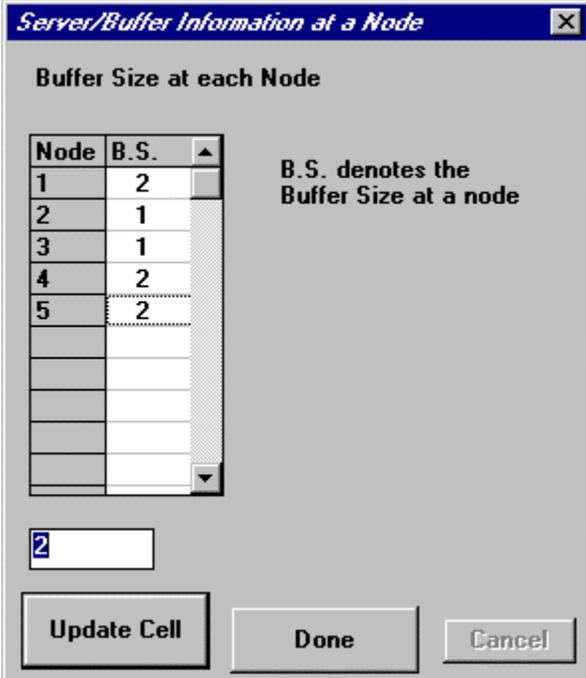From the Select a Mode dialog box, choose the Advanced Mode and click OK.

The next dialog box asks for the arrival rate, interarrival time scv and the number of nodes in the tandem line.
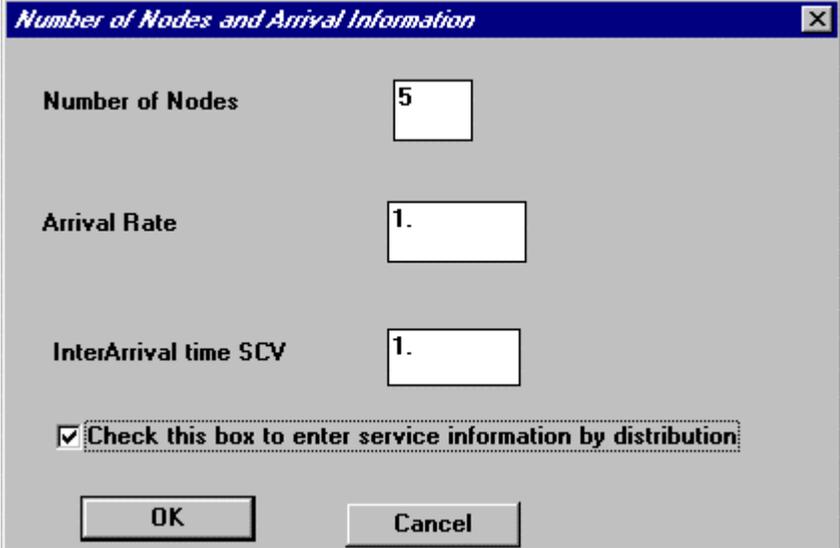
After entering the information, click OK and the application space comes up with just the title "Input Information." To enter buffer and service information, choose Edit - Advanced Mode - Tandem Line with finite buffers- Service and Buffer information from the menu structure. The following dialog box comes up:
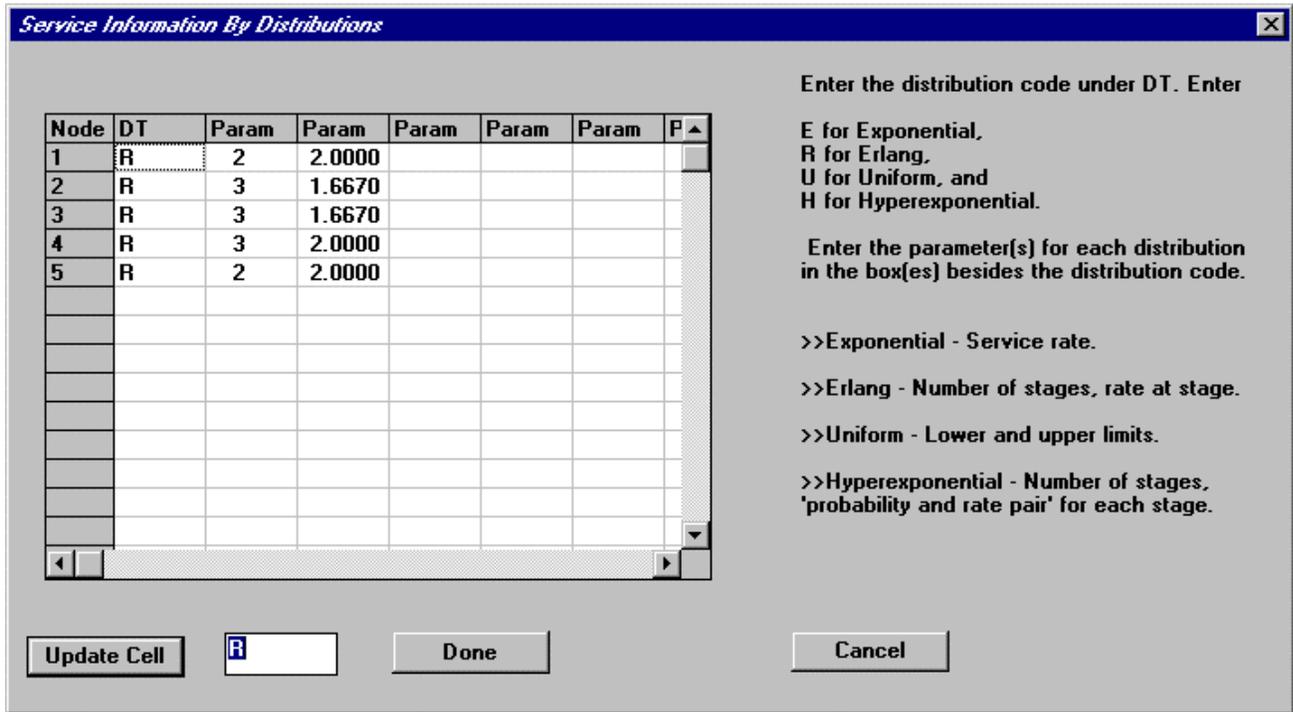

followed by

Service Information By Distributions

Node	DT	Param	Param	Param	Param	Param	P
1	R	2	2.0000				
2	R	3	1.6670				
3	R	3	1.6670				
4	R	3	2.0000				
5	R	2	2.0000				

Enter the distribution code under DT. Enter

E for Exponential,
R for Erlang,
U for Uniform, and
H for Hyperexponential.

Enter the parameter(s) for each distribution in the box(es) besides the distribution code.

>>Exponential - Service rate.

>>Erlang - Number of stages, rate at stage.

>>Uniform - Lower and upper limits.

>>Hyperexponential - Number of stages, 'probability and rate pair' for each stage.

[Update Cell]   [R]   [Done]   [Cancel]

Here, enter the service time information at each node in the network and click Done.

This completes the model and the input information is displayed in the application workspace.

To edit arrival, service and buffer information, use the menu structure and the appropriate menus to edit the required information.

MODEL EXECUTION AND RESULTS

Once any of the models described above is built, all you need to do to execute it is to choose the Run Model option from the Execute menu. At this point RAQS carries out certain validity checks upon your model. For example, if the input you have supplied for an open network is such that the utilization of any of the nodes is greater than or equal to 1, the model will not be executed. Instead a message box is displayed which tells the number of the node that has the infeasible utilization. You have a choice of editing your model so that it will run. Refer to the section on Editing Input for details.

Once you have entered a feasible model, it can be executed, and the result will be displayed in the Output Reports window. Choose Window - Output Window to view the output. The information given in the output report is described below. All measures are steady-state measures.

OPEN NETWORK, SINGLE CLASS

- Average number in the network
- Average time spent in the network

For each node:
- Utilization
- Average Time at Node
- Variance of Time at Node
- Average Number at Node
- Variance of Number at Node
- Average Time in Queue
- Variance of Time in Queue
- Average Number in Queue

CLOSED NETWORK, SINGLE CLASS

Same output as single class open network, except that average number in network is not a part of results. Also, the variance results are not calculated.

OPEN NETWORK, MULTIPLE CLASSES, RELIABLE/UNRELIABLE SERVERS

- Average Number in the Network
- Average time spent in the network by a customer.

For each node:
- Utilization
- Average Time at Node
- Variance of Time at Node
- Average Number at Node
- Variance of Number at Node
- Average Time in Queue
- Variance of Time in Queue
- Average Number in Queue

For each class:
- Average Response Time
- Variance of Response Time

EDITING INPUT

As you build models, you might find it necessary to edit some or all of the input that you have specified. We have provided the option of changing information like arrival information, service information, etc. You cannot, however, change basic information like the number of nodes or number of classes in the network, or the type of the network.

- For a single class open network model with reliable servers, you can change the number of servers at a node, edit arrival information, service information, or the routing matrix information. Arrival and Service Information can be accessed through the Edit - Basic Mode -Arrival Information and the Edit-Basic Mode - Service Information options. Routing information can be accessed through the Edit - BasicMode- Routing Matrix option.

- For the single class closed network model, you can edit service information and routing information in the same manner as described above.

- For the multiple class open/closed network model with reliable servers, you can change the number of servers at a node, arrival information for a class for open networks, number of customers in a class for closed networks, and service information for a class. Number of servers at a node can be accessed through the Edit - Intermediate Mode - Node Info-Reliable Servers option. Arrival information can be accessed through the Edit - Intermediate Mode - Arrival Information option. Number of customers information can be accessed through the Edit - Intermediate Mode - Number of Customers option. Service information can be accessed through the Edit - Intermediate Mode - Routing Information option. This option brings up a Class Number Information dialog box which prompts you to enter the number of the class for which the service information has to be edited. The required dialog box then comes up.
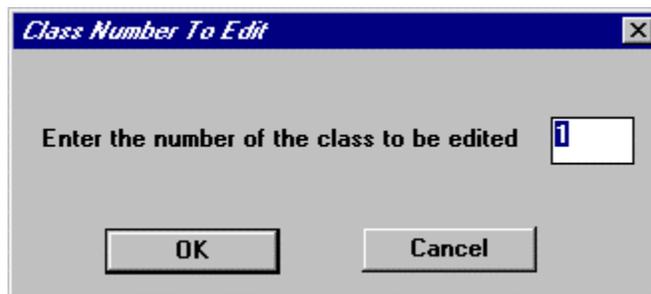
- For the multiple class open/closed networks with unreliable servers, apart from the information described above for the multiple class open/closed network with reliable servers, reliability information for servers might have to be edited. This can be accessed through the Edit - Intermediate Mode - Node Information - Unreliable Servers (Multiple Class) option.

- For the finite buffer open tandem network model, you can change the buffer size at a node, edit arrival information, and service information. Arrival Information can be accessed through the Edit - Advanced Mode - Tandem line with finite buffers - Arrival Information. Service and Buffer Information can be accessed through the Edit - Advanced Mode - Tandem line with finite buffers - Service and Buffer Information.

CONCLUDING REMARKS

As we have said before, this software is still under development.

- There might be certain cases when you get irrevocably stuck, with no option but to reboot (because of Windows problems, of course). We hope such occasions are few and far between.
- If you build large models, your direct printouts will be incomplete, since at present the length of printouts is limited to one page. For large models use "print to file" option to save either input or output to files and print these files using any word processor.
- It is advisable to save models before trying to execute them. If the software crashes and you have not saved the model, you will have all the weary work to go through again.

We are aware of many of these drawbacks in the software and are working to correct them. Some of the things that are being worked on are:

- Context sensitive help.
- Advanced mode.

We sincerely hope that you find this software useful in spite of these minor inconveniences. We not only welcome but encourage any comments or suggestions that you might have about RAQS.

You can e-mail us your comments at:

mkamath@okway.okstate.edu OR *sivaras@master.ceat.okstate.edu*

APPENDIX A

BASIC OPEN NETWORK EXAMPLE

Number of nodes = 6

Node	Arrival rate	Arrival SCV	Mean Service Time	Service SCV	No. of servers
1	2.0	1.0	0.20	1.0	1
2	0.0	0.0	0.25	1.0	2
3	0.0	0.0	0.25	1.0	1
4	0.0	0.0	0.33	1.0	3
5	0.0	0.0	0.25	1.0	1
6	0.0	0.0	0.28	1.0	2

$P_{12} = P_{23} = P_{34} = P_{45} = P_{56} = 1$

Output Report

```
This Model has been developed in the Basic Mode
Type of Network - Open Network

Network Measures
Average Number in the Network =    4.440
Average Response Time   =    2.220

Node Measures
Node  Rho    AvTAN    VarTAN   AvNAN    VarNAN   AvTIQ    VarTIQ   AvNIQ
   1  0.400  0.333    0.111    0.667    1.111    0.133    0.071    0.267
   2  0.250  0.259    0.063    0.519    0.333    0.009    0.001    0.019
   3  0.500  0.500    0.250    1.000    2.000    0.250    0.188    0.500
   4  0.220  0.333    0.109    0.667    0.275    0.003    0.000    0.007
   5  0.500  0.500    0.250    1.000    2.000    0.250    0.188    0.500
   6  0.280  0.294    0.080    0.588    0.392    0.014    0.001    0.028


Thruput - Output rate per server at a node
AvTAN - Average time spent at a node
AvNAN - Mean number of customers at a node
AvTIQ - Average waiting time in queue at a node
AvNIQ - Mean queue length at a node
```

BASIC CLOSED NETWORK EXAMPLE

Number of nodes = 4;   Number of customers = 5

Node	Mean Service time	Service SCV	Number of servers
1	0.25	1.0	2
2	0.33	1.0	4
3	0.28	1.0	3
4	0.40	1.0	3

$P_{11} = 0.00$ $P_{12} = 0.30$ $P_{13} = 0.35$ $P_{14} = 0.35$

$P_{21} = 0.15$ $P_{22} = 0.25$ $P_{23} = 0.50$ $P_{24} = 0.10$

$P_{31} = 0.45$ $P_{32} = 0.50$ $P_{33} = 0.00$ $P_{34} = 0.05$

$P_{41} = 0.24$ $P_{42} = 0.48$ $P_{43} = 0.12$ $P_{44} = 0.16$

Output Report

```
This Model has been developed in the Basic Mode
Type of Network - Closed Network

Network Measures
Average Time in the Network =    1.340

Node Measures
Node  Rho     thruPut  AvTAN    AvNAN    AvTIQ    AvNIQ
   1  0.407   3.25794  0.294    0.959    0.044    0.145
   2  0.457   5.54270  0.336    1.865    0.006    0.036
   3  0.390   4.18359  0.297    1.242    0.017    0.071
   4  0.302   2.26634  0.412    0.934    0.012    0.027


AvTAN, VarTAN - Mean and Variance of time spent at a node
AvNAN, VarNAN - Mean and Variance of the number of customers at a node
AvTIQ, VarTIQ - Mean and Variance of waiting time in queue at a node
AvNIQ - Mean queue length at a node
```

MULTIPLE CLASS OPEN NETWORK WITH RELIABLE SERVERS EXAMPLE

Number of nodes = 5   Number of classes = 7

Node Information

Node	No. of servers
1	10
2	6
3	9
4	12
5	8

Class Arrival Information

Class	Arrival Rate	Arrival SCV	No. of Visits
1	1.0	0.25	5
2	1.5	0.33	6
3	2.3	0.50	4
4	1.7	0.25	3
5	1.6	0.50	6
6	0.67	0.33	2
7	1.0	0.33	5

Class 1 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	1	0.50	0.25
2	5	0.40	0.33
3	4	0.75	0.50
4	3	0.46	0.23
5	2	0.16	0.25

Class 2 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	1	0.24	0.13
2	3	0.25	0.33
3	4	0.49	0.25
4	2	0.40	0.10
5	1	0.64	0.50
6	3	0.29	0.50

Class 3 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	5	0.45	0.25
2	2	0.50	0.33
3	3	0.46	0.50
4	5	0.33	0.25

Class 4 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	1	0.48	0.25
2	2	0.49	0.33
3	3	0.18	0.50

Class 5 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	4	1.1	0.25
2	3	0.79	0.33
3	1	1.6	0.50
4	5	1.7	0.36
5	2	0.49	0.50
6	3	0.79	0.23

Class 6 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	2	0.79	0.25
2	5	0.49	0.33

Class 7 Service and Routing Information

Visit	Node	Service Mean	Service SCV
1	3	0.46	0.25
2	4	0.19	0.33
3	5	0.36	0.33
4	2	0.67	0.50
5	4	0.23	1.0

Output Report

This Model has been developed in the Intermediate Mode
Type of Network - Open Network

Network Measures
Average Number in the Network =   27.875
Average Response Time   =   2.853

Node Measures

Node	Rho	AvTAN	VarTAN	AvNAN	VarNAN	AvTIQ	VarTIQ	AvNIQ
1	0.520	0.718	0.585	5.241	0.883	0.006	0.000	0.045
2	0.788	0.695	0.182	6.787	9.875	0.211	0.071	2.061
3	0.625	0.477	0.133	5.822	1.159	0.016	0.001	0.200
4	0.305	0.601	0.273	3.665	0.376	0.000	0.000	0.000
5	0.700	0.717	0.494	6.360	3.247	0.085	0.015	0.758

Class Specific Output

Class	AvRT	VarRT
1	2.589	0.538
2	2.566	0.423
3	2.138	0.368
4	1.383	0.224
5	6.805	3.180
6	1.576	0.321
7	2.223	0.471

Thruput - Output rate per server at a node
AvTAN - Average time spent at a node
AvNAN - Mean number of customers at a node
AvTIQ - Average waiting time in queue at a node
AvNIQ - Mean queue length at a node
AvRT - Average time spent in the network by a customer in a class

MULTIPLE CLASS OPEN NETWORK WITH UNRELIABLE SERVERS EXAMPLE

All of the input is the same as that for the multiple class open network with reliable servers example, except the node information, which is given below:

Node	No. of Servers	Uptime Mean	Downtime Mean	Downtime SCV
1	10	500	5	0.25
2	6	460	3	0.33
3	9	540	6	0.50
4	12	600	10	0.25
5	8	380	2	0.33

```
Output Report
This Model has been developed in the Intermediate Mode
Type of Network - Open Network

Network Measures
Average Number in the Network =   28.166
Average Response Time   =    2.883

Node Measures
Node  Rho    AvTAN    VarTAN    AvNAN    VarNAN    AvTIQ    VarTIQ    AvNIQ
   1  0.530  0.732    0.614     5.344    0.926     0.007    0.000     0.049
   2  0.794  0.684    0.182     6.682    9.076     0.196    0.063     1.917
   3  0.636  0.486    0.180     5.932    1.295     0.017    0.001     0.211
   4  0.322  0.633    0.519     3.862    0.471     0.000    0.000     0.000
   5  0.706  0.715    0.490     6.346    3.079     0.079    0.014     0.702

Class Specific Output
Class  AvRT      VarRT
    1    2.569    0.530
    2    2.554    0.416
    3    2.112    0.358
    4    1.370    0.217
    5    6.787    3.171
    6    1.555    0.312
    7    2.203    0.463


Thruput - Output rate per server at a node
AvTAN - Average time spent at a node
AvNAN - Mean number of customers at a node
AvTIQ - Average waiting time in queue at a node
AvNIQ - Mean queue length at a node
AvRT - Average time spent in the network by a customer in a class
```

MULTIPLE CLASS CLOSED NETWORK WITH RELIABLE SERVERS EXAMPLE

Number of nodes = 5   Number of classes = 3

Node Information

Node	No. of servers
1	4
2	3
3	1
4	1
5	2

Number of Customers

Class	No. of Node Visits	No. of customers
1	4	5
2	4	5
3	3	5

Class 1 Service and Routing Information

Visit	Node	Service Time Distribution
1	1	U(5, 15)
2	2	H(2, 0.5, 0.1, 0.5, 0.025)
3	3	R(2, 0.133)
4	1	U(5, 10)

Class 2 Service and Routing Information

Visit	Node	Service Time Distribution
1	1	U(5, 15)
2	2	H(2, 0.5, 0.0667, 0.5, 0.0222)
3	4	R(2, 0.2)
4	1	U(5, 10)

Class 3 Service and Routing Information

Visit	Node	Service Time Distribution
1	1	U(5, 15)
2	5	R(2, 0.05)
3	1	U(5, 10)

Output Report

This Model has been developed in the Intermediate Mode
Type of Network - Closed Network

Network Measures
Average Time in the Network = 227.046

Node Measures

Node	Rho	thruPut	AvTAN	AvNAN	AvTIQ	AvNIQ
1	0.577	0.26395	9.442	2.492	0.692	0.183
2	0.829	0.08999	67.970	6.116	40.336	3.630
3	0.641	0.04261	33.177	1.414	18.139	0.773
4	0.474	0.04738	16.360	0.775	6.360	0.301
5	0.840	0.04199	100.097	4.203	60.097	2.523

Class Specific Output

Class	AvRT
1	117.398
2	105.582
3	118.981

AvTAN, VarTAN - Mean and Variance of time spent at a node
AvNAN, VarNAN - Mean and Variance of the number of customers at a node
AvTIQ, VarTIQ - Mean and Variance of waiting time in queue at a node
AvNIQ - Mean queue length at a node
AvRT, VarRT- Mean and Variance of time spent in the network by a customer in a
class

OPEN TANDEM NETWORK EXAMPLE

Number of nodes = 5;   Arrival rate = 1.0;   IAT SCV = 1.0

Node	Service Time Distribution	Buffer Size
1	R(2, 2)	2
2	R(3, 1.667)	1
3	R(3, 1.667)	1
4	R(2, 2)	2
5	R(2, 2)	2

Output Report

```
This Model has been developed in the Advanced Mode
Type of Network - Open Tandem Network

Network Measures
Network Throughput =    0.448

Node Measures
Node  Rho     avWtTm  avBlkTm  ProbBlk
   1  0.949   3.271    1.459    0.765
   2  0.951   3.145    1.261    0.255
   3  0.841   1.381    1.029    0.074
   4  0.689   0.637    0.750    0.049
   5  0.448   0.164    0.000    0.000


Rho - Utilization at a node
AvWtTm - Mean waiting time in queue at a node
AvBlkTm - Average Block Time at a Node
ProbBlk - Probability of the Node being blocked
```