USING INS TO MODEL SYSTEMS WITH ACTIVE RESOURCES

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Abstract

Procedural modeling languages utilize transactions as their only active entity. These transactions can flow through a network simulating the logical and physical properties of a real world system. It is natural for the transactions to represent units of demand using a set of resources. However resources, especially within social systems, are not passive and play an active role in choosing transactions to service. To model those environments in a transaction-oriented language requires the simultaneous treatment of resources and demands as transactions and compels the modeler to explicitly consider their interface and synchronization. In INS the modeling of combined active transactions-active resources is facilitated by the introduction of a second active entity, namely resources whose role is different than but easily coordinated with transactions. The INS resource allocation processor permits the high level manipulation of these dual entities allowing the modeler to represent very complex systems easily.

INTRODUCTION

The development of simulation languages relieves the user of the complex burden of keeping track of many simulation details. Nonetheless, in many languages, the user must fit his model into a next event structure and write the routines for event processing. However, another world view arises from a process or procedural perspective. Procedural languages, such as GPSS (1,2), Q-GERT (3) and their derivatives, are primarily an outgrowth of modeling the queuing phenomena -- where queuing is a generic term referring to the delay or inventory that arises as a result of demand sometimes exceeding supply.

Consistent with a concern for queuing, process-oriented languages are keyed on the flow of traffic generally called transactions. Transactions typically move within a network simulating the physical and logical processes of a real world system. Through the use of well defined nodes (blocks) and branches integrated within a network (flowchart), transactions are created, routed through the network, queued due to scarce resources or synchronization requirements, serviced by resources, and eventually destroyed or removed from consideration. The logical processing may require transactions to be assigned attributes and cause the functional evaluation of decision processes. All of these processes can occur within a setting of random processes whose activity needs to be evaluated through the collection of statistical measures on transaction transit, queue, and activity times.

INS (Integrated Network Simulation language) is a network-based, process-oriented simulation language which employs a transaction entity whose activity in a graphical depiction of branches and nodes can model a broad range of problems. INS incorporates many of the GPSS and Q-GERT features related to transactions including: (1) the depiction of various transaction creation and destruction processes; (2) the ability to assign and alter transaction attributes; (3) the creation of sets of related transactions; (4) the modeling of complex processing dependencies among transactions; (5) the delay of transactions due to resource unavailability, synchronization requirements, transaction priorities, and activity processing; (6) logical routing of transactions through the network; (7) the selection of substitutable resources needed at activities based on priority or prior processing information; and (8) the collection of statistics on transactions for node times, node counts, transit times, etc.

For many purposes and problems, an active transaction capability is sufficient when supported by a rich set of concepts that can be used to interpret their processing. Nevertheless, within a number of environments, particularly social systems, the resources which service the transactions are active in the processes. Yet to model explicitly the behavior of resources within a transaction-oriented language requires either treating the resources as transactions or resorting to user-written functions outside the parent language. If multiple resources exist and the processes of servicing transactions are complex, their treatment within a transaction framework would be difficult, if not impossible. User written routines, as an alternative, force the modeler to be competent in a general programming language and greatly reduce the high level interface offered by the simulation language.

Within Q-GERT and GPSS, resources are passive and only to be acted upon by the transaction or its logical derivative. Q-GERT considers resources fixed and stationary. GPSS permits flexible definition (through storages and facilities) and mobility of resources, but requires the modeler to directly manipulate GPSS chains. Furthermore the language algorithms that process the state changes are triggered solely by transaction movement.

To enhance the modeling process when resources play an active role with transactions in the network, INS can explicitly consider resources to be active--reflecting the organizational and operational characteristics of a multi-activity, multi-resource system. Specifically, this "active resource" concept can mean that: (1) activities may have multiple resource requirements; (2) resources may substitute for each other in fulfilling resource requirements at activities; (3) resources may perform sequences of activities on one or more transactions; (4) resources may utilize an explicit decision algorithm in selecting an eligible transaction among activities; (5) resources have specific arrival and departure characteristics; and (6) preemption relationships for resources may exist among some activities. Furthermore these concepts are implemented easily with language constructs and without resort to user written routines or complex transaction manipulation.

In this paper, the resource-related concepts are described by example. The documentation of the specifics of the INS language, including the symbol set and processing algorithms used in the computer simulation program are found elsewhere (4,5,6). Two examples are taken from transaction-based language literature so that comparison and contrast of concepts and features are possible. The third is abstracted from an ambulatory care problem (4,7) to more comprehensively demonstrate the power and sophistication of active resource simulation.

HARBOR OPERATION

The problem of ships arriving at a harbor for unloading and loading of cargo is described by Schriber (1, p. 251). Two unloading/loading complexes serve two different types of ships. For ships berthing or deberthing, a tug is required. One tug is available in the harbor and gives priority to deberthing ships. If two ships are equally eligible, the choice is based on shortest expected activity time, which gives preference to ship type #1 during deberthing and type #2 when berthing. Both a tug and berth must be available before the berthing starts.

The INS network model is given as Figure 1. In this model, ships are represented by transactions while the resources are the tug and complexes. Ships are introduced into the network at source node #1 (node numbers are boldly labeled on left side of nodes). Their interarrival time is sampled from the distribution specified in parameter set #1 (parameter set is denoted by a negative number referencing the parameter set, while a constant interarrival time is denoted by a non-negative constant). The ships will arrive in a block size of one (1) beginning at time zero (0.0) and will continue until the total number (NBR) of arrivals has reached one thousand (1000). The ship transaction, after creation, flows (conceptually) in zero simulated time to assignment node #2 where the ship type attribute is assigned the transaction. The assignment occurs probabilistically (PRB) and is given an individual, integer attribute (IAI) whose label (TTP) specifies the ship type. Ship type #1 is assigned 30% of the time and type #2 is assigned 70%. From the assignment node, still within zero simulated time, the ship branches based on the value (ATV) of TTP. Ships of type #1 are routed to queue node #3 while type #2 is routed to queue node #4. If resources are available to start the activity the ship initiates the berthing process, otherwise it waits in the queue. Activity node #5 represents the berthing process and requires two resources (denoted by two columns of resource symbols above the activity node and the two resource selection nodes P, P). The first resource group above the activity depicts the need for the tug (identified by number as 1). The second resource group above the activity (denoted by the two stacked squares) represents the complexes where each complex is identified by its resource number in the top triangles in the squares. The right-hand triangles indicate the queue which the resource will serve (a blank means all queues associated with the activity are served) so that complex type will service the proper ship type. Activity times for all resources are given in the left-hand triangles (a negative number identifies sampling from a specific parameter set, while a non-negative number indicates a constant) and are specified for each resource combination.

Transactions in INS once placed in motion continue in zero simulated time until they enter a queue, initiate an activity, or exit the network. Any other transactions freed during the process are similarly processed. The activity node provides the intersection of resources and transactions. Thus the creation of a transaction initiates its "transaction-initiated search for resources". The search for resources at an activity node such as #5, utilizes the resource selection modes (P, P) to indicate the manner of resource selection by the transaction and the number of resources required. At activity #5, two resources are required, each chosen on a priority (P) basis (which in this case is trivial since only one resource is available to satisfy each resource requirement).

While transaction arrivals can initiate the search for resources, so too can the end of an activity. For example, upon the berthing of the ship, the transaction flows into the unload-load activity node #6. Here the only resource selection mode is C, indicating that one resource is required and it is to be selected from those used in the current (C) realized activity (which is activity #5). The possible resources are given in the resource group and their activity time specification is based on the complex type. No queue is needed at the activity #6 since the resource is known to be available from the previous activity (the ship is in the complex).

Although the complex is now being used in the unload/load (end of activity scheduled in the event file), the tug is freed for other duties. In INS, the tug now becomes active in choosing the queue it will service and uses its queue selector tree (the tree whose root node is selector node #10) to examine queues of transactions. By the priorities given in the problem, it preferentially (PRE) examines the deberthing queue #7 first for waiting transactions (the queue ranking method will assure ship type #1 is considered before type #2). If no ships require deberthing, the tug examines queue #4 (since type #2 has a shorter activity time than type #1 as stated by the problem). Finally, if still unsuccessful in finding a transaction to start, it examines queue #3. If no transactions can be brought into the activity for service, the tug will enter the idle state. Notice that the berthing and deberthing require two resources, and even though a ship may be available, if the complex is not the tug cannot start the activity and will move on the next specified queue.

The initiation of a "resource-initiated search for transactions" will occur when resources are freed after the transactions have updated their status. In INS the transaction search is called stage 1 of the resource allocation process, with the resource search called stage 2. Stage 1 will be initiated upon transaction arrival or end of activity while stage 2 will be initiated upon resource arrival or end of activity. The stage 1/stage 2 resource allocation process gives INS its unique ability to model systems with both active transactions and active resources.

Returning to the network of Figure 1, once the ship unloads/loads at activity #6, it proceeds to queue #7. Ships are ranked in the queue according to type (TTP), with lowest value (LOW) placed at the head (secondary ranking is FIFO) to conform to the needed priority of the tug. Within this queue a provision is made to capture (C) the complex (second resource group) in the queue to prevent its release until deberthing. Resource group one (the tug) is not to be captured (N). The capture insures that the complex is captured in stage 1 (capturing in stage 2 is possible, but must be exercised with care to avoid deadlock).

The ship deberthing at activity #8 employs a priority (P) resource selection in the first resource group and a continuation (C) resource selection for the second resource since it is taken from the previous activity or captured with the transaction in the queue. Activity times are sampled from a parameter set in accordance with the resource combination. Finishing deberthing the transaction exits the network via sink node #9 and decrements the system termination counter by one (1).

The choice process employed by the complexes in the network is trivial since they can only "choose" one queue each. All activities serviced by the complexes are performed sequentially on the same transaction and, while they float from activity to activity, they are passive in the allocation process.

HARBOR PROBLEM ENRICHED

Suppose the distinction between type #1 and type #2 ships is size with type #1 being larger. Now only complex #1 can serve the larger ships, but it may also serve the smaller ships if it is free or if the wait by ships of type #2 exceeds that of type #1. In addition, suppose also that the bigger ships require two tugs when berthing and deberthing and harbor management feels that the tugs which help to berth a particular ship should also deberth it (a feature found in Schriber's library problem on p. 339). After 25 ships are served in a complex, it is shut down for preventive maintenance for a specified period. In this harbor there are four tugs, one of complex type #1 and two of complex type #2.

The new INS network model is given as Figure 2. This model has seven resources, in accordance with the new harbor description. INS allows the grouping of resources by type (represented by negative numbers) as well as their identification by number to provide flexible addressing by the modeler. Overall the network is more involved, due to complex maintenance and greater choice capability by the complexes, as depicted by their queue selection trees.

Nodes #1, #2, #3, and #4 present no change in the creation, type assignment, and routing. At activity #5, the berthing of type #1 ships, the two tug requirements are specified in the first two resource groups and the complex in the third. Note the use of resource type to implicitly specify the resources as well as resource number. The addition of labels T1, T2, and CPX within activity node #5 utilizes the INS feature of permitting transaction attribute assignment of resource type on an activity node. Thus within the transaction record, attribute T1 and T2 will contain the resource number of the two tugs utilized at activity #5 while attribute CPX will indicate the complex number. A similar attribute assignment is made for the two resources in activity #6.

Activity #6 also contains a non-trivial use of the priority (P) resource selection mode for the second resource group (complexes). When the transaction attempts to start the activity in stage 1 (and the tug is available) the transaction search for the second resource examines first resources of type three (-3) as denoted by the 1 in the lower triangle of the resource in the second resource group associated with complex #2. If complex #2 is unavailable, it next examines resource #5 (complex #1) for availability. If it is not being used, it can then be scheduled by the type #2 ship.

The assignment node #7 assigns the unloading/loading activity time distribution set. Specifically an individual, integer attribute (IAI) labeled (TME) is assigned a value (VAL) conditioned on the transaction attribute CPX.

If the ship used complex #1, its parameter set is #4 whereas if it used complex #2, its parameter set is #5. Consequently at activity #8, the activity time is specified by the sampling from the parameter set contained in the transaction attribute TME.

In contrast to the model of Figure 1, the deberthing activity is represented as two activities each servicing different ship types. The configuration of activities #9 and #10 mirror those of the berthing activities. The only change is that the resource selection mode for the tug requirements is based on transaction attribute assignment (A). This method of resource selection is to insure that the same tugs which berthed this ship (transaction) also deberth it. The appropriate transaction attribute labels T1 and T2 are found in the lower triangles on the resource symbols. Thus resource selection by the transaction during stage 1 can be dependent on prior information.

The capture specification on queues #9 and #10 and the C resource selection modes of activities #8, #11, and #12 insure the continued use of the complexes by the ships during the harbor encounter.

The assignment nodes #13, #14, and #15 are network attributes (NAI) associated with each of the complexes (C1, C21, C22) to count the ship usage so preventive maintenance can be scheduled. The counters are incremented with each ship processed (note branching from activity #12 is based on resource utilized (URE) for the specific complex #2). Branching from the assignment counters, when a count reaches 25, the transaction is routed to one of the tree queues for initiating complex maintenance. After maintenance the counter is reset at nodes #20, #21, or #22.

At activity #19, the resource alternatives are associated with only one queue. A constant activity time of 8 time units is specified for each.

Within the Figure 2 INS model all resources have the opportunty for some choice. The tugs follow the previous allocation mechanism of Figure 1, even though the deberthing queues for ship types are separate. Complex #1 selection process is more complicated in that just as soon as the complex is free after the maintenance is indicated, it will service queue #16. Otherwise it will service either queue #3 or #4 depending on which queue wait is longest (LQW). Complexes #2 follow a similar pattern of preferring (PRF) maintenance, but will service the berthing of smaller ships next. Notice that after deberthing, several resources are released and in stage 2 INS utilizes the queue selection tree of each to seek out transactions that will simultaneously satisfy the choice mechanism (note that a C resource selection mechanism in activity #19 would reduce the need for resource searches but provide identical results).

PROCESSING JOBS WITH MACHINE BREAKDOWN

Resources can become active by virtue of their preemptable relationships. Consider a problem described by Pritsker (3, p. 279). In this problem, jobs arrive at a machine whose operator must set-up the machine before processing the job. If, during the processing, the machine breaks down, the machine undergoes a repair process after which it returns to finish the interrupted job. However, before the repaired mahcine can be placed back into service, an additional set-up for the machine is required.

The INS model for the problem is given in Figure 3. The first network (nodes #1 to #5) depicts the jobs as they are processed. The second network (nodes #6 to #9) reflects the processing of machine breakdowns.

Jobs arrive at the source node #1 according to interarrival distribution specified by parameter set #1. They enter one at a time beginning at time 0.0 and continue to enter intermittently until simulation time (TIM) 1000. Departing the source they may queue in node #2 for the machine and/or operator. If resources are available (P, P), the machine is set up, after which the job flows to activity #4 and using the (C, C) resource selection modes initiates the job processing. After processing the jobs exit via sink node #5.

At source node #6, transactions representing machine breakdowns are introduced one at a time according to interarrival distribution given by parameter set #4. This transaction proceeds to activity node #7 where it attempts to preempt for resources. In INS, activities can be classified to reflect their preempt characteristics and labeled in the center box of the activity node. Activites #3 and #8 are regular, non-preemptable (RNP), so their resources cannot be preempted. However activity #4 is regular, preemptable (RP) and thus a preempt (P) activity like #7 can preempt resources from #5. Hence, only when the machine is processing a job can it be preempted.

Preempt activities have no queues since if transactions are unsuccessful in obtaining the needed resources, they are destroyed. If the transaction is able to preempt the machine, the machine is removed from activity #4 where the operation is halted and the repair at activity #7 is scheduled. Upon completion of the repair the machine undergoes the additional set-up at activity #8 via the (C) specification for the time period specified, after which the machine becomes free to return to the job interrupted at activity #4 to finish the processing.

AMBULATORY CARE

The modeling of ambulatory care systems in doctors' offices and hospital outpatient departments motivated the development of INS. Ambulatory care reflects the properties of many social systems, the most important being the character of resources in the delivery system. Observations of such systems suggest that resources:

(1) are often people (rather than machines or equipment) who exercise considerable influence over the service process; (2) use decision making processes in service that is a reflection of organizational and operational policies; (3) serve in roles that often overlap and interrelate; and (4) will be a mix of "passive" facilities and equipment as well as "active" personnel.

The INS network model in Figure 4 is an example of an ambulatory care setting (4). The demands on the system are naturally represented by transactions who become patients, telephone calls, lunch breaks (as depicted by the three apparently separate networks). A fourth use of the transaction is to model the simulation clock for terminating the simulation run.

The network exemplifies a number of additional transaction-oriented concepts: (1) nodes for routing transactions logically (e.g. nodes #7,#14) and for deriving indogenously transactions (e.g. nodes #5,#29); (2) introduction of synchronization to gather (node #8), assemble (node #12), and match (node #34) transactions; (3) a broader range of transaction assignment mechanisms (e.g. node #52); (4) reneging at a queue (node #55); and (5) more comprehensive use of potential node characteristics and specification. Space limits the present discussion of these transaction-oriented concepts and further detail may be found in the references (4,5,6). Clearly the active, complex role of transactions are present and needed to accurately depict the real demand for health service.

Resources within the model are composed of health team members and facilities. The facilities are inactive, but can constrain the patient processing and "flow" in the network, modeling the activities performed within the exam room or laboratory. The health team members interact with themselves and the facilities. The people perform multiple and overlapping tasks and while there is sometimes clear organizational distinction (M.D. performs direct patient care and secretary never does), there are operating policies which permit substitution of resources (the FNP will place patients in the exam room if the RN is busy). The choice processes can be explicitly or implicitly based on either self-imposed, professional or organizational, or system state dependent criteria. Different resource conbinations can yield different performance, reflected in such characteristics as activity times. The resource arrival may also influence system performance (a feature introduced in the Figure 4 resource table).

In health care, a prevailing problem is the relationship between provider role and system performance. The introduction of mid-level health practitioners, the specialization of medicine, and the changing role of nurses force the focus of attention on the nature of resource. Models which are used to examine these issues need to predict resource behavior as well as resource use.

INS COMPUTER PROGRAM

INS is coded in ANSI FORTRAN and written using a structured format. It features free format input, extensive output capabilities, and provides input and execution diagnostics. Its use requires no user programming and the network base provides a rich syntax.

The program is a product of four years of successive refinements of the active transaction-active resource network based simulation concept. Its development and support is provided by the Health Systems Research Group of the Regenstrief Institute for Health Care.

CONCLUSIONS

In INS resources are considered a separate, active entity which moves throughout the network from activity to activity servicing the demands of the transactions. Activities serviced by a resource may be sequential (i.e. performed in a sequence on one or more related transactions in a transaction set) or choice (i.e. where the resource has freedom of choice in initiating an activity).

Resource allocation in INS is performed using a two-stage process. Stage 1 is the transaction-initiated search for resources and is the resource allocation mechanism employed by the transaction when it is active. Stage 2 is the resource-initiated search for transactions and is the resource allocation mechanism employed by the resource when it becomes active. Stage 1 is initiated upon the transaction arrival while stage 2 is initiated upon resource arrival. An end of activity initiates the two stages sequentially. The processor furthermore employs mechanisms for handling multiple transactions and resources, reinitiating the stages as the motion of transactions and resources dictate. Detailed knowledge of the processor permits the modeler to orchestrate very complex systems of resources and transactions.

To implement the choice process employed by the stage 2 processor, INS depicts the decision making as a queue selection tree. The tree has several characteristics: (1) selector trees are not a part of the networks through which transactions flow; (2) each tree employs at least one selector node and can utilize more to model very complex decision processes; (3) the same selector tree can be referenced by any number of resources; (4) each queue referenced in the tree is associated with an activity specifying a (P) or (A) resource selection mode for the resource group the resource is in; (5) referencing queues (rather than activities) in the resource's queue selector tree enhance the modeling of priorities especially when multiple queues are served by the same resource at an activity; and (6) selection trees can be subtrees of other selection trees so that the complexity of the decision algorithm can be further enhanced.

Although other languages offer active transaction-oriented capabilities of considerable merit, INS provides for combining such capabilities with the direct modeling of active resources. This world view can further enhance the procedural modeling of complex systems and provide the model builder an expanded insight.

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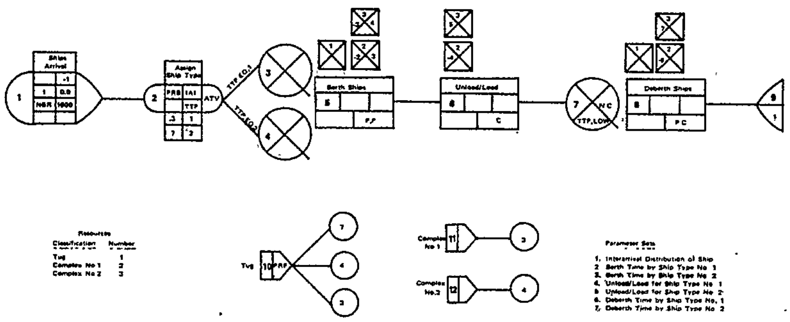


Figure 1-
Harbor Operation Problem

Resources

Classification	Number
Tug	1
Complex No 1	2
Complex No 2	3

Parameter Sets

1. Interarrival Distribution of Ship
2. Berth Time by Ship Type No 1
3. Berth Time by Ship Type No 2
4. Unload/Load for Ship Type No 1
5. Unload/Load for Ship Type No 2
6. Deberth Time by Ship Type No. 1
7. Deberth Time by Ship Type No 2

Figure 2:
Enriched Harbor Problem

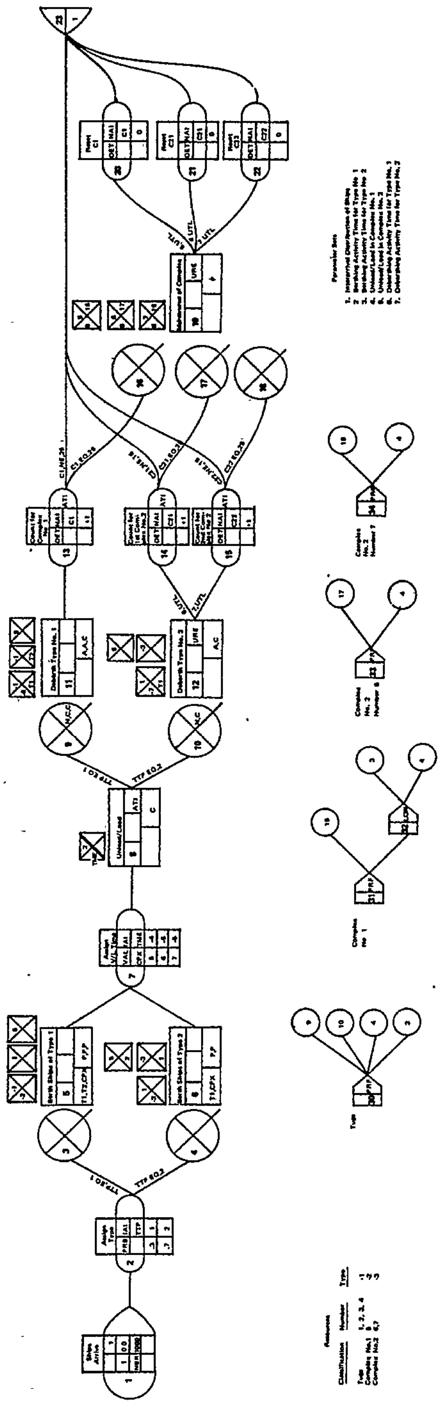
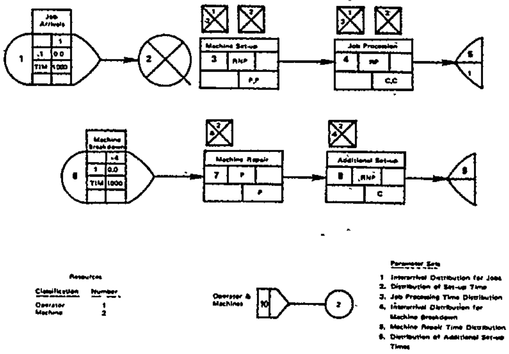


Figure 3.
Job Processing with Machine Subject to Breakdown



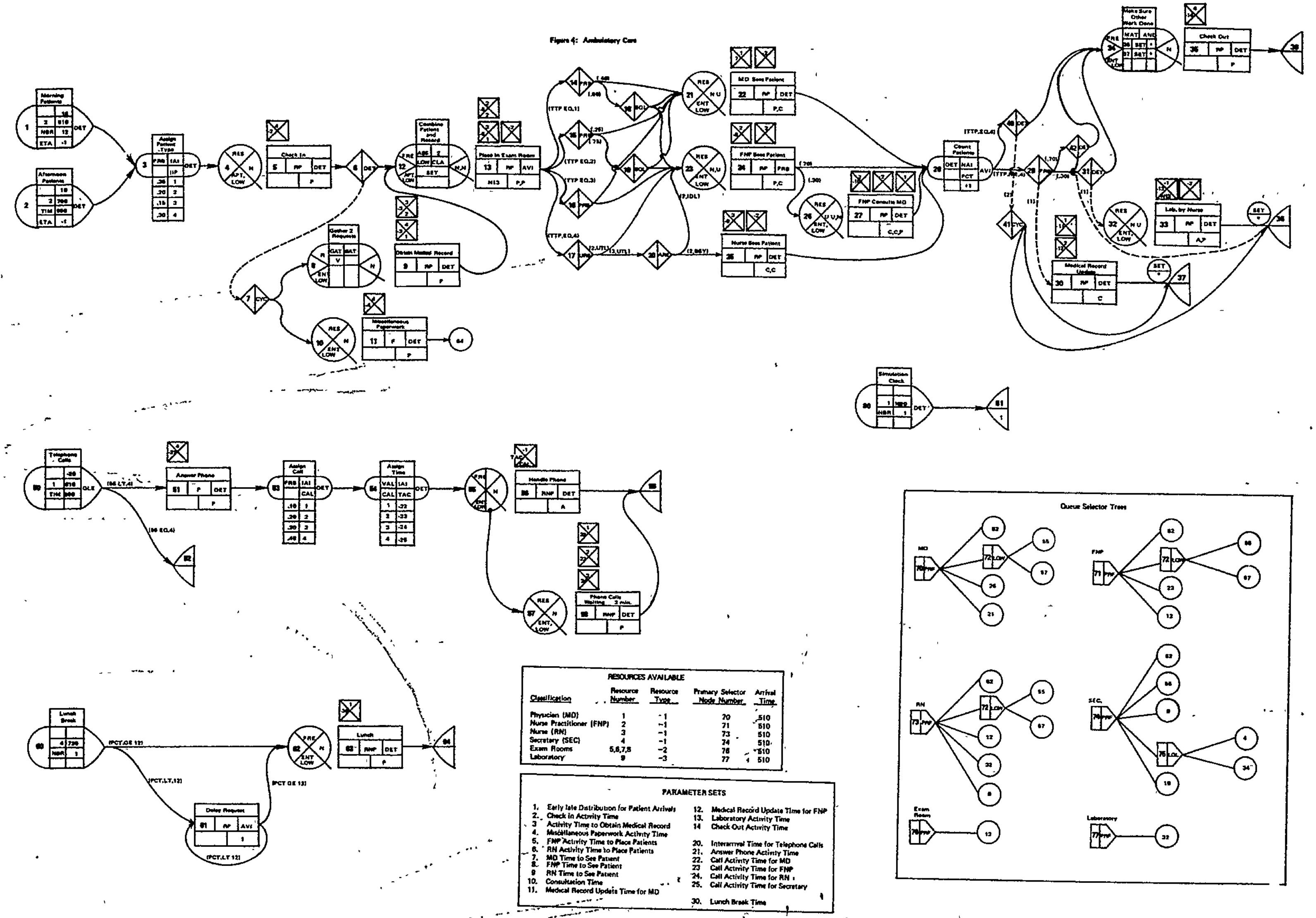


Figure 4: Ambulatory Care

RESOURCES AVAILABLE

Classification	Resource Number	Resource Type	Primary Selector Node Number	Arrival Time
Physician (MD)	1	-1	70	510
Nurse Practitioner (FNP)	2	-1	71	510
Nurse (RN)	3	-1	73	510
Secretary (SEC)	4	-1	74	510
Exam Rooms	5,6,7,8	-2	76	510
Laboratory	9	-3	77	510

PARAMETER SETS

1. Early late Distribution for Patient Arrivals
2. Check In Activity Time
3 Activity Time to Obtain Medical Record
4. Miscellaneous Paperwork Activity Time
5. FNP Activity Time to Place Patients
6. RN Activity Time to Place Patients
7. MD Time to See Patient
8. FNP Time to See Patient
9 RN Time to See Patient
10. Consultation Time
11. Medical Record Update Time for MD
12. Medical Record Update Time for FNP
13. Laboratory Activity Time
14 Check Out Activity Time

20. Interarrival Time for Telephone Calls
21. Answer Phone Activity Time
22. Call Activity Time for MD
23 Call Activity Time for FNP
24. Call Activity Time for RN
25. Call Activity Time for Secretary

30. Lunch Break Time