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A COMPUTERIZED TRANSPORTATION MODEL FOR THE NRC PHYSICAL PROTECTION PROJECT VERSIONS I AND II

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U. S. Nuclear Regulatory Commission

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Abstract

Details on two versions of a computerized model for the transportation system of the NRC Physical Protection Project are presented. The Version I model permits scheduling of all types of transport units associated with a truck fleet, including truck trailers, truck tractors, escort vehicles and crews. A fixed-fleet itinerary construction process is used in which iterations on fleet size are required until the service requirements are satisfied. The Version II model adds an aircraft mode capability and provides for a more efficient non-fixed-fleet itinerary generation process. Test results using both versions are included.

1.0 INTRODUCTION

A vital part of the system for safeguarding special nuclear material used in the nuclear fuel cycle is the transportation system for this material. In order to analyze the requirements for this transportation system, both in terms of size and security, a realistic computerized model of the system is required. This model must include all the major features of this transportation network, including the shipment schedule for the nuclear material, different transportation modes (truck, aircraft and trains), requirements for security escort vehicles, different maintenance requirements for trucks and escort vehicles, personnel assignment policies, and provisions for convoying trucks and escort vehicles. It must provide for both fleet sizing and system simulation. The fleet sizing problem is complicated by the large amount of flexibility in the shipping schedule and the varied maintenance requirements of the different transport unit elements, including personnel. Unfortunately, the maintenance requirements appear to preclude the application of previously developed fleet sizing algorithms based on integer linear programming.

Reference [1] presents an analysis of the problems that must be addressed in developing a computerized model of this transportation system, reviews previously developed methods for fleet sizing, and provides a recommended approach for the development of this computerized model.

An important aspect of our recommended approach is the decomposition of this problem, in part to increase computational efficiency. The bases for decomposition used are time (schedule over a limited time period), transportation mode (separately schedule trucks, aircraft and trains), transport unit elements (sequentially schedule truck trailers, truck tractors, escort vehicles and personnel), and, if needed, geography. Each step of the sequential scheduling process establishes a service requirement that must be covered by the next step. For example, the schedule of trucks assigned to cover the required shipments, in turn, defines a set of services to be covered by the assignment of drivers. A basic assignment mechanism for covering the required services has been identified which involves linking together services that can be sequentially handled by one transport unit element to form itineraries. This linking process includes a new approach for enforcing maintenance requirements.

Reference [1] also outlines an overall plan for the development of this model. The development will be carried out in a sequence of versions as described in Table 1.1. An overall model design has been identified which provides for this sequential development, so that each version is useful for a rational set of analyses. Furthermore, proceeding from one version to the next involves only refinements and/or additional modules rather than wholesale changes to previously developed code.

Version I provides for complete sizing of all transport unit types for a single mode (trucking), using a fixed-fleet oriented approach in which it will be necessary to iterate on the fleet size to find the required number of each type of transport unit element. A limited simulation capability without provision for breakdowns will also be provided.

Version II incorporates a non-fixed-fleet approach to sizing in which no iterations on fleet size are required. The capability for considering an aircraft mode in addition to the trucking mode is included.

Version III will extend the model to handle several modes (i.e.,

Table 1.1. Proposed model development.

Indicates New Or Modified Feature (boxed)				
COMPONENT FEATURES	VERSION 1	VERSION 2	VERSION 3	VERSION 4
Modes	[One]	[Two]	[Several]	Several
Transport Unit Elements	[Several]	Several	Several	Several
Convoying	No	No	[Yes]	Yes
Simulation	[Yes; No Breakdown]	Yes; No Breakdown	[Yes; With Breakdowns]	Yes; With Breakdowns
Sizing Options	[Fixed-Fleet Only]	[Fixed-Fleet and Non-Fixed Fleet]	Fixed-Fleet and Non-Fixed-Fleet	Fixed-Fleet and Non-Fixed-Fleet
Special Input/Output Options	None	None	None	[Automated Sensitivity Analyses]

rail and water in addition to trucks and aircraft), convoying, and to provide for breakdowns in the simulation.

Version IV will extend input and output options to simplify sensitivity analyses, i.e., provide for a succession of model runs and subsequent graphical displays.

This report presents details on the Versions I and II models of this transportation system. The capabilities and some test results for each of these versions are discussed respectively in Sections 2.0 and 3.0. Detailed presentations of the significant algorithms used in this model are presented in Section 4.0. Appendices give details of the data structures of the Versions I and II models, descriptions of each of the major subroutines, the sample shipment schedule used to test the model, and an example of a set of itineraries generated by the model.

2.0 DESCRIPTION OF VERSION I MODEL

The purpose of this section is to present a general description of the Version I model, and to outline its general capabilities and limitations. Detailed technical discussions of the important algorithms used in this model are presented in Section 4.0. The detailed data structures of the computer model are given in Appendix A, followed in Appendix B by descriptions of the operations of each of its major subroutines.

2.1 General Description

A simplified flow diagram for the Version I model of the transportation system is shown in Figure 2.1. The input which drives the model is the shipment schedule for the nuclear fuel cycle materials. In general, each individual shipment is specified by its origin base, destination base, earliest departure time, latest arrival time, material type, quantity of material, and any prespecified transportation requirements for that shipment (e.g., must be shipped in a specified truck-trailer type). The method for generating itineraries in the Version I model is based on a fixed-fleet approach in which the fleet size for a given transport unit element type is varied until the minimum fleet size is found which satisfies the service requirements. In order to provide a set of representative initial conditions for the fixed-fleet, the shipment schedule is expanded to include a "warm-up" period at the beginning to establish these initial conditions.

The next step is to partition this augmented shipment schedule by truck trailer type. In the Version I model the only criterion for this partitioning is the type of material being shipped.

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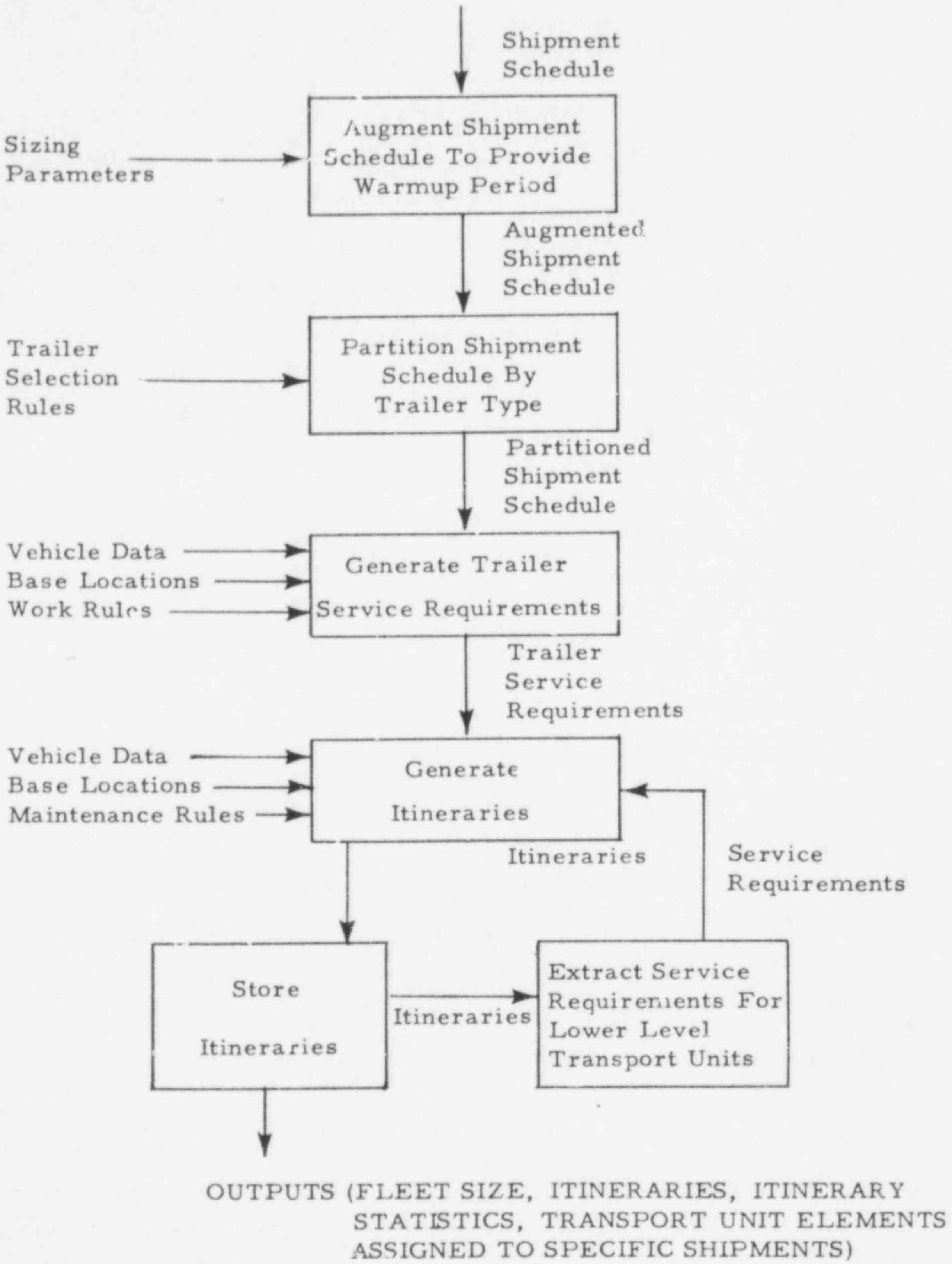

Figure 2.1. Simplified flow diagram for the Version I model.

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The partitioned shipment schedule is then combined with work rules (e.g., no working at bases on weekends) to generate the service requirements for each type of truck trailer. One set of service requirements will be generated for each truck trailer type, so that if three trailer types are being considered, three separate sets of service requirements will be generated.

The itineraries for each of the trailer types are then generated by a process of linking services together to form composite services. Technical details of this process are given in Section 4.1. The generation of these itineraries requires that iterations be performed on the trailer fleet size until the minimum number is found which satisfies the service requirements. An efficient search technique, which is described in Section 4.2, has been developed to speed this process of finding the minimum fleet size.

The truck trailer itineraries now levy requirements on lower level transport unit elements. For example, on both active and deadhead itinerary legs, each trailer must be pulled by a truck tractor. In addition, on active trailer itinerary legs, escort vehicles must be assigned. The service requirements imposed by the trailer itineraries on the lower level transport unit elements are extracted and the itineraries for these transport unit elements are generated. These new itineraries, in turn, levy service requirements on other lower level transport unit elements, e.g., crews. This process of sequentially generating itineraries and extracting services continues until the itineraries for all the transport unit element types have been considered.

Outputs provided by the model are the required number of each transport unit type, detailed itineraries for each transport unit element, statistics on the itineraries (e.g., percent of total distance

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traveled in active service), and the assignments of specific transport unit elements to each shipment.

2.2 Version I Capabilities

In this section the general capabilities of the Version I model are discussed.

2.2.1 Types of Transport Unit Elements

The Version I model is designed to provide both a sizing and simulation capability for a truck fleet to be used to transport material for the nuclear fuel cycle. Later versions will provide for a multi-mode capability, i.e., aircraft, railroad and water transportation modes in addition to the truck mode.

Up to nine types of transport unit elements can be considered. Each type is labeled by a number starting with 11 and ending with 19. Table 2.1 summarizes the numerical designations currently assigned to various transport unit elements. Of these the numbers 11 through 13 are reserved for types of truck trailers, while 14 through 19 can be used to designate specific types of truck tractors, escort vehicles and crews.

The user of this Version I model specifies the order in which the different types of transport unit elements are to be considered. For example, a sequence might be truck trailer type I (11), truck trailer type II (12), truck tractors (15), escort vehicles (16), and crews (17). It is also possible to require that two or more types of transport unit elements (e.g., truck trailers and tractors) always remain together as a unit. Details of the procedures for specifying the order in which the transport unit elements are to be considered are given in Section 4.4.

Table 2.1. Numerical designations of transport unit elements.

NUMBER	TRANSPORT UNIT ELEMENT
11	Truck Trailer Type I
12	Truck Trailer Type II
13	Truck Trailer Type III
14	(Unassigned)
15	Truck Tractors
16	Escort Vehicles
17	Truck/Escort Vehicle Crews
18	(Unassigned)
19	(Unassigned)

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2.2.2 Maintenance Procedures

The requirements for periodic maintenance of vehicles and rest breaks for personnel preclude the application of standard integer linear programming techniques to this model and, therefore, required that new techniques for fleet sizing be developed.[1] This section summarizes the maintenance procedures and options which are included in the Version I model for both vehicles and personnel.

2.2.2.1 Vehicle Maintenance Procedures

Vehicles require maintenance when either a specific time period has elapsed or the vehicle has traveled a specific distance since the last maintenance. The Version I model allows both these time and distance maintenance criteria to be specified. The vehicle must return to a base for maintenance before either of these limits is exceeded.

There are three ways in which maintenance bases can be designated for vehicles: (1) the vehicle must return to its home base for maintenance, (2) it can receive maintenance at the nearest maintenance base, or (3) there is only one maintenance base. The Version I model allows for specification of either a nearest-base or a single-base maintenance policy. There are a number of difficulties in providing for a home-base maintenance policy. Because of these difficulties, which are discussed in Section 4.5, an option for specifying a home-base maintenance policy is not included in either the Version I or Version II model but will be included in a later version.

2.2.2.2 Personnel Maintenance Policies

Generally drivers and guards will spend up to some maximum number of days on the road without a rest break at home base. Thus the criterion on which crew rest breaks are determined in the Version I model is the total time without such a break, which cannot exceed a specified amount.

It is mandatory that personnel be returned to their home bases for these rest breaks so that a home-base maintenance policy is required for the crews and guards. If there is only a single crew home base no difficulties arise. However, with multiple home bases many of the same difficulties arise as occur with a home-base maintenance policy for vehicles. In the Version I model a home-base policy for crews is approximated by a nearest-base maintenance policy. This approximation seems reasonable because the time required for a crew to travel to and from the nearest crew home base should be representative of the time it takes to travel to and from the actual home base, possibly via commercial airline. The implications of a home-base maintenance policy are discussed in more detail in Section 4.5.

2.2.3 <u>Work Rules</u>

Work rules for personnel located at bases and traveling on the road can have significant impact on the fleet size and the resultant itineraries.

Specific quantities that can be designated by the user of the Version I computer model are the length of the working day in hours at bases and on the road. In the model the working day on the road is used as a basic time unit.

The user is also able to specify whether or not loading and unloading trailers is permitted on Saturdays, Sundays, and holidays. Similar restrictions can be imposed for traveling with a load on weekends and holidays. However, the Version I model has no provision to prohibit an empty trailer from traveling on weekends and holidays.

2.2.4 Itinerary Optimization Criteria

In the Version I model, itineraries are generated by linking together services to form composite services which are themselves then used in the linking process. At each step the feasible linkings are ranked in a candidate linking list according to an optimization criterion which is called a "linking value function". The linking with the best linking value is selected, saved to be used as part of an itinerary, and then deleted from the candidate linking list.

The linking value function in the Version I model is a linear combination of

(1) added deadhead time in the linking

(2) added idle time in the linking

(3) loss of flexibility in the composite service compared to the flexibility in the two linked services

(4) length (in time) of the first service to be linked

(5) length (in time) of the second service to be linked.

The first two criteria penalize added deadhead and idle time, both of which are undesirable from the viewpoint of efficient fleet utilization. The loss of flexibility penalty term is also very important in the generation of efficient itineraries. By retaining as much flexibility as possible in the composite services as the linking process proceeds, more feasible linkings are available for consideration toward the end of the linking process. This wider choice of feasible linkings potentially allows more minimization of idle and deadhead time, resulting in a more efficient set of itineraries. The importance of this penalty term on loss of flexibility is discussed in detail in Section 2.2. The last two terms in the linking value function which penalize the length of the two individual services in the candidate linking are included to force balanced itineraries to be generated.

The user of the Version I model is able to control the itinerary generation process by specifying the weightings to be placed on each of these penalty factors in the linking value function.

2.2.5 Fleet Sizing Option

The Version I model is basically designed as a tool to study the fleet size required to handle shipments of the nuclear fuel cycle materials. The driving input which probably has the greatest effect on the fleet size is the shipment schedule. Within the shipment schedule itself the flexibility in possible shipping dates has a major impact on the fleet size.

The fleet size is also affected by the sequence in which the types of transport unit elements are considered, the maintenance procedures, the work rules, and the linking value function, all of which are controlled by the user.

Recall that this model builds itineraries using a fixed-fleet approach, which requires the specification of the initial conditions for the transport unit elements. To reduce the effect of arbitrary selection of initial conditions on fleet size, provision is made for a warm-up period to be attached to the beginning of the schedule to establish reasonable initial conditions. The shipments in this warm-up period are obtained by taking all the shipments in a specified interval of the original schedule. The length of the warm-up period and the portion of the original schedule from which the warm-up shipments are extracted are under the control of the user. At the start of the warm-up period the transport unit elements are randomly distributed among the maintenance bases with random amounts of accumulated use, i.e., distance traveled and time since last maintenance. Transport unit element usage statistics are not collected during the warm-up period, but only for the actual shipment schedule.

The user is also able to specify the desired planning horizon. This option could be used when it is not necessary to use the complete shipment schedule for sizing studies. Specification of a planning horizon causes the model to ignore those shipments with earliest shipping dates after the planning horizon date.

2.2.6 Simulation Option

The Version I model provides a limited simulation capability. This capability allows a user to examine the effect of a specified fleet size, which may be greater than the minimum, on the resulting itineraries. In addition, the initial conditions on the transport unit elements can be either specified or can be generated using a warm-up period as is done in the fleet sizing option.

2.3 Version I Test Results

In order to test the Version I model, a sample schedule consisting of 152 individual truckload shipments of nuclear material was used. The earliest shipment dates in this sample shipment schedule are distributed over a period of 88 days. Flexibility in shipping dates was set at 21 days for about 75 percent of the shipments and at 7 days for the remainder. This sample shipment schedule is given in Appendix B. The reason for using this sample schedule is that fleet sizing results using the TRUCKING I algorithm [2] are available for comparison with the Version I results. The length of the warm-up interval used with this shipment schedule and the Version I model was only two days, and consisted of three shipments with a total additional distance service requirement of 680 km.

In this section we first discuss test results which compare the Version I results with those obtained with the TRUCKING I algorithm. Then we present an analysis of the effect of the loss of flexibility penalty term in the linking value function on the fleet size and itineraries attained with the Version I model.

2.3.1 Comparison with TRUCKING I Algorithm

Table 2.2 summarizes the maintenance, work, and vehicle parameters assumed with the sample shipment schedule for the application of the TRUCKING I algorithm. These same parameters were used in testing the Version I model. Although the maintenance intervals for the tractors and the trailers are different, the TRUCKING I algorithm was run in a mode which requires the tractor and trailer fleet sizes to be the same. The result was a fleet size of three for each. Table 2.3 summarizes some of the statistics for the itineraries

Table 2.2. Assumed sizing parameters.

Ave. Vehicle Speed	55 km/hr (35 mi/hr)
Length of working day	24 hrs
Length of working day on road	24 hrs
Weekend/Holiday working restrictions	none
Maximum distance for a trailer without maintenance	40,232 km (25,000 mi)
Maximum distance for a tractor without maintenance	12,874 km (8,000 mi)
Trailer maintenance time	4 days
Tractor maintenance time	2 days
Loading time	2 hrs
Unloading time	2 hrs

Table 2.3. Statistics from runs with TRUCKING I algorithm.

Trailer	km Total	km Full	km Empty	km Travel to Maintenance	Days in Maintenance	Days Idle
1	57,878	14,588	38,469	4,821	6.9	19.3
2	60,720	14,497	37,740	8,483	6.7	21.0
3	54,148	13,385	35,364	5,399	10.5	21.1
Ave	57,582	14,157	37,191	6,234	8.1	20.5

Percent of Total km Full 24.6

Percent of Total Days Idle 22.7

Total Active (full) Distance 42,470 km

Tractor	km Total	km Full	km Empty	km Travel to Maintenance	Days in Maintenance	Days Idle
1	56,528	15,586	33,536	7,406	10.4	17.8
2	61,624	12,918	41,887	6,819	12.7	12.7
3	54,595	13,966	36,150	4,479	12.0	20.5
Ave	57,582	14,157	37,191	6,234	11.7	17.0

Percent of Total km Active 24.6

Percent of Total Days Idle 18.9

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generated using the TRUCKING I algorithm. Note that 24.6 percent of the distance traveled by the fleet was on active service, i.e., the trailer was loaded.

The Version I model was first employed to sequentially schedule the truck trailers and tractors without the restriction that the trailer and tractor fleet sizes be the same. The result was two trailers and four tractors required to handle the shipment schedule compared to three each with the TRUCKING I algorithm. Table 2.4 presents the statistics for these itineraries while Figure 2.2 depicts the resulting itineraries. The percent of total kilometers that the trailers are on active service (i.e., loaded) is 42.6 compared to 24.6 for the TRUCKING I itineraries.

A comparison of the statistics from the TRUCKING I runs (Table 2.3) with those for Version I (Table 2.4) reveals that the total distance traveled by loaded trailers (i.e., active service) is 42,470 km for TRUCKING I and 48,052 km for the Version I model. These two figures should actually be equal since the total distance that the trailers travel loaded is a function only of the shipping schedule. The reason for this difference is the different means employed to calculate distances between bases in the two algorithms. The TRUCKING I program employs a Rand-McNally computer tape which provides accurate road distances between major cities. In contrast, the Version I model approximates the road distance by multiplying the calculated great circle distance by a penalty factor. For the runs presented in this report, the penalty factor used was 1.2, so that the road distance was calculated from

$$\text{RD. DIST.} = 1.2\ (\text{GT. CIRCLE DIST.})$$

Since the total active distance with the Version I model is about 13 percent greater than the actual distance, reducing this factor to about 1.06

Table 2.4

Statistics from Version I run which sequentially scheduled trailers and tractors (linking value penalties: trailers, idle - 10, deadhead - 1, flexibility loss - 0.1; tractors, idle - 1, deadhead - 1).

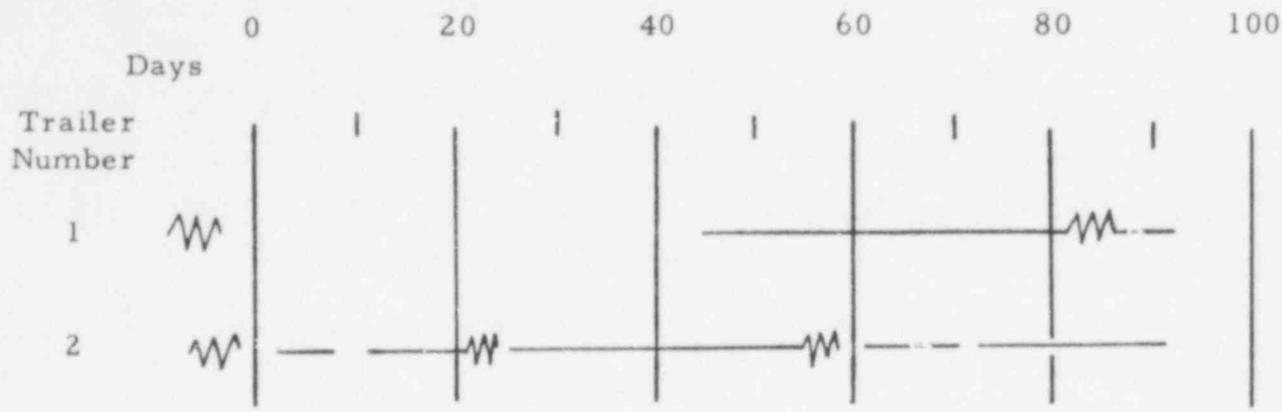
Trailer	km Total	km Active	km Deadhead	Days in Maintenance	Days Idle
1	41,357	18,036	23,321	4	47
2	71,445	30,016	41,429	8	12
Ave	56,401	24,026	32,375	6	30

Percent of Total km Active	42.6
Percent of Total Days Idle	32.8

Tractor	km Total	km Active*	km Deadhead	Days in Maintenance	Days Idle
1	18,160	17,095	1,065	2	71
2	38,090	33,533	4,557	8	45
3	52,963	48,534	4,430	8	30
4	15,512	13,638	1,874	2	76
Ave	31,181	28,200	2,981	5	56

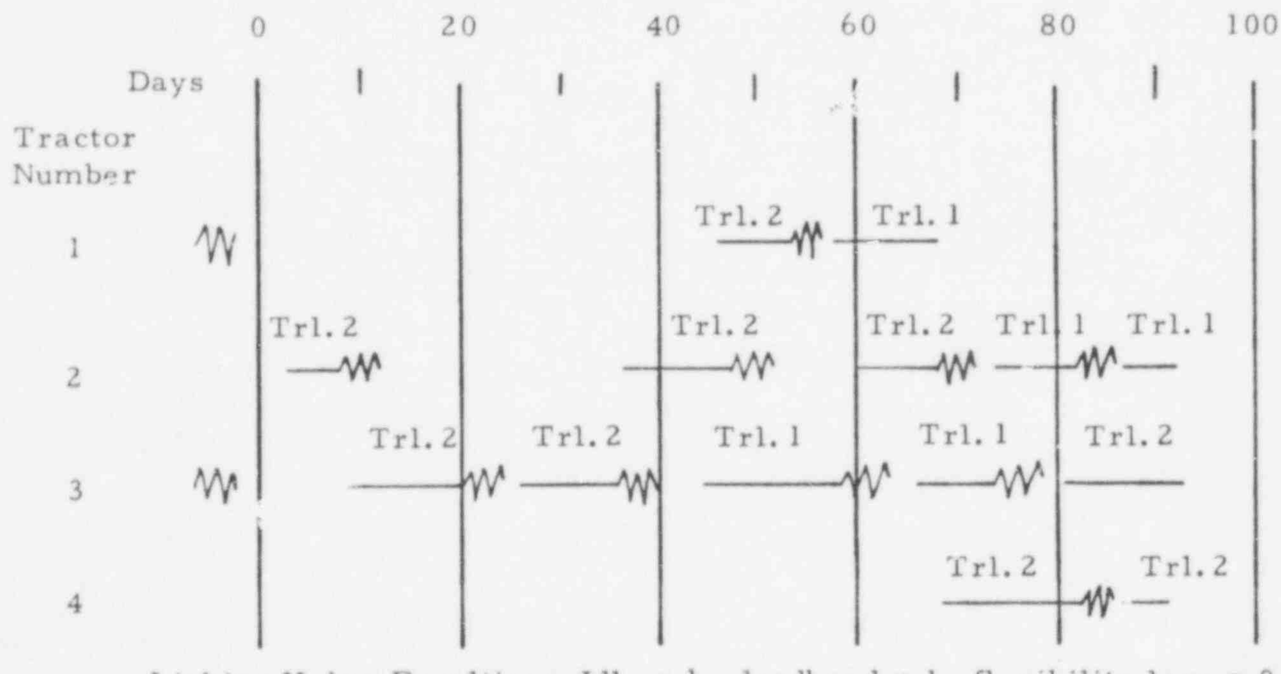
Percent of Total km Active*	90.4
Percent of Total Days Idle	61.3

*Active service for tractors is defined to be when trailers are being pulled, whereas deadhead service is defined to be when the tractors are traveling without towing a trailer.



Linking Value Penalties: Idle = 10, deadhead = 1, flexibility loss = 0.1.

(a) Trailer itineraries.



Linking Value Penalties: Idle = 1, deadhead = 1, flexibility loss = 0.

(b) Tractor itineraries.

——— = Active or deadhead service ⩘W = Maintenance

Figure 2.2. Trailer and tractor itineraries from Version I model when the trailers and tractors are sequentially scheduled. On the tractor itineraries, the trailer being serviced on each leg is labeled.

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should provide a more accurate representation of road distance for this shipment schedule.

A study of the itineraries in Figure 2.2 reveals that one tractor serves one trailer itinerary until either the tractor requires maintenance, the trailer requires maintenance, or the trailer starts an idle period. Note that it is almost possible to merge tractor itineraries 1 and 4 to form one longer itinerary. The last active service for tractor itinerary 1 ends at day 68.9 at base TMI (Harrisburg, PA), while the first active leg of itinerary 4 starts at day 71.6 at base BRL (Baton Rouge, LA). The merging of these two itineraries, however, requires a four day maintenance stop which precludes this possibility. If a less conservative penalty factor on great circle distance was used to approximate road distance, it is likely that the tractor requirements would be reduced to three since either a backward shift of itinerary 1 or a forward shift of itinerary 4 of 3 days would allow them to be merged into one composite itinerary.

The linking value penalties used in generating the trailer itineraries were 10.0 for idle time, 1.0 for deadhead time, and 0.1 for loss of flexibility. The logic used in weighting the idle time more heavily than deadhead time is that choosing feasible linkings with the least amount of idle time should produce compact composite services which, in turn, can be linked to give the minimum number of itineraries and fleet size. The weighting penalty on the loss of flexibility is discussed in Section 2.3.2.

The trailer itineraries levy service requirements on the truck tractors. These service requirements have no flexibility since all the flexibility in the original shipment schedule was removed in constructing the trailer itineraries. Because both the active and deadhead legs of the trailer itineraries levy service requirements for tractors, a

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large number of feasible tractor service linkings have zero idle and deadhead time. Each such linking has a linking value of zero when the only quantities penalized in the linking value function are idle and deadhead times, as is the case here. These linkings are always chosen as long as maintenance rules are not violated, regardless of the specific penalties on idle and deadhead time. This is the reason why a specific tractor tends to service one trailer itinerary until the tractor requires maintenance. The specific linking value penalties used were 1.0 for both idle and deadhead time. The reason for choosing equal weightings on the idle and deadhead times is that both are equally undesirable in the generation of good tractor itineraries. Because of the large number of feasible linkings with a zero linking value, the sensitivity of the tractor itineraries to changes in these idle and deadhead time penalties is probably very small.

In order to provide another comparison of the Version I results with TRUCKING I, itineraries were generated using the Version I model in which specific trailer/tractor combinations were assumed to remain together at all times. This is accomplished by requiring each tractor/trailer combination to go to maintenance before 12,874 km has been traveled (the tractor requirement) and to then remain in maintenance for four days (the trailer requirement). The linking value penalties used were the same as those used for the scheduling of the trailers alone, with the logic for this choice the same as discussed earlier. The resulting tractor/trailer fleet size is three, the same as found with TRUCKING I. The itineraries are shown in Figure 2.3 and the itinerary statistics are summarized in Table 2.5. The Version I itineraries have 40.5 percent of the total distance traveled on active (i.e., useful) service, as opposed to 24.6 percent for TRUCKING I. This indicates a more efficient utilization of the truck fleet in the

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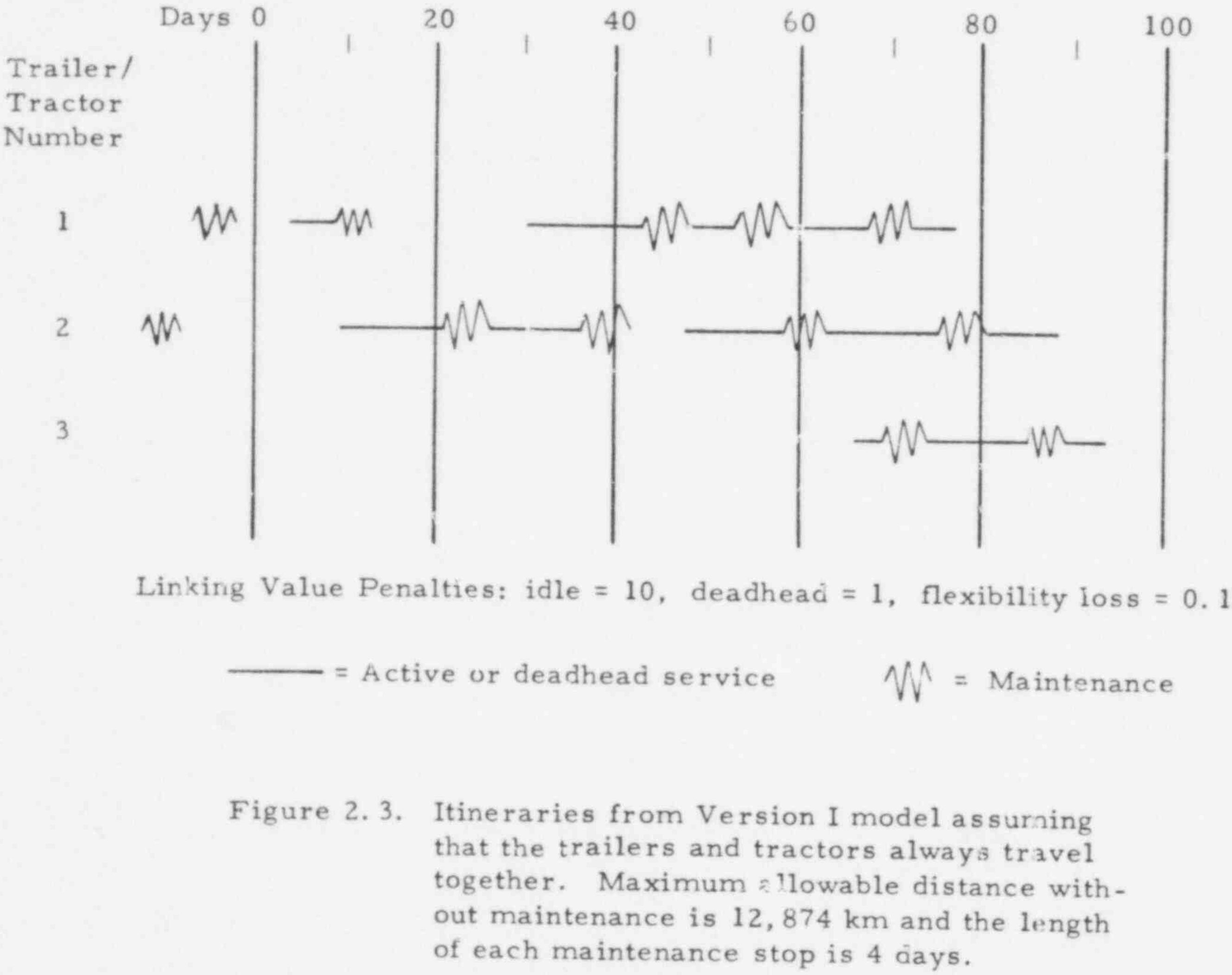

Figure 2.3. Itineraries from Version I model assuming that the trailers and tractors always travel together. Maximum allowable distance without maintenance is 12,874 km and the length of each maintenance stop is 4 days.

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Table 2.5

Statistics from Version I run which required trailers and tractors to travel together (maximum allowable distance without maintenance is 12,874 km and the length of each maintenance stop is four days). Linking value penalties: idle - 10, deadhead - 1, flexibility loss - 0.1.

Tractor/ Trailer	km Total	km Active	km Deadhead	Days in Maintenance	Days Idle
1	39,085	14,315	24,770	16	35
2	56,718	22,755	33,963	16	17
3	22,813	10,981	11,832	8	66
Ave	39,539	16,017	23,522	13	39

Percent of Total km Active 40.5

Percent of Total Days Idle 42.9

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Version I itineraries. Note that itineraries 1 and 3 have about a 12 day overlap between days 66 and 78. Since itinerary 2 is also active during this period, this indicates that the requirements for trucks is greater during this part of the shipment schedule. This is also confirmed by the trailer itineraries in Figure 2.2a.

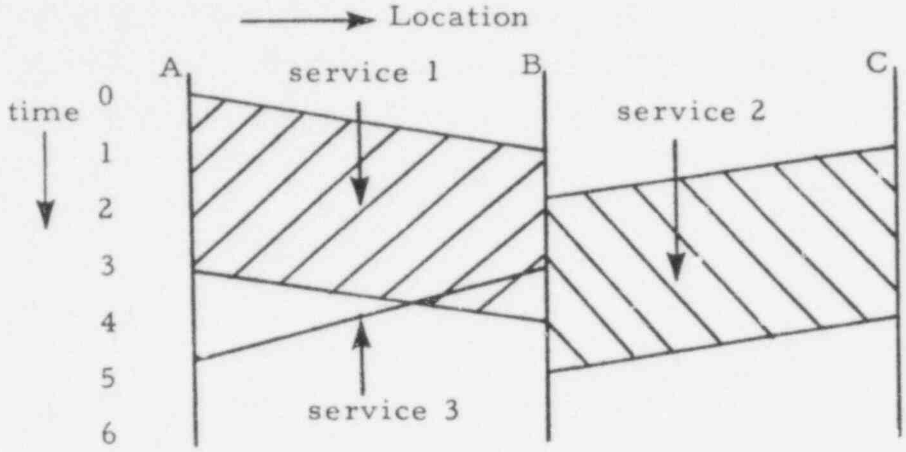
If escort vehicles are assumed to have the same maintenance requirements as truck tractors, the itineraries generated by considering the tractor/trailer combination can be interpreted to be the itineraries for trailers, tractors, and escort vehicles which are required to always remain together. Again three of each of these transport unit elements are required to handle the sample shipping schedule.

An important observation from these results is that in some cases it may be preferable to require two or more types of transport unit elements to travel together. For example, if specific tractor/trailer combinations are required to remain together, a total of three tractor/trailer combinations are required to handle the shipment schedule, whereas two trailers and four tractors are required when the trailers and tractors are sequentially scheduled. If tractors are more expensive than trailers, a less expensive transportation fleet results when the trailers and tractors are assumed to remain together in the scheduling process. Even though the maintenance requirements for the tractor/trailer combinations are more severe than either the tractors or trailers considered separately, a lesser tractor fleet size is obtained because the flexibility in the schedule allows itineraries to be generated which are, in a sense, optimized for the tractor/trailer combination maintenance requirements. In contrast, when these transport unit elements are sequentially scheduled, the flexibility in the schedule is used to optimize only the trailer itineraries, regardless of the other types of transport unit elements to be scheduled later. This is the reason why four tractors are required to service the two trailer itineraries.

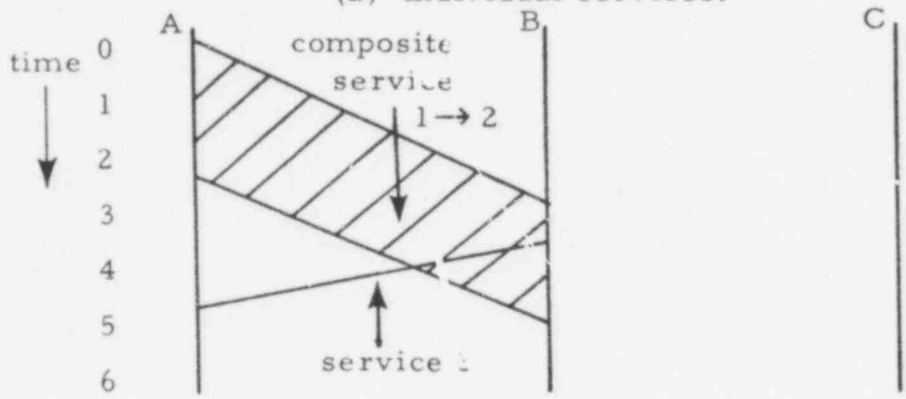
2.3.2 Effect of Penalty on Flexibility Loss

Some early Version I test runs for scheduling trailers were made using the sample shipment schedule without any penalty on loss of flexibility in the linking value function. The resulting itineraries tended to have short periods of active and deadhead time, separated by many short idle periods. This usually resulted in a larger fleet size. However, including a small penalty for loss of flexibility in the linking value function produced more efficient itineraries in which there were long periods of active and deadhead service with few idle periods. The itineraries in Figures 2.2a and 2.3 illustrate this effect.

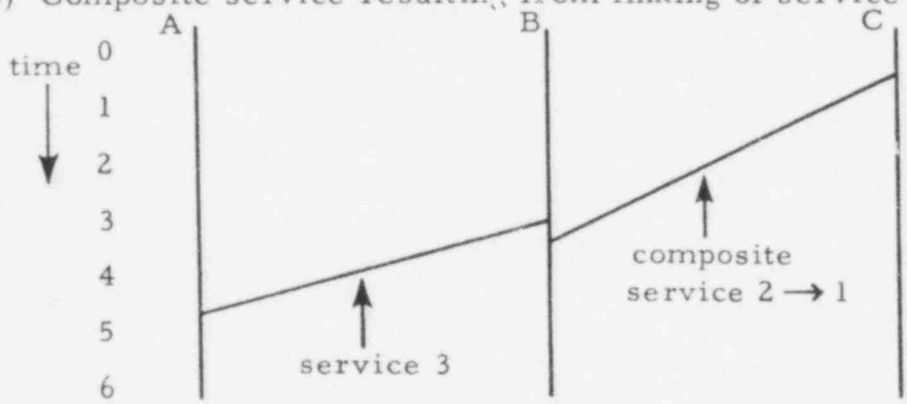
To explain the effect of this flexibility-loss penalty, consider the three service requirements shown in Figure 2.4a. Service 1 is a shipment from location A to B with an earliest shipment date of 0 and a latest shipment date of 3 for a flexibility of 3 days. Shipment 2 from location C to B has an earliest shipment date of 1 and a latest shipment date of 4 for a flexibility of 3 days. Shipment 3 from B to A starts at 3.5 with zero flexibility. Assume that the distances from A to B and from B to C are exactly the same, and that the corresponding travel times (both active and deadhead) are exactly one day. Now consider the possible ways in which services 1 and 2 can be linked. First consider linking of 1 followed by 2. This requires a one day deadhead from B to C to pick up shipment 2. The resulting composite service is shown in Figure 2.4b. This composite service has an earliest service time of 0 days, a composite service time of 3 days (1 day for service 1, 1 day for service 2, and 1 day deadhead from B to C), and a flexibility of 2 days. Note that now service 3 can be linked to this composite service so that a fleet size of one is adequate to handle these three services.



(a) Individual services.



(b) Composite service resulting from linking of service 1 followed by 2.



(c) Composite service resulting from linking of service 2 followed by 1.

Figure 2.4. Example illustrating effect of flexibility loss penalty in linking value function.

Consider the linking value penalty for linking of services 1 followed by 2. Assuming penalties of one for both idle and deadhead, and zero for flexibility loss, the linking value is 1 due to the deadhead from B to C.

Next consider the linking of service 2 followed by service 1. This requires a deadhead from B to A to handle service 1. The resulting composite service, shown in Figure 2.4c, has a zero flexibility. Since this composite service ends at B at time 4 days, it <u>cannot</u> be linked with service 3 which starts at 3.5 days. However, the linking value for this composite service is 1, the same as was obtained by the linking of service 1 followed by 2, even though the latter choice is more desirable for the building of efficient itineraries.

The tie between these two choices of linkings services 1 and 2 can be broken by including in the linking value function a penalty for loss of flexibility. This flexibility loss is defined by

$$\text{(Flex. loss)} = 1/2(\text{Flex. of service 1} + \text{Flex. of service 2}) - (\text{Flex. of composite service})$$

For the composite service obtained by linking service 1 followed by 2, the flexibility loss is

$$\text{(Flex. loss, 1-2)} = 1/2(3 + 3) - 2 = 1$$

For the composite service of service 2 followed by 1, we have

$$\text{(Flex. loss, 2-1)} = 1/2(3 + 3) - 0 = 3$$

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Therefore, if we include a flexibility loss penalty in the linking value function, the more desirable linking of 1 followed by 2 will be chosen since it has the lesser of the two penalties.

Including this loss of flexibility penalty in the linking value function allows flexibility to be retained in the composite services as the linking process proceeds. Thus more feasible linkings are available toward the end of the linking process permitting those linkings which minimize idle and deadhead time to be selected. This then results in a more efficient set of itineraries.

3.0 DESCRIPTION OF VERSION II MODEL

The Version II model incorporates all the features of the Version I model. In addition, it provides for both truck and aircraft transport modes, and allows for selection of a more efficient non-fixed-fleet itinerary construction method. This section provides a general description of the Version II model and a discussion of its capabilities. Emphasis is placed on the additional capabilities of the Version II model compared to Version I. Test results using the Version II model are presented in Section 3.3. This includes a comparison of itineraries obtained using the non-fixed-fleet approach of Version II with those generated using the fixed-fleet approach.

3.1 General Description

A simplified flow diagram of the Version II model is shown in Figure 3.1. Comparing this flow diagram with the flow diagram for the Version I model shown in Figure 2.1, the following improvements contained in the Version II model can be noted:

(1) The user has a choice of selecting a fixed-fleet or a non-fixed-fleet option for generating itineraries. Selection of the non-fixed-fleet option bypasses the step which augments the shipping schedule with a warm-up period.

(2) The shipment schedule is first partitioned by mode, i.e., each shipment is assigned to either the truck mode or the aircraft mode. Then the schedule is further partitioned by aircraft type for the aircraft mode and by trailer type for the truck mode. This partitioned schedule is then used to generate service requirements for the aircraft and truck trailers.

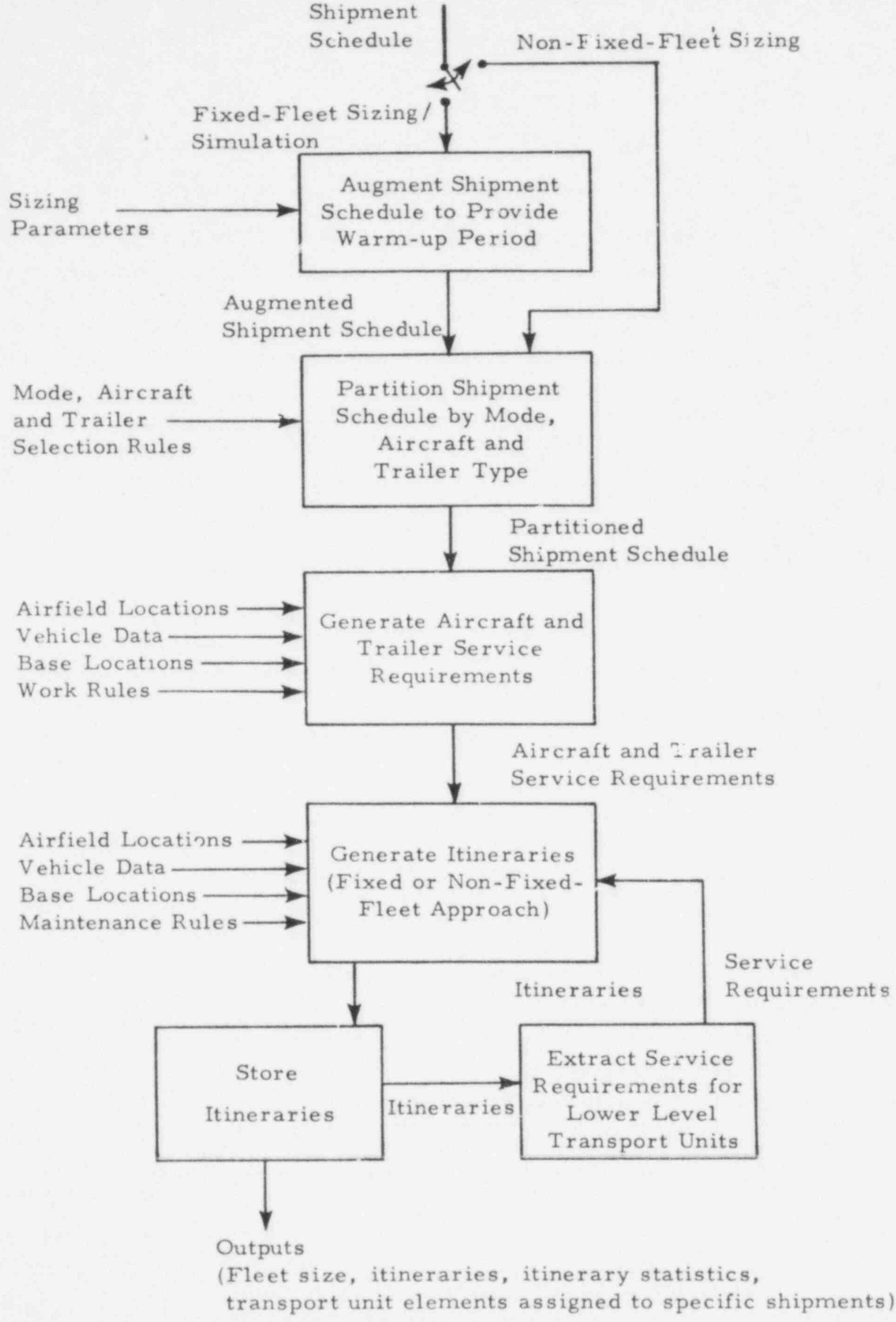

Figure 3.1. Simplified flow diagram for the Version II model.

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The itineraries for the aircraft are generated first. These aircraft itineraries then impose service requirements on the truck trailers because of the need to transport the shipments between the bases and airfields. In addition, truck trailers must be provided to handle the shipments assigned to the truck mode.

The aircraft itineraries now levy requirements for assignment of aircraft crews and guards, while the trailer itineraries place requirements for the tractors and escort vehicles. In turn, the tractors and escort vehicle itineraries require the assignment of crews.

3.2 Version II Capabilities

In this section the general capabilities of the Version II model which are not provided in the Version I model are discussed. The provisions for maintenance procedures, work rules and itinerary optimization criteria are identical to the Version I model and are covered in Sections 2.2.2 through 2.2.4. The simulation option, discussed in Section 2.2.6, is also the same since it requires the selection of the fixed-fleet itinerary construction process.

3.2.1 Types of Transport Unit Elements

The Version II model provides for an aircraft mode capability in addition to the truck mode. Up to nine types of transport unit elements associated with the aircraft mode can be considered. Each type is labeled by a number starting with 21 and ending with 29. Table 3.1 summarizes the numerical designations currently assigned to the aircraft transport unit elements. Of these numbers, 21 through 23 are reserved for specific types of aircraft.

The itineraries for the aircraft must be generated before those for the truck trailers because the aircraft itineraries levy service requirements for truck trailers to transport the material between the bases and airfields. These service requirements have no flexibility since all of the flexibility in the original shipments designated for the aircraft mode were used in the generation of the aircraft itineraries. To illustrate these trailer service requirements resulting from the aircraft itineraries, consider an active leg of an aircraft itinerary. This leg starts at time s_a when the loading of the material onto the aircraft commences. The truck trailer used to transport this material from the base to the airfield must then be scheduled so that the material can be loaded onto the trailer at the base, the trailer can travel to the airfield, and it can be off-loaded at the airfield, with off-loading being complete at s_a, the time that loading of the aircraft commences.

The user of the Version II model specifies the order in which the different types of transport unit elements are to be considered, subject to this restriction that the aircraft itineraries be generated before the truck trailer itineraries. Complete details on these ordering procedures are given in Section 4.4.

Table 3.1. Aircraft mode transport unit designations.

Numerical Designations	Transport Unit Element
21	Aircraft Type 1
22	Aircraft Type 2
23	Aircraft Type 3
24	undesignated
25	undesignated
26	undesignated
27	Aircraft Crews
28	Aircraft Guards
29	undesignated

3.2.2 Fleet Sizing Option

An important capability of the Version II model is the option to select a non-fixed-fleet itinerary construction process where the conditions at the end of the planning interval are used as initial conditions at the beginning. The motivating factor in this approach is that these terminal conditions should provide a representative set of initial conditions for the transport unit element type under consideration. The resulting connection of the terminal and initial conditions effectively results in a set of closed itineraries. The selection of this non-fixed-fleet option eliminates the need to provide for a warm-up period in the schedule to reduce the effects of arbitrary selection of initial conditions. The user still specifies the desired planning horizon in the non-fixed-fleet approach.

The major advantage of the non-fixed-fleet approach is that it is much more efficient from the viewpoint of computer time than the fixed-fleet approach. The reason for this is that with the fixed-fleet approach the iterations on the fleet size require that itineraries for each type of transport unit element be generated until the number of itineraries equals the specified fleet size. This generally requires that itineraries be generated three times for each type of transport unit element. In contrast, with the non-fixed-fleet approach no iterations on fleet size are required and the itineraries for each type of transport unit element must be generated only once. Technical details on this non-fixed-fleet approach are given in Section 4.1.

3.3 Version II Test Results

Three types of tests were made with the Version II model. The first was to employ the non-fixed-fleet sizing option to schedule the trailers and tractors to provide a comparison with the TRUCKING I results and the fixed-fleet results of Version I, which were presented in Section 2.3. Then the tractors and trailers were required to travel together and the restriction of no loading or unloading on weekends was imposed. The final test checked the multimode capability in which aircraft and truck trailers were sequentially scheduled.

3.3.1 Comparison of Non-Fixed-Fleet Option, Fixed-Fleet Option and TRUCKING I

The non-fixed-fleet sizing option was employed to sequentially schedule the trailers and tractors to satisfy the sample shipment schedule. The statistics of the resultant itineraries are given in Table 3.2 and the itineraries are depicted in Figure 3.2. Note that the resultant fleet size is three trailers and three tractors. Trailer itinerary 2 is very short and starts at day 85.5 at DJI (Morris, IL), while itinerary 3 comes out of maintenance on day 85.2 at HNC (Youngsville, NC). The resulting fraction of a day between the end of itinerary 3 and the start of itinerary 2 is not quite sufficient to allow a deadhead leg to merge these two itineraries. It is expected that reducing the conservative penalty factor in the road distance calculation (see Section 2.3.1) or expanding the planning horizon slightly would make this merger feasible, thereby reducing the required trailer fleet size to two.

It is interesting to note that three tractors are required compared to four for the fixed-fleet approach. However, this is not significant since, as was discussed in Section 2.3.1, a small change

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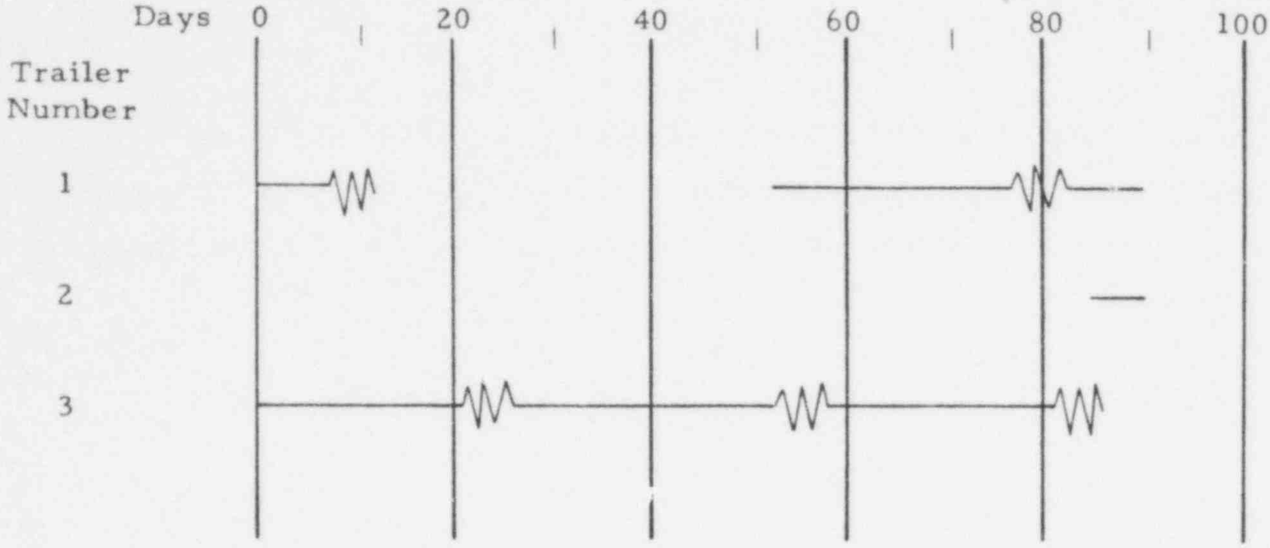
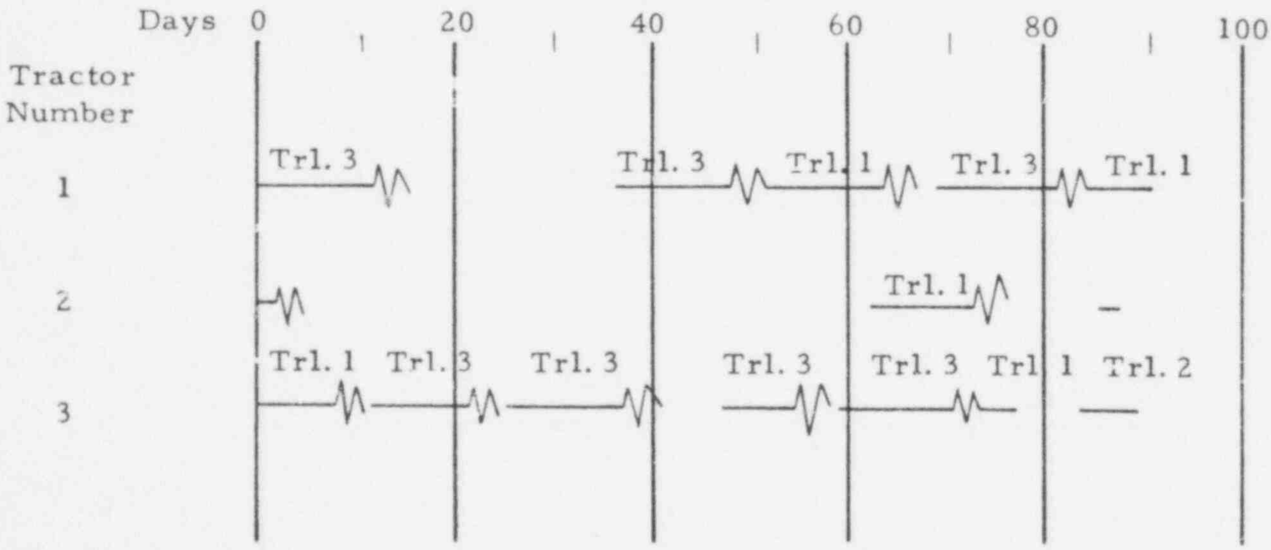


Linking Value Penalties: idle = 10, deadhead = 1, flexibility loss = 0.1



Linking Value Penalties: idle = 1, deadhead = 1, flexibility loss = 0.1

——— = Active or deadhead service   /\/\/\ = Maintenance

Figure 3.2. Trailer and tractor itineraries using non-fixed fleet itinerary construction process wl. trailers and tractors are sequentially scheduled.

Table 3.2

Statistics from non-fixed-fleet runs in which trailers and tractors are sequentially scheduled (linking value penalties: trailers, idle - 10, deadhead - 1, flexibility loss - 0.1; tractors, idle - 1, deadhead - 1).

Trailer	km Total	km Active	km Deadhead	Days in Maintenance	Days Idle
1	41,330	18,250	23,080	8	43
2	6,407	2,545	3,862	0	85
3	73,572	27,476	46,096	12	5
Ave	40,436	16,090	24,346	7	44

Percent of Total km Active 39.8

Percent of Total Days Idle 49.2

Tractor	km Total	km Active*	km Deadhead	Days in Maintenance	Days Idle
1	57,474	51,366	6,108	8	29
2	13,087	10,586	2,501	4	73
3	73,572	56,862	5,488	10	21
Ave	44,304	39,605	4,699	7	41

Percent of Total km Active* 89.4

Percent of Total Days Idle 45.6

*Active service for tractors is defined to be when trailers are being pulled, whereas deadhead service is defined to be when the tractors are traveling without towing a trailer.

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in the road distance penalty factor should reduce the fixed-fleet tractor fleet size by one.

The non-fixed-fleet option was also tested for the case in which the tractors and trailers are always required to remain together. The resulting statistics and itineraries are given in Table 3.3 and Figure 3.3, respectively. The required fleet size is four. As in some of the earlier cases considered, it is almost possible to combine two of the itineraries into one composite itinerary to reduce the fleet size by one. In this case the last active service in itinerary 2 ends at day 72.5 at base PPM (Bourne, MA), while itinerary 4 starts at day 72.8 at base DJI (Morris, IL). There is not sufficient time for a deadhead leg from Bourne, MA, to Morris, IL to merge these itineraries. Again it is likely that a reduction of the road distance penalty factor would allow these itineraries to be merged. Note that 37.9 percent of the total distance traveled is on active service as compared to 24.6 for TRUCKING I and 40.6 for the fixed-fleet option.

3.3.2 Effect of Weekend Loading/Unloading Restrictions

The non-fixed-fleet option was used to investigate the effects of not allowing loading or unloading of the trailers on weekends. In this case the trailers and tractors were required to always remain together. The statistics of the resulting itineraries are presented in Table 3.4 and the itineraries themselves are shown in Figure 3.4. The resulting required fleet size is five, compared to three or four without this weekend restriction. By reducing the road distance penalty factor below 1.2 to a more reasonable value, it may be possible to merge itineraries 3 and 4 to reduce the fleet size to four.

Table 3. 3.

Statistics from non-fixed-fleet run in which trailers and tractors always remain together. Maximum allowable distance without maintenance is 12, 874 km, length of maintenance stay is 4 days, and linking value penalties used are: idle - 10, deadhead - 1, flexibility loss - 0. 1.

Trailer/ Tractor	km Total	km Active	km Deadhead	Days in Maintenance	Days Idle
1	14, 733	4, 772	9, 961	4	72
2	55, 864	22, 698	33, 166	20	17
3	53, 909	19, 407	34, 502	20	18
4	5, 207	1, 395	3, 812	4	82
Ave	32, 428	12, 067	20, 360	12	47

Percent of Total km Active	37. 2
Percent of Total Days Idle	52. 5

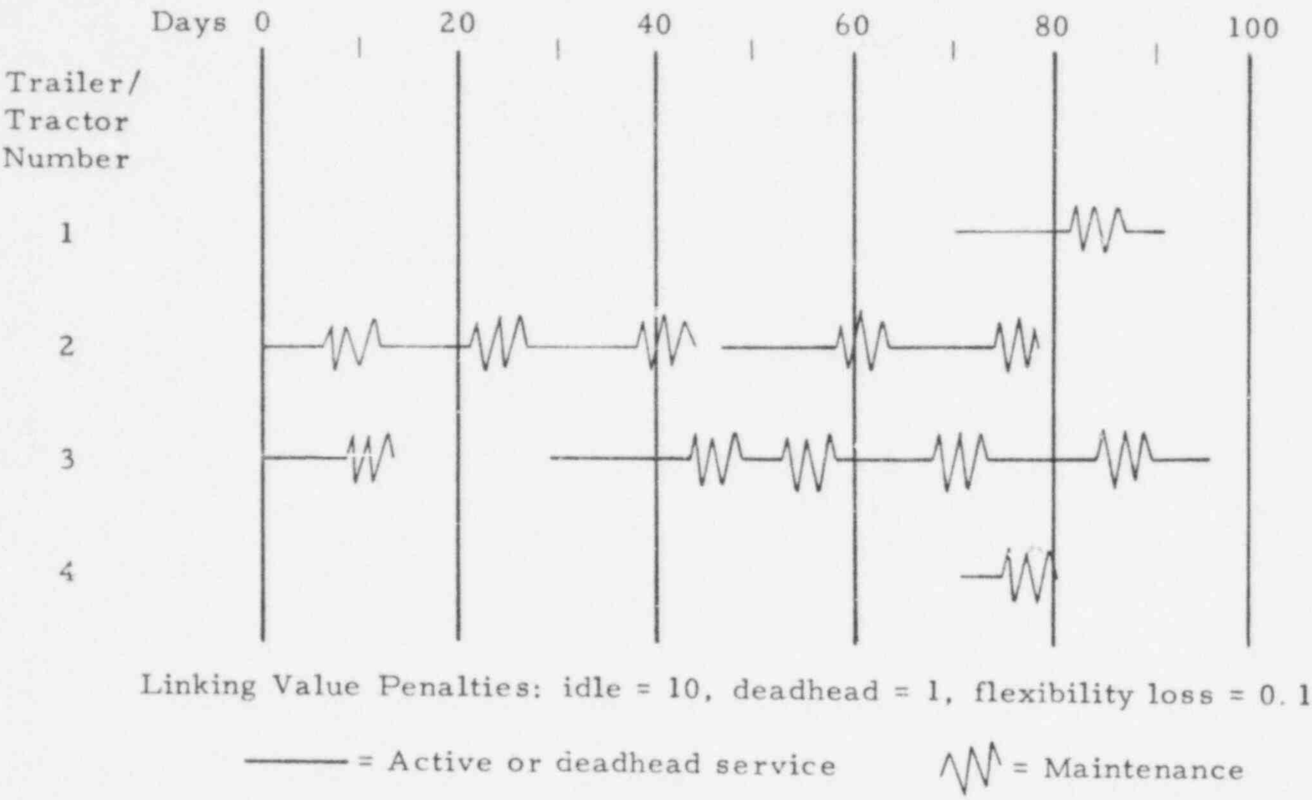

Figure 3.3. Combined trailer/tractor itineraries using non-fixed-fleet approach. A 4-day maintenance is required before 12,874 km has been travelled without maintenance.

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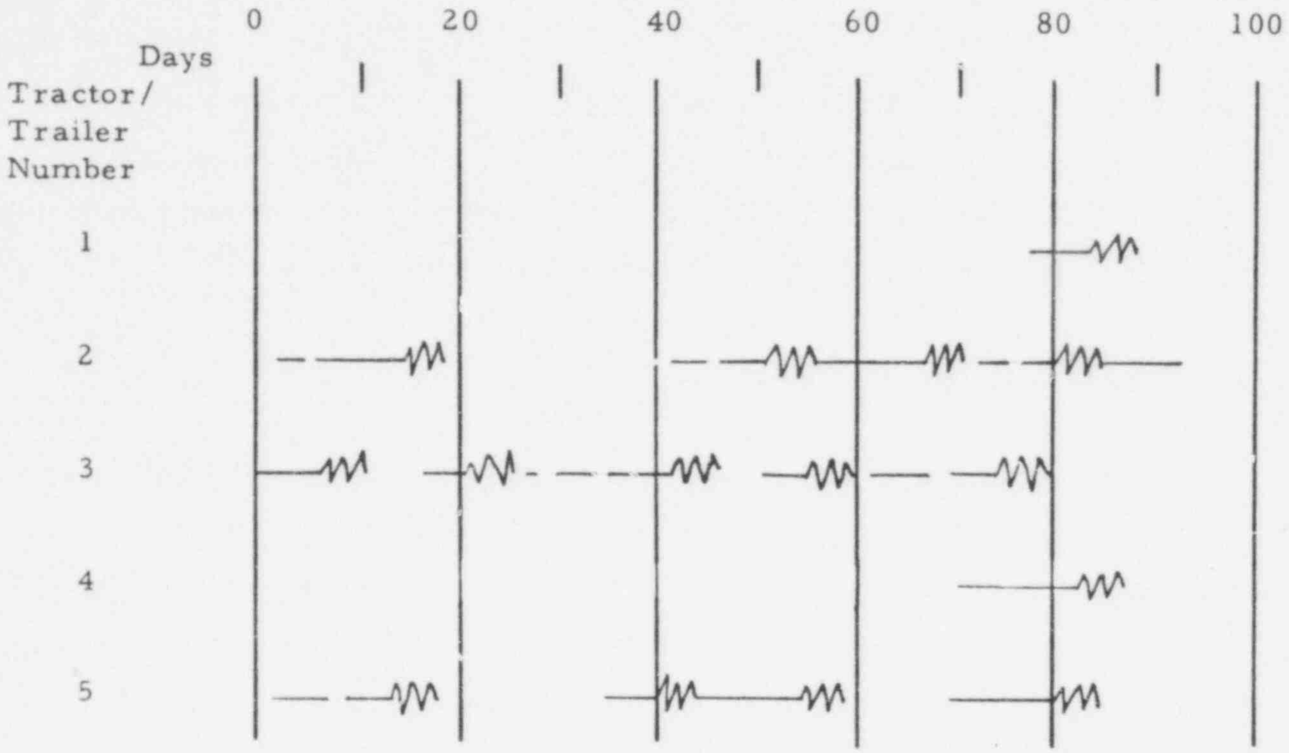
Table 3.4

Statistics from non-fixed-fleet run in which trailers and tractors remain together subject to no loading or unloading allowed on weekends. Maximum allowable distance without maintenance is 12,874 km, length of maintenance stay is 4 days, and linking value penalties used are idle - 10, deadhead - 1, flexibility loss - 0.1.

Trailer/ Tractor	km Total	km Active	km Deadhead	Days in Maintenance	Days Idle
1	6,006	1,678	4,328	4	83
2	44,658	15,715	28,943	16	35
3	36,473	10,869	25,604	20	31
4	11,387	4,562	6,825	4	76
5	39,317	15,447	23,8[illegible]0	16	40
Ave	27,568	9,654	17,914	12	53

Percent of Total km Active 35.0

Percent of Total Days Idle 58.3



Linking Value Penalties: Idle - 10, deadhead - 1, flexibility loss - 0.1.

——— = Active or deadhead service   ⋀⋀⋀ = Maintenance

Figure 3.4. Combined trailer/tractor itineraries with no loading or unloading allowed on weekends using non-fixed-fleet itinerary construction process. A 4 day maintenance stop is required before 12,874 km has been travelled without maintenance.

The linking value penalties used were idle time - 10, deadhead time - 1, and flexibility time - 0.1. The heavy penalty on idle time compared to deadhead time tended to force the vehicles to deadhead rather than idle on weekends, resulting in 35.5 percent of the distance traveled being active service compared to 37.9 without the loading/unloading restrictions. It is likely that reducing the idle penalty relative to the deadhead penalty in the linking value function will increase this figure for the itineraries with and without the loading restriction.

3.3.3 Multimode Capability

To test the multimode capability of the Version II model, aircraft and truck trailers were sequentially scheduled to meet the requirements of the shipment schedule. The rules used for assigning a shipment to an aircraft and the assumed aircraft parameters are summarized in Table 3.5. Note that the loading and unloading times are sufficiently long to allow for routine aircraft maintenance between flights.

The resulting itineraries for this sequential scheduling of aircraft and truck trailers are depicted in Figure 3.5. Fleet sizes of 2 and 6 for the aircraft and trailers are required, respectively. Less than 9 percent of the total distance traveled by the trailers is on active service. Of the total of 152 shipments, 67 were assigned to the aircraft mode and the remaining ones (the shorter trips) to the truck mode. Trucks are also required to transport the material between the bases and airfields, for 134 additional short trips. Whereas all the active truck trips are short, there are no restrictions on length of deadhead trips resulting in close to 91 percent of the total distance traveled being deadhead service. A large portion of the deadhead trips are simply between bases where aircraft transported shipments are leaving and arriving.

Table 3.5

Aircraft parameters and rules for assignment of aircraft to a shipment used for test of Version II multimode capability.

(a) Aircraft parameters.

Velocity	550 km/hr
Capacity	Equal to one truck trailer
Loading Time	12 hours
Unloading Time	12 hours
Maintenance	Time for routine maintenance included in loading/unloading times.

(b) Assignment rules.

(1) Time via truck must exceed 8 hours.

(2) Maximum allowable distance between origin base and nearest airfield is 100 km.

(3) Maximum allowable distance between destination base and nearest airfield is 100 km.

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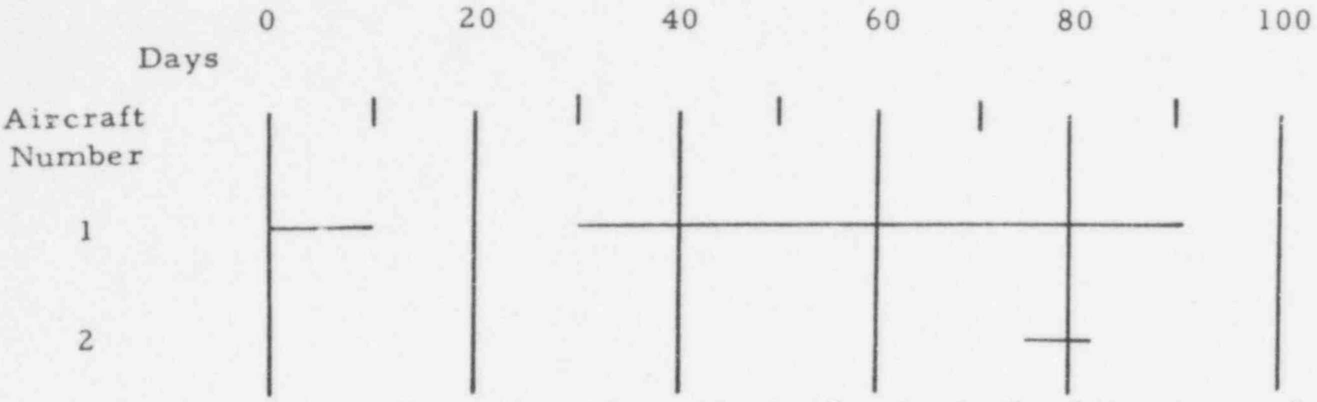
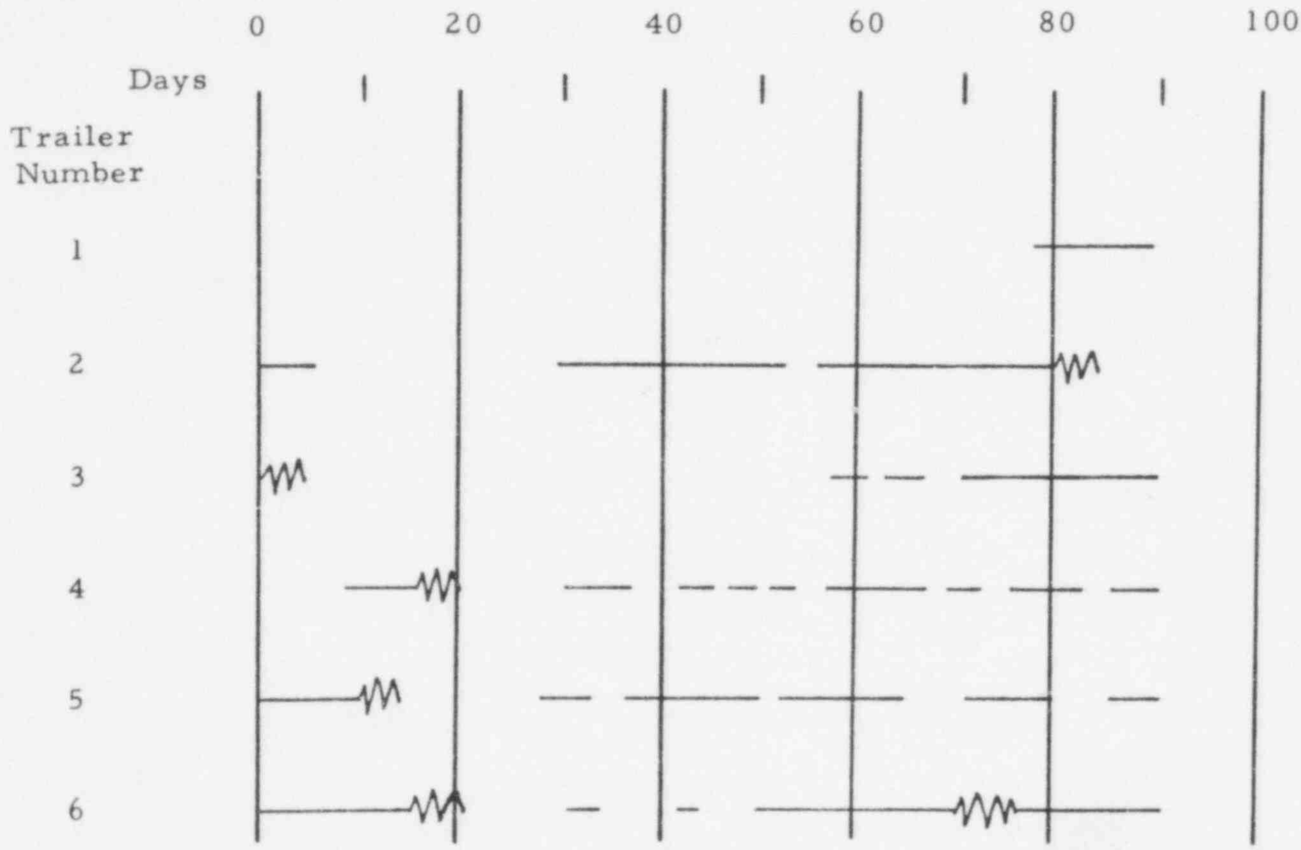


Linking Value Penalties: Idle 10, deadhead - 1, flexibility loss - 0.1.

(a) Aircraft itineraries.



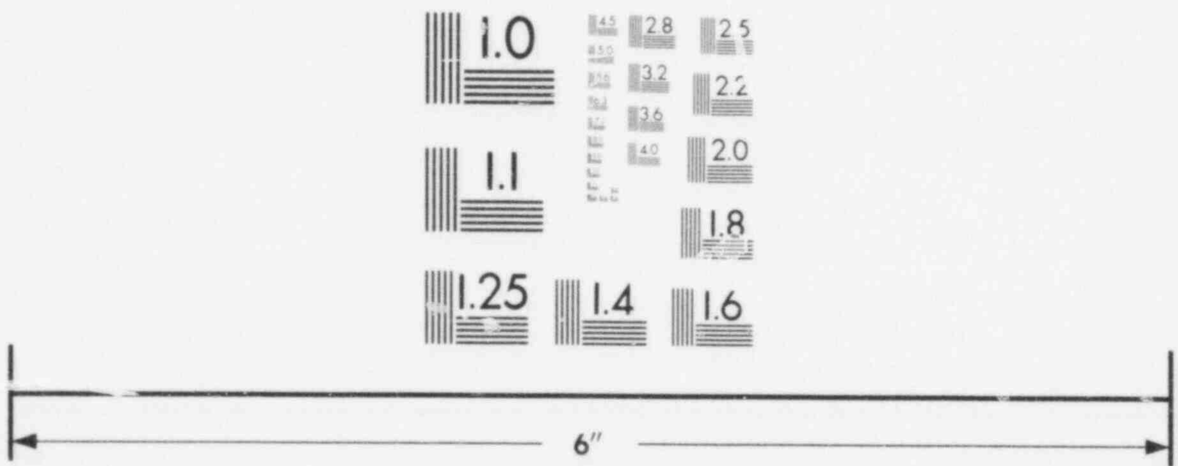
Linking Value Penalties: Idle - 10, deadhead - 1, flexibility loss - 0.1.

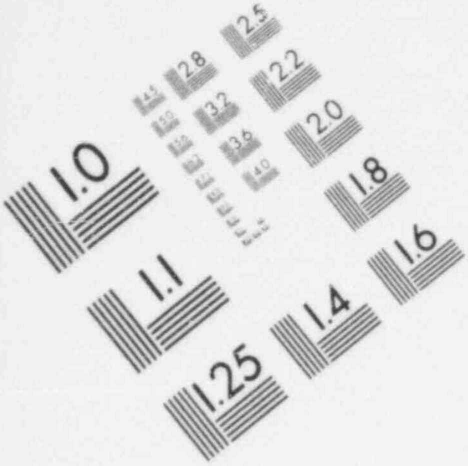
(b) Trailer itineraries.

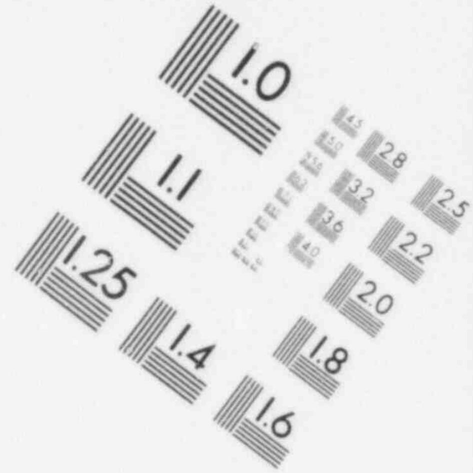
——— = Active or deadhead service   ⋀⋀⋀ = Maintenance

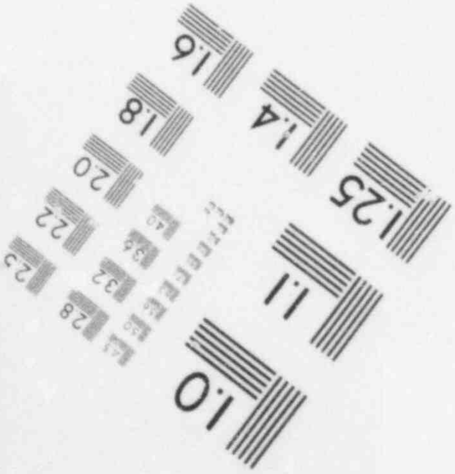
Figure 3.5. Itineraries resulting from sequential scheduling of aircraft and trailers.

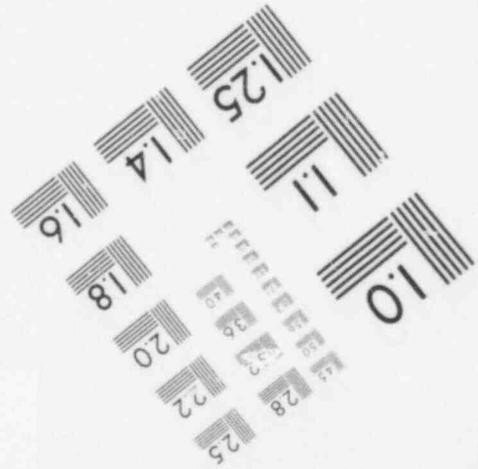
IMAGE EVALUATION TEST TARGET (MT-3)

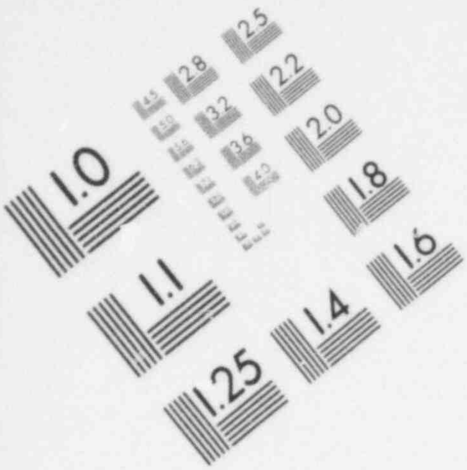












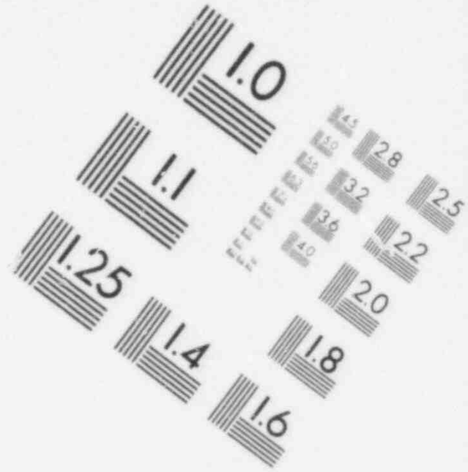
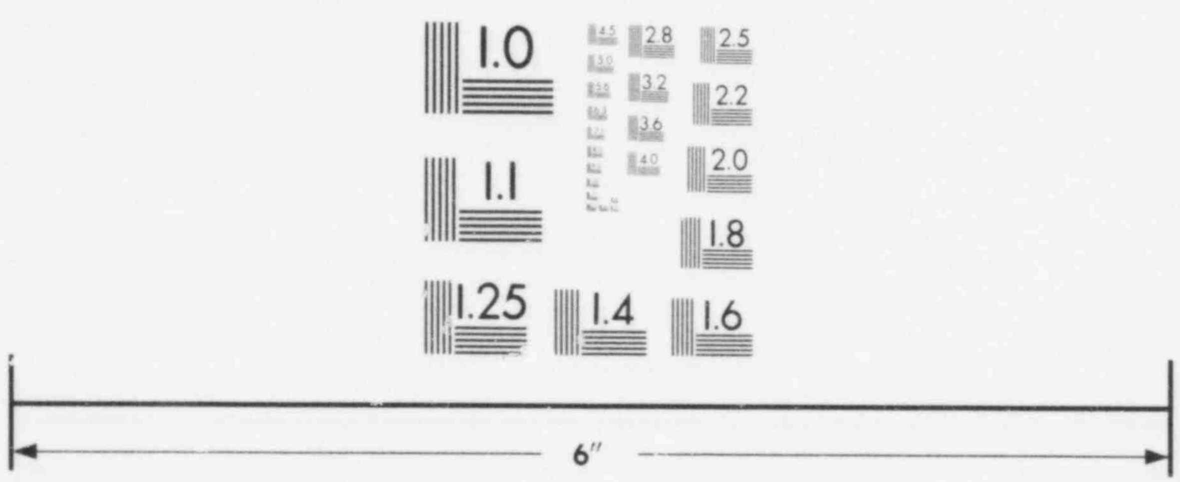
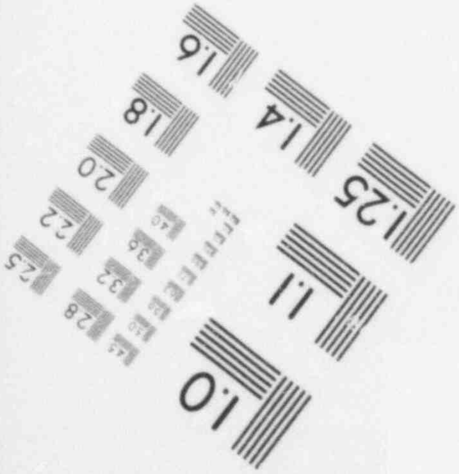
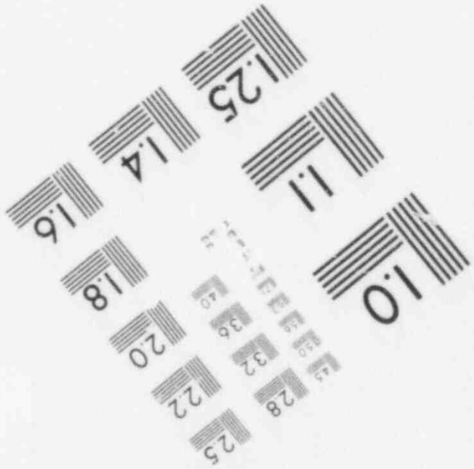
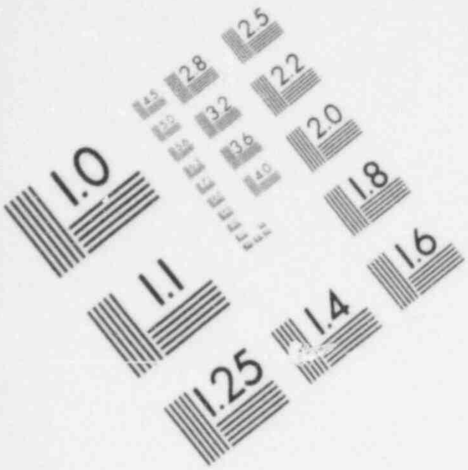


IMAGE EVALUATION TEST TARGET (MT-3)









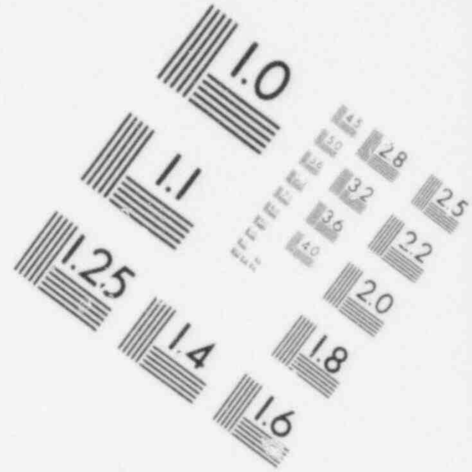
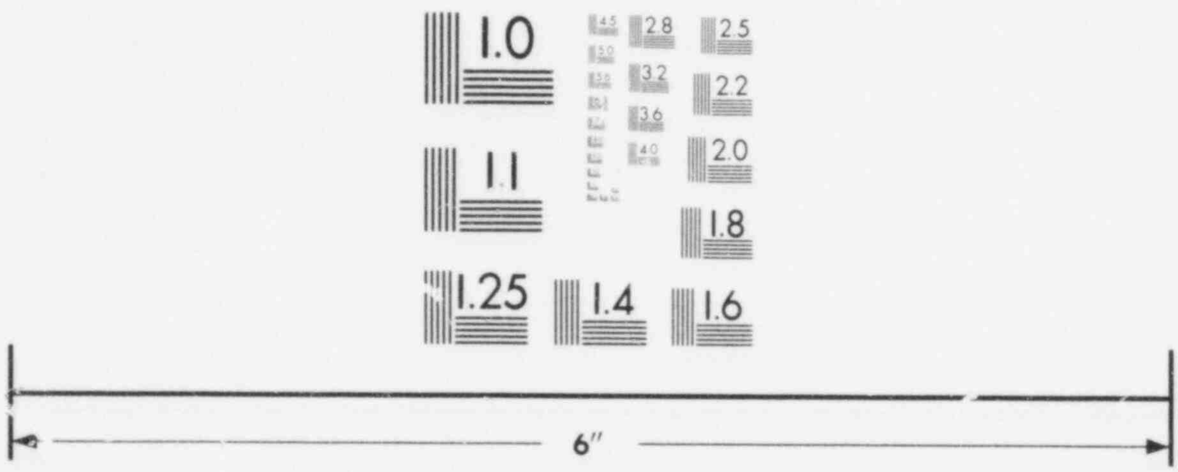
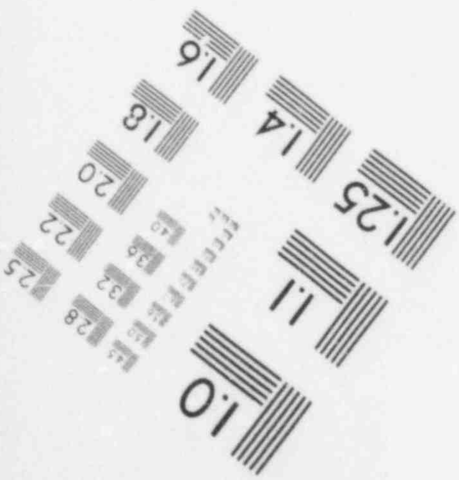
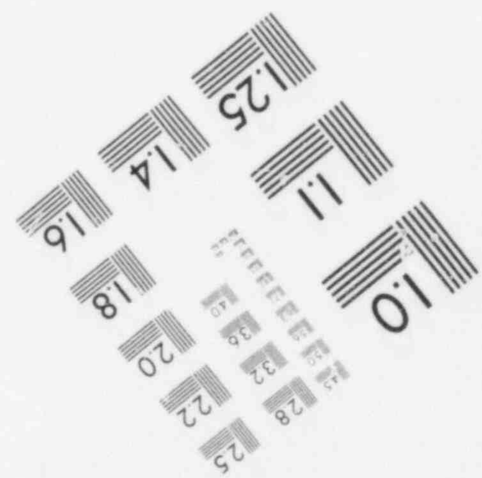


IMAGE EVALUATION TEST TARGET (MT-3)







4.0 TECHNICAL DISCUSSION OF PROCEDURES

The main purpose of this section is to provide technical details on the major algorithms used in the Version I and II models. A secondary purpose is to discuss the overall efficiency of the models and possible techniques for improving their efficiency.

Figure 4.1 shows a block diagram of the Version I and II models with the major subroutines. Subsequent discussions will refer to this figure.

4.1 Generation of Itineraries

In simulating the performance of a specific transportation system, the numbers and initial statuses of all transport unit elements are specified. Typically, one also specifies a shipping schedule for a fixed, finite interval. In this instance, there is an end effect which is related to the finite length of the schedule. At the end of the time for which shipments are required, the lack of yet more shipments introduces an artificial degree of flexibility in scheduling. This may yield more optimistic results than would actually occur. The nature of this effect can be identified by running the simulation for successively extended shipment schedules, i.e., schedules augmented by a "wrap-up" segment. In practice, it is recommended that one build itineraries for a shipping schedule corresponding to an interval which exceeds the interval of interest, and use the results only for the shorter interval.

In fleet sizing, we do not have the initial conditions for all transport units; we do not even have the number of transport units. Thus we encounter difficulties related to both ends of a finite shipping schedule. The end-of-interval end effect can be handled as for the simulation. To handle to the beginning-of-interval end effect, a

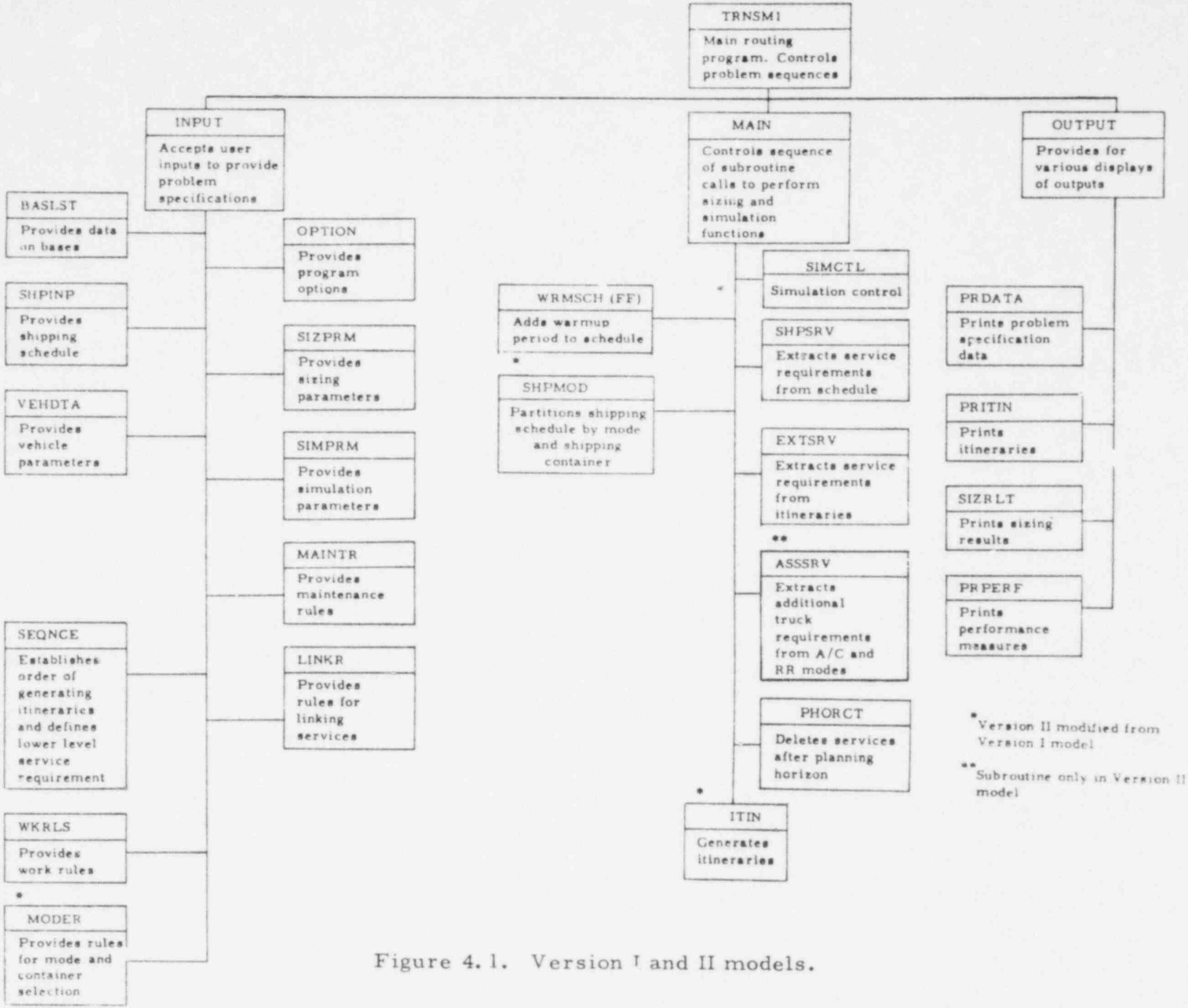


Figure 4.1. Version I and II models.

warm-up technique is commonly applied. In essence, one needs a schedule which extends before the interval of interest. To achieve this, we have adopted a warm-up technique in which a schedule segment is added to the beginning of the schedule for our fixed-fleet sizing option. Though we have not done this, it may be worthwhile to also add a schedule segment to the end of the schedule, i.e., a "wrap-up" segment. Final results would be drawn from the original, smaller interval. Details of the warm-up technique are given in Section 4.1.3.

An alternate approach to dealing with the end effects, which is the basis of our non-fixed-fleet sizing option, is to embed the problem with the fixed shipping schedule into a periodic problem for which the shipping schedule is repeated with a period equal to the original interval over which the schedule is defined. In effect, this technique makes the end of the itineraries act also as initial conditions, and obviates the use of a "warm-up" or a "wrap-up" schedule segment.

An itinerary which results from this approach is also periodic, but it can, in general, have a period equal to any integer multiple of the basic period, i.e., the interval of definition for the shipping schedule.

Figure 4.2 illustrates these notions. First, an itinerary with period = T, the basic schedule period, is illustrated. Next, there is illustrated an itinerary with period = 2T. Since the overall assignments to itineraries is identical in each interval of length T, it follows that there must be a complementary itinerary, also of period 2T and shifted from the first itinerary of period 2T by a time T, i.e., one basic period.

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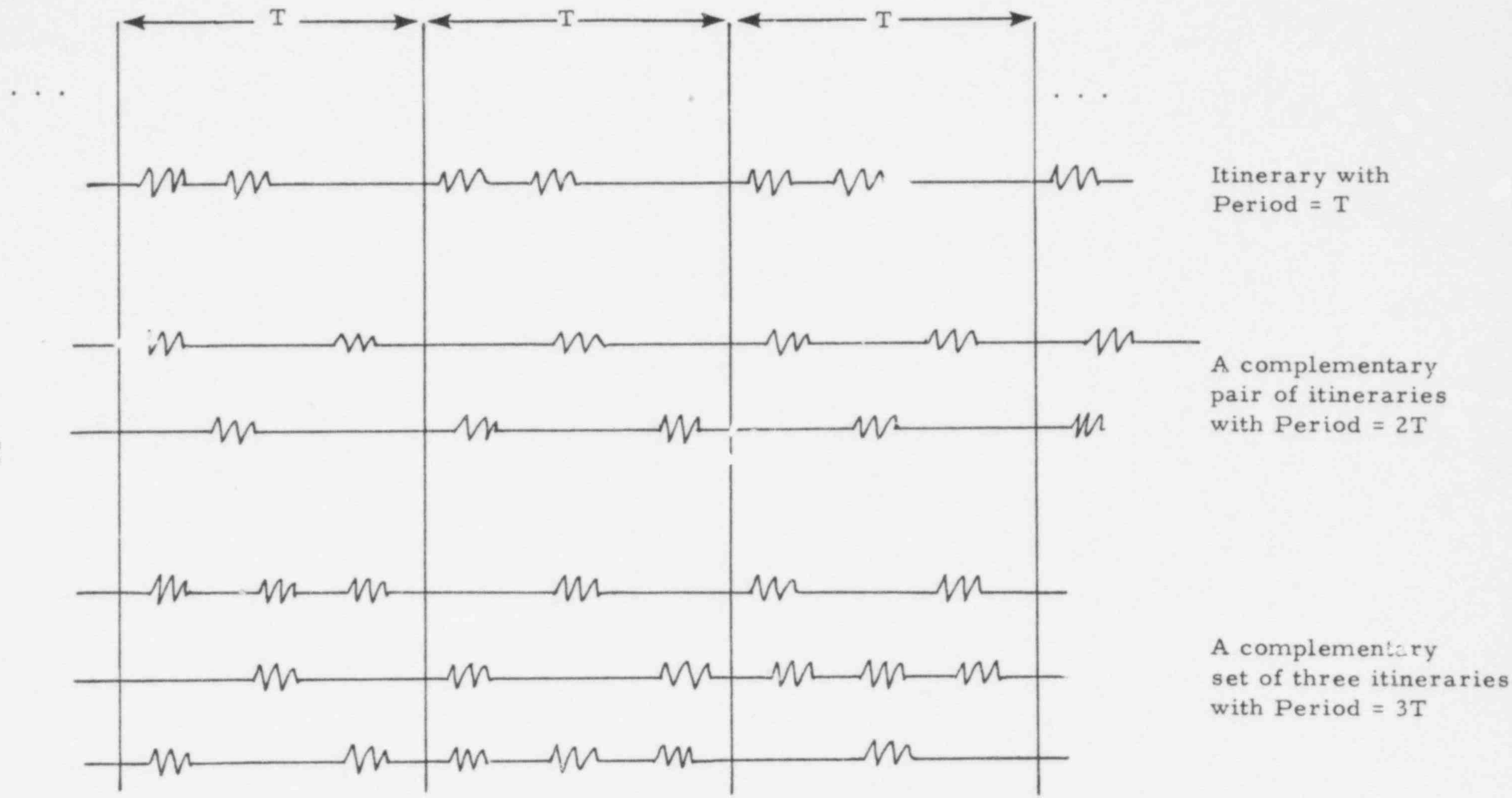

Figure 4.2 Periodic itineraries on a periodic schedule.

The argument carries on for complementary sets of itineraries of any number. In Figure 4.2, there is also illustrated a complementary set of three itineraries.

Each complementary set of itineraries can be represented by a single closed itinerary with a number of "return arcs" equal to the number of itineraries in the set. This is illustrated in Figure 4.3, with the illustrated sets of one, two and three itineraries corresponding to the itineraries of Figure 4.2.

The generation of itineraries is performed in subroutine ITIN. The basic technique used in building itineraries is to sequentially link services together to form composite services. This linking process then proceeds until no further linkings are possible.

This section discusses the four major aspects of the itinerary construction process: the process of linking services (with emphasis on checking the feasibility of candidate linkings) in both the fixed-fleet and non-fixed-fleet approaches, the setting of initial conditions in the itinerary construction process for the fixed-fleet sizing approach, the actual construction of itineraries by choosing the best of the feasible linkings, and the recovery of the details of the itineraries from the final set of composite services and the history of the linking process.

To discuss the procedures for generating itineraries, we require a mathematical representation of a service in its most general form. Figure 4.4 shows such a service. Note that this general service may include bands in which travel is allowed. The bands shown in this figure are based on the assumption that no work is allowed on bases on weekends. The actual service can occur in any one of these bands.

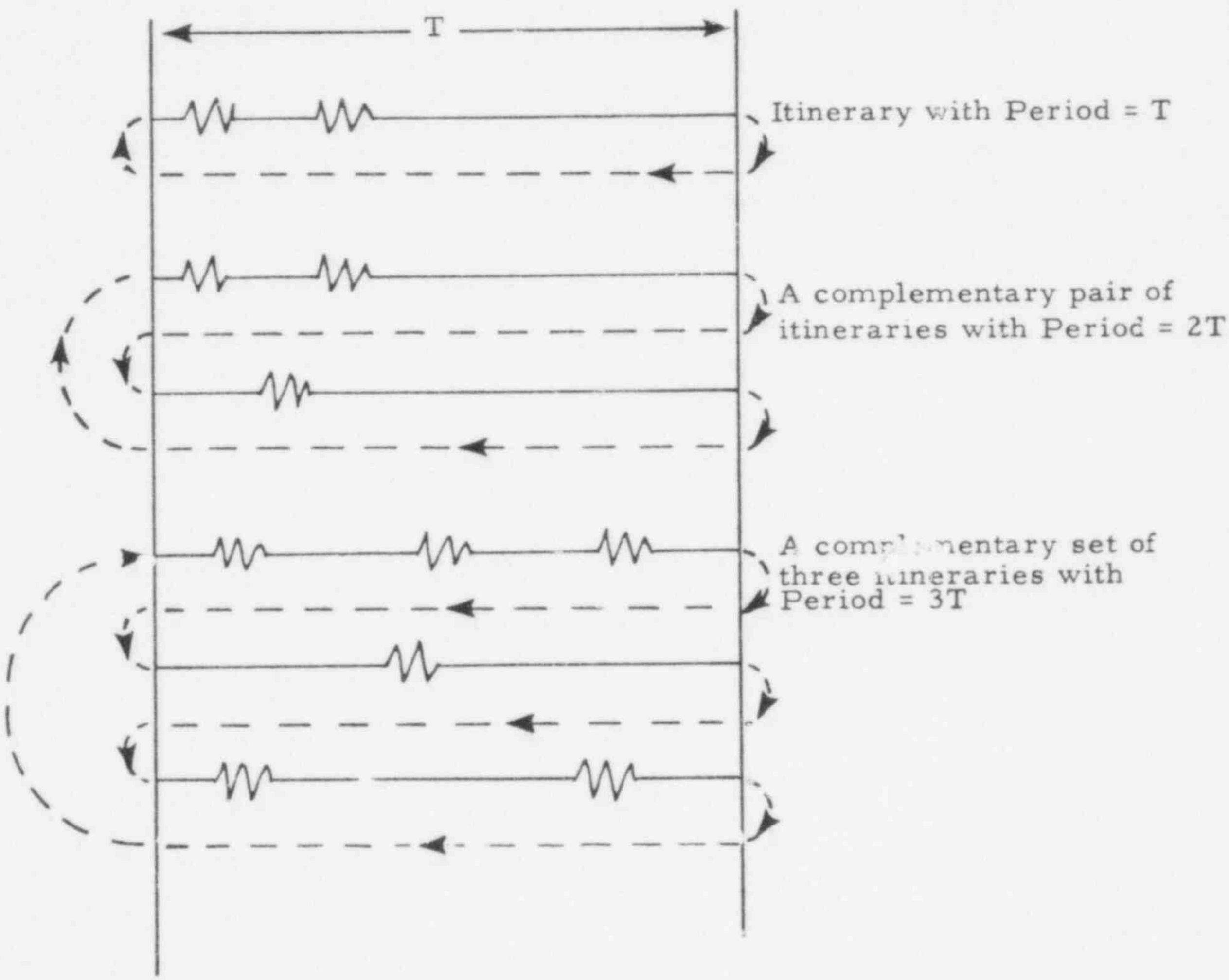

Figure 4. 3 Representation of periodic itineraries as closed itineraries.

A set of required services is in the form of a list, the i^{th} element of which has the form

$$a_i, b_i, c_i, \{(s_i^p, t_i^p, n_i^p, u_i^p, v_{1i}^p, v_{2i}^p, m_i^p, w_{1i}^p, w_{2i}^p), p = 1, \ldots, P_i\}$$

where

a_i origin

b_i destination

c_i quantity of service

s_i^p earliest departure in p^{th} interval

t_i^p earliest arrival time in p^{th} interval

n_i^p number of return arcs corresponding to (s_i^p, t_i^p) (This quantity is used only in the non-fixed-fleet approach of the Version II model.)

u_i^p width (flexibility) of p^{th} interval

v_{1i}^p, v_{2i}^p accumulated use variables from beginning of this service

m_i^p logical variable for inclusion of a maintenance stop within this service

w_{1i}^p, w_{2i}^p accumulated use variables to the end of this service

P_i number of alternative time intervals

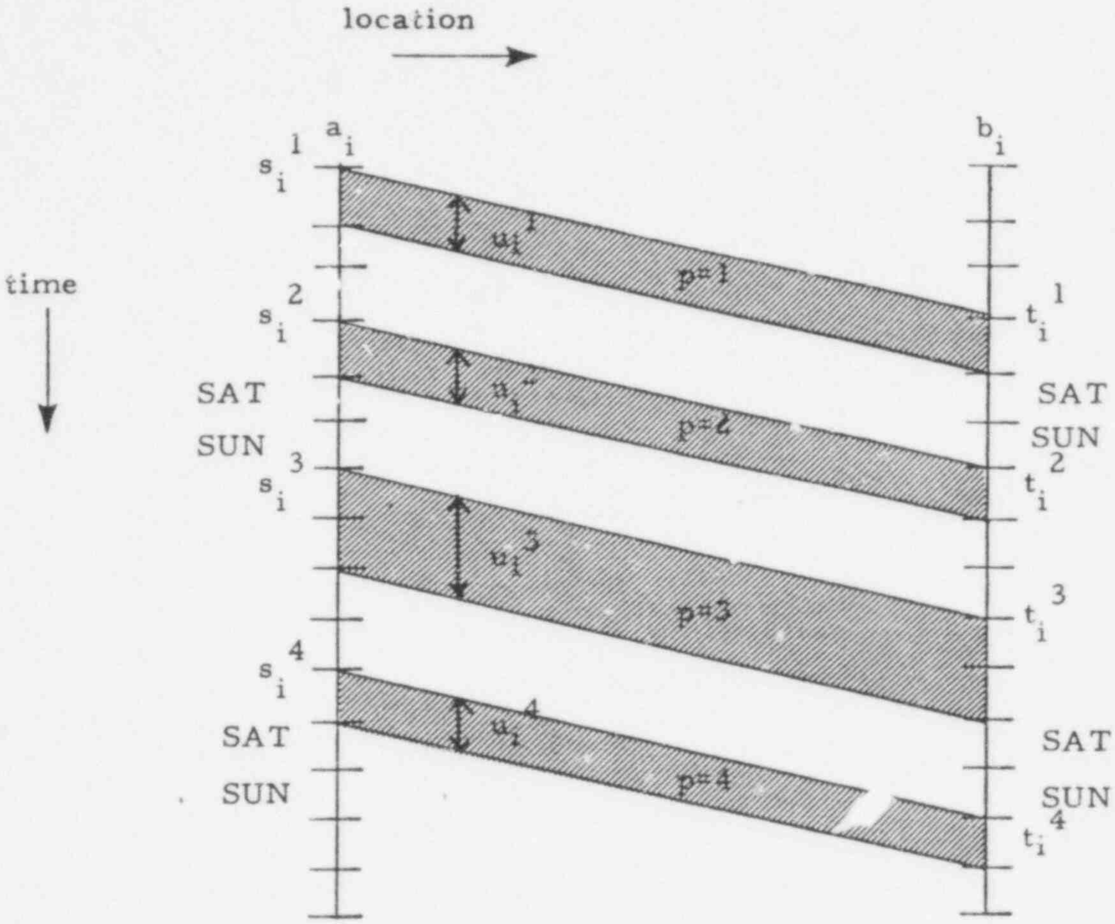

Figure 4.2. A service representation with multiple intervals.

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The service time alternatives are defined by a choice of a departure interval $p \in (1, \ldots, P_i)$ and then a departure time τ within the interval $\left[0, u_i^p\right]$. For these choices, the departure time is $s_i^p + \tau$ and the arrival time is $t_i^p + \tau$.

The accumulated use variables are related to maintenance requirements, i.e., maintenance (or rest) is required before a specified time has been exceeded (v_{1i}^p, w_{1i}^p) or a specified distance has been traveled (v_{2i}^p, w_{2i}^p) without maintenance. The presence of the two types of accumulated use variables (v and w) will be explained subsequently in Section 4.1.1.

4.1.1 Linking of Services in Fixed-Fleet Approach

Here we provide details on how two services can be linked to produce one composite service. This process includes both temporal and maintenance feasibility checks, and the mathematical description of the composite service if the linking is feasible.

Consider the possibility of linking service i with a following service j. As many as three steps are required to check the feasibility of this linking. These steps are depicted in Figure 4.5.

The temporal feasibility condition for linking services i and j is based on checking whether or not the departure time for the second service (j) can be delayed to a time equal to or later than the latest arrival time at a_j following the first service (i). This arrival time must account for any required intermediate maintenance stops and deadheading.

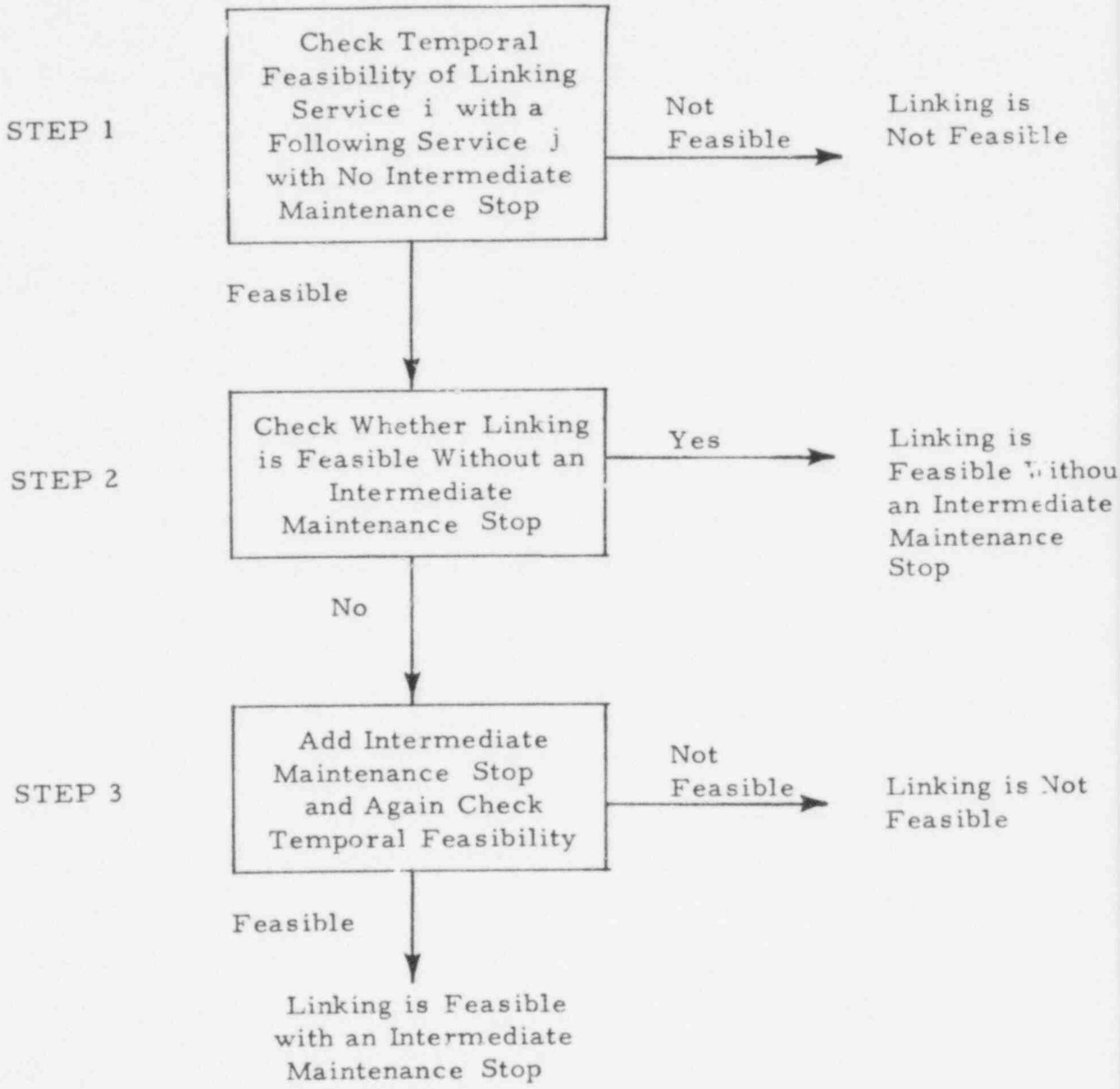

Figure 4.5. Linking feasibility checks.

To mathematically address this temporal feasibility question, define for service i, fixed p, and τ, $\tau \in [0, u_i^p]$:

$$s_i = s_i^p + \tau$$

$$t_i = t_i^p + \tau$$

$$u_i = u_i^p$$

$$\tau \in [0, u_i^p]$$

and for ser ice j, fixed q, and θ, $\theta \in [0, u_j^q]$:

$$s_j = s_j^q + \theta \quad ,$$

$$t_j = t_j^q + \theta$$

$$u_j = u_j^q$$

Furthermore, define

ξ = travel time from b_i to a_j.

The temporal feasibility condition for given values of p and τ, which define the departure time of service i, can be stated as

$$s_j^q + u_j^q \geq t_i + \xi$$

for at least one value of q. Services i and j can be connected if this inequality is satisfied for at least one set of values of p and τ.

If this temporal feasibility test is satisfied, the next step is to check whether or not this linking of services i and j without an intermediate maintenance stop violates the upper limits on the time and distance accumulated use variables. Maintenance requirements are defined by (1) upper bounds on time and distance traveled between maintenance stops and (2) the required duration of a stay in maintenance. To simplify the following discussion of maintenance feasibility, we will suppress the dependence of the accumulated use variables on departure interval.

Consider a sequence of services, as illustrated in Figure 4.6, which are linked together to form composite service i. This sequence contains a stay at maintenance. In considering the possible linking of this composite service (i) with another (possibly composite) service (j), it is necessary to distinguish between the accumulated use variables from the beginning of service i, v_{1i}, v_{2i}, and those to the end of the service, w_{1i}, w_{2i}. This distinction is necessary only if there is at least one stay at maintenance contained in the sequence. To specify this condition, we define the logical variable m_i by

$$m_i = \begin{cases} 1 & \text{if the service contains a stay at maintenance} \\ 0 & \text{otherwise} \end{cases}$$

If $m_i = 0$, we have, by definition, $w_{1i} = v_{1i}$ and $w_{2i} = v_{2i}$.

In considering the feasibility of linking services i and j, there are four possible combinations of m_i and m_j which can occur. To investigate these cases, the following additional variables are required:

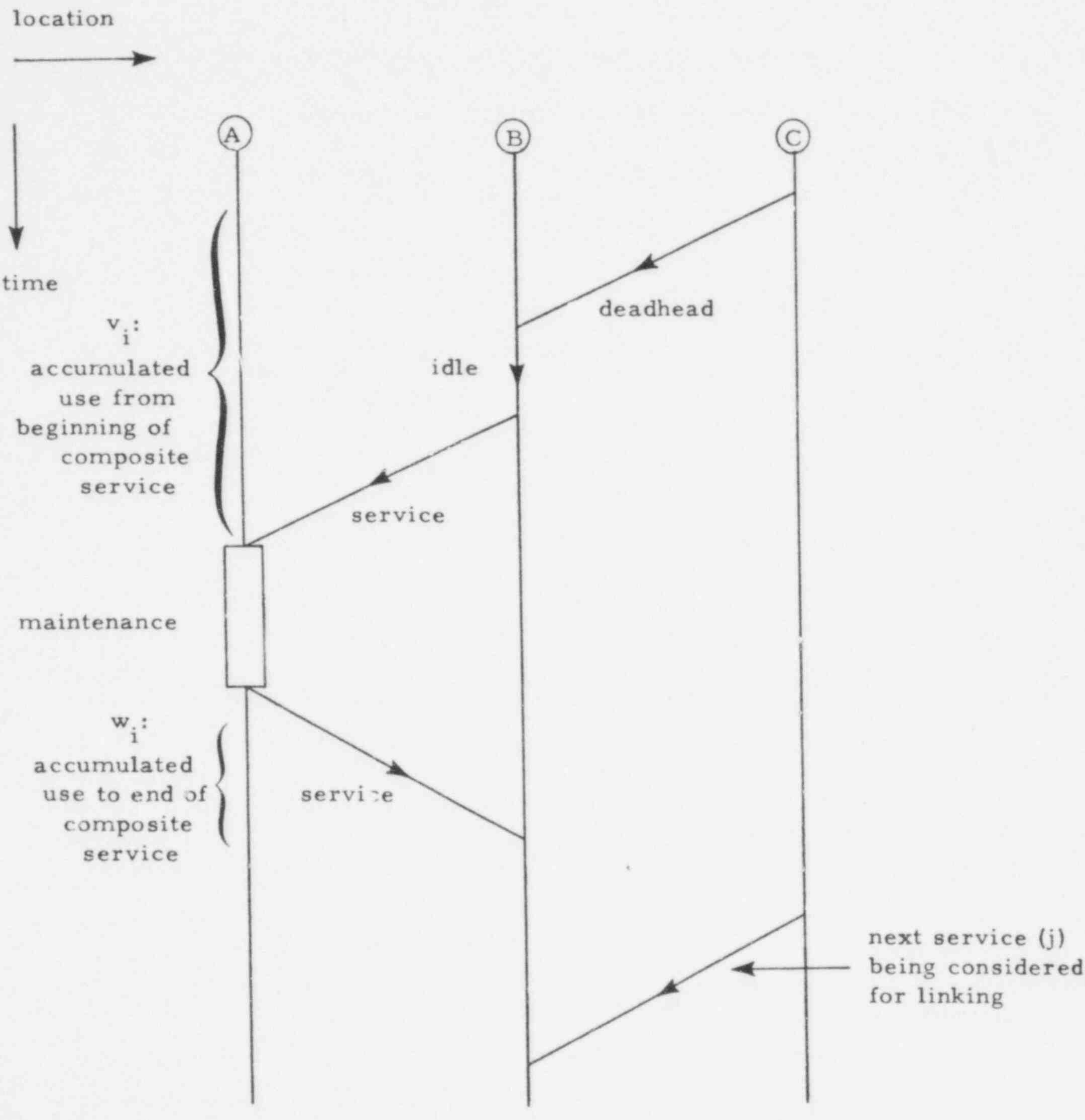

Figure 4.6. Accumulated use for a service.

η = distance between b_i and a_j

$\beta_i(\beta_j)$ = travel time from $b_i(b_j)$ to maintenance base

$\alpha_i(\alpha_j)$ = travel time from maintenance base to $a_i(a_j)$

$\gamma_i(\gamma_j)$ = distance between $b_i(b_j)$ and maintenance base

$\delta_i(\delta_j)$ = distance between $a_i(a_j)$ and maintenance base

The accumulated use variables are additive by journey leg, e.g., if neither service (i or j) includes a stop at maintenance ($m_i = m_j = 0$), the accumulated use variables for the new combined service (k) is

$$v_{1k} = v_{1i} + \xi + w_{1j}$$

$$v_{2k} = v_{2i} + \eta + w_{2j}$$

If we also account for necessary travel to and from maintenance at either end of the service, we find the constraints to be

$$v_{1k} + \alpha_i + \beta_j \leq T$$

$$v_{2k} + \gamma_i + \delta_j \leq D$$

where T and D are the bounds on time and distance respectively allowed between maintenance stops.

Maintenance feasibility conditions, and the resultant accumulated use variables are given in Table 4.1 as functions of m_i and m_j assuming no maintenance stop between services i and j .

Table 4.1. Maintenance feasibility checks and resultant accumulated use variables.

$m_i = 0, \; m_j = 0$:

$$v_{1k} = v_{1i} + v_{1j} + \xi \qquad v_{2k} = v_{2i} + v_{2j} + \eta$$

feasible if $\alpha_i + \beta_j + v_{1k} \le T$ and $\gamma_i + \delta_j + v_{2k} \le D$

$m_k = 0$

$$w_{1k} = v_{1k} \qquad w_{2k} = v_{2k}$$

$m_i = 0, \; m_j = 1$:

$$v_{1k} = v_{1i} + v_{1j} + \xi \qquad v_{2k} = v_{2i} + v_{2j} + \eta$$

feasible if $\alpha_i + v_{1k} \le T$ and $\gamma_i + v_{2k} \le D$

$m_k = 1$

$$w_{1k} = w_{1j} \qquad w_{2k} = w_{2j}$$

$m_i = 1, \; m_j = 0$:

$$v_{1k} = v_{1i} \qquad v_{2k} = v_{2i}$$

$m_k = 1$

$$w_{1k} = w_{1i} + \xi + v_{1j} \qquad w_{2k} = w_{2i} + \eta + v_{2j}$$

feasible if $w_{1k} + \beta_j \le T$ and $w_{2k} + \delta_j \le D$

$m_i = 1, \; m_j = 1$:

$$v_{1k} = v_{1i} \qquad v_{2k} = v_{2i}$$

$m_k = 1$

$$w_{1k} = w_{1j} \qquad w_{2k} = w_{2j}$$

feasible if $w_{1i} + \xi + v_{1j} \le T$ and $w_{2i} + \eta + v_{2j} \le D$

If a bound on one of the accumulated use variables is violated, an intermediate stop at maintenance must be provided for the linking of services i and j to be feasible, and temporal feasibility must again be checked. This requires a redefinition of the travel time from b_i to a_j to include the maintenance stop, i.e.,

$$\xi = \text{travel time from } b_i \text{ to maintenance} \\ + \text{required time in maintenance} \\ + \text{travel time from maintenance to } a_j$$

With this new definition of ξ, the temporal feasibility check discussed above is again used.

Table 4.2 summarizes the resultant accumulated use variables in linking services i and j with an intermediate maintenance stop as functions of m_i and m_j.

If the linking between services i and j is feasible, the complete representation for the composite service k is required. Of major importance is the division of the composite service k into bands from the bands of the original two services. In general, the criterion used in selecting the bands of the composite service is minimum idle time. To illustrate the process of defining the bands of the composite service, consider the example shown in Figure 4.7 in which service i has three bands and j has four bands. For simplicity, we assume that a_j and b_i are the same locations. Table 4.3 describes the possible linkings of the individual bands. Consider the linking of band 1 of service i with each of the four bands of service j. The linking of p = 1 with q = 1 is infeasible since the earliest arrival time of i, t_i^1 is greater than the latest departure time of j, $s_j^1 + u_j^1$. The band p = 1 can be linked with

Table 4.2. Accumulated use variables assuming an intermediate stop for maintenance.

$m_i = 0,\ m_j = 0$:

$$v_{1k} = v_{1i} + \beta_i \qquad v_{2k} = v_{2i} + \gamma_i$$

$$m_k = 1$$

$$w_{1k} = \alpha_{1j} + v_{1j} \qquad w_{2k} = \delta_j + v_{2j}$$

$m_i = 0,\ m_j = 1$:

$$v_{1k} = v_{1i} + \beta_i \qquad v_{2k} = v_{2i} + \gamma_i$$

$$m_k = 1$$

$$w_{1k} = w_{1j} \qquad w_{2k} = w_{2j}$$

$m_i = 1,\ m_j = 0$:

$$v_{1k} = v_{1i} \qquad v_{2k} = v_{2i}$$

$$m_k = 1$$

$$w_{1k} = v_{1j} + \alpha_j \qquad w_{2k} = v_{2j} + \delta_j$$

$m_i = 1,\ m_j = 1$:

$$v_{1k} = v_{1i} \qquad v_{2k} = v_{2i}$$

$$m_k = 1$$

$$w_{1k} = w_{1j} \qquad w_{2k} = w_{2j}$$

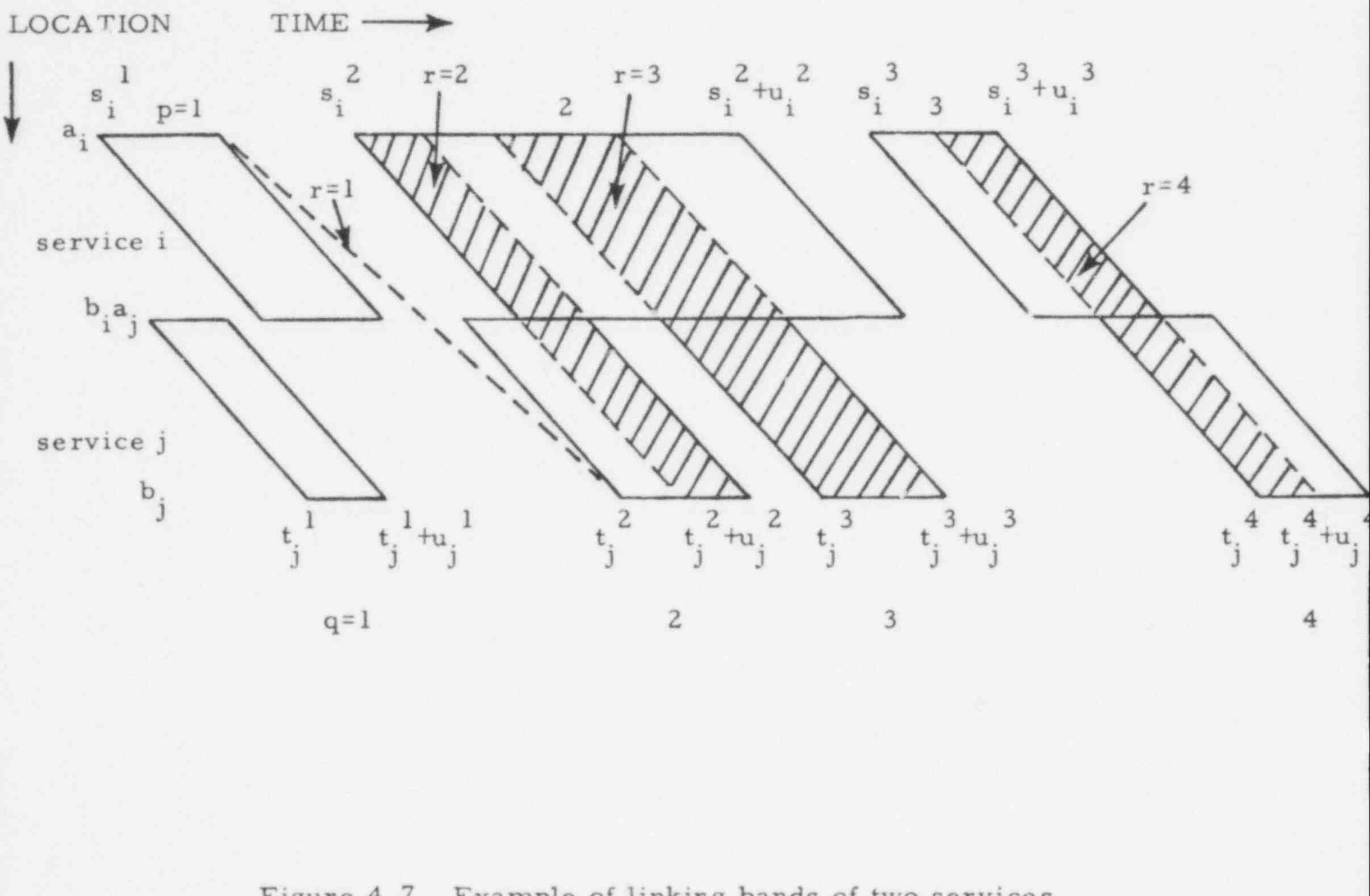

Figure 4. 7. Example of linking bands of two services to form bands of a composite service.

Table 4.3. Feasibility of band linking for example.

q \ p	1	2	3
1	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
2	r=1	r=2	NOT FEASIBLE
3	EXCESS IDLE	r=3	NOT FEASIBLE
4	EXCESS IDLE	EXCESS IDLE	r=4

Table 4.4. Times and flexibility for composite bands in example.

r	s_k^r	t_k^r	u_k^r
1	$s_i^1 + u_i^1$	t_j^2	0
2	s_i^2	$t_i^2 + (t_j^2 - s_j^2)$	$u_j^2 - (t_i^2 - s_j^2)$
3	$s_j^3 - (t_i^2 - s_i^2)$	t_j^3	u_j^3
4	$s_j^4 - (t_i^3 - s_i^3)$	t_j^4	$t_i^3 + u_i^3 - s_j^4$

the q = 2 band by means of an added idle of minimum length, $s_j^2 - t_i^1 - u_i^1$. Note that this added idle time is minimized by requiring zero flexibility in the new composite band. Although linkings of the p = 1 band with the bands q = 3 and 4 are feasible, they require more idle time that does the linking with the q = 2 band so they are not used. Next consider the band p = 2. This can be linked to the bands q = 2 and q = 3 with zero idle time as shown to produce two composite bands. Again linking of p = 2 with q = 4 is feasible, but requires idle time so is not used. Finally, the band p = 3 can only be linked to the q = 4 band. The resulting values of earliest departure time, earliest arrival time, and flexibility are summarized in Table 3.4.

If the locations b_i and a_j are not the same, travel time from b_i to a_j must be included in these calculations.

The following equations summarize the values of earliest departure time, earliest arrival time, and flexibility for band r of composite service k which is obtained by linking band p of service i with band q of service j .

$$t_k^r = \max\,[t_i^p + t_j^q - s_j^q + \xi\ ,\ t_j^q]$$

$$s_k^r = \min\,[t_k^r - \xi - (t_i^p - s_i^p) - (t_j^q - s_j^q),\ s_i^p + u_i^p]$$

$$u_k^r = \min\,[u_j^q - (t_k^r - t_j^q),\ s_i^p + u_i^p - s_k^r]$$

The origin and destination of the composite service are simply given by

$$a_k = a_i$$

$$b_k = b_j$$

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When services i and j are linked together, the quantities of the two services c_i and c_j may differ. To describe how to handle this situation, consider the case when

$$c_i > c_j$$

In this linking, service i is divided into two services which are identical to i except for quantity. One has quantity equal to c_j, so that this service can be linked directly to service j, and the other accounts for the remaining quantity $c_i - c_j$. Therefore the linking of services i and j with $c_i > c_j$ produces one composite service with

$$c_k = c_j$$

and a copy of service i with quantity of service reduced to $c_i - c_j$.

The values of the accumulated use and maintenance variables for the composite service were given previously in Tables 4.1 and 4.2.

4.1.2 Linking of Services in Non-Fixed-Fleet Approach

As was discussed in Section 4.1.1, the basis for the non-fixed-fleet approach is the assumption that the shipment schedule is periodic with period equal to the planning horizon.

Consider a set of services with period T, as illustrated in Figure 4.8. To define a periodic set of services, it is of course only necessary to list services associated with a single designated interval of duration equal to T. For this purpose, the departure time for a service will be taken in the designated interval. If the associated arrival time then happens to fall beyond the end of this designated interval, as illustrated in Figure 4.8, an equivalent representation with an arrival time within the interval is obtained by considering the service to be in two pieces. The first piece is obtained from the original service by terminating it at the end of the period. The second piece is obtained from a second service identical to this service but arriving one period earlier than actual arrival time. It is generated by cutting this new service off at the beginning of the period. The connection of these two pieces can then be represented by a return arc, as illustrated in Figure 4.8.

It should also be noted that services can cover several periods. For example, with a period of two days, a seven-day service will cover four or five periods. An extension of the ideas presented above leads to the identification of several pieces and associated return arcs within one period.

Linking of services in a periodic set can be reduced to linking of services as described in Section 4.1.1 for the fixed-fleet approach. This is accomplished in three steps:

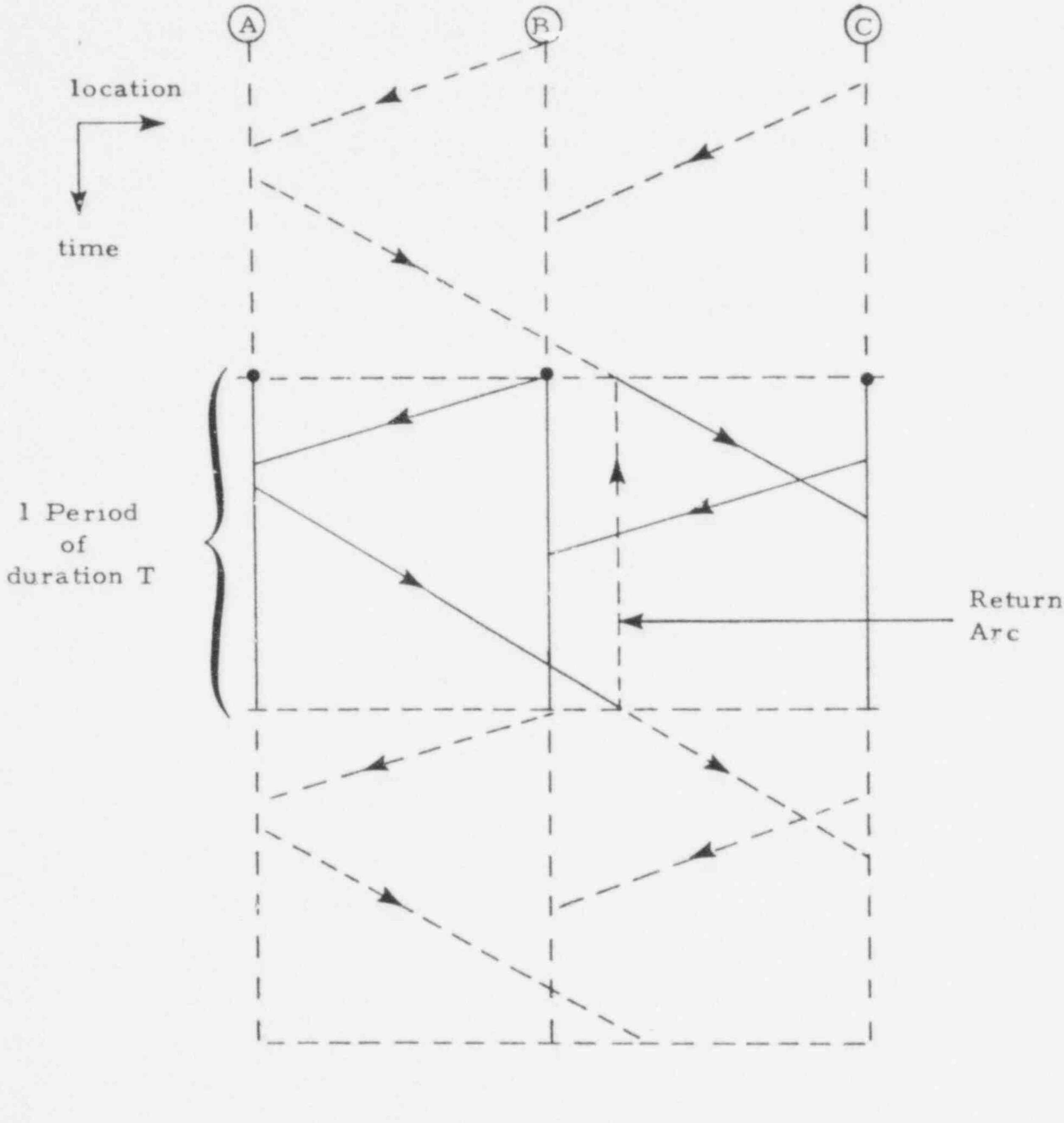


Figure 4. 8. A periodic set of services.

(1) transform all service times to aperiodic form

(2) execute linking of services as in fixed-fleet approach (Section 4. 1. 1)

(3) transform resultant linked service to periodic notation.

Details of these steps are now provided.

In transforming service times to aperiodic form, it is most convenient to arrange for the arrival times t_i^p for service i, and the departure times s_j^q for service j to fall in the standard interval, with other times being adjusted accordingly. Specifically, if t_i^p does not fall in the interval, adjust the departure time of i according to

$$s_i^p \leftarrow s_i^p - Tn_i^p, \qquad p = 1, \ldots , P_i$$

Similarly, if s_j^q does not fall in the desired interval, adjust the arrival time of j according to

$$t_j^q \leftarrow t_j^q + Tn_i^q, \qquad q = 1, \ldots , P_j$$

For the second step, we attempt a linking of services. If not feasible, service times for service j are increased by the amount T, and linking is again attempted. This process of increasing the times for service j is repeated until the linking is feasible from both temporal and maintenance considerations.

In either case, for the third step, the resultant service alternatives are transformed to periodic form by first defining

$$z_k^r = [s_k^r / T]$$

where [x] is the greatest positive or negative integer which is not greater than x, and

$$y_k^r = [t_k^r / T]$$

In periodic form the resultant departure time, arrival time, and number of return arcs are found from

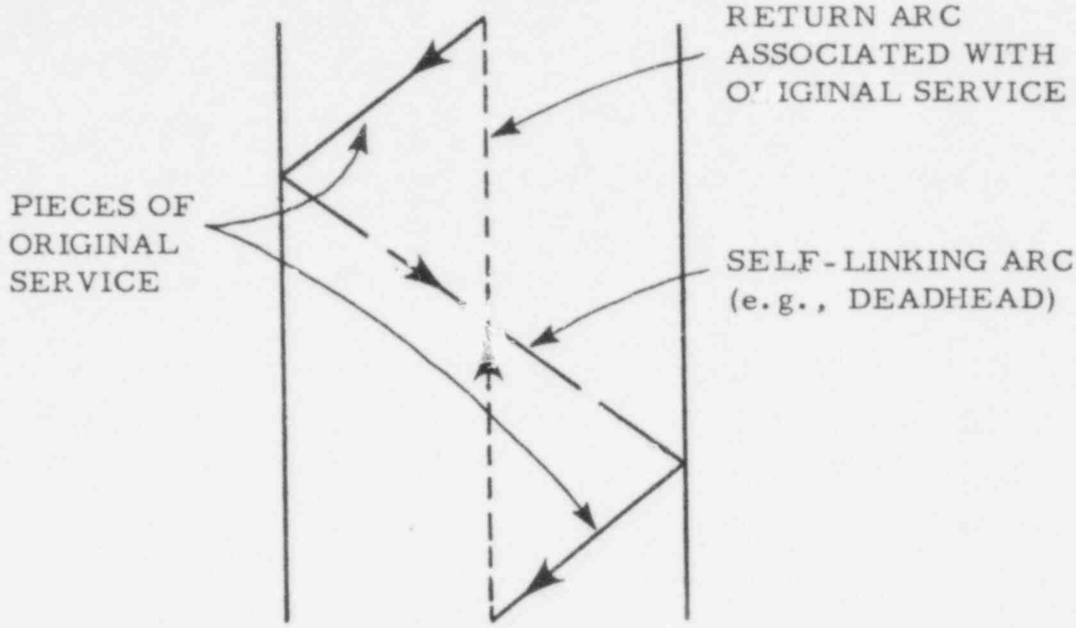
$$s_k^r \leftarrow s_k^r - T z_k^r$$

$$t_k^r \leftarrow t_k^r - T y_k^r$$

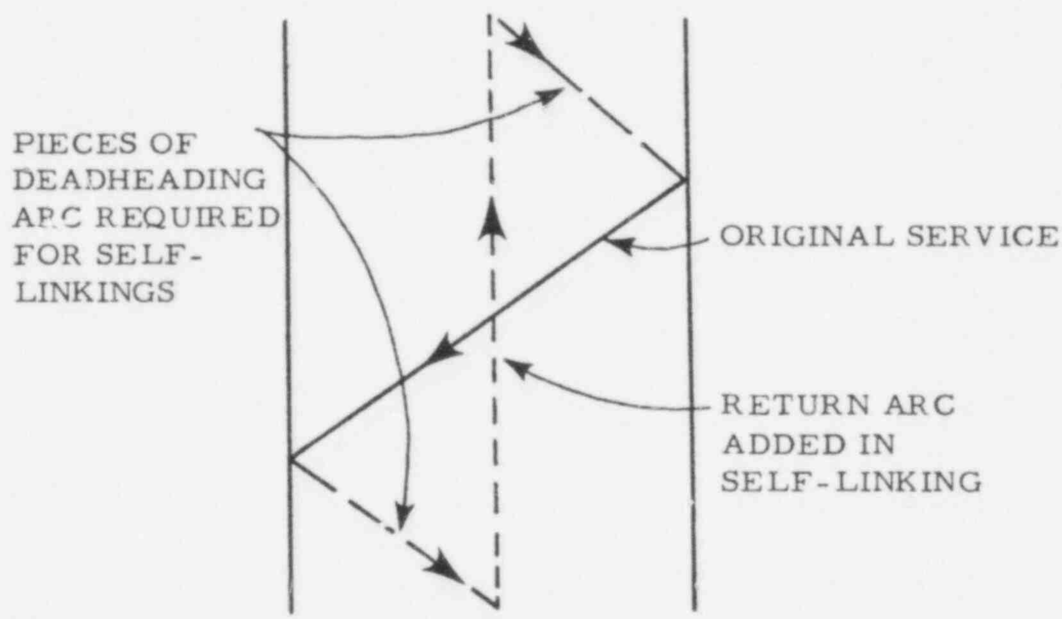
$$n_k^r \leftarrow y_k^r - z_k^r$$

Self-linking is a special case of linking which can arise with services in a periodic set. The resultant service is a closed loop which involves connecting the destination of the service to its origin by means of a return arc. The methods described above are directly applicable to this case. Note that self-linking always requires either zero or one additional return arc as illustrated in Figure 4.9.

In this non-fixed-fleet itinerary generation process, the self-linking feature obviates the need to specify initial conditions since the conditions at the end of the period actually serve as initial conditions for the beginning of the period.



a) Self-linking with no additional return arcs.



b) Self-linking with one additional return arc.

Figure 4.9. Examples of self-linking.

4.1.3 Establishment of Initial Conditions for Fixed-Fleet Approach

In the fixed-fleet approach for itinerary construction, iterations must be performed on the number of each type of transport unit element (TRU) to find the minimum number required to satisfy the service requirements. Each iteration requires an initial condition for each of the TRUs.

In order to reduce the sensitivity of the results to initial conditions, provision is provided for augmenting the original shipment schedule with a warm-up period at the beginning of the scheduling period. This is accomplished by subroutine WRMSCH in Figure 4.1 which extracts a user specified portion of the shipping schedule and places it before the start of the actual schedule (see Figure 4.10).

At the beginning of the warm-up period the individual TRU elements are evenly distributed among the maintenance bases with random values of accumulated use variables and availability time assigned. These initial conditions are used to augment the set of required services. If additional TRU elements are later required, the initial conditions on the previous TRU elements are retained. If fewer TRU elements are required, the last elements which were added are deleted

When the fixed-fleet approach is used for simulation, the initial conditions can be generated using the procedures just discussed or can be specified by the user.

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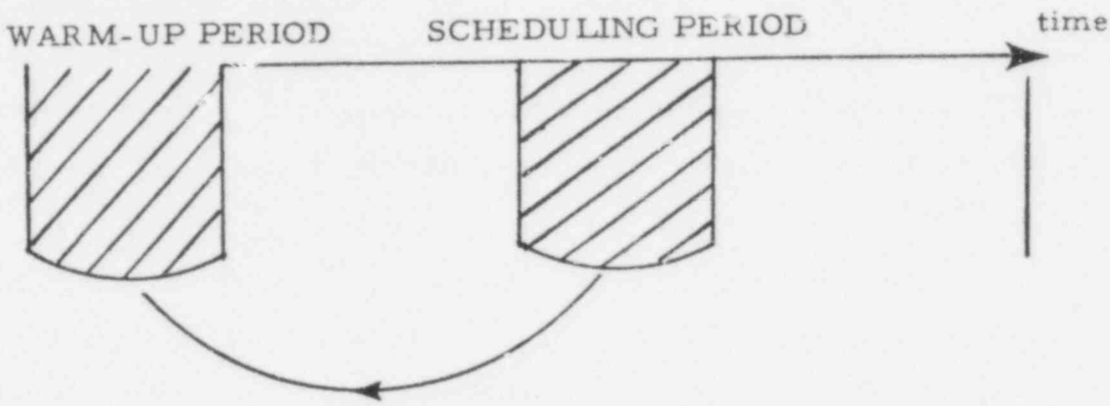

Figure 4.10. Augmentation of schedule with warm-up period.

4.1.4 Itinerary Construction for Fixed-Fleet Approach

At the start of the itinerary construction process, the feasibility of all possible service linkings is first checked. The service linkings are then ordered based on a linking value function which describes the desirable features of the linking. This linking value function is a weighted linear combination of

(1) added idle time in linking

(2) added deadhead time in linking

(3) loss in flexibility of combined service compared to its constituent services

(4) length of first constituent service $(t_i^1 - s_i^1)$

(5) length of second constituent service $(t_j^1 - s_j^1)$

When the feasibility of all possible linkings has been checked, the feasible linking with the smallest linking value is selected. The details of this linking are recorded, the constituent services i and j are replaced by composite service k , and all prior feasible linkings involving i and j are deleted. Then all possible linkings involving the new composite service k are checked for feasibility and those that are feasible are included in the list of feasible linkings, ordered by linking value function. The best linking from this list is again chosen, the linking data recorded, and the whole process is repeated until there are no more feasible linkings possible. The end result is a set of final composite services and the recorded data on the selected linkings.

In case of a tie among two or more feasible linkings, each of which have the same smallest linking value, the linking with the earliest departure in the resulting composite service is selected.

4.1.5 Itinerary Construction for Non-Fixed Fleet Approach

The itinerary construction process for the non-fixed-fleet approach is essentially the same as in the fixed-fleet approach except that now all possible linkings are feasible. This includes the self-linkings discussed in Section 4.1.2.

The fleet size is determined after the linking process has resulted in a set of closed itineraries which include all the required services. This fleet size is then equal to the total number of return arcs in the resulting closed itineraries. This is illustrated in Figure 4.11 which shows the linking of two services into a single closed itinerary which requires two return arcs. Thus a fleet size of two is required to handle these two services.

4.1.6 Recovery of Itineraries

The same process is used in the recovery of itineraries in both the fixed and non-fixed-fleet approaches. It is basically a two part process. The first part is to represent a final composite service by a binary tree which represents all the linkings of services which were used to build the service. This is illustrated in Figure 4.12. Here, for example, combined service 16 was formed by linking original service 1 and combined service 17, which, in turn, was formed by linking original services 5 and 6. This tree can be built with the time order of the original services increasing to the right, as shown. In the non-fixed-fleet approach this temporal ordering will usually cover more than one period. In this example, the itinerary handles, in order, original services 1, 5, 6, 7, 8, 11, and 13.

The next step in this recovery process is to use an "in order" traversal algorithm [3] to recover the legs of the itinerary. The

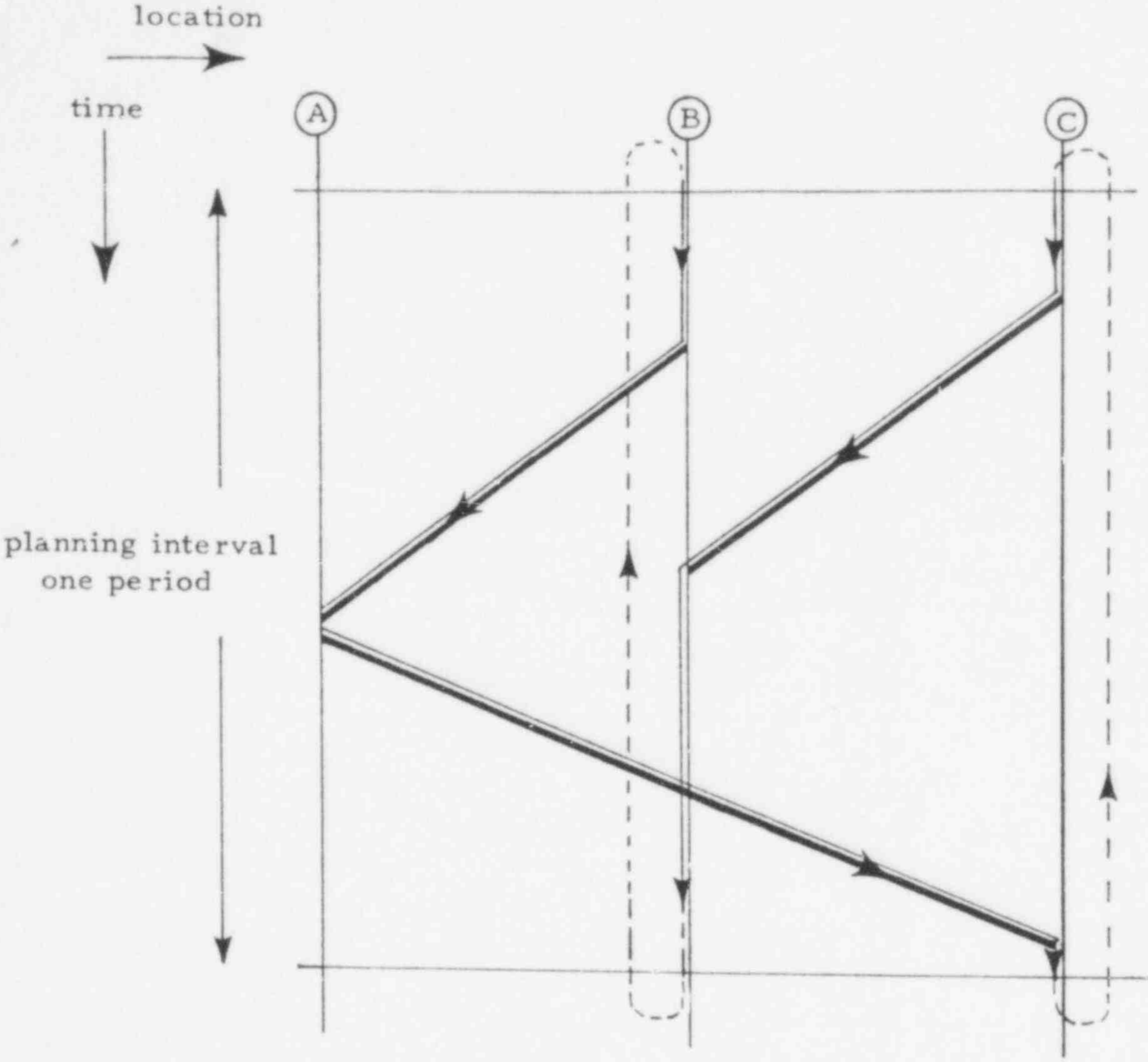

Figure 4.11. Closed itinerary construction (one two-period chain).

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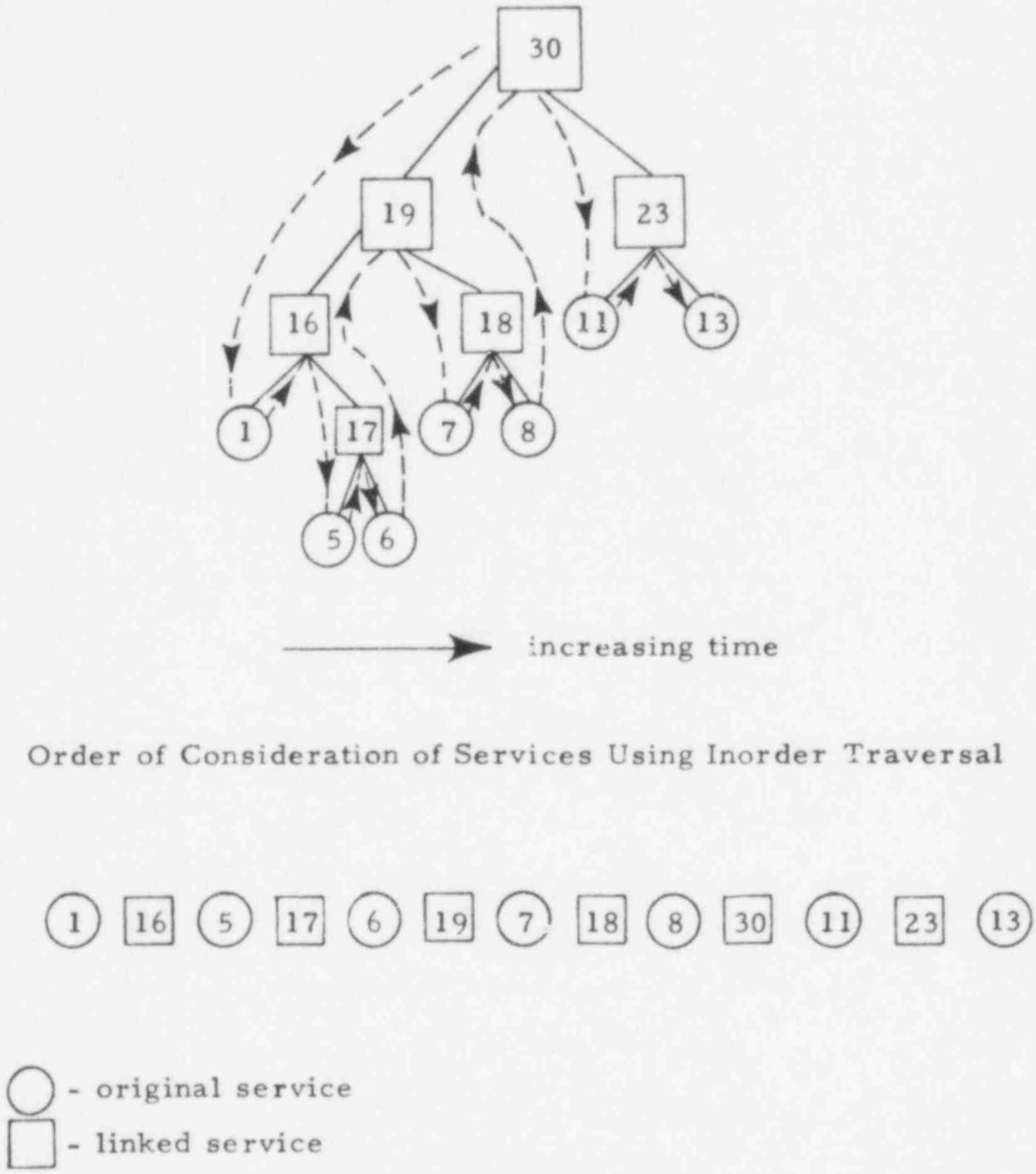

Figure 4.12. Example of recovery of itineraries.

"in order" traversal algorithm is illustrated by the dotted lines in Figure 4.12. Starting with combined service 30 at the top of the tree, the algorithm searches down and to the left until an original service is encountered, in this case number 1. It then searches up the tree to find that original service 1 is part of combined service 16. At this point the details of the linking of services 1 and 17, e.g., a maintenance stop, a deadhead leg and/or idle time, are extracted. Then the search proceeds down until original service 5 is encountered. Proceeding up to combined service 17, the details of the linking of services 5 and 6 are extracted. At this point we have extracted the details of the linkings between original services 1 and 5, and 5 and 6. This process then continues, as indicated by the dotted line in Figure 4.10, until all the original services in the itinerary are considered.

4.2 Fixed-Fleet Searching Procedure

The fixed-fleet sizing approach requires iterations on the fleet size until the smallest fleet size is found which satisfies all the required services for the transport unit types under consideration. The efficiency of this fixed-fleet approach is highly dependent on this required fleet size. This section presents a new efficient search technique for this fixed-fleet approach. Section 4.2.1 briefly reviews the characteristics of the fixed-fleet approach and how they affect the search process. Three possible search methods are then reviewed and compared in Section 4.2.2: the Fibonacci-type lattice search [4], the dichotomous search [4], and the new searching procedure, the L - I Search, which is designed to take advantage of all the information that is available from the fixed-fleet algorithm.

4.2.1 Characteristics of Fixed-Fleet Sizing

In the fixed-fleet itinerary construction process, the number of transport unit elements and their initial conditions are specified. These initial conditions are used to augment the original set of required services. The service linking process then proceeds until no further linkings are possible from temporal considerations. Now two situations are possible: (1) the final number of composite services is equal to the specified fleet size, or (2) the final number of composite services is greater than the specified fleet size. In the first situation, the fleet size is adequate to handle the required services, but may be larger than necessary. In the second situation, the fleet size is too small and must be increased.

The optimal fleet size is the minimum value for which the fleet size equals the final number of composite services, but such that reducing the fleet size by one results in the fleet size being less than the resulting final number of composite services

It is possible to find this optimal fleet size by adjusting upper and lower bounds on the fleet size. To address this issue, let us define

$b_{\ell i}$ = lower bound on fleet size at iteration i

b_{ui} = upper bound on fleet size at iteration i

f_i = fleet size at iteration i

f^* = optimal fleet size

n_i = final number of composite services at iteration i

In the discussion to follow, it will be assumed that

$$f_i = n_i \qquad \text{for all } f_i \geq f^*$$

$$f_i < n_i \qquad \text{for all } f_i < f^*$$

This is equivalent to the existence of only one local optimal fleet size.

Consider a process for adjusting b_{ui} and $b_{\ell i}$ to find f^*. Assume that for a fleet size in the range $b_{\ell i} < f_i < b_{ui}$, we obtain

$$f_i = n_i$$

We can now set a new upper bound for the next iteration

$$b_{u,\ i+1} = f_i$$

Conversely, if we obtain

$$f_i < n_i$$

we can set a new lower bound

$$b_{\ell,\ i+1} = f_i$$

In the latter situation there is also some additional information available. The difference between the final number of composite services n_i and the fleet size f_i may be close to the required increase in the fleet size needed to satisfy the required services. Note that similar information is not available when $f_i = n_i$.

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By always choosing a fleet size in the range $b_{\ell i} < f_i < b_{ui}$, eventually a situation will be reached for which

$$b_{\ell i} + 1 = b_{ui}$$

In this case the minimum fleet size is given by $f^* = b_{ui}$. The problem is to choose the successive values of f_i such that the minimum fleet size is found in the fewest iterations. In the following section, three search techniques for doing this are discussed.

4.2.2 Search Methods

The three search methods discussed here are all based on the evaluation of a function of a discrete variable. In our case, the discrete variable can be taken as the fleet size, f_i, while the function is the quantity

$$F_i = n_i(f_i) - f_i \quad (4.1)$$

If $F_i = 0$, we can set the upper bound for the next iteration

$$b_{u,\ i+1} = f_i$$

while taking

$$b_{\ell,\ i+1} = b_{\ell i}$$

If $F_i > 0$, we set the lower bound for the next iteration

$$b_{\ell,\ i+1} = f_i$$

while taking

$$b_{u,\ i+1} = b_{ui}$$

At iteration i, each of the search methods gives the next estimate of fleet size based on the current bounds b_{ui} and $b_{\ell i}$, the previous estimates of f_{i-1} and f_{i-2}, and the previous value of the function F_{i-1}.

4.2.2.1 Fibonacci Type Lattice Search [4]

This is a standard Fibonacci search modified for discrete independent variables. It is designed to efficiently find the maximum of a unimodal function [4]. Although it can be directly applied to our problem, it is not as efficient as the dichotomous search discussed in the next section because the information available from the evaluation of the function given by Eq. (4 ') is not used effectively.

The poor performance of the Fibonacci search compared to the dichotomous search for this minimum fleet size problem is illustrated in Table 4.5 which gives the maximum number of evaluations of the function $F_i(f_i)$ that are required for different initial intervals between the original upper and lower bounds on fleet size.

The interested reader is referred to Reference [4] for a complete discussion of the Fibonacci search methods.

4.2.2.2 Dichotomous Search [4]

The main disadvantage of the Fibonacci type lattice search is that is does not immediately take advantage of the result of each function evaluation to reset one of the bounds on fleet size. The dichotomous search, as discussed here, is designed to take immediate advantage of this information.

This search method simply takes as the next value of f_i the integer value midway between the current bounds. This one function

Table 4.5. Maximum number of function evaluations versus original interval length for Fibonacci and Dichotomous search methods applied to the minimum fleet size problem.

Maximum No. of Function Evaluations	Original Interval of f_i	
	Fibonacci	Dichotomous
0	0	0
1	1	1
2	2	2-3
3	3-4	4-7
4	5-7	8-15
5	8-12	16-31
6	13-20	32-63
7	21-33	64-127
8	34-54	128-255

evaluation immediately allows half of the current interval to be discarded. It is easy to show that an original interval with $2^n - 1$ values of f_i requires exactly n evaluations of F to find the optimal fleet size. If the number of values in the interval is between $2^{n-1} - 1$ and $2^n - 1$, the maximum possible number of function evaluations is n, but it could be less in some cases.

Table 4.5 shows the maximum required number of evaluations of $F_i(f_i)$ as a function of the number of f_i's in the original interval between the upper and lower bounds for this dichotomous search.

4.2.2.3 L - I Search

The advantage of the dichotomous search is that it guarantees that no more than a specified maximum number of function evaluations are required to determine the optimal fleet size. However, it is not designed to use all the available information that may allow a better sequence of f_i values to be chosen to reduce the number of function evaluations. Specifically, the information that is not used is that, when $f_i < f^*$, the function $F_i(f_i) > 0$ may represent a close approximation to the difference between the unknown optimal fleet size f^* and f_i. The L - I (Lower-Intelligent) Search discussed here is specifically designed to use this information to minimize the number of function evaluations required to find f^*. This is the method implemented in the fixed-fleet approach.

Note that this additional information is available when $f_i < f^*$ and not when $f_i \geq f^*$. For this reason it is desirable to design the search altorithm so that f_i generally approaches f^* from below.

The basic rules for the L -I Search procedure are as follows. If at iteration i, $F_i(f_i) > 0$, we set $b_{\ell i} = f_i$ and take as the next estimate of fleet size

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$$f_{i+1} = f_i + F_i(f_i) - k$$

where

$$0 \leq k < F_i(f_i)$$

Note that k = 0 if $F_i(f_i) = 1$. In the situation when $F_i(f_i) > 1$ the value of k that is used is based on the accuracy with which $F_i(f_i)$ represents the difference $f^* - f_i$, with less accuracy requiring higher values of k. Experience with the Version I model indicates that a value of k = 1 gives the best results when $F_i(f_i) > 1$, i.e., it appears that usually $F_i(f_i) = f^* - f_i$. If $F_i(f_i) = 0$, we set $b_{ui} = f_i$. If, in addition $b_{\ell i} = f_i - 1$, f_i represents the optimal fleet size. If $b_{\ell i} < f_i$, we can take either

$$f_{i+1} = f_i - c(f_i - b_{\ell i}), \quad 0 < c < 1$$

or

$$f_{i+1} = f_i - k, \quad 1 \leq k < f_i - b_{\ell i}$$

Lower values of c and k should be used if $F_i(f_i)$ is a good approximation to $f^* - f_i$.

The optimal fleet size is determined when

$$b_{ui} = b_{\ell i} + 1$$

with $f^* = b_{ui}$.

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: method can be started by choosing the initial fleet size) be the lower bound on fleet size or close to the lower bound. ses it has been found that three function evaluations are For example, in this situation we might have

$$= b_{\ell 0} \text{ or } b_{\ell 0} + 1 \Rightarrow F(f_1) > 1 \Rightarrow b_{\ell 1} = f_1$$

$$= f_1 + F(f_1) - 1 \Rightarrow F(f_2) = 1 \Rightarrow b_{\ell 2} = f_2$$

$$= f_2 + F(F_2) \Rightarrow F(f_3) = 0 \Rightarrow b_{u3} = f_3 = f_2 + 1$$

se $f^* = f_3$. (See Figure 4.13.)

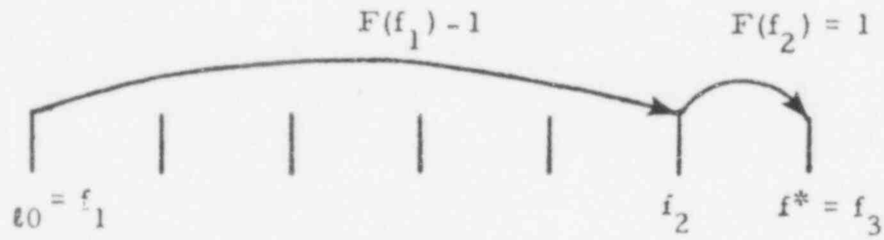

Figure 4.13. Example of efficient L - I search.

lote that it is possible to have more than three function eval- but a specific maximum number cannot be s . The l number of function evaluations should increase as the accur- e approximation of $F_i(f_i)$ to $f^* - f_i$ decreases.

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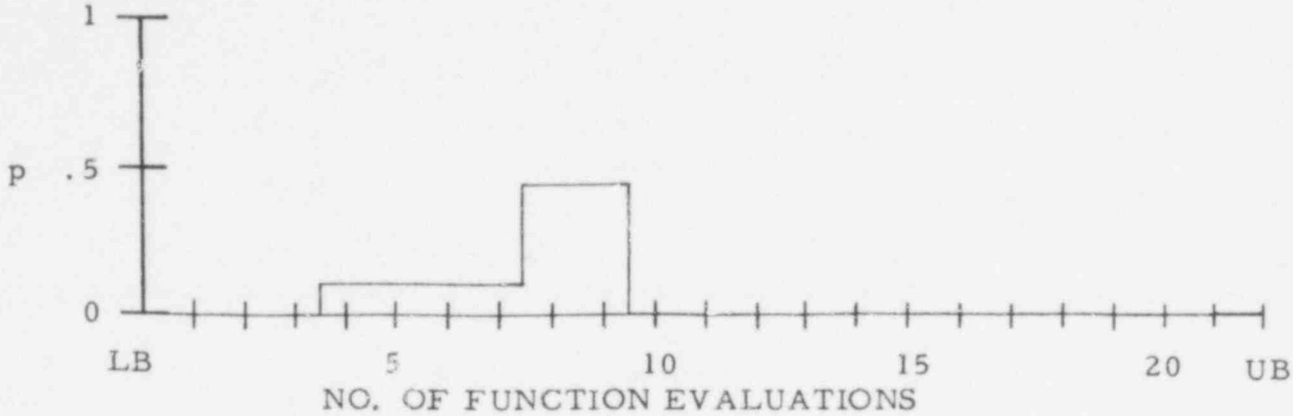
4.2.2.4 Comparison of Search Methods

The dichotomous search is designed to find the optimal fleet size in not more than a maximum number of function evaluations. In contrast, the L - I method is intended to minimize the number of function evaluations by using all the available information, but it does not directly place a maximum on the number of possible function evaluations. Because of the different goals of these two methods, a reasonable way of comparing them is to look at the probability that any given number of function evaluations will be required to find the fleet size in an initial interval of specified length.

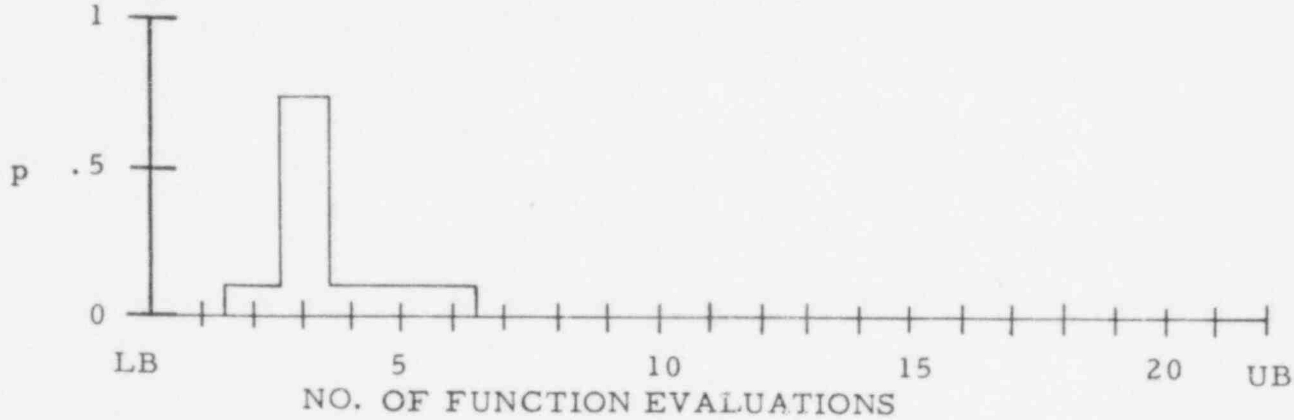
It is important in this comparison to include all required function evaluations, including initial checking of the validity of the initial upper and lower bounds, if necessary. In addition, the last fleet size to be checked must be the optimal fleet size, since the data on the linking of services is required to generate the itineraries of the transport unit type. Therefore, if on the last iteration on f_i we find that $F_i(f_i) = 1$ and $b_{ui} = f_i + 1$, one more function evaluation with $f^* = f_{i+1} = b_i$ is required to generate the required itineraries.

To start the dichotomous search, it is necessary to first establish valid upper and lower bounds on fleet size. This generally requires two function evaluations before the search starts. There is also about a 50 percent probability that an additional evaluation will be required at the end to generate the itineraries for the optimal fleet size.

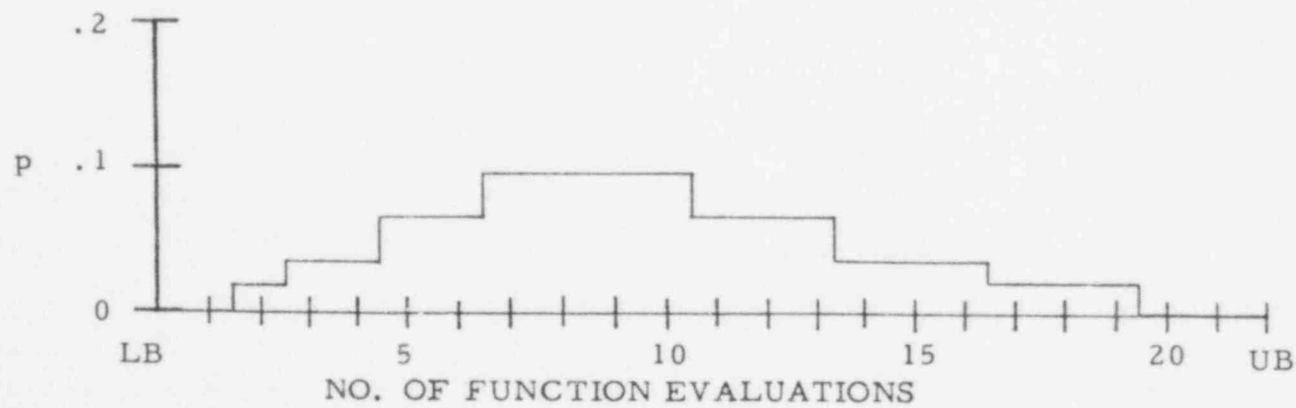
Figure 4.14 illustrates an estimate of a probability distribution of the number of function evaluations for an initial interval of $b_{u0} - b_{\ell 0} = 20$. Note that about 80 percent of the time either 7 or 8 function evaluations are required, while the remaining 20 percent is distributed among 4, 5, and 6 evaluations.



(a) Dichotomous search



(b) L - I search, $F_i(f_i)$ good approximation to $f^* - f_i$



(c) L - I search, $F_i(f_i)$ poor approximation to $f^* - f_i$

Figure 4.14. Possible probability distributions of number of function evaluations required for search methods.

Figure 4.14 presents a possible probability distribution for the L - I search assuming that the function $F_i(f_i)$ represents a good approximation to the difference between f^* and f_i when $f_i < f^*$. To start the L - I search, only the lower bound need first be evaluated. In this situation the most likely number of evaluations is three. Experience with the Version I model indicates that this is the usual situation.

If $F(f_i)$ is a very poor approximation to $f^* - f_i$, it is difficult to construct an exact representation of the corresponding probability distribution. Such a probability distribution may have a low peak somewhere near the middle of the interval and extend from two function evaluations to 22 (the worst possible case). The worst characteristic of this distribution is that there is a finite and not necessarily small probability that more function evaluations would be required than the maximum of eight required with the dichotomous search, as is illustrated in Figure 4.14.

In comparing the three probability distributions in Figure 4.14, it is apparent that the best search method for finding the minimum fleet size is dependent on how good an approximation $F_i(f_i)$ is to the difference between the optimal fleet size f^* and f_i. If the approximation is good, the L - I Search should be more efficient, while if it is poor, the conservative dichotomous search is likely to give better overall results. Experience has indicated that the L - I Search generally converges in three iterations, the minimum number, in most cases.

4.3 Generation of Service Requirements

Before itineraries for a TRU can be constructed, it is first necessary to generate the service requirements for that TRU. In the Version II model the aircraft and truck trailer itineraries are the first to be built. The service requirements for these aircraft and trailers are generated from the shipment schedule itself using subroutine SHPSRV in Figure 4.1.

The aircraft itineraries levy additional requirements on trailers to transport the shipments between the bases and airfields. Both the aircraft and trailer itineraries then levy requirements on lower level TRUs. For example, active and deadhead legs of trailer itineraries require truck tractors to pull the trailers. This extraction of service requirements from itineraries is performed in subroutine EXTSRV.

The basic algorithms for subroutines SHPSRV and EXTSRV are discussed in the description of the subroutines presented in Appendix B.

4.4 Sequencing Procedures for Transport Unit Elements

The Version II model is sufficiently flexible to accommodate requirements ranging from determining just the number of trucks (trailer/tractor combinations) required to handle a given shipment schedule up to sizing all the TRU elements associated with truck and aircraft fleets. These elements might include a number of aircraft types, trailer types, tractors, escort vehicles, aircraft crews, and truck/escort vehicle crews.

The model also includes provision for varying the rules which determine the service requirements levied on lower level TRUs by an itinerary. For example, consider the rules for assignment of escort vehicles. One such rule might be to require an escort vehicle to travel

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with a truck only when the truck is loaded with nuclear material. On the other hand, an excort vehicle might be required any time a truck (loaded or empty) is traveling.

The user of the model specifies the TRUs to be sized, the order in which they are to be considered, and how the itinerary legs for a given TRU levy service requirements on lower level TRUs. This is accomplished through the input data SEQSRV (see the data structure in Appendix A). The SEQSRV data consists of a sequence of sets of four numbers. These four numbers specify in order

(1) the TRU itinerary levying the service requirement

(2) the TRU on which the service requirement is levied

(3) two numbers which indicate the legs of itinerary which must be covered by the lower level itinerary.

This SEQSRV data also controls the calling of subroutines in subroutine MAIN. For example, itineraries are not generated for a given TRU until all the service requirements for that TRU have been found.

An example of SEQSRV data is given in Table 4.6, along with the subroutines which are called with each set of four numbers. Note that the TRU index of 0 is used to indicate that the shipment schedule levies the service requirements on aircraft and truck trailers, with subroutine SHPSRV being used to generate these service requirements. This subroutine automatically specifies the service requirements levied by the shipment schedule on the aircraft and truck trailers so that the SEQSRV data is not used for this purpose. The additional service requirements levied by the aircraft itineraries on truck trailers are generated by subroutine ASSRV (associated services) In all other cases subroutine EXTSRV is used to extract the service requirements based on the SEQSRV data.

Table 4.6. Example of sequencing with aircraft and truck modes.

INDITN	INDTRU	CALLS	
0 (Sch)	11 (Tk. trailer type 1)	SHPSRV	
0 (Sch)	12 (Tk. trailer types)	SHPSRV	
0 (Sch)	21 (A/C type 1)	SHPSRV	ITIN
0 (Sch)	22 (A/C type 2)	SHPSRV	ITIN
21 (A/C type 1)	11 (Tk. trailer type 1)	ASSRV	
22 (A/C type 2)	11 (Tk. Trailer type 1)	ASSRV	ITIN
21 (A/C type 1)	12 (Tk. trailer type 2)	ASSRV	
22 (A/C type 2)	12 (Tk. trailer type 2)	ASSRV	ITIN
11 (Tk. trailer 1)	15 (Tk. tractors)	EXTSRV	
12 (Tk. trailers)	15 (Tk. tractors)	EXTSRV	ITIN
15 (Tk. tractors)	16 (Escorts)	EXTSRV	ITIN
15 (Tk. tractors)	17 (Crews)	EXTSRV	
16 (Escorts)	17 (Crews)	EXTSRV	ITIN
21 (A/C type 1)	27 (A/C crews)	EXTSRV	
22 (A/C type 2)	27 (A/C crews)	EXTSRV	ITIN
21 (A/C type 1)	28 (A/C guards)	EXTSRV	
22 (A/C type 2)	28 (A/C guards)	EXTSRV	ITIN

4.5 Effects of Home-Base Maintenance Policies

The Version I model can accommodate either a single-base or a nearest-base maintenance policy, but not a home-base maintenance policy. However, if there is more than one home base for crews, it is mandatory that the crews be periodically returned to their home bases for rest, i.e., a home-base maintenance policy is required. Furthermore, home-base maintenance policies may sometimes be specified for other types of transport unit elements.

In the Versions I and II models a home-base maintenance policy for crews is approximated by a nearest-base maintenance policy. This approximation seems reasonable since a nearest-base maintenance policy should produce travel times which are representative of the time to travel to and from the actual home base, possibly via commercial airline.

The purpose of this section is to discuss the problems in implementing a home-base maintenance policy and to outline possible solutions.

4.5.1 Problems With Home-Base Maintenance Policies

The discussion of the itinerary construction processes in Section 4.1 is based on a nearest-base maintenance policy. For example, in the maintenance linking feasibility checks the quantities α_i and β_i which give travel times to and from the maintenance base, and γ_i and δ_i which define the distances to the maintenance base are all calculated using the nearest maintenance base.

If a home-base maintenance policy is specified, the representation of service i must be modified to indicate the home base at which maintenance must be performed when the service includes an internal maintenance stop. This can be easily done by redefining the quantity m_i as follows

$$m_i = \begin{cases} \text{maintenance base if service contains a stay in maintenance} \\ 0 \qquad \text{otherwise} \end{cases}$$

This redefinition of m_i still does not completely solve the problems associated with a home-base maintenance policy. For example, consider the possible linking of services i and j, with $m_i = m_j = 0$. Since no maintenance base is associated with either service, it is not clear what maintenance base should be used to calculate the quantities α_i and β_j which are required in the maintenance feasibility check. Furthermore, if an intermediate maintenance stop is necessary, it is not clear what maintenance base should be used.

The linking of services i and j for which $m_i = 0$ and $m_j =$ (Maintenance base for service j) causes no difficulties since the composite service k would have the same maintenance base as j, i.e., $m_k = m_j$.

If neither m_i nor m_j is zero, an additional maintenance feasibility check is $m_i = m_j$ (i.e., both services i and j must have the same home maintenance base). The composite service k would then have $m_k = m_i = m_j$. The linking between i and j is not feasible if $m_i \neq m_j$.

This linking of services to form itineraries can be used with both the fixed-fleet and non-fixed-fleet approaches. In the fixed-fleet approach, a warm-up shipping period is generally attached to

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the beginning of the actual shipping schedule to provide a reasonable set of initial conditions for the transport unit elements. With a nearest-base maintenance policy, the transport unit elements are equally distributed among the maintenance bases with a random value of accumulated use initially assigned to each unit. With a home-base maintenance policy, the initial assignment of the transport unit elements to maintenance bases, if it is required, is not clear. The solution for these home maintenance base assignments may require additional computation to determine these quantities as well as the fleet size.

With the non-fixed-fleet approach, in which services are linked together to form closed chains, a home-base maintenance policy introduces many of the same complications into the scheduling problem as occur in the fixed-fleet approach. The major difference is that initial conditions of the transport unit elements, along with the maintenance base of each element, are not used with the non-fixed-fleet methods. This precludes the use of some of the possible solution techniques from the fixed-fleet approach, which are discussed in Section 4.5.3.

4.5.2 Home-Base Maintenance Policies for Crews

It is expected that the personnel work rules for the transportation system will require each crew to return to its home base for rest before some specific maximum duty time is exceeded. The special characteristics of the crew transport unit elements allows a home-base maintenance policy to be incorporated into the transportation system model in a reasonably straightforward manner.

Since the crew assignments are generally the last to be made, it can be expected that crew deadheading will be required for travel to and from their home bases. If it is assumed that commercial airline transportation will be used for this purpose, a maximum travel time to and from home base of one day may be reasonable. This relatively short travel time then allows for the following two simplified approaches to crew/guard scheduling with a home-base maintenance policy. The more general methods of Section 4.5.3 are also applicable here.

4.5.2.1 Approach I - Specified Constant Travel Time

The simplest approach, which is valid for both the fixed-fleet and non-fixed-fleet algorithms, is to always allow one day of travel time to the home base and from home base to the point at which the next active duty starts. Since the one day of travel time should allow the crew to reach any point in the United States using air transportation, no crew home bases need be explicitly specified.

A disadvantage of this approach is that is does not allow advantage to be taken of the situations in which no deadheading is required. The next approach is designed to take this situation into account.

4.5.2.2 Approach II - Dual Level Travel Times

This approach requires a listing of the home bases for the crews. As in the first approach, a one-day travel time will be specified for all cases except in the following situations when no travel time will be scheduled.

(1) A shipment is scheduled from a crew home base and a fresh crew is required at the start of the shipment. In this case the m_i variable for the crew will be temporarily labeled with that home base designation.

(2) A shipment arrives at a crew home base when that crew is scheduled for a break. If the m_i variable for that crew is either undesignated or indicates that the destination base is also the home base, zero travel time is allowed. However, if m_i designates a home base for the crew other than the destination base, one day of travel time is scheduled.

In this approach the m_i variable is used to temporarily designate a home base for the crew only for the purpose of determining travel time. Once a crew starts a break at home base, this home base designation is eliminated.

This approach should be adequate for sizing purposes if the number of situations in which zero travel time is allowed is small compared to the number for which one day of deadhead travel time is allowed. If this is not the case, then either the first approach or one of the more general approaches from Section 4.5.3 should be used.

4.5.3 General Solution Approaches for Home-Base Maintenance Policies

When a home-base maintenance policy is specified for a given type of transport unit element, the computerized model of the transportation network should provide the required number of elements and their distribution by home maintenance base. This section presents a number of possible approaches to incorporating home-base maintenance policies into the model. The subsequent discussion separately considers the possible modifications to the fixed-fleet and non-fixed-fleet algorithms.

4.5.3.1 Fixed-Fleet Algorithms

Possible approaches to incorporation of home-base maintenance policies into the fixed-fleet algorithms range from relatively simple to rather extensive and complex modifications. Here an attempt is made to discuss some possible modifications in order of increasing complexity.

(1) Geographical Decomposition

With geographical decomposition, the United States would be divided into a number of regions, each of which contains one maintenance base. Any shipment from a base in a given region would then be assigned to a transport unit element with its designated home maintenance base in that region. Geographical decomposition would allow for essentially separate treatment of each of the regions, thereby decreasing the required computation time by reducing the number of possible service linkings that must be considered.

This approach would be very useful if the maintenance bases were co-located with the fuel fabrication facilities since, for boiling water reactors and pressurized water reactors, example shipment schedules which have been generated indicate that each such facility supplies the fuel for the reactors in a given geographical region. However, for high temperature gas reactors, the fuel elements may be supplied for the whole country by one fabricator. In this case, geographical decomposition may be overly restrictive and result in conservative sizing results.

(2) Sequential Linking of Individual Services to Existing Itineraries

In this approach, linking of required services would be allowed only when a service is linked to the end of an existing itinerary. In effect, this is a temporal decomposition with a short planning horizon. Here each itinerary would be associated with a home maintenance base.

The major disadvantage of this approach is that the short effective planning horizon could produce a larger fleet size than would be required with a longer planning horizon.

(3) Sequential Linking of Composite Services to Existing Itineraries

This is similar to the last approach except that now the standard procedures are used to link services as long as no internal maintenance stops are required in the composite services. A key factor in this linking process is the specification of the maintenance base to be used in the calculation of the accumulated use variables α_i and β_i for travel to and from maintenance. A conservative approach is to always use the furthest maintenance base. Probably more reasonable choices might be to base the calculation of α_i and β_i on some average distance to all the maintenance bases, or on the distance to the second or third nearest base.

As part of the general linking process, favorable linkings of individual and composite services to the ends of itineraries (e.g., to initial conditions) should also be allowed. Then by allowing intermediate maintenance stops only in linkings of services with the ends of itineraries, a sequential linking of composite services to the ends of itineraries should result.

(4) Use of Nearest-Base Maintenance Policy

A home-base maintenance policy can be implemented by using a modified nearest-base maintenance policy in the linking of services. Once an internal maintenance stop is required, the m_i variable for that composite service is used to designate the nearest maintenance base. In subsequent linkings, this composite service can be linked only to services with either no internal maintenance stops or to other composite services with the same designated maintenance base.

In this approach it is not necessary to preassign a number of transport unit elements to each maintenance base. If a service without an internal maintenance stop is linked to an initial condition, the initial location of the transport unit elements is taken to be the maintenance base which is nearest to the origin of the service. The resulting composite service is then assigned to this maintenance base. If a composite service with an internal maintenance stop is linked to an initial condition, the initial location of the transport unit element is placed at the maintenance base for the composite service.

(5) Retaining Linkings for Multiple Maintenance Bases

A disadvantage with the above approaches of accounting for a home-base maintenance policy is that no more than one possible maintenance base is considered for each possible linking. The end result could be an inefficient set of itineraries. One possible way to circumvent this difficulty is to provide for alternative representations of composite services in the service list, where each alternative has a different home maintenance base.

This can be implemented by first using the standard procedures for linking of services, basing the calculations of α_i and β_i on the nearest maintenance base. At some point in this process the candidate linking with the highest value will be one which requires an intermediate maintenance stop between two services i and j with $m_i = m_j = 0$, i.e., the individual services have no internal maintenance stops. Suppose that this linking is feasible when any one of the k nearest maintenance bases is used for the intermediate maintenance stop. These k alternatives of this composite service are added to the service list, each with a different maintenance base. All of these alternatives are retained in the service list until the linking of one or more of the composite service alternatives with another composite service has the highest linking value. At this point all alternatives of the original composite service for which this new linking is not feasible are deleted from the service list, while all the feasible linkings involving the composite service alternatives are added to the service list.

(6) Retaining All Possible Linkings by Band for Multiple Home Maintenance

This is probably the most general approach to the solution to this problem. Here the maintenance feasibility linking check would be expanded to consider all the maintenance bases. Since the results may be dependent on the particular band of the composite service, the feasible linkings would be ordered and stored by band. The service representation described in Section 4.1 is sufficiently general to accommodate this change. By considering linkings through all the feasible maintenance bases, it should be possible to generate efficient itineraries with a home base maintenance policy.

Further work is required to completely define the procedures for selecting the best linkings in this case. It is hoped that experience with the Version II model will provide insight into the best procedures for this general approach.

4.5.3.2 Non-Fixed-Fleet Algorithms

The main characteristic of non-fixed-fleet algorithms (the Version II model) is the self-linking of services, which avoids the need to specify initial conditions and to provide for a warm-up period.

Of the methods for handling a home-base maintenance policy discussed above for the fixed-fleet algorithms, four of them can be directly used with the non-fixed-fleet approaches. These are the (1) geographical decomposition, (4) use of nearest-base maintenance policy, (5) retaining linkings for multiple maintenance bases, and (6) retaining all possible linkings by band. The other two possibilities require services to be linked to the end of partial itineraries, which are not defined in the non-fixed-fleet approach.

4.5.4 Conclusions on Home-Base Maintenance Policies

The major conclusion to be reached from this discussion is that it is possible to accommodate a home-base maintenance policy with both the fixed-fleet and non-fixed-fleet sizing algorithms. A decision on the best technique for handling this policy should be deferred until experience is gained with Version II of this computerized model.

4.6 Efficiency Considerations

One possible shortcoming of these models is the computer time required to exercise them with a reasonably large shipment schedule, e.g., about 150 shipments. With the fixed-fleet approach, it takes about 10 minutes of CPU time on a DEC-10 computer to generate the final set of composite services for one TRU with one value of fleet size.

Since it generally takes three iterations on fleet size to find the minimum, the generation of itineraries for one TRU requires approximately 30 minutes of DEC-10 CPU time. If this figure is multiplied by the number of TRUs for which itineraries are to be generated, up to two hours of DEC-10 CPU time might be required to size a fleet consisting of truck trailers, truck tractors, escort vehicles and crews. However, it is important to note that the CDC 6600 computer is about an order of magnitude faster than the DEC-10, so that about 12 minutes of CDC 6600 CPU time might be required.

One problem is unique to the fixed-fleet approach in that three iterations on fleet size are generally required to find the minimum fleet size. Each of these iterations requires that the procedure of linking services be completely repeated. This problem has been eliminated with the non-fixed-fleet approach. of the Version II model which does not require iterations on fleet size. This non-fixed-fleet approach requires about one-third of the CPU time compared with the fixed-fleet approach

A second cause of large required CPU time, which is present in both approaches, results from the process of checking the feasibility of all possible service linkings at the start of the itinerary construction process. If there are n original services, then the feasibility of $n^2 - n$ potential linkings must be checked. If $n = 150$, the number of linkings to be checked is 22, 350, many of which are not feasible, and of those that are feasible, many are very poor linkings based on the linking value function criterion.

We have identified two possible approaches to reducing the number of linkings to be checked.

(1) Consider the linking of service i to other services that are located within a time interval around service i . For example, if this time interval were half the planning horizon, this might reduce the number of linkings to be checked by about one-half. Smaller time intervals would reduce the number of feasible linkings even further.

(2) A second approach is to initially consider only the first m services ordered by starting time. Each time the number of services is reduced by one, the next service in time is added to this group and the feasibility of the linkings involving this service are checked.

It is recommended that modifications to these procedures to increase efficiency be deferred until more experience is gained with the Version II model.

REFERENCES

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2. Hasseltine, E.H. and Leary, P.L. "TRUCKING I, A Computerized Transportation Model," Sandia Laboratories, SAND 75-8236, July 1975.

3. Wirth, N., Algorithms + Data Structures = Programs, Prentice Hall, Englewood Cliffs, N.J., 1976.

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APPENDIX A - DATA STRUCTURES

This appendix presents the data structures used in both the Versions I and II models. These structures are designed to be sufficiently general so that they will be applicable to later versions with little or no modification.

```
      BLOCK DATA
C
C            /BASDAT/

      INTEGER BASE
      REAL LAT,LONG,DISTAC,DISTRR,DISTWA
      COMMON /BASDAT/BASE(150),LAT(150),LONG(150),DISTAC(150),
     +       DISTRR(150),DISTWA(150)

C     /BASDAT/
C            BASE     = BASE IDENTIFIER(A3)
C            LAT      = LATITUDE OF BASE (RADIANS)
C            LONG     = LONGITUDE OF BASE (RADIANS)
C            DISTAC   = DISTANCE FROM BASE TO NEAREST AIRFIELD
C            DISTRR   = DISTANCE FROM BASE TO NEAREST RAILHEAD
C            DISTWA   = DISTANCE FROM BASE TO NEAREST PORT
C
C            /SHPSCH/

      INTEGER NOSHP,OBASE,MATTYP,INDMOD,DBASE,SHPNO
      REAL ETMSH,LTMAR,QUAN
      COMMON /SHPSCH/NOSHP,OBASE(1000),DBASE(1000),ETMSH(1000),
     +               LTMAR(1000),MATTYP(1000),QUAN(1000),
     +               INDMOD(1000),SHPNO(1000)

C     /BSCH/
C            NOSHP    = NUMBER OF SHIPMENTS IN SCHEDULE
C            OBASE    = ORIGIN BASE
C            DBASE    = DESTINATION BASE
C            ETMSH    = EARLIEST TIME FOR SHIPMENT
C            LTMAR    = LATEST TIME FOR ARRIVAL
C            MATTYP   = MATERIAL TYPE(1=FRESH FUEL,2=FRESH FUEL RODS,
C                                     3=SPENT FUEL)
C            QUAN     = QUANTITY OF MATERIAL
C            INDMOD   = MODE INDICATION (SEE /MAINTV/ TRANSPORT UNIT LIST)
C            SHPNO    = SHIPMENT ID NUMBER
C
C            /VEHP/

      REAL CAP,VEL,TMLD,TMUN
      COMMON /VEHP/CAP(12,50),VEL(50),TMLD(12,50),TMUN(12,50)

C     /VEHP/
C            CAP(J,I)=CAPACITY OF VEHICLE TYPE I
C                     FOR FUEL MATERIAL TYPE
C                     J(SEE MATTYP OF /SHPSCH/)
C            VEL      = VELOCITY OF VEHICLE TYPE
C            TMLD(J,I)= LOADING TIME OF VEHICLE TYPE I
C                     FOR FUEL MATERIAL TYPE J
C            TMUN(J,I)= UNLOADING TIME OF VEHICLE TYPE I
C                     FOR FUEL MATERIAL TYPE J
C
C            /MODTA/
```

779 062

```
      LOGICAL MODAC,MODRR,MODWA
      COMMON /MODTA/MODAC,MODRR,MODWA

C     /MODTA/
C           MODAC    = TRUE IF AIRCRAFT MODE ALLOWED
C           MODRR    = TRUE IF TRAIN MODE ALLOWED
C           MODWA    = TRUE IF WATER MODE ALLOWED
C
C     MODE CHOICE DATA. THIS WILL NOT BE FULLY DEFINED
C     UNTIL VERSION 3. FOR NOW THIS DATA WILL CONSIST
C     OF LOGICAL VARIABLES WHICH INDICATE THE PRESENCE
C     OF DIFFERENT MODES
C
C           /MAINTV/

      INTEGER MNTBS,MNTPL
      REAL ALPDY,MAXDY,MNTIME
      COMMON /MAINTV/ALPDY(50),MAXDY(2,50),MNTIME(50),MNTBS(5,50),
     +              MNTPL(50)

C     /MAINTV/
C           INDICES FOR TRANSPORT UNIT TYPES
C           NEGATIVE INDEX MEANS DO NOT SHIP THIS WAY
C           10= SHIPMENTS DESIGNATED FOR TRUCK MODE
C           11= TRUCK TRAILER TYPE 1
C           12= TRUCK TRAILER TYPE 2
C           13= TRUCK TRAILER TYPE 3
C           15= TRUCK TRACTOR
C           16= ESCORT VEHICLE
C           17= TRACTOR/ESCORT CREWS
C
C           20= SHIPMENTS DESIGNATED FOR A/C MODE
C           21= AIRCRAFT TYPE 1
C           22= AIRCRAFT TYPE 2
C           23= AIRCRAFT TYPE 3
C           27= A/C CREWS
C           28= A/C GUARDS
C
C           30= SHIPMENTS DESIGNATED FOR RR MODE
C           31= RR CONTAINER CAR TYPE 1
C           32= RR CONTAINER CAR TYPE 2
C           33= RR CONTAINER CAR TYPE 3
C           35= LOCOMOTIVE
C           36= CHASE CARS
C           37= TRAIN CREWS
C           38= TRAIN GUARDS
C           39= CHASE VEHICLE CREW
C
C           40= SHIPMENTS DESIGNATED FOR WATER MODE
C           41= VESSEL TYPE 1
C           42= VESSEL TYPE 2
C           43= VESSEL TYPE 3
C
C           ALPDY    = NOT USED VERSION 1
C           MAXDY    = MAXIMUM ALLOWABLE ACCUMULATED DUTY BEFORE
C                        MAINTENANCE IS REQUIRED
```


779 063

```
C                   FIRST ELEMENT IS ACCUMULATED TIME
C                   SECOND IS IS ACCUMULATED DISTANCE
C          MNTIME = TIME TO PERFORM MAINTENANCE
C          MNTBS(J,I)= LISTING OF MAINTENANCE BASES(J)
C                    FOR TRANSPORT UNIT ELEMENT I
C          MNTPL = MAINTENANCE POLICY, 0 FOR HOME
C                  BASE MAINTENANCE ONLY, 1 FOR NEAREST
C                  BASE MAINTENANCE POLICY
C
C          /SIZVAR/

      REAL PLHOR,WARMTM,WARMST
      LOGICAL SZFF
      INTEGER FLTSIZ,BNDUP,BNDLOW
      COMMON /SIZVAR/PLHOR,WARMTM,WARMST,SZFF,FLTSIZ(50),
     +      BNDUP(50),BNDLOW(50)

C     /SIZVAR/
C          PLHOR   = PLANNING HORIZON
C          WARMTM  = WARM UP TIME
C          WARMST  = START OF WARMUP
C          SZFF    = TRUE FOR FIXED FLEET SIZING
C          FLTSIZ  = FLEETSIZE
C          BNDUP   = UPPER BOUND ON FLEETSIZE
C          BNDLOW  = LOWER BOUND ON FLEETSIZE
C
C          /WKPAR/

      LOGICAL SATTR,SUNTR,HOLTR,SATLD,SUNLD,HOLLD
      REAL LTDYBA,LTDYRD
      COMMON /WKPAR/SATTR,SUNTR,HOLTR,SATLD,SUNLD,HOLLD,
     +              LTDYBA,LTDYRD

C     /WKPAR/
C          SATTR   = TRUE IF TRAVEL ON SAT FORBIDDEN
C          SUNTR   = TRUE IF TRAVEL ON SUN FORBIDDEN
C          HOLTR   = TRUE IF TRAVEL ON HOLIDAY FORBIDDEN
C          SATLD   = TRUE IF LOADING ON SAT FORBIDDEN
C          SUNLD   = TRUE IF LOADING ON SUN FORBIDDEN
C          HOLLD   = TRUE IF LOADING ON HOLIDAY FORBIDDEN
C          LTDYBA  = LENGTH OF WORKING DAY AT BASE
C          LTDYRD  = LENGTH OF WORKING DAY ON ROAD
C
C          /SRVREP/

      INTEGER MTSRV
      INTEGER NOSRV,OBSRV,DBSRV,QUSRV,RTA,SRVSRV
      INTEGER ETDSRV,ETASRV,FLXSRV
      INTEGER DYBSRV,DYESRV
      COMMON /SRVREP/NOSRV,SRVSRV(1000),OBSRV(1000),DBSRV(1000),
     +              QUSRV(1000),ETDSRV(1000),ETASRV(1000),
     +              RTA(1000),FLXSRV(1000),DYBSRV(1000),MTSRV(1000),
     +              DYESRV(1000)

C     /SRVREP/
C          NOSRV   = NUMBER OF SERVICE REQUIREMENTS
```

```
C           SRVSRV  =  0 IF SERVICE NOT YET TAKEN CARE OF
C           OBSRV   = ORIGIN BASE FOR SERVICE
C           DBSRV   = DESTINATION BASE FOR SERVICE
C           QUSRV   = QUANTITY FOR SERVICE
C           ETDSRV  = POINTER TO INTERVALS EARLIEST DEPARTURE
C                     TIME
C           ETASRV  = POINTER TO INTERVALS EARLIEST ARRIVAL
C                     TIME
C           RTA     = POINTER TO INTERVALS RETURN ARC
C           FLXSRV  = POINTER TO INTERVALS FLEXIBILITY
C           DYBSRV  = POINTER TO  A 2 DIM. ARRAY WHERE THE FIRST
C                     INDEX IS TIME AND THE SECOND IS DISTANCE
C                     ACCUMULATED DUTY FROM BEGINNING
C           MTSRV   = POINTER TO INDICATORS THAT MAINT.
C                     IS INCLUDED IN THIS BAND
C                     IF NEGATIVE THEN HOME BASE FOR INTERVAL,BUT
C                     DOES NOT MEAN THAT MAINT. IS REQUIRED
C           DYESRV  = POINTER TO 2 DIM. ARRAY WHERE THE FIRST INDEX
C                     IS TIME AND THE SECOND IS DISTANCE ACCUMULATED
C                      DUTY FOR SERVICE TO END
C
C
C           /SEQSRV/

      INTEGER ISEQST,ISEQLN,INDITN,INDTRU,IDSER
      COMMON /SEQSRV/ISEQST,ISEQLN,INDITN(20),INDTRU(20),IDSER(2,20)

C     /SEQSRV/
C           ISEQST  = STARTING INDEX OF SEQUENCE
C           ISEQLN  = LAST INDEX OF SEQUENCE
C           INDITN  = ITINERARY
C           INDTRU  = TRANSPORTION UNIT TYPE
C           IDSER   = TYPE OF 1TINERARY LEGS IMPOSING SERVICE
C                     REQUIREMENT
C                             1=ACTIVE SERVICE
C                             2=DEADHEAD
C                             3=IDLE
C                             4=MAINTENANCE
C                     WILL HOLD UP TO 2 TYPES FOR EACH STEP
C
C           /ITINS/

      INTEGER NOITN,ITINPT
      COMMON /ITINS/NOITN,ITINPT(1000)

C     /ITINS/
C           NOITN   = NUMBER OF ITINERARIES FOR THE GIVEN TRANSPORT
C                     UNIT TYPE
C           ITINPT  = POINTER TO ITINS RECORD WHERE THE FORMAT IS
C                             LEG VECTOR
C                                 :
C                             LEG VECTOR
C           WHERE LEG VECTOR
C                           LEGTYP
C                           SRVNUM
C                           BASTRT
```

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```
      INTEGER IMACTR
      COMMON /CTRPRT/IMACTR(4,12)

C     /CTRPRT/
C           IMACTR(J,I)     = LISTING OF UNIQUE CONTAINER
C                             J FOR EACH MODE ALLOWED
C                             FOR SHIPMENT MATERIAL TYPE I
C
C     /ITNPRM/

      INTEGER TOPN,RNSEED
      COMMON /ITNPRM/TOPN,RNSEED

C     /ITNPRM/
C           TOPN     = NUMBER OF BEST MATCHES TO SAVE
C                      IN GENERATING ITINERIES
C           RNSEED   = START SEED FOR RANDOM NUMBER GEN.
C                      FOR AUINT
C
C     /BMATCH/

      INTEGER BLIST,BLEN
      REAL ULIST
      COMMON /BMATCH/BLEN,BLIST(2,100),ULIST(100)

C     /BMATCH/
C     CONTAINS SORTED LIST OF COMBINED SERVICES BY
C     UTILIZATION FACTOR
C           BLIST    = SERVICES COMBINED
C           ULIST    = UTILIZATION FACTOR FOR MATCH
C           BLEN     = LENGTH OF BEST MATCH LIST
C
C           /SIMVAR/

      REAL TMICSM,USICSM
      LOGICAL SIM,AUSMIC
      INTEGER NOTRUE,BSICSM
      COMMON /SIMVAR/SIM,AUSMIC,NOTRUE(50),BSICSM(15,50),
     +      TMICSM(15,50),USICSM(2,15,50)

C     /SIMVAR/
C           SIM      = TRUE FOR SIMULATION
C           AUSMIC   = TRUE FOR AUTOMATIC GENERATION OF INITIAL
C                      CONDITIONS
C           NOTRUE   = NUMBER OF TRANSPORT UNIT ELEMENTS OF
C                      EACH TYPE
C           BSICSM   = INITIAL CONDITION BASE
C           TMICSM   = TIME TRU AVAILABLE
C           USICSM   = INITIAL ACCUMULATED USE
C
C
C     /TRUD/

      INTEGER TRUDES
      COMMON /TRUD/TRUDES(7,50)
```


779 066

```
C       /TRUD/
C             TRUDES = ASCII DESCRIPTIONS OF TRANSPORT UNIT TYPES
C       /TOTS/

      REAL TOTALS
      COMMON /TOTS/TOTALS(6,50)

C       /TOTS/
C             TOTALS  = HOLDS TOTALS FOR TIME AND DISTANCE
C                                FOR SUMMARY FROM PRITIN, SIZRLT
C       DATA STATEMENTS
C
C       /TRUD/

      DATA (TRUDES(J,10),J=1,7)/'SHIPMENTS DESIGNATED FOR TRUCK MODE'/
      DATA (TRUDES(J,11),J=1,7)/'TRUCK TRAILER TYPE 1               '/
      DATA (TRUDES(J,12),J=1,7)/'TRUCK TRAILER TYPE 2               '/
      DATA (TRUDES(J,13),J=1,7)/'TRUCK TRAILER TYPE 3               '/
      DATA (TRUDES(J,15),J=1,7)/'TRUCK TRACTOR                      '/
      DATA (TRUDES(J,16),J=1,7)/'ESCORT VEHICLE                     '/
      DATA (TRUDES(J,17),J=1,7)/'TRACTOR/ESCORT CREWS               '/
      DATA (TRUDES(J,20),J=1,7)/'SHIPMENTS DESIGNATED FOR A/C MODE  '/
      DATA (TRUDES(J,21),J=1,7)/'AIRCRAFT TYPE 1                    '/
      DATA (TRUDES(J,22),J=1,7)/'AIRCRAFT TYPE 2                    '/
      DATA (TRUDES(J,23),J=1,7)/'AIRCRAFT TYPE 3                    '/
      DATA (TRUDES(J,27),J=1,7)/'A/C CREWS                          '/
      DATA (TRUDES(J,28),J=1,7)/'A/C GUARDS                         '/
      DATA (TRUDES(J,30),J=1,7)/'SHIPMENTS DESIGNATED FOR RR MODE   '/
      DATA (TRUDES(J,31),J=1,7)/'RR CONTAINER CAR TYPE 1            '/
      DATA (TRUDES(J,32),J=1,7)/'RR CONTAINER CAR TYPE 2            '/
      DATA (TRUDES(J,33),J=1,7)/'RR CONTAINER CAR TYPE 3            '/
      DATA (TRUDES(J,35),J=1,7)/'LOCOMOTIVE                         '/
      DATA (TRUDES(J,36),J=1,7)/'CHASE CARS                         '/
      DATA (TRUDES(J,37),J=1,7)/'TRAIN CREWS                        '/
      DATA (TRUDES(J,38),J=1,7)/'TRAIN GUARDS                       '/
      DATA (TRUDES(J,39),J=1,7)/'CHASE VEHICLE CREW                 '/
      DATA (TRUDES(J,40),J=1,7)/'SHIPMENTS DESIGNATED FOR WATER MODE'/
      DATA (TRUDES(J,41),J=1,7)/'VESSEL TYPE 1                      '/
      DATA (TRUDES(J,42),J=1,7)/'VESSEL TYPE 2                      '/
      DATA (TRUDES(J,43),J=1,7)/'VESSEL TYPE 3                      '/

C
C       /VEHP/

      DATA CAP/600*1/
      DATA VEL/50*55/
      DATA TMLD,TMUN/600*4,600*4/

C
C       /MODTA/

      DATA MODAC,MODRR,MODWA/.FALSE.,.FALSE.,.FALSE./

C
C       /WKPAR/
```


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```
      DATA SATTR,SUNTR,HOLTR,SATLD,SUNLD,HOLLD
     +        /.FALSE.,.FALSE.,.FALSE.,.FALSE.,.FALSE.,.FALSE./
      DATA LTDYRD,LTDYBA/24.,24./

C
C     /LNKPAR/

      DATA PRLKID,PRLKDH,PRLKFL,PRLKTT/50*1.,50*2.,50*0.,50*0./

C
C     /IODEV/

      DATA IIN,IOUT/5,5/

C
C     /CTRPRT/

      DATA IMACTR(1,1),IMACTR(1,2),IMACTR(1,3)/11,11,11/

C
C     /ITNPRM/

      DATA TOPN/20/
      DATA RNSEED/1042157079/

C
C     /SIZVAR/

      DATA WARMTM,WARMST/3.,0./
      DATA SZFF/.TRUE./

C
C     /BASDAT/

      DATA BASE/150*5H     /

C
C     /BMATCH/

      DATA ULIST/100*1.E6/,BLEN/0/

C     /SCRAT/

      DATA NXTOPN/1/

C     /ITIN/

      DATA NOITN/0/

C     /SIMVAR/

      DATA AUSMIC/.TRUE./
      END
```


779 068

APPENDIX B - DESCRIPTION OF MAJOR SUBROUTINES

This appendix describes the major subroutines which perform the operations required for fleet sizing and itinerary construction. Figure B.1 shows these subroutines. They have been designed as much as possible to be compatible with later versions of the transportation model. Therefore, the descriptions of these subroutines sometimes refer to capabilities (e.g., providing for truck, aircraft, train and water modes) which are not incorporated in the Version I or II models.

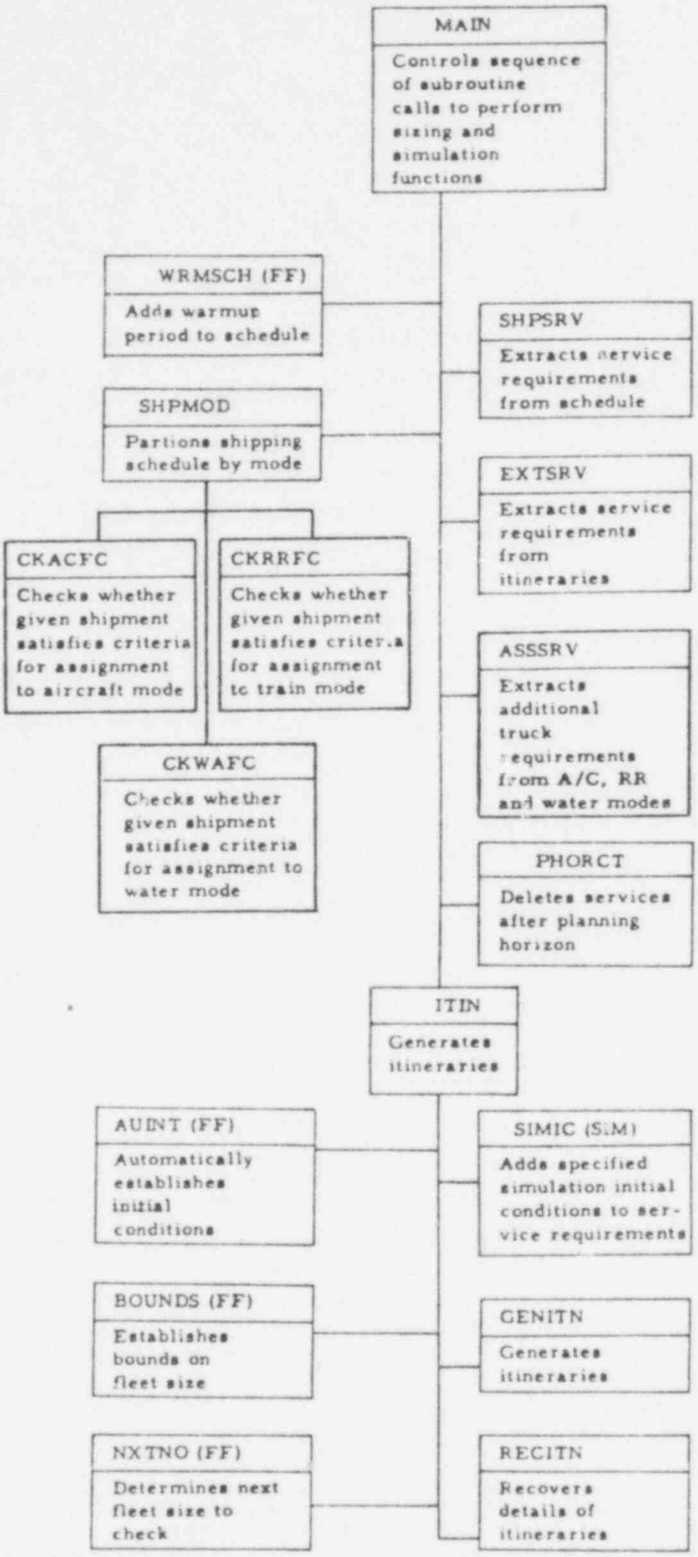


Figure B.1. Major subroutines of transportation model.

B. 1 MAIN

Controls sequence of subroutine calls to perform sizing and simulation functions.

Called by TRNSM1.

(1) Augments shipping schedule to provide warm-up for fixed-fleet sizing (subroutine WRMSCH).

(2) Deletes shipments which do not start within the planning horizon (subroutine PHORCT).

(3) Partitions shipping schedule by mode (aircraft, train, water, truck) and by mode container type (e.g., truck trailer type) (subroutine SHPMOD).

(4) Goes through sequencer to successively generate desired itineraries. (See Table B.1.)

The subroutines called by MAIN and the data inputs and outputs are summarized in Table B.2. Input named commons are designated by underlining, e.g., SHPSCH in Table B.2.

779 071

Table B.1

EXAMPLE OF SEQUENCER

INDITN	INDTRU	CALLS	
0 (Sch)	11 (Tk. trailer type 1)	SHPSRV	
0 (Sch)	12 (Tk. trailer types)	SHPSRV	
0 (Sch)	21 (A/C type 1)	SHPSRV	ITIN
0 (Sch)	22 (A/C type 2)	SHPSRV	ITIN
21 (A/C type 1)	11 (Tk. trailer type 1)	ASSSRV	
22 (A/C type 2)	11 (Tk. Trailer type 1)	ASSSRV	ITIN
21 (A/C type 1)	12 (Tk. trailer type 2)	ASSSRV	
22 (A/C type 2)	12 (Tk. trailer type 2)	ASSSRV	ITIN
11 (Tk. trailer 1)	15 (Tk. tractors)	EXTSRV	
12 (Tk. trailers)	15 (Tk. tractors)	EXTSRV	ITIN
15 (Tk. tractors)	16 (Escorts)	EXTSRV	ITIN
15 (Tk. tractors)	17 (Crews)	EXTSRV	
16 (Escorts)	17 (Crews)	EXTSRV	ITIN
21 (A/C type 1)	27 (A/C crews)	EXTSRV	
22 (A/C type 2)	27 (A/C crews)	EXTSRV	ITIN
21 (A/C type 1)	28 (A/C guards)	EXTSRV	
22 (A/C type 2)	28 (A/C guards)	EXTSRV	ITIN

Table B.2

SUBROUTINES CALLED BY MAIN

CALLED SUBROUTINE	INPUTS	OUTPUTS
WRMSCH	SHPSCH, SIZVAR	SHPSCH
PHORCT	SHPSCH, SIZVAR	SHPSCH
SHPMOD	SHPSCH, BASDAT MODTA, VEHP	SHPSCH
SHPSRV (INDTRU)	SHPSCH, INDTRU WKPAR, VEHP BASDAT	SRVREP
ASSSRV	SRVREP	SRVREP
ITIN (INDTRU, NOV)	SRVREP, INDTRU MAINTV, LNKPAR BASDAT, OPTDTA SIZVAR, SIMVAR CNVPAR, FALVAR	ITINS, NOV
EXTSRV (INDITN, INDTRU)	ITINS, SEQSRV INDITN, INDTRU	SRVREP

779 075

B.2 WRMSCH

Extracts specified portion of shipping schedule and places at start of schedule to provide warm-up for fixed-fleet sizing — called by subroutine MAIN.

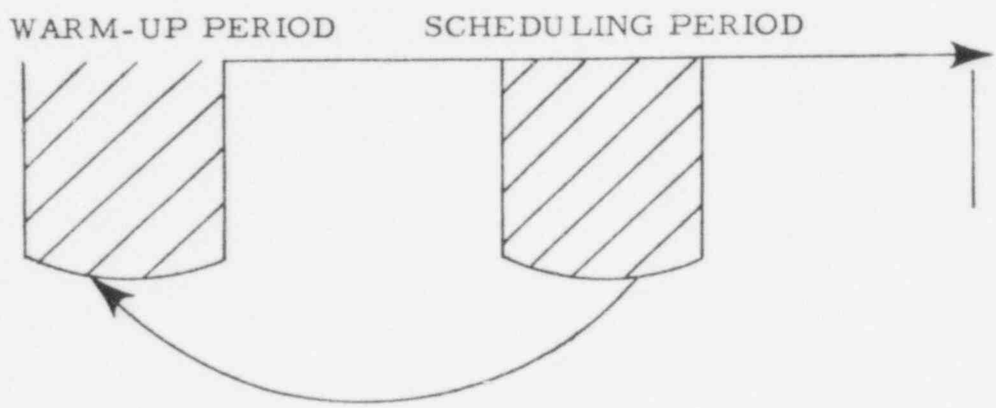


Figure B.2. Operation of subroutine WRMSCH.

(1) Counts shipments in warm-up interval.

(2) Shifts each shipment index upward by number of shipments in warm-up.

(3) Places warm-up shipments at beginning of schedule. Warm-up shipments have negative earliest departure times.

B.3 PHORCT

Deletes shipments scheduled outside of planning horizon.

Called by subroutine MAIN.

Checks each shipment and deletes those with earliest shipping times outside of specified planning horizon.

B.4 SHPMOD

Specifies mode and container type for each shipment. (For Version I, provision is provided only for truck mode and the only criterion for designation of truck trailer type is the type of material being shipped. For Version II, the capability for considering an aircraft mode is also included.)

Called by subroutine MAIN.

Shipment data enters SHPMOD with each shipment labeled by mode and container type as follows:

0 - Undesignated

10 - Truck mode, trailer type undesignated

20 - Aircraft mode, aircraft type undesignated

30 - Train mode, container car type undesignated

40 - Water mode, vessel type undesignated

11-13 - Truck trailer type designation

21-23 - Aircraft type designation

31-33 - Train car type designation

41-43 - Vessel type designation

(1) Checks undesignated shipments for aircraft mode (check made by subroutine CKACFC). Those that satisfy aircraft mode criteria labeled (20).

(2) Aircraft type designated for each shipment labeled 20, based on type of material being shipped by re-labeling each shipment with (21), (22) or (23).

(3) Shipping times adjusted to account for time to truck shipments to and from airfields.

(4) Steps (1) - (3) repeated for train mode (30) (subroutine CKRRFC) and train car types (31), (32), and (33).

(5) Steps (1) - (3) repeated for water mode (40) (subroutine CKWAFC) and vessel types (41), (42), and (43).

(6) Remaining undesignated shipments assigned to truck mode (10).

(7) Truck trailer type (11), (12), or (13) designated based on type of material being shipped.

077

B.5 SHPSRV

Translates shipping schedule into service requirement for each container type.

Called by subroutine MAIN.

For each shipment

(1) Specifies service origin and destination (same as shipment).

(2) Specifies number of units (e.g., trucks)
No. units = (quan. of mat.)/capacity

(3) Determines active service time
(loading + travel + unloading)

(4) Arrival and departure times
- (a) Earliest departure - same as shipment
- (b) Earliest arrival - earliest dep. time + active service time
- (c) Latest arrival time - same as shipment
- (d) Latest departure - latest arr. time - active service time

(5) Searches for violations of Sat., Sun., Hol. work rules between earliest departure and latest arrival. These portions are then eliminated dividing schedule into bands. This is accomplished with subroutine BANDIT.

Figure B.3 illustrates the results of applying SHPSRV to a shipment subject to the restriction that no loading or unloading is allowed at a base on weekends.

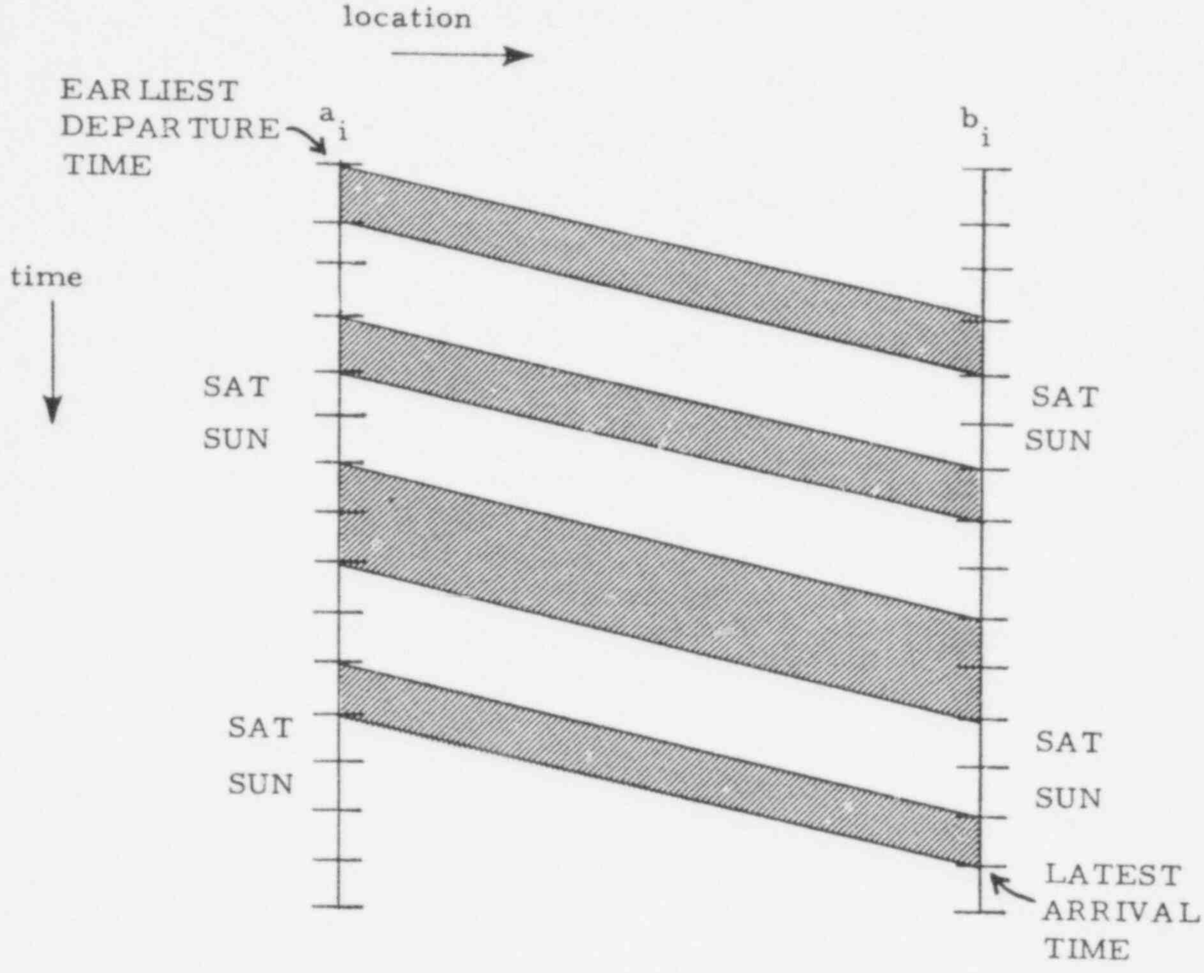


Figure B. 3. SHPSRV example with no loading or unloading allowed on weekends.

B.6 EXTSRV

Extracts service requirements for transport unit type TRU levied by itinerary for transport unit type ITIN.

Called by subroutine MAIN.

(1) Determines leg types in i that must be covered by transport unit elements of type j (SEQSRV gives this information).

(2) Extracts service requirement

Example: truck trailers (ITIN) levy service requirements for truck tractors (TRU)

Figure B. 4 illustrates the operation of EXTSRV.

TYPE OF ACTIVITIES

(1) = ACTIVE SERVICE (2) = DEADHEAD

(3) = IDLE (4) = MAINTENANCE

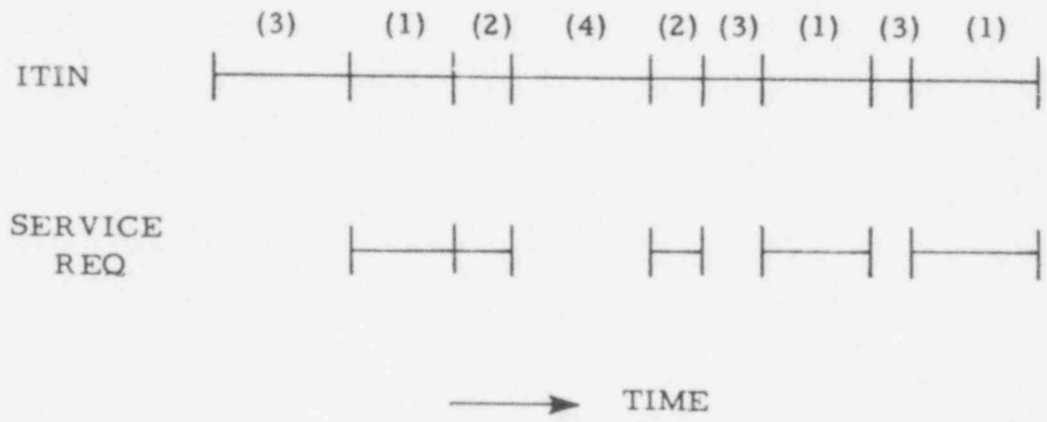


Figure B. 4. Example of EXTSRV operation.

B. 7 ASSSRV

Extracts service requirements levied on trucks by aircraft, railroad and water modes. For example, trucks are required to transport the material between the bases and airfields when that material is designated for shipment by aircraft mode.

Called by subroutine MAIN.

To illustrate the logic used in ASSSRV, the following steps are employed to extract the truck service requirements levied by the aircraft itineraries. An important characteristic of these aircraft itineraries is that any residual flexibility has been removed in the recovery of itineraries (subroutines RECITN) by always choosing the earliest possible arrival and departure times.

(1) For a departing aircraft, the truck service end time t_i is set equal to the departure time for the active aircraft service.

(2) The truck service start time s_i is found from

$$s_i = t_i - t_{\ell d} - \xi - t_{un}$$

where

$t_{\ell d}$ = truck loading time

ξ = travel time from the base to the airfield

t_{un} = truck unloading time.

(3) For an arriving aircraft, the truck service start time s_i is set equal to the arrival time of the aircraft.

(4) The corresponding truck service end time t_i is found from

$$t_i = s_i + t_{\ell d} + \xi + t_{un}$$

Similar steps are used to extract additional truck service requirements when train and water modes are employed.

B.8 ITIN

Generates itineraries for the transport unit element type (INDTRU) specified by subroutine MAIN.

Called by subroutine MAIN.

The first step is to check whether the program is in a simulation or sizing mode.

Simulation Mode:

(1) Checks whether automatic initial conditions should be generated.

- a. If so, subroutine AUINT is called which performs this function and augments service list with these initial conditions.
- b. If not, subroutine SIMIC is called which augments service list with the specified initial conditions.

(2) Linking of services is accomplished by subroutine GENITN. History of the linkings is stored in labeled common LNKSRV. This results in specification of required number of transport unit elements.

(3) Check is made to ensure that the number of transport unit elements required does not exceed number available.

(4) If the check in step (3) is satisfactory, itineraries are recovered from the final composite services from step 2 and the data from LNKSRV using subroutine RECITN.

Sizing Mode:

(1) Checks whether fixed-fleet sizing is specified. (Version 1 provides for only a fixed-fleet sizing capability.) If non-fixed-fleet sizing specified, go to step 9.

(2) Subroutine AUINT generates initial conditions for the fixed-fleet transport unit elements and augments the service list to include these initial conditions.

(3) Linking of services is accomplished by subroutine GENITN. History of the linkings is stored in labeled common data LNKSRV.

(4) If the final number of composite services from step 3 exceeds the specified fleet size, the lower bound on fleet size is set to the fleet size. If this final number of composite services is less than o. qual to the specified fleet size, the upper bound on fleet size is set to the fleet size. This is accomplished by subroutine BOUNDS.

(5) If the difference between the upper and lower bounds is greater than one, the L - I search algorithm is used to determine the next fleet size to be tested. (See Section 3.2). This is accomplished by subroutine NXTNO.

(6) Steps (2) through (5) are repeated until the difference between the upper and lower bounds on fleet size (from step 4) is equal to one. The upper bound gives the required fleet size.

(7) If the fleet size last used in step (3) (linking of services) is equal to the <u>lower</u> bound or fleet size, step (3) is repeated with fleet size specified at the upper bound.

ITIN (Concluded)

(8) Itineraries are recovered using subroutine RECITN from the final composite services and the linking history data in LNKSRV. This is the last step in fixed fleet sizing.

(9) For non-fixed-fleet sizing, linking of services is first accomplished (including self-linking) with subroutine GENITN in a non fixed-fleet mode. The linking history data is stored in LNKSRV.

(10) Itineraries are recovered with subroutine RECITN in a non-fixed-fleet mode.

Table B. 3 shows the subroutines called by ITIN and the input/output data for each of these subroutines.

Table B. 3

SUBROUTINES CALLED BY ITIN

CALLED SUBROUTINE	INPUTS	OUTPUTS
AUINT (INDTRU)	SRVREP, SIZVAR INDTRU, MAINTV	SRVREP
SIMIC (INDTRU)	SRVREP, SIMVAR INDTRU	SRVREP
GENITN (INDTRU, NOCMSR)	SRVREP, LNKPAR VEHP, MAINTV, BASDAT, WKPAR INDTRU	SRVREP LNKSRV NOCMSR
BOUNDS (INDTRU, NOCMSR)	SIZVAR, INDTRU NOCMSR	SIZVAR
NXTNO (INDTRU)	SIZVAR, INDTRU	SIZVAR

779 087

B.9 AUINT

Automatically generates initial conditions for transport unit elements based on a single or nearest-base maintenance policy.

Called by ITIN.

(1) Counts number of maintenance bases for the transport unit type under consideration.

(2) For each transport unit element assigns random initial accumulated duty and evenly distributes the TRU elements among the maintenance bases.

(3) The time of availability for each transport unit element is set sufficiently early to ensure that it can be linked to other services even if an intermediate maintenance stop is required.

(4) Augments service list to include initial conditions.

In the process of iterating on the fleet size, if additional initial conditions for the transport unit elements are required, the initial conditions on the previous elements are retained.

B. 10 SIMIC

Augments service list to include specified initial conditions for simulation option.

Called by ITIN.

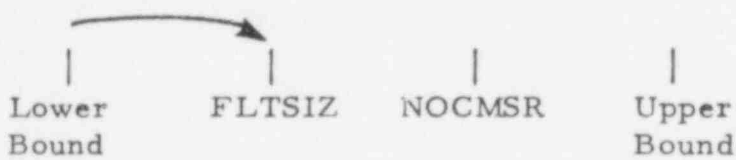
B. 11 BOUNDS

Adjusts upper and lower bounds on fleet size.

Called by ITIN.

Inputs are the current specified fleet size (FLTSIZ) and the final number of combined services (NOCMSR) from GENITN.

(1) If NOCMSR is greater than FLTSIZ, lower bound is set to the value of FLTSIZ. (In this case the value of FLTSIZ is too small.)



(2) If NOCMSR is less than FLTSIZ, upper bound is set to the value of FLTSIZ. (In this case the fleet size is adequate to handle the service requirements, but may possibly be reduced further.)

779 090

B. 12 NXTNO

Increases or decrease fleet size for next iteration using the L - I search method (see Section 4. 2).

Called by ITIN.

Inputs are the current fleet size (FLTSIZ) the final number of combined services (NOCMSR) from the last iteration, the upper bound on the fleet size (BNDUP), and the lower gound on fleet size (BNDLOW).

(1) If BNDUP - BNDLOW = 1, this subroutine immediately returns to ITIN, since this is the condition which indicates that the minimum required fleet size has been found.

(2) If FLTSIZ = BNDLOW, the new value of FLTSIZ is set according to

$$(FLTSIZ)_{new} = NOCMSR \text{ if } NOCMSR - FLTSIZ = 1$$

$$(FLTSIZ)_{n\ w} = NOCMSR - 1 \text{ if } NOCMSR - FLTSIZ > 1$$

(3) If FLTSIZ = BNDUP, FLTSIZ is simply reduced by one.

779 091

B. 13 GENITN

Links required services into composite services (fixed-fleet and non-fixed-fleet options.

Called by ITIN.

Figure B. 5 shows the subroutines called by GENITN.

For the fixed-fleet option the steps are:

(1) Checks temporal and maintenance feasibility of linking of every pair of required services for the transport unit element type under consideration (this is done with subroutine TMFEAS).

(2) For each feasible linking, subroutine TMFEAS calculates a linking value function UFAC.

(3) Subroutine INMAT inserts each feasible linking into a list orderd by UFAC, with the best linking at the top.

(4) Steps (1)-(3) are repeated until all possible linkings have been checked. Only the best N linkings are saved. The value of UFAC for the Nth best linking is set as a bound to determine whether future feasible linkings are added to the list or discarded.

(5) The best composite service from the list of feasible linkings is obtained from subroutine GETMAT.

(6) This composite service is added to the service list, the two individual services are labeled as having been considered, and the details of the linking are recorded in common data LNKSRV (subroutine TMFEAS).

(7) All linkings involving the two individual services are deleted from the list of feasible linkings (subroutine DELMAT).

79 092

(8) Steps (1) - (3) are repeated considering only the feasible linkings with the new composite service. Only those linkings with value of UFAC better than the bound previously set in step (4) are stored in the linking list.

(9) Steps (5) - (7) are repeated.

(10) Steps (8) and (9) are repeated until the list of feasible linkings is exhausted.

(11) Steps (1) - (10) are repeated until there are no more feasible linkings.

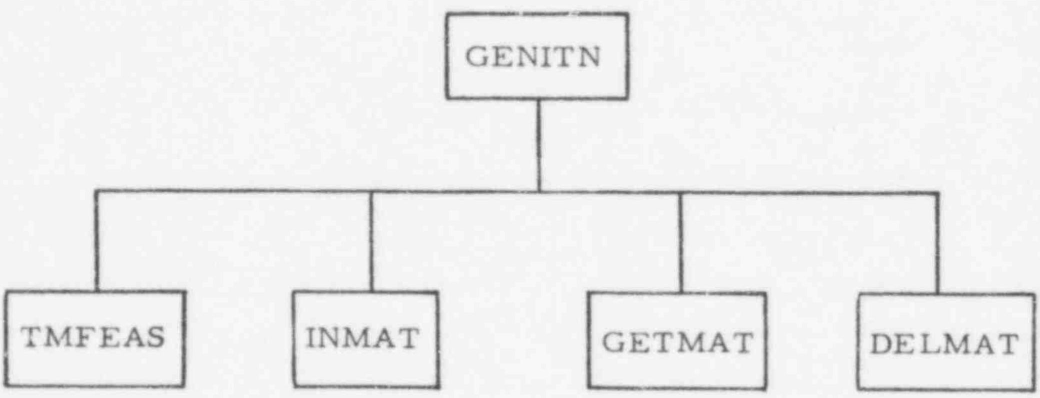


Figure B. 5. Subroutines called by GENITN.

779 095

With the non-fixed-fleet option the procedure for linking services is the same with the following exception:

In step (1), if either the temporal or maintenance feasibility check fails, the second service is shifted forward by one period and the feasibility tests are again made. This process is repeated until the linking is feasible. Self-linking are also considered in this process. The technical details of these procedures for the non-fixed-fleet option are given in Section 4.1.2.

B.14 RECITN

Recovers itineraries from composite services generated by GENITN and from linking data in LNKSRV.

Called by ITIN.

Uses "in-order" traversal algorithm (see Section 4.4) to recover itineraries.

APPENDIX C - SAMPLE SHIPMENT SCHEDULE

This appendix lists the sample shipment schedule that was used to test the Versions I and II models. Also included are the definitions of the three-letter symbols used to denote the base locations.

SAMPLE SHIPMENT SCHEDULE

Page 1

	Origin Base	Destination Base	Earliest Shipping Day	Latest Arrival Day	Material Type	Material Quantity	Mode/Container Designation	Shipment Number
00001	JOH	HNT	1	22	3	16	0	30
00002	DJI	DJI	1	8	1	12	0	43
00003	DJI	DJI	2	9	1	12	0	42
00004	TMI	SWV	3	24	2	7	0	1
00005	JOH	JOH	3	10	1	12	0	39
00006	JOH	HNT	4	25	3	16	0	17
00007	TMI	TMI	4	11	1	12	0	45
00008	DJI	DJI	5	12	1	12	0	41
00009	JOH	BFD	6	27	3	16	0	4
00010	JOH	HNT	8	29	3	16	0	21
00011	OAS	CNC	8	29	2	7	0	24
00012	OAS	CNC	8	29	2	7	0	25
00013	OAS	FDA	9	30	2	7	0	15
00014	JOH	HNT	9	30	3	16	0	16
00015	DJI	CSJ	10	31	2	7	0	13
00016	TMI	LPP	11	32	3	16	0	31
00017	TMI	TMI	11	18	1	12	0	46
00018	TMI	SWV	12	33	2	7	0	2
00019	BSC	BSC	12	19	1	12	0	35
00020	OAS	OAS	12	19	1	12	0	37
00021	OAS	OAS	12	19	1	12	0	38
00022	TMI	LPP	13	34	3	16	0	29
00023	JOH	BFD	14	35	3	16	0	8
00024	TMI	TMI	14	35	1	12	0	11
00025	TMI	LPP	14	35	3	16	0	28
00026	DJI	DJI	15	22	1	12	0	44
00027	TMI	TMI	16	37	1	12	0	10
00028	JOH	HNT	16	37	1	12	0	23
00029	TMI	LPP	18	39	3	16	0	30
00030	JOH	BFD	21	42	3	16	0	7
00031	OAS	FDA	23	44	2	7	0	14
00032	DJI	DBO	23	44	2	7	0	3[illegible]
00033	DJI	CSJ	24	45	2	7	0	12
00034	JOH	HNT	24	45	3	16	0	19
00035	JOH	JOH	24	31	1	12	0	40
00036	JOH	BFD	25	46	3	16	0	5
00037	JOH	HNT	25	46	3	16	0	22
00038	BSC	BSC	26	33	1	12	0	34
00039	JOH	BFD	27	48	3	16	0	6

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Page 2

	Origin Base	Destination Base	Earliest Shipping Day	Latest Arrival Day	Material Type	Material Quantity	Mode/Container Designation	Shipment Number
00040	JOH	HNT	27	48	3	16	0	18
00041	DJI	DBO	27	48	2	7	0	32
00042	BSC	BSC	27	34	1	12	0	36
00043	JOH	BFD	28	49	3	16	0	3
00044	TMI	LPP	28	49	3	16	0	26
00045	TMI	LPP	29	50	3	16	0	27
00046	JOH	BFD	30	51	3	16	0	9
00047	BSC	TPF	32	53	2	7	0	48
00048	DJI	DJI	31	52	1	12	0	61
00049	JOH	JOH	31	38	1	12	0	92
00050	TMI	PAO	32	53	3	16	0	67
00051	TMI	SHP	32	53	3	16	0	79
00052	TMI	TMI	35	42	1	12	0	96
00053	OAS	OAS	36	43	1	12	0	88
00054	TMI	TMI	36	43	1	12	0	93
00055	DJI	GPH	37	58	2	7	0	69
00056	TMI	PAO	38	59	3	16	0	66
00057	OAS	CNC	38	59	2	7	0	71
00058	TMI	SHP	39	60	3	16	0	77
00059	TMI	NMP	40	61	2	7	0	53
00060	BSC	BSC	40	47	1	12	0	84
00061	TMI	TMI	40	47	1	12	0	94
00062	TMI	PAO	41	62	3	16	0	65
00063	TMI	JNY	41	62	2	7	0	82
00064	OAS	SCT	42	63	2	7	0	57
00065	TMI	PAO	44	65	3	16	0	68
00066	DJI	FCN	44	65	2	7	0	81
00067	TMI	JNY	45	66	2	7	0	83
00068	BSC	TPF	47	68	2	7	0	47
00069	TMI	NMP	46	67	2	7	0	50
00070	OAS	CNC	46	67	2	7	0	58
00071	TMI	SHP	46	67	3	16	0	73
00072	BSC	BSC	46	53	1	12	0	86
00073	BSC	CRF	47	68	2	7	0	54
00074	OAS	CNC	48	69	2	7	0	59
00075	TMI	SHP	48	69	3	16	0	74
00076	TMI	NMP	49	70	2	7	0	51
00077	TMI	NMP	49	70	2	7	0	52
00078	TMI	SHP	49	70	3	16	0	76
00079	JOH	JOH	49	56	1	12	0	89

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POOR ORIGINAL

Page 3

	Origin Base	Destination Base	Earliest Shipping Day	Latest Arrival Day	Material Type	Material Quantity	Mode/Container Designation	Shipment Number
00080	OAS	SCT	50	71	2	7	0	56
00081	BSC	BSC	50	57	1	12	0	85
00082	BSC	CRF	51	72	2	7	0	55
00083	TMI	TMI	52	59	1	12	0	95
00084	TMI	SHP	54	75	3	16	0	78
00085	JOH	JOH	54	61	1	12	0	91
00086	TMI	PAO	55	76	3	16	0	62
00087	OAS	CNC	55	76	2	7	0	72
00088	OAS	OAS	55	62	1	12	0	87
00089	DJI	DJI	56	77	1	12	0	60
00090	TMI	PAO	56	77	3	16	0	63
00091	JOH	JOH	56	63	1	12	0	90
00092	TMI	PAO	57	78	3	16	0	64
00093	DJI	GPH	57	78	2	7	0	70
00094	TMI	SHP	57	78	3	16	0	75
00095	TMI	NMP	58	79	2	7	0	49
00096	DJI	FCN	58	79	2	7	0	80
00097	TMI	PAO	59	80	3	16	0	124
00098	TMI	PAO	59	80	3	16	0	129
00099	DJI	BRI	60	81	2	7	0	106
00100	OAS	BRL	61	82	2	7	0	134
00101	OAS	FDA	61	82	2	7	0	99
00102	DJI	BRI	61	82	2	7	0	105
00103	BSC	BSC	61	68	1	12	0	137
00104	BSC	BSC	61	68	1	12	0	140
00105	OAS	OAS	61	68	1	12	0	142
00106	OAS	OAS	61	68	1	12	0	144
00107	TMI	PAO	62	83	3	16	0	130
00108	DJI	GPH	62	83	2	7	0	132
00109	BSC	BSC	62	69	1	12	0	139
00110	JOH	JOH	62	69	1	12	0	145
00111	TMI	PAO	64	85	3	16	0	125
00112	OAS	OAS	64	71	1	12	0	143
00113	TMI	PPM	65	86	3	16	0	111
00114	DJI	QCI	65	86	3	16	0	117
00115	DJI	DJI	66	73	1	12	0	150
00116	TMI	PAO	67	88	3	16	0	128
00117	DJI	SOC	70	91	2	7	0	120
00118	TMI	GCC	68	89	2	7	0	123
00119	DJI	QCI	70	91	3	16	0	119

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Page 4

	Origin Base	Destination Base	Earliest Shipping Day	Latest Arrival Day	Material Type	Material Quantity	Mode/Container Designation	Shipment Number
00120	DJI	GPH	70	91	2	7	0	131
00121	JOH	JOH	70	77	1	12	0	146
00122	JOH	JOH	70	77	1	12	0	147
00123	BSC	BSC	71	78	1	12	0	138
00124	DJI	DJI	71	78	1	12	0	148
00125	OAS	OAS	72	93	1	12	0	98
00126	TMI	FPM	72	93	3	16	0	112
00127	TMI	PPM	73	94	3	16	0	107
00128	TMI	GCC	73	94	2	7	0	122
00129	TMI	PAO	74	95	3	16	0	126
00130	BSC	BSC	74	81	1	12	0	135
00131	DJI	DJI	74	81	1	12	0	152
00132	TMI	PPM	76	97	3	16	0	109
00133	TMI	PPM	76	97	3	16	0	110
00134	TMI	PPM	78	99	3	16	0	108
00135	TMI	PPM	78	99	3	16	0	113
00136	DJI	QCI	78	99	3	16	0	116
00137	DJI	SOC	80	101	2	7	0	121
00138	BSC	BSC	78	85	1	12	0	136
00139	BSC	SSS	80	101	2	7	0	103
00140	TMI	PAO	80	101	3	16	0	127
00141	OAS	FDA	81	102	2	7	0	100
00142	DJI	QCI	81	102	3	16	0	114
00143	OAS	OAS	83	104	1	12	0	97
00144	OAS	SCT	84	105	2	7	0	101
00145	DJI	QCI	84	105	3	16	0	115
00146	OAS	OAS	84	91	1	12	0	141
00147	BSC	SSS	85	106	2	7	0	104
00148	DJI	DJI	85	91	1	12	0	149
00149	OAS	SCT	87	108	2	7	0	102
00150	DJI	QCI	87	108	3	16	0	118
00151	OAS	BRL	88	109	2	7	0	133
00152	DJI	DJI	88	95	1	12	0	151

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Definition of Symbols for Base Locations

Symbol	Base Location
JOH	Erwin, TN
HNT	Nashville, TN
DJI	Morris, IL
TMI	Harrisburg, PA
SWV	Williamsburg, VA
BFD	Decatur, AL
OAS	Anderson, SC
CNC	Charlotte, NC
FDA	Dothan, AL
CSJ	St. Joseph, MI
LPP	Pottstown, PA
BSC	Barnwell, SC
DBO	Fremont, OH
TPF	Miami, FL
PAO	Ashtabula, OH
SHP	Hazleton, PA
GPH	Port Huron, MI
NMP	Oswego, NY
JNY	Riverhead, NY
SCT	Chattanooga, TN
FCN	Blair, NB
CRF	Ocala, FL
BRI	Rockford, IL
BRL	Baton Rouge, LA
PPM	Bourne, MA
QCI	Clinton, IA
SOC	Oceanside, CA
GCC	Catskill, NY
SSS	Sumter, SC

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APPENDIX D - SAMPLE OUTPUT OF RESULTS OF ITINERARY CONSTRUCTION

This appendix presents the computer output of the results of scheduling truck trailers to satisfy the sample shipment schedule using the fixed-fleet option. The statistics for these itineraries were presented in Table 2.3a and the itineraries were depicted in Figure 2.3a.

Initially, the results of the fixed-fleet searching procedures are presented. In this case a fleet size of 2 is found in two iterations. This is followed by a listing of the sizing parameters and the randomly generated initial conditions. Then the itineraries and the itinerary statistics are given. The last portion of the listing relates the shipment numbers (from the shipment schedule to specific itinerary legs.

The output for the non-fixed-fleet option has the same format except that no iterations on the fleet size are required, nor are any initial conditions.

TRAILER ITINERARIES

UP,LOW,NO,FLTS	10	1	2	1
UP,LOW,NO,FLTS	10	1	2	2

```
PLANNING HORIZON (DAYS) =90.0
WARMUP TIME (DAYS) = 3.0
WARMUP START (DAY) = 0.0
TRAVEL FORBIDDEN ON SAT, SUN, HOLIDAY -  F  F  F
LOADING FORBIDDEN ON SAT, SUN, HOLIDAY -  F  F  F
LENGTH OF DAY AT BASE (HRS) =24.0
LENGTH OF DAY ON ROAD (HRS) =24.0
LENGTH OF BEST MATCH LIST =**

TRUCK TRAILER TYPE 1
VELOCITY =55.0
TIME TO UNLOAD (HRS) FUEL TYPE  1 = 2.0
TIME TO LOAD (HRS) FUEL TYPE  1 = 2.0
CAPACITY =12.0
TIME TO UNLOAD (HRS) FUEL TYPE  2 = 2.0
TIME TO LOAD (HRS) FUEL TYPE  2 = 2.0
CAPACITY = 7.0
TIME TO UNLOAD (HRS) FUEL TYPE  3 = 2.0
TIME TO LOAD (HRS) FUEL TYPE  3 = 2.0
CAPACITY =16.0
TIME TO UNLOAD (HRS) FUEL TYPE  4 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  4 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE  5 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  5 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE  6 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  6 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE  7 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  7 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE  8 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  8 = 4.0
CAPACITY = 1.0
```

```
TIME TO UNLOAD (HRS) FUEL TYPE  9 = 4.0
TIME TO LOAD (HRS) FUEL TYPE  9 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE 10 = 4.0
TIME TO LOAD (HRS) FUEL TYPE 10 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE 11 = 4.0
TIME TO LOAD (HRS) FUEL TYPE 11 = 4.0
CAPACITY = 1.0
TIME TO UNLOAD (HRS) FUEL TYPE 12 = 4.0
TIME TO LOAD (HRS) FUEL TYPE 12 = 4.0
CAPACITY = 1.0
MAX DAYS DUTY =  10000.00
MAX DIST DUTY (KM) =  40232.00
MAINTENANCE TIME (DAYS) =   4.0
MAINTENANCE POLICY = 1
MAINTENANCE BASE(S) - HNC
FACTOR PENALIZING IDLE TIME =10.0
FACTOR PENALIZING DEADHEAD TIME = 1.0
FACTOR PENALIZING LOSS OF FLEX = 0.1
FACTOR PENALIZING TOTAL TIME = 0.0
UNIT  1 START BASE HNC
DAY AVAILABLE -8.1
INITIAL ACCUMULATED DAYS =      0.00
INITIAL ACCUMULATED KM =  13757.86
UNIT  2 START BASE HNC
DAY AVAILABLE -6.2
INITIAL ACCUMULATED DAYS =      0.00
INITIAL ACCUMULATED KM =  38762.65
```

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ITINERARY FOR TRANSPORT UNIT TYPE - TRUCK TRAILER TYPE 1

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(1,	1)	ACTVE	---	HNC	-8.146	-8.146	156
(1,	2)	MAINT	HNC	HNC	-8.146	-4.146	156
(1,	3)	IDLE	HNC	HNC	-4.146	46.867	312
(1,	4)	DEADH	HNC	DJI	46.867	47.812	69
(1,	5)	ACTVE	DJI	FCN	47.812	48.588	69
(1,	6)	DEADH	FCN	DJI	48.588	49.197	58
(1,	7)	ACTVE	DJI	GPH	49.197	49.811	58
(1,	8)	DEADH	GPH	TMI	49.811	50.311	59
(1,	9)	ACTVE	TMI	PAO	50.311	50.816	59
(1,	10)	DEADH	PAO	TMI	50.816	51.155	61
(1,	11)	ACTVE	TMI	SHP	51.155	51.420	61
(1,	12)	DEADH	SHP	TMI	51.420	51.519	62
(1,	13)	ACTVE	TMI	NMP	51.519	52.010	62
(1,	14)	DEADH	NMP	TMI	52.010	52.333	65
(1,	15)	ACTVE	TMI	PAO	52.333	52.839	65
(1,	16)	DEADH	PAO	TMI	52.839	53.177	66
(1,	17)	ACTVE	TMI	JNY	53.177	53.674	66
(1,	18)	DEADH	JNY	TMI	53.674	54.005	86
(1,	19)	ACTVE	TMI	TMI	54.005	54.172	86
(1,	20)	ACTVE	TMI	PAO	54.172	54.677	68
(1,	21)	DEADH	PAO	TMI	54.677	55.016	70
(1,	22)	ACTVE	TMI	JNY	55.016	55.513	70
(1,	23)	DEADH	JNY	TMI	55.513	55.843	74
(1,	24)	ACTVE	TMI	SHP	55.843	56.108	74
(1,	25)	DEADH	SHP	TMI	56.108	56.207	72
(1,	26)	ACTVE	TMI	NMP	56.207	56.698	72
(1,	27)	DEADH	NMP	TMI	56.698	57.022	78
(1,	28)	ACTVE	TMI	SHP	57.022	57.287	78
(1,	29)	DEADH	SHP	TMI	57.287	57.386	81
(1,	30)	ACTVE	TMI	SHP	57.386	57.651	81
(1,	31)	DEADH	SHP	TMI	57.651	57.749	79
(1,	32)	ACTVE	TMI	NMP	57.749	58.240	79
(1,	33)	DEADH	NMP	TMI	58.240	58.564	80
(1,	34)	ACTVE	TMI	NMP	58.564	59.055	80
(1,	35)	DEADH	NMP	TMI	59.055	59.378	87
(1,	36)	ACTVE	TMI	SHP	59.378	59.644	87
(1,	37)	DEADH	SHP	TMI	59.644	59.742	89
(1,	38)	ACTVE	TMI	PAO	59.742	60.248	89
(1,	39)	DEADH	PAO	TMI	60.248	60.586	93

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(1,	40)	ACTVE	TMI	PAO	60.586	61.092	93
(1,	41)	DEADH	PAO	TMI	61.092	61.430	97
(1,	42)	ACTVE	TMI	SHP	61.430	61.695	97
(1,	43)	DEADH	SHP	TMI	61.695	61.794	95
(1,	44)	ACTVE	TMI	PAO	61.794	62.299	95
(1,	45)	DEADH	PAO	TMI	62.299	62.638	98
(1,	46)	ACTVE	TMI	NMP	62.638	63.129	98
(1,	47)	DEADH	NMP	TMI	63.129	63.452	100
(1,	48)	ACTVE	TMI	PAO	63.452	63.958	100
(1,	49)	DEADH	PAO	TMI	63.958	64.296	101
(1,	50)	ACTVE	TMI	PAO	64.296	64.802	101
(1,	51)	DEADH	PAO	DJI	64.802	65.353	102
(1,	52)	ACTVE	DJI	BRI	65.353	65.627	102
(1,	53)	DEADH	BRI	DJI	65.627	65.734	105
(1,	54)	ACTVE	DJI	BRI	65.734	66.008	105
(1,	55)	DEADH	BRI	DJI	66.008	66.115	111
(1,	56)	ACTVE	DJI	GPH	66.115	66.729	111
(1,	57)	DEADH	GPH	TMI	66.729	67.229	110
(1,	58)	ACTVE	TMI	PAO	67.229	67.735	110
(1,	59)	DEADH	PAO	TMI	67.735	68.073	114
(1,	60)	ACTVE	TMI	PAO	68.073	68.579	114
(1,	61)	DEADH	PAO	TMI	68.579	68.917	116
(1,	62)	ACTVE	TMI	PPM	68.917	69.591	116
(1,	63)	DEADH	PPM	TMI	69.591	70.098	119
(1,	64)	ACTVE	TMI	PAO	70.098	70.604	119
(1,	65)	DEADH	PAO	TMI	70.604	70.942	121
(1,	66)	ACTVE	TMI	GCC	70.942	71.412	121
(1,	67)	DEADH	GCC	BSC	71.412	72.491	126
(1,	68)	ACTVE	BSC	BSC	72.491	72.657	126
(1,	69)	DEADH	BSC	JOH	72.657	72.967	124
(1,	70)	ACTVE	JOH	JOH	72.967	73.134	124
(1,	71)	ACTVE	JOH	JOH	73.134	73.300	125
(1,	72)	DEADH	JOH	DJI	73.300	74.000	134
(1,	73)	ACTVE	DJI	DJI	74.000	74.167	134
(1,	74)	ACTVE	DJI	DJI	74.167	74.333	127
(1,	75)	ACTVE	DJI	QCI	74.333	74.663	117
(1,	76)	DEADH	QCI	DJI	74.663	74.825	120
(1,	77)	ACTVE	DJI	SOC	74.825	77.477	120
(1,	78)	DEADH	SOC	BSC	77.477	80.520	141
(1,	79)	ACTVE	BSC	BSC	80.520	80.687	141

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(1,	80)	ACTVE	BSC	BSC	80.687	80.853	133
(1,	81)	DEADH	BSC	HNC	80.853	81.185	306
(1,	82)	MAINT	HNC	HNC	81.185	85.185	306
(1,	83)	DEADH	HNC	OAS	85.185	85.541	128
(1,	84)	ACTVE	OAS	OAS	85.541	85.708	128
(1,	85)	ACTVE	OAS	OAS	85.708	85.874	149
(1,	86)	DEADH	OAS	BSC	85.874	86.050	142
(1,	87)	ACTVE	BSC	SSS	86.050	86.315	142
(1,	88)	DEADH	SSS	OAS	86.315	86.517	144
(1,	89)	ACTVE	OAS	FDA	86.517	87.089	144
(1,	90)	DEADH	FDA	OAS	87.089	87.494	146
(1,	91)	ACTVE	OAS	OAS	87.494	87.661	146
(1,	92)	ACTVE	OAS	SCT	87.661	88.054	147
(1,	93)	DEADH	SCT	BSC	88.054	88.442	150
(1,	94)	ACTVE	BSC	SSS	88.442	88.707	150
(1,	95)	DEADH	SSS	OAS	88.707	88.909	152
(1,	96)	ACTVE	OAS	SCT	88.909	89.303	152
(1,	97)	DEADH	SCT	OAS	89.303	89.529	154
(1,	98)	ACTVE	OAS	BRL	89.529	90.531	154

TRAVEL DAYS ACTIVE 22.
TRAVEL DAYS DEADHEAD 18.
TRAVEL DAYS IDLE 47.
DAYS IN MAINTENANCE 4.

TRAVEL KILOMETERS ACTIVE 18[illegible]36.
TRAVEL KILOMETERS DEADHEAD 23321.

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(2,	1)	ACTVE	---	HNC	-6.188	-6.188	157
(2,	2)	MAINT	HNC	HNC	-6.188	-2.188	157
(2,	3)	IDLE	HNC	HNC	-2.188	3.889	311
(2,	4)	DEADH	HNC	DJI	3.889	4.833	2
(2,	5)	ACTVE	DJI	DJI	4.833	5.000	2
(2,	6)	ACTVE	DJI	DJI	5.000	5.167	3
(2,	7)	ACTVE	DJI	DJI	5.167	5.333	5
(2,	8)	ACTVE	DJI	DJI	5.333	5.500	6
(2,	9)	ACTVE	DJI	DJI	5.500	5.667	11
(2,	10)	DEADH	DJI	JOH	5.667	6.366	8
(2,	11)	ACTVE	JOH	JOH	6.366	6.533	8
(2,	12)	ACTVE	JOH	HNT	6.533	7.048	1
(2,	13)	DEADH	HNT	JOH	7.048	7.396	4
(2,	14)	ACTVE	JOH	HNT	7.396	7.911	4
(2,	15)	IDLE	HNT	HNT	7.911	9.946	307
(2,	16)	DEADH	HNT	TMI	9.946	10.833	10
(2,	17)	ACTVE	TMI	TMI	10.833	11.000	10
(2,	18)	ACTVE	TMI	TMI	11.000	11.167	20
(2,	19)	ACTVE	TMI	SWV	11.167	11.636	7
(2,	20)	DEADH	SWV	JOH	11.636	12.120	9
(2,	21)	ACTVE	JOH	HNT	12.120	12.635	9
(2,	22)	DEADH	HNT	JOH	12.635	12.984	12
(2,	23)	ACTVE	JOH	BFD	12.984	13.549	12
(2,	24)	DEADH	BFD	OAS	13.549	13.909	15
(2,	25)	ACTVE	OAS	CNC	13.909	14.242	15
(2,	26)	DEADH	CNC	OAS	14.242	14.408	14
(2,	27)	ACTVE	OAS	CNC	14.408	14.741	14
(2,	28)	DEADH	CNC	OAS	14.741	14.907	16
(2,	29)	ACTVE	OAS	FDA	14.907	15.479	16
(2,	30)	DEADH	FDA	BSC	15.479	15.893	22
(2,	31)	ACTVE	BSC	BSC	15.893	16.059	22
(2,	32)	DEADH	BSC	OAS	16.059	16.235	23
(2,	33)	ACTVE	OAS	OAS	16.235	16.402	23
(2,	34)	ACTVE	OAS	OAS	16.402	16.568	24
(2,	35)	DEADH	OAS	JOH	16.568	16.733	13
(2,	36)	ACTVE	JOH	HNT	16.733	17.248	13
(2,	37)	DEADH	HNT	JOH	17.248	17.596	17
(2,	38)	ACTVE	JOH	HNT	17.596	18.111	17
(2,	39)	DEADH	HNT	DJI	18.111	18.663	18

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(2,	40)	ACTVE	DJI	CSJ	18.663	18.963	18
(2,	41)	DEADH	CSJ	DJI	18.963	19.096	29
(2,	42)	ACTVE	DJI	DJI	19.096	19.263	29
(2,	43)	DEADH	DJI	HNC	19.263	20.207	308
(2,	44)	MAINT	HNC	HNC	20.207	24.207	308
(2,	45)	IDLE	HNC	HNC	24.207	25.186	308
(2,	46)	DEADH	HNC	TMI	25.186	25.661	19
(2,	47)	ACTVE	TMI	LPP	25.661	25.923	19
(2,	48)	DEADH	LPP	TMI	25.923	26.018	21
(2,	49)	ACTVE	TMI	SWV	26.018	26.488	21
(2,	50)	DEADH	SWV	TMI	26.488	26.791	25
(2,	51)	ACTVE	TMI	LPP	26.791	27.052	25
(2,	52)	DEADH	LPP	TMI	27.052	27.148	27
(2,	53)	ACTVE	TMI	TMI	27.148	27.314	27
(2,	54)	ACTVE	TMI	LPP	27.314	27.576	28
(2,	55)	DEADH	LPP	TMI	27.576	27.671	30
(2,	56)	ACTVE	TMI	TMI	27.671	27.838	30
(2,	57)	ACTVE	TMI	LPP	27.838	28.100	32
(2,	58)	DEADH	LPP	JOH	28.100	28.785	31
(2,	59)	ACTVE	JOH	HNT	28.785	29.300	31
(2,	60)	DEADH	HNT	JOH	29.300	29.648	26
(2,	61)	ACTVE	JOH	BFD	29.648	30.214	26
(2,	62)	DEADH	BFD	JOH	30.214	30.613	38
(2,	63)	ACTVE	JOH	JOH	30.613	30.780	38
(2,	64)	DEADH	JOH	BSC	30.780	31.090	45
(2,	65)	ACTVE	BSC	BSC	31.090	31.257	45
(2,	66)	ACTVE	BSC	BSC	31.257	31.423	41
(2,	67)	DEADH	BSC	JOH	31.423	31.733	52
(2,	68)	ACTVE	JOH	JOH	31.733	31.900	52
(2,	69)	ACTVE	JOH	BFD	31.900	32.466	33
(2,	70)	DEADH	BFD	OAS	32.466	32.826	34
(2,	71)	ACTVE	OAS	FDA	32.826	33.398	34
(2,	72)	DEADH	FDA	JOH	33.398	33.950	37
(2,	73)	ACTVE	JOH	HNT	33.950	34.465	37
(2,	74)	DEADH	HNT	JOH	34.465	34.813	39
(2,	75)	ACTVE	JOH	BFD	34.813	35.379	39
(2,	76)	DEADH	BFD	JOH	35.379	35.778	40

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Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
2	77	ACTVE	JOH	HNT	35.778	36.293	40
2	78	DEADH	HNT	JOH	36.293	36.642	43
2	79	ACTVE	JOH	HNT	36.642	37.157	43
2	80	DEADH	HNT	JOH	37.157	37.505	42
2	81	ACTVE	JOH	BFD	37.505	38.071	42
2	82	DEADH	BFD	JOH	38.071	38.470	46
2	83	ACTVE	JOH	BFD	38.470	39.036	46
2	84	DEADH	BFD	JOH	39.036	39.435	49
2	85	ACTVE	JOH	BFD	39.435	40.001	49
2	86	DEADH	BFD	OAS	40.001	40.361	56
2	87	ACTVE	OAS	OAS	40.361	40.528	56
2	88	DEADH	OAS	BSC	40.528	40.703	63
2	89	ACTVE	BSC	BSC	40.703	40.870	63
2	90	DEADH	BSC	TMI	40.870	41.659	55
2	91	ACTVE	TMI	TMI	41.659	41.826	55
2	92	ACTVE	TMI	TMI	41.826	41.993	57
2	93	ACTVE	TMI	TMI	41.993	42.159	64
2	94	DEADH	TMI	DJI	42.159	43.023	36
2	95	ACTVE	DJI	CSJ	43.023	43.324	36
2	96	DEADH	CSJ	DJI	43.324	43.457	35
2	97	ACTVE	DJI	DBO	43.457	44.000	35
2	98	DEADH	DBO	DJI	44.000	44.376	51
2	99	ACTVE	DJI	DJI	44.376	44.543	51
2	100	ACTVE	DJI	DBO	44.543	45.086	44
2	101	DEADH	DBO	TMI	45.086	45.575	48
2	102	ACTVE	TMI	LPP	45.575	45.837	48
2	103	DEADH	LPP	TMI	45.837	45.932	47
2	104	ACTVE	TMI	LPP	45.932	46.194	47
2	105	DEADH	LPP	TMI	46.194	46.289	54
2	106	ACTVE	TMI	SHP	46.289	46.555	54
2	107	DEADH	SHP	TMI	46.555	46.653	53
2	108	ACTVE	TMI	PAO	46.653	47.159	53
2	109	DEADH	PAO	BSC	47.159	48.029	50
2	110	ACTVE	BSC	TPF	48.029	48.958	50
2	111	IDLE	TPF	TPF	48.958	49.072	304
2	112	DEADH	TPF	BSC	49.072	49.833	75
2	113	ACTVE	BSC	BSC	49.833	50.000	75
2	114	ACTVE	BSC	BSC	50.000	50.167	84

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Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(2,	115)	DEADH	BSC	JOH	50.167	50.476	82
(2,	116)	ACTVE	JOH	JOH	50.476	50.643	82
(2,	117)	DEADH	JOH	OAS	50.643	50.807	60
(2,	118)	ACTVE	OAS	CNC	50.807	51.140	60
(2,	119)	DEADH	CNC	OAS	51.140	51.306	67
(2,	120)	ACTVE	OAS	SCT	51.306	51.700	67
(2,	121)	DEADH	SCT	OAS	51.700	51.927	73
(2,	122)	ACTVE	OAS	CNC	51.927	52.260	73
(2,	123)	DEADH	CNC	BSC	52.260	52.460	71
(2,	124)	ACTVE	BSC	TPF	52.460	53.388	71
(2,	125)	DEADH	TPF	HNC	53.388	54.407	310
(2,	126)	MAINT	HNC	HNC	54.407	58.407	310
(2,	127)	IDLE	HNC	HNC	58.407	60.347	310
(2,	128)	DEADH	HNC	JOH	60.347	60.667	94
(2,	129)	ACTVE	JOH	JOH	60.667	60.833	94
(2,	130)	ACTVE	JOH	JOH	60.833	61.000	88
(2,	131)	DEADH	JOH	OAS	61.000	61.164	91
(2,	132)	ACTVE	OAS	OAS	61.164	61.331	91
(2,	133)	DEADH	OAS	BSC	61.331	61.507	76
(2,	134)	ACTVE	BSC	CRF	61.507	62.093	76
(2,	135)	DEADH	CRF	OAS	62.093	62.633	77
(2,	136)	ACTVE	OAS	CNC	62.633	62.966	77
(2,	137)	DEADH	CNC	OAS	62.966	63.132	83
(2,	138)	ACTVE	OAS	SCT	63.132	63.526	83
(2,	139)	DEADH	SCT	BSC	63.526	63.914	85
(2,	140)	ACTVE	BSC	CRF	63.914	64.500	85
(2,	141)	DEADH	CRF	JOH	64.500	65.203	113
(2,	142)	ACTVE	JOH	JOH	65.203	65.369	113
(2,	143)	DEADH	JOH	OAS	65.369	65.533	109
(2,	144)	ACTVE	OAS	OAS	65.533	65.700	109
(2,	145)	ACTVE	OAS	OAS	65.700	65.867	108
(2,	146)	DEADH	OAS	BSC	65.867	66.043	106
(2,	147)	ACTVE	BSC	BSC	66.043	66.209	106
(2,	148)	ACTVE	BSC	BSC	66.209	66.376	107
(2,	149)	ACTVE	BSC	BSC	66.376	66.543	112
(2,	150)	DEADH	BSC	OAS	66.543	66.718	115
(2,	151)	ACTVE	OAS	OAS	66.718	66.885	115

Itinerary No.	Itinerary Leg	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(2	152)	ACTVE	OAS	CNC	66.885	67.218	90
(2	153)	DEADH	CNC	OAS	67.218	67.384	104
(2	154)	ACTVE	OAS	FDA	67.384	67.956	104
(2	155)	DEADH	FDA	OAS	67.956	68.361	103
(2	156)	ACTVE	OAS	BRL	68.361	69.363	103
(2	157)	IDLE	BRL	BRL	69.363	71.554	309
(2	158)	DEADH	BRL	DJI	71.554	72.702	118
(2	159)	ACTVE	DJI	DJI	72.702	72.869	118
(2	160)	ACTVE	DJI	DJI	72.869	73.035	92
(2	161)	ACTVE	DJI	GPH	73.035	73.649	96
(2	162)	DEADH	GPH	DJI	73.649	74.097	99
(2	163)	ACTVE	DJI	FCN	74.097	74.873	99
(2	164)	DEADH	FCN	DJI	74.873	75.482	122
(2	165)	ACTVE	DJI	QCI	75.482	75.811	122
(2	166)	DEADH	QCI	DJI	75.811	75.974	123
(2	167)	ACTVE	DJI	GPH	75.974	76.588	123
(2	168)	DEADH	GPH	TMI	76.588	77.088	129
(2	169)	ACTVE	TMI	PPM	77.088	77.762	129
(2	170)	DEADH	PPM	TMI	77.762	78.269	130
(2	171)	ACTVE	TMI	PPM	78.269	78.943	130
(2	172)	DEADH	PPM	TMI	78.943	79.450	131
(2	173)	ACTVE	TMI	GCC	79.450	79.920	131
(2	174)	DEADH	GCC	TMI	79.920	80.224	132
(2	175)	ACTVE	TMI	PAO	80.224	80.729	132
(2	176)	DEADH	PAO	TMI	80.729	81.068	135
(2	177)	ACTVE	TMI	PPM	81.068	81.742	135
(2	178)	DEADH	PPM	TMI	81.742	82.249	136
(2	179)	ACTVE	TMI	PPM	82.249	82.923	136
(2	180)	DEADH	PPM	TMI	82.923	83.430	138
(2	181)	ACTVE	TMI	PPM	83.430	84.104	138
(2	182)	DEADH	PPM	TMI	84.104	84.611	137
(2	183)	ACTVE	TMI	PPM	84.611	85.285	137
(2	184)	DEADH	PPM	TMI	85.285	85.792	143
(2	185)	ACTVE	TMI	PAO	85.792	86.298	143
(2	186)	DEADH	PAO	DJI	86.298	86.849	148
(2	187)	ACTVE	DJI	QCI	86.849	87.179	148
(2	188)	DEADH	QCI	DJI	87.179	87.341	153

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Itinerary No.	Itinerary Leg.	Type Service	Origin Base	Destination Base	Departure Time	Arrival Time	Shipment No.
(2,	189)	ACTVE	DJI	QCI	87.341	87.671	153
(2,	190)	DEADH	QCI	DJI	87.671	87.833	151
(2,	191)	ACTVE	DJI	DJI	87.833	88.000	151
(2,	192)	ACTVE	DJI	DJI	88.000	88.167	155
(2,	193)	ACTVE	DJI	QCI	88.167	88.496	145
(2,	194)	DEADH	QCI	DJI	88.496	88.659	139
(2,	195)	ACTVE	DJI	QCI	88.659	88.988	139
(2,	196)	DEADH	QCI	DJI	88.988	89.151	140
(2,	197)	ACTVE	DJI	SOC	89.151	91.802	140

TRAVEL DAYS ACTIVE 41.
TRAVEL DAYS DEADHEAD 32.
TRAVEL DAYS IDLE 12.
DAYS IN MAINTENANCE 8.

TRAVEL KILOMETERS ACTIVE 30016.
TRAVEL KILOMETERS DEADHEAD 41429.

FLEETSIZE OF 2 FOR - TRUCK TRAILER TYPE 1

TOTAL DAYS ACTIVE 63.
TOTAL DAYS DEADHEAD 50.
TOTAL DAYS IDLE 59.
TOTAL DAYS IN MAINTENANCE 12.

TOTAL KILOMETERS ACTIVE 48052.
TOTAL KILOMETERS DEADHEAD 64750.

32. % DAYS ACTIVE
25. % DAYS DEADHEAD
33. % DAYS IDLE
10. % DAYS IN MAINTENANCE

43. % KILOMETERS ACTIVE
57. % KILOMETERS DEADHEAD

31. AVERAGE DAYS ACTIVE
25. AVERAGE DAYS DEADHEAD
32. AVERAGE DAYS IDLE
6. AVERAGE DAYS IN MAINTENANCE

24026. AVERAGE KILOMETERS ACTIVE
32375. AVERAGE KILOMETERS DEADHEAD

779 113

SHIP. NO. 1

1	30	(2, 12)
2	43	(2, 5)
3	42	(2, 6)
4	30	(2, 14)
5	43	(2, 7)
6	42	(2, 8)
7	1	(2, 19)
8	39	(2, 11)
9	17	(2, 21)
10	45	(2, 17)
11	41	(2, 9)
12	4	(2, 23)
13	21	(2, 36)
14	24	(2, 27)
15	25	(2, 25)
16	15	(2, 29)
17	16	(2, 38)
18	13	(2, 40)
19	31	(2, 47)
20	46	(2, 18)
21	2	(2, 49)
22	35	(2, 31)
23	37	(2, 33)
24	38	(2, 34)
25	29	(2, 51)
26	8	(2, 61)
27	11	(2, 53)
28	28	(2, 54)
29	44	(2, 42)
30	10	(2, 56)
31	23	(2, 59)
32	30	(2, 57)
33	7	(2, 69)
34	14	(2, 71)
35	33	(2, 97)
36	12	(2, 95)
37	19	(2, 73)
38	40	(2, 63)
39	5	(2, 75)
40	22	(2, 77)
41	34	(2, 66)
42	6	(2, 81)
43	18	(2, 79)
44	32	(2,100)
45	36	(2, 65)
46	3	(2, 83)
47	26	(2,104)

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48	27	(2,102)
49	9	(2, 85)
50	48	(2,110)
51	61	(2, 99)
52	92	(2, 68)
53	67	(2,108)
54	79	(2,106)
55	96	(2, 91)
56	88	(2, 87)
57	93	(2, 92)
58	69	(1, 7)
59	66	(1, 9)
60	71	(2,118)
61	77	(1, 11)
62	53	(1, 13)
63	84	(2, 89)
64	94	(2, 93)
65	65	(1, 15)
66	82	(1, 17)
67	57	(2,120)
68	68	(1, 20)
69	81	(1, 5)
70	83	(1, 22)
71	47	(2,124)
72	50	(1, 26)
73	58	(2,122)
74	73	(1, 24)
75	86	(2,113)
76	54	(2,134)
77	59	(2,136)
78	74	(1, 28)
79	51	(1, 32)
80	52	(1, 34)
81	76	(1, 30)
82	89	(2,116)
83	56	(2,138)
84	85	(2,114)
85	55	(2,140)
86	95	(1, 19)
87	78	(1, 36)
88	91	(2,130)
89	62	(1, 38)
90	72	(2,152)
91	87	(2,132)
92	60	(2,160)
93	63	(1, 40)
94	90	(2,129)
95	64	(1, 44)
96	70	(2,161)

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97	75	(1, 42)
98	49	(1, 46)
99	80	(2,163)
100	124	(1, 48)
101	129	(1, 50)
102	106	(1, 52)
103	134	(2,156)
104	99	(2,154)
105	105	(1, 54)
106	137	(2,147)
107	140	(2,148)
108	142	(2,145)
109	144	(2,144)
110	130	(1, 58)
111	132	(1, 56)
112	139	(2,149)
113	145	(2,142)
114	125	(1, 60)
115	143	(2,151)
116	111	(1, 62)
117	117	(1, 75)
118	150	(2,159)
119	128	(1, 64)
120	120	(1, 77)
121	123	(1, 66)
122	119	(2,165)
123	131	(2,167)
124	146	(1, 70)
125	147	(1, 71)
126	138	(1, 68)
127	148	(1, 74)
128	98	(1, 84)
129	112	(2,169)
130	107	(2,171)
131	122	(2,173)
132	126	(2,175)
133	135	(1, 80)
134	152	(1, 73)
135	109	(2,177)
136	110	(2,179)
137	108	(2,183)
138	113	(2,181)
139	116	(2,195)
140	121	(2,197)
141	136	(1, 79)
142	103	(1, 87)
143	127	(2,185)
144	100	(1, 89)

779 116

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130      107      ( 2,171)
131      122      ( 2,173)
132      126      ( 2,175)
133      135      ( 1, 80)
134      152      ( 1, 73)
135      109      ( 2,177)
136      110      ( 2,179)
137      108      ( 2,183)
138      113      ( 2,181)
139      116      ( 2,195)
140      121      ( 2,197)
141      136      ( 1, 79)
142      103      ( 1, 87)
143      127      ( 2,185)
144      100      ( 1, 89)
145      114      ( 2,193)
146       97      ( 1, 91)
147      101      ( 1, 92)
148      115      ( 2,187)
149      141      ( 1, 85)
150      104      ( 1, 94)
151      149      ( 2,191)
152      102      ( 1, 96)
153      118      ( 2,189)
154      133      ( 1, 98)
155      151      ( 2,192)


COL. - TRANSPORT UNIT TYPE
 1          TRUCK TRAILER TYPE 1

END OF EXECUTION
CPU TIME: 3:47.71        ELAPSED TIME: 27:25.32
EXIT
[:03:48 :27:51 286 103]

.COPY DSKC:SR11.FF=SAII:SR11.TMP
[22:00:10]
[0.26 2.05 58 54]

.COPY DSKC:IT11.FF=SAII:IT11.TMP
[22:00:15]
[0.16 1.13 25 21]

.DEL SAII:IT11.TMP,SAII:SR11.TMP
[22:00:19]
Files deleted:
IT11.TMP
15 Blocks freed
SR11.TMP
48 Blocks freed
[0.16 4.56 8 4]

.
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Details on two versions of a computerized model for the transportation system of the NRC Physical Protection Project are presented. The Version I model permits scheduling of all types of transport units associated with a truck fleet, including truck trailers, truck tractors, escort vehicles and crews. A fixed-fleet itinerary construction process is used in which iterations on fleet size are required until the service requirements are satisfied. The Version II model adds an aircraft mode capability and provides for a more efficient non-fixed-fleet itinerary generation process. Test results using both versions are included.

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