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A STUDY OF WORKLOAD SCHEDULING AND RESOURCE PLANNING AT AN OVERHAUL FACILITY

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ABSTRACT

This study analyzes the C-141 overhaul operations at Warner Robins Air Logistic Center (WR-ALC). The literature review covers overhaul operations, techniques for scheduling in a constrained resource environment, and techniques for simulation optimization. The body of the study compares traditional formula based methods for computing facility requirements and aircraft induction scheduling to integer linear programming and simulation heuristic approaches.

The study objectives are twofold. First, a schedule that maximizes the release of excess hangar, ramp, and functional test facilities to WR-ALC for the pursuit other workload (the release schedule) is needed. These facilities must be available as quickly as possible. However, the release schedule must leave sufficient capacity to allow C-141 Production Division to meet its overhaul commitments. The second study must recommend an aircraft induction schedule that will enable the first objective (the induction schedule) to be achieved. At each step, the study analyzes the traditional formula approaches used to solve the problem, a mathematical programming approach, and a simulation approach to the problem. The schedules these three techniques generate are run through a simulation models and the key parameters of resource utilization and makespan are evaluated. Each technique is then evaluated against the trade-off criteria of speed, accuracy, and level of detail. The study finds that direct manipulation of the simulation model, i.e., the simulation approach, yields the most desirable results.

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Ruben L. Bell Jr.

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1.0 INTRODUCTION

In optimization studies analysts typically attempt to determine the ideal parameters for a physical or theoretical system through manipulation of a mathematical representation of the system. The system itself could represent a natural phenomenon, community, or an industrial process. The objective of most optimization models and techniques is to attempt to describe an ideal set of parameters for the system being studied, as they relate to some quantitative or qualitative measure of overall system performance. In general analysts, or in many cases the decision maker, must determine the definition/criteria of what ideal parameters represent. Unfortunately, in many cases real-world cases a truly optimal set of parameters cannot be obtained. Either the system is too complex or variant to be represented by a precise mathematical model, or the cost of such a precise representation is economically impractical (Akbay 1996).

For purposes of this study, optimization studies are broken into four tiers. The tiers span the simplest algebraic and calculus models (arithmetic models), deterministic models, stochastic models, and heuristics and algorithms. Characteristics of these models include simplicity of application, modeling precision and realism, modeling versatility and flexibility, modeling speed, economics or implementation cost, and technical acceptance. Three characteristics often considered in real world studies are economics, time, and level of detail. Decision makers and analysts must trade-off between model characteristics when modeling real-world systems.

The first tier of optimization models is the arithmetic approach. In general, arithmetic approaches are relatively inexpensive to develop and solve. Algebraic models may consist of simple formulas that are used to determine one system attribute/characteristic or systems of attributes/characteristics. Calculus based optimization models provide answers to a wider range of problems through the use of derivation and integration. Arithmetic approaches provide precise answers to question asked. However, arithmetic approaches lack the ability to model complex multi-faceted systems. Consequently, analysts use arithmetic approaches in a relatively narrow range of problems.

The second and third tiers of optimization studies, deterministic and stochastic, involve mathematical modeling. In either case these modeling techniques strive to represent a real world or theoretical process/system. Deterministic models strive to develop a precise process/system representation. Workload scheduling, resource allocation, and transportation models are all classic examples of deterministic models. Key to the study of deterministic modeling is the field of mathematical programming, both linear and nonlinear. Stochastic models attempt to provide a representation of a process/system where probability distributions are needed to represent certain system characteristics. Key to the study of stochastic models is the field of simulation.

The fourth tier of optimization studies involves hybrid models that take features from different fields and try to adapt them for optimization studies using algorithms and heuristics. Examples of these models include genetic algorithms and simulated annealing. Actual applications of these approaches are limited to specific classes of problems.

This paper deals with a specific class of optimization problems, resource constrained scheduling problems. In particular, this paper addresses the scheduling of an overhaul facility in a declining workload environment. The overhaul facility being studied is the C-141 Production Division (LJP) at Warner Robins Air Logistics Center (WR-ALC), Robins Air Force Base (RAFB), GA. A complete description of WR-ALC/LJP operation is given in Section 3.

2.0 LITERATURE REVIEW & BACKGROUND INFORMATION

This section reviews literature relating to optimization techniques as well as some background issues important to this particular study. The review discusses the differences between overhaul and manufacturing environments, and current issues affecting the studied depot overhaul facility. The review then looks at some current optimization techniques.

Overhaul vs. Manufacturing

Sawaya and Giauque (1986, pp 38) characterize manufacturing systems on a continuum from job shops, to batch flow, to assembly line/worker-paced, to assembly line/machine-paced, and finally continuous flow. What all these system have in common is their goal of producing a predetermined number of identical end products. The authors characterize Job shops by the general-purpose equipment which is oriented into like processes. The job shop produces a relatively low quantity of the same item. However, job shops are capable of producing a great variety of different types of products. Whereas, continuous flow processes are characterized by specific purpose equipment arranged in a fashion to produce a specific product. Common to any manufacturing system is that it strives to produce a product using known inputs and processes. Once the manufacturer determines the methodology it uses to produce an end product, the system the manufacturer uses to produce that end product remains relatively fixed. The manufacture may then optimize the parameters it uses to produce the product or group of products. Eventually, the manufacturing processes become stable and repeatable.

The goal of an overhaul system differs from that of a manufacturing system. An overhaul system takes a product, at some point in its service life, and attempts to restore the product to a condition it was in earlier in its product lifecycle (Gharbi, Pellerin, and Villeneuve 1999). While an end item is produced only once in its lifecycle, it may be overhauled dozens of time before its eventual disposal. The lifecycle of products such as aircraft, machinery, and ships follow a general pattern of design—manufacturing—operations & maintenance (to include overhaul and modifications)—disposal (ACQ 201 1999). Military weapon systems, such as aircraft and ships, have a lifecycle cost distribution that roughly follows 10% design, 25% manufacturing, 55% operations and maintenance, 10% disposal. With such a large portion of the cost of a system actually going to its operations and maintenance it is valuable to consider the long-term maintenance and overhaul process organizations use to keep a systems serviceable.

Overhaul systems are characterized by three primary phases of work: look, fix, and test. During the look phase, consistent inspection techniques are employed to each end item. The results of these inspections may lead to other more in-depth inspections. Nevertheless, the look phase follows a relatively consistent process. The fix phase may require replacement, repair, or refurbishment of sub-components of the end item based on what is found in the look phase. Consequently, a high degree of unpredictability and variability characterizes the fix phase. Not only do the number of fixes vary from end item to end item, but also the nature of the fixes for the same or similar discrepancies vary as well. The test phase generally occurs at the end of the fix phase and is relatively consistent from fix to fix, and item to item. However, the overhaul process for complex items such as military aircraft normally does not move smoothly from phase to phase. The three phases quickly intermingle as one fix leads to deeper looks, or a test fails leading to another fix, or a sub-component must go completely through the look—fix—test cycle before the next higher assembly completes its cycle.

Gharbi, Pellerin, and Villeneuve (1999) recognize the challenges of scheduling work through a workspace constrained overhaul facility such as WR-ALC. They note that traditional project scheduling methodologies focus on prioritizing a set of activity attributes such as resource utilization or job duration (makespan) rather than focusing on solutions around bottleneck resources. Goldratt (1992) also teaches the bottleneck resource lesson in his book "The Goal." In general, Gharbi, Pellerin, and Villeneuve (1999) treat workspace constraints in the same manner that other analysts treat machine resource constraints. The authors present a heuristic for scheduling an overhaul facility which aims at reducing the total overhaul time (makespan). They accomplish this by dividing the workspace into working zones. The heuristic, they call MAXCON, (Maximum Constrained activity), prioritizes the scheduling of activities based on the delay to a project's minimum remaining duration if the activity does not start when scheduled. The authors treat work zones like other constrained resources such as machine resources. They test MAXCOM against eight other project scheduling heuristics. Using deterministic processing times, the authors are able to develop schedules with shorter durations in most of the 300 problems they consider. When MAXCON does not produce the shortest durations it is less than 5% away from the shortest times.

Gemmill and Edward (1999) propose a heuristic similar to the MAXCON heuristic. Their "look-ahead" heuristic attempts to schedule lower priority activities when there are not enough resources to begin higher priority activities. Typically, lower priority activities must wait in a queue behind higher priority activities. If some resources are idle but insufficient resources are available to begin the highest priority job, then all jobs must wait. Thus idles resources, delays activities and increases makespan. Gemmill and Edwards (1999) show their heuristic performs well against 110 test problems J.H. Patterson had developed in 1984. "Look-ahead" yields a 5-8% reduction in makespan against the test problems.

The ability to predict the process is a key difference in studies of manufacturing versus overhaul systems. Overhaul systems are much more variable than manufacturing systems (Gharbi, Pellerin, Villeneuve, 1999). Therefore, analysts must consider system variability when designing or studying overhaul systems.

Depot Overhaul

Congress and the President are driving the Department of Defense (DoD) to compete more of DoD's depot maintenance operations in the public sector. The DoD operates 30 major depots, employing over 89,000 workers, with over $14 billion of workload (Edwards 1996). Under the base realignment and closure process (BRAC) much of this workload is being pushed into the private sector. Recently, San Antonio Air Logistics Center (SA-ALC) and Sacramento Air Logistics Centers (SM-ALC) (sister depots to Warner Robins Air Logistics Center, WR-ALC) were privatized under BRAC realignments. A 1998 anonymous article in the Government Executive speaks to some depot employee and leadership concerns. The President wants to eliminate the 60/40 rule that requires DoD to do 60% of all depot work in house and no more than 40% of the work should be done by contractors. The Secretary of Defense strikes a compromise in the 1998 Defense Authorization bill that changes the ratio to 50/50. However, the President still wants to make all depot workload available for public-private competition.

Today, the effort at WR-ALC is to bring more workload in-house. Several high level meetings were held to review current and future workload to see what can be brought back into the depot. Special attention is paid to the C-141 Production Division. Depot leadership needs firm answers on when and how many facilities can be made available to the depot so WR-ALC can compete for future depot workload. If WR-ALC does not compete for business it may find itself in the same position as SA-ALC and SM-ALC, out of business.

Current Optimization Approaches

Anderson, Sweeney, and Williams (1994, page 8) define a stochastic model as a model in which the decision maker cannot control all environmental factors or inputs. These factors and inputs are subject to variation. Computer simulation is one of the fundamental approaches to stochastic modeling. Kelton, Sadowski, and Sadowski (1998, page 7) define computer simulation as methods for studying a real world system by numerical evaluation using software designed to imitate system operations or characteristics, often over time. Kelton, Sadowski, and Sadowski (1998, pp 433-450) also provide some basic steps for conducting a simulation study:

- Problem formulation
- Solution methodology
- System and simulation specifications
- Model formulation and construction
- Verification and validation
- Experimentation and analysis
- Presenting and preserving results

Akbay (1996) provides an overview of simulation optimization techniques practiced in real-world environments. Simulation is often the best tool to use when trying to account for randomness and dynamic interactions in a system over time. The key to simulation optimization is being able to construct a realistic model. Once the analyst creates a realistic model, he/she may run "what-if" analysis by changing the model parameters. As a method to guide the study, design of experiments (DOE) greatly enhances these "what-if" analyzes. However, traditional DOE procedures may require a simulation to be run many times. Akbay (1996) introduces a software package called SimRunner 1.0 which runs in a PROMODEL simulation environment. SimRunner runs DOE experiments for analysts. IBM, Sverdrup, and Baystate Health have all use SimRunner to successfully tackle real world problems.

Construction of a confidence interval around a simulation optimization parameter is a standard approach to model testing. Alexopoulos and Seila (1996) develop conservative estimates for confidence intervals based on small sample sizes. Their objective is to lower the number of required simulation runs when the cost of a simulation run is high. However, no real-world experience is given for these proposed intervals.

Common random numbers (CRN) can enhance the results of a simulation study. Kleinman, Spall, and Naiman (1999) and Glasserman, and Yao (1992) discuss the benefits of using CRN in simulation studies. CRN reduces the experimental error when comparing two means by introducing dependence and thus positive covariance. Formula 2.1 shows the computation for the variance of the difference of two means. When $f(x)$ and $g(y)$ are independent then the covariance is zero. Kelton, Sadowski, and Sadowski (1998, pp 410-418) show that, when using CRN, a paired-t test can be used to evaluate the difference of two means.

$$\mathrm{Var}[f(\mathrm{x}) - g(\mathrm{y})] = \mathrm{Var}[f(\mathrm{x})] + \mathrm{Var}[g(\mathrm{y})] - 2 * \mathrm{Cov}[f(\mathrm{x}),,g(\mathrm{y})] \qquad (2.1)$$

Several researchers have developed heuristic approaches and algorithms for both simulation optimization and resource constrained scheduling. Such approaches as the Strong Factional Cutting-Plane Algorithm (Sankaran, Bricker, and Juang 1999), the Dynamic Priority-Dynamic Programming Scheduling Method (Khamooshi 1999), Metaheuristics (Viana and Sousa 2000), and Genetic Algorithms (Azadivar and Tompkins 1999), provide alternative methods for simulation optimization and constrained scheduling.

Optimization by simulated annealing (Kikrpatrick, Gelatt, and Vecchi 1983) (Haddock and Mittenhal 1992) attempts to solve an optimization problem by mimicking a process found in nature. Annealing is a process of toughening a material through the application of heating and then slow, controlled cooling. Simulated annealing applies a controlled random search methodology to optimization. Park and Kim (1998) summarize the simulated annealing algorithm for global minimization:

1. Generate an initial solution S.
2. Select a value for the initial temperature, $T_1 > 0$
3. Set the epoch count k=1
    a. Generate a neighborhood solution S' of S
    b. Let $\Delta = C(S') - C(S)$ *difference in objective function values*
    c. If $\Delta < 0$, let S be S' {downhill move}
    d. If $\Delta \geq 0$, let S' be S' with probability, $\exp(-\Delta T_k)$ {uphill move}
4. If a given stopping condition* is satisfied, stop. Otherwise, let $T_k + 1 = F(T_k)$ and k = k+1, and go to Step 3.

Where:

T_k Temperature – represents the maximum distance between S and S'. As T_k gets smaller, the random search area around S become tighter.

$F(T_k)$ Cooling Function – the rate at which T_k becomes smaller and the search area tightens.

C(S) Objective Function – value of objective function at S.

Epoch the number of trails allowed at each temperature

* Stopping conditions vary. For example: maximum number of trails, maximum computer processing time, or maximum epoch count.

Essentially, simulated annealing randomly searches the feasible solution space in smaller and smaller patterns until it reaches an optimal solution. Step 3d attempts to provide the algorithm to escape from a local minima in the search for a global optimum. The algorithm does this by allowing movement in a non-improving direction. The only information needed from outside the algorithm at each iteration is a neighborhood for the current solution and the value of the objective function at that new point. Essentially, this information comes from a "black box." The value of S' and C(S') could come from an arithmetic formula, deterministic model, or stochastic model. Kolonko (1999) and Reynolds and McKeown (1999) apply simulated annealing to manufacturing scheduling problems.

3.0 WARNER ROBINS AIR LOGISTICS CENTER & C-141 PRODUCTION DIVISION OVERVIEW

This section provides an overview of the Warner Robins Air Logistics Center's C-141 Production Division (WR-ALC/LJP) overhaul system. It begins with an overview of the Lockheed C-141 aircraft and the depot maintenance/overhaul philosophy and ends with the workflow of a typical C-141 overhaul.

Lockheed C-141

The Lockheed C-141 has long been the backbone of America's strategic airlift forces. Since it entered the United States Air Force (USAF) inventory in 1963 these aircraft have averaged over 35,000 flying hours each. The C-141 carries a maximum payload of over 94,000 pounds of cargo or over 200 troops. The aircraft has an unloaded range of over 5,000 nautical miles. However, the aircraft was given air-refueling capabilities in 1982 when the aircraft fuselage was stretched some 23 feet. The airframe currently has a viable projected life span of 45,000 flying hours. As such, the Air Force is currently retiring these aircraft and replacing them with Boeing C-17s. In its prime the C-141 boasted over 240 aircraft in the fleet. Current plans for the fleet are to drawdown to less than 70 airframes. These final airframes are planned to transition out of the USAF inventory in fiscal year 2006 (2003 for Active Duty Air Force, 2006 for Air Force Reserves and Air National Guard units). However, there is some discussion of maintaining the C-141 in the Guard and Reserve inventories until 2010 or 2015.

Depot Maintenance/Overhaul

Most aircraft in the USAF inventory undergo an extensive preventive maintenance process referred to as depot overhaul. These overhauls occur at regular intervals, the length of which is dependent on the type of airframe. During these periods of maintenance, highly skilled mechanics perform complex inspections and repairs that cannot be easily preformed at operational units, commonly referred to as "in the field." Typical workload includes modifications and upgrades (glass cockpits, air defensive systems, etc.), major structural (frames, longerons, etc.) and skin repairs, and major component replacements/overhaul (landing gear, flight controls, etc.).

During its lifetime, a C-141 aircraft goes through the depot maintenance overhaul process every 5 years. This process is commonly referred to as a Programmed Depot Maintenance (PDM). During a PDM the aircraft receives intensive structural inspections and repairs. During its lifetime the C-141 has undergone several major structural modifications to extend the life of the airframe. Currently, the depot is replacing the main structural frame that holds the main landing gear onto the aircraft, referred to as fuselage station 998. A core number of C-141s have also undergone an avionics upgrade to replace analog systems with digital "glass cockpit" technology. A basic PDM work package requires over 30,000 man-hours and 250 calendar days to accomplish. A PDM is described in three major phases: look, fix, and operational/functional tests.

Considering the different structural repairs and modifications an aircraft may need, no two PDMs are alike. While there are a significant number of repetitive tasks performed from aircraft to aircraft, the overhaul process is quite variable.

Currently, there are five different overhaul work packages. However, only three of these work packages (Mini PDM, PDM, and PDM/998) will be inducted in between October 2000 and September 2005. The term "induction" refers to bringing an aircraft to the depot to begin its overhaul. Listed below are the five major work packages currently underway for the C-141:

- PDM — Basic package of inspections, repairs, and time change component replacements and overhauls.
- Inspect PDM — Inspect aircraft and repair as necessary
- Mini PDM — Scaled down basic package for aircraft retiring within three years.
- PDM/998 — Basic package with replacement of fuselage station 998 (FS998) main frames.
- PDM/998/MODs — Basic package with FS998 replacement and "glass-cockpit" avionics upgrades.

Warner Robins Air Logistic Center (WR-ALC)

WR-ALC is one of three USAF depots. Located on Robins AFB, adjacent to Warner Robins GA, the center is the largest employee in central Georgia. The center is divided into several directorates, which focus on major weapons systems like the C-141, C-5, C-130 and F-15 aircraft, or major functional areas like avionics, financial management, and contracting. The C-141 System Program Office (SPO) is the directorate primarily responsible for the lifecycle management of the C-141 aircraft. Within the C-141 SPO, the C-141 Production Division (LJP) is responsible for the depot maintenance on all C-141 aircraft.

At its prime the LJP had employed over 1200 mechanics working three shifts with facilities to work on over 40 aircraft. During this era the division had accomplished over 50 PDMs per year. Currently, the division employs less that 500 mechanics on one primary shift with facilities for 23 aircraft accomplishing less than 20 PDMs per year. Future projections are for a workforce around 200 mechanics with yet to be determined facilities conducting less than 15 PDMs per year. Figure 3.1 shows the current LJP organization.

Current Induction Scheduling Method

The C-141 is currently scheduled on a simple 5-year induction cycle. Once an aircraft completes a PDM it is automatically scheduled to return for is next PDM in 60 months. This methodology has worked well for the past 20 to 25 years. The system had reached a steady predictable workload. However, as workload has declined LJP has struggled to accurately predict the facility size requirements, concerning the ALC.

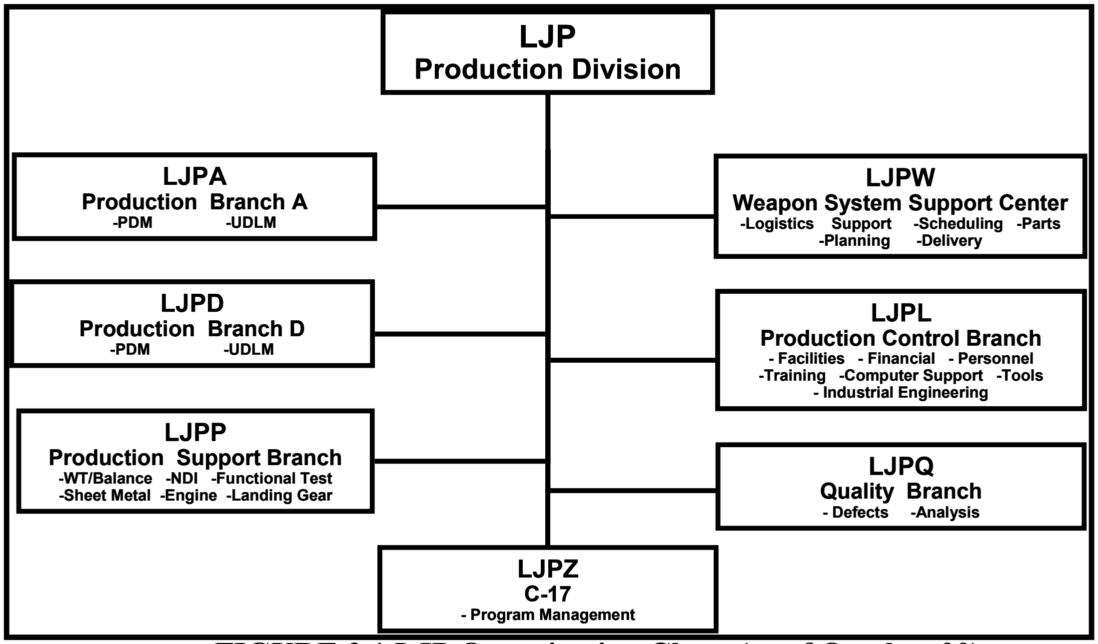

FIGURE 3.1 LJP Organization Chart (as of October 00)

The challenge LJP faces with in the C-141 depot maintenance business is to size the workforce and capabilities to the fleets needs in the midst of the aircraft's retirement. The C-141 also has regulatory requirement to send a C-141 aircraft through some PDM process at least once every 72 months.

Typical PDM Workflow

The flow of work through the C-141 production division is described at five different levels, the highest level being overall flowdays, the lowest level being individual operations. Table 3.1 provides an overview of the different levels of workflow, the data available at each level, and the reliability of the data. Figure 3.2

shows a flow diagram of a C-141 PDM broken into its 4 docks and 11 phases. For the purposes of this study, workflow will be limited to the second level. Accurate actual flowday data for work done at the lower levels is not readily available. Level 2 represents the lowest level of actual flowday data.

TABLE 3.1 Workflow Level

LEVEL	1 FLOWDAYS	2 DOCKS	3 PHASES	4 MAJOR JOBS	5 OPERATIONS
NUMBER OF DATA NODES	1	4	11	> 100	> 16,000
AVAILABLE DATA	Planned Flowdays Actual Flowdays Actual Hours Planned Hours	Planned Flowdays Actual Flowdays	Planned Flowdays Planned Hours	Planned Flowdays Actual Hours Planned Hours	Planned Hours

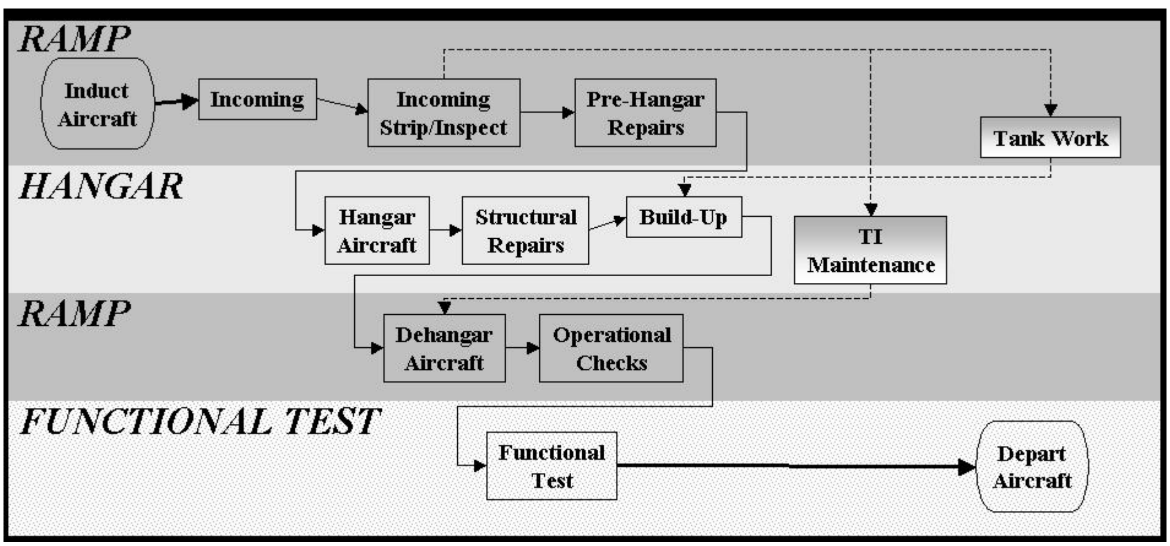

FIGURE 3.2 Workflow Diagram (4 Docks & 11 Phases)

Figure 3.2 Notes: The shaded areas represent the four docks, from top to bottom Pre-Hangar, Hangar, Post-Hangar, and Functional test. “Tank Work” and “TI Maintenance” are phases of work that cross dock boundaries but do not drive the actual location of the aircraft. “Induct Aircraft” and “Depart Aircraft” are not phases, they represent aircraft entering and departing the depot.

4.0 THE STUDY

For organizational purposes the study follows general steps outlined in Kelton, Sadowski, and Sadowski (1998, pp 433-449). These seven steps are also outlined the literature review section. The study tailors the steps to fit the study objectives. At each step the study considers the first three tiers of an optimization study as defined in Section 1: arithmetic, deterministic, and stochastic. Furthermore, the study is framed around three trade-off characteristics: speed, accuracy, and level of detail.

4.1 STUDY OBJECTIVE (Step 0)

The study objectives are twofold. First, the study recommends a schedule to maximize the release of C-141 Production Division's (LJP) hangar, ramp, and functional test facilities to Warner Robins Air Logistics Center (WR-ALC) for pursuit of other workload (release schedule). These facilities are made available as quickly as possible. However, the release schedule leaves LJP sufficient capacity to meet its remaining PDM commitments. Second, the study recommends an aircraft induction schedule that enables the first objective (induction schedule). At each step, the study analyzes the traditional formula approaches LJP uses to solve the problem, a mathematical programming approach, and simulation approach to the problem.

4.2 PROBLEM FORMULATION (Step 1)

The problem of interest is to develop an induction schedule that maximizes the use of limited ramp, hangar, and functional test utilization, while simultaneously maximizing the release of excess facility capacity to the air logistics center. These induction and release schedules must, as a minimum, meet the following constraints:

1. The number of facilities LJP requires to meet the induction schedule can not exceed the available facilities.
2. The number of aircraft LJP inducts in each fiscal year (October – September) must exactly match the number of aircraft scheduled for each work package.
3. Once LJP releases a facility, it is no longer be available to the C-141 Production Division.
4. Release schedules must not significantly delay the average flowdays of each work package.

The key parameters the study measures are:

- Flowdays: The time from when an aircraft enters the depot until it departs regardless of the amount of man-hours expended.
- Facility Utilization: The percentage of time a facility (ramp, hangar, or functional test) is occupied by an aircraft.

It is necessary to define/compute a "cost" function for comparing the different scenarios. The function measures the release schedule as a single value in terms of the amount of total capacity released. The scenario yielding the highest value is deemed the best solution given it meets the overall study objectives, and all objective constraints.

4.3 METHODOLOGY (Step 2)

In general, the study develops models that represent the C-141 overhaul process in terms of flowdays and facility utilization. Each step first looks at the traditional methods LJP uses to study the system. Traditional methods involve mostly arithmetic formulas. Next, each step reviews deterministic and stochastic approaches to solving the objective. The methods are not mutually exclusive. Each method may rely on information from another method to determine its results.

The induction and release schedule each method develops is run on a computer simulation of the overhaul system to determine a baseline for comparison. The flowday and utilization parameters of each scenario are compared to determine the affects of the different induction and release schedules on the study objective and problem formulation. The simulation also employs common random numbers (CRN) and paired-t comparisons. This limits the random variance in the model as discussed in Section 2.

Traditional Approach

Current approaches for scheduling aircraft into the depot involve an annual process called the Material Requirements Review Board (MRRB). At this review the Engineering Branch and Program Control Division of the C-141 System Program Office (C-141 SPO) works with the various field organizations to determine the depot overhaul workload for the next five years. This allows the field organizations to include overhaul requirements in their budgeting cycle. At this point, the sole determining factor for when an aircraft receives its next Programmed Depot Maintenance (PDM) is the date of its last PDM. The C-141 is on a five year PDM cycle. Consequently, the number of PDMs that are required each year is based on the number of PDMs done five years ago, less aircraft lost to retirement or otherwise destroyed. The date of a C-141's arrival at WR-ALC is generally 60 months from its last PDM departure but no later than 72 months. To extend a C-141 PDM beyond 72 months takes Headquarters, United States Air Force, approval.

Within any given fiscal year the production division negotiates with the owner of the aircraft on whether to induct an aircraft earlier or later than the 60th month scheduled induction date. However, LJP must induct all aircraft within the fiscal year in which they are scheduled. No aircraft may extend beyond the 72 month time period. Decisions to change the induction schedule for an aircraft are normally based on the progress of the workload currently on station. Workload scheduling is based on published planned flowdays for each major package involved (i.e. Mini PDM, PDM, PDM/998). However, actual times vary. Table 4.1 shows the current flowdays LJP advertises for several packages along with some actual results. Appendix A gives a complete flowday discussion.

Table 4.1 Package Flowdays

PACKAGE	ADVERTISED FLOWDAYS	FY 98 FLOWDAY AVERAGE	FY 99 FLOWDAY AVERAGE
Inspect PDM	**103 Days**	**159 Days**	**150 Days**
Mini PDM	**200 Days**	**226 Days**	**247 Days**
PDM	**218 Days**	**283 Days**	**273 Days**
PDM/998	**278 Days**	**320 Days**	**324 Days**
PDM/998/MODs	**278 Days**	**371 Days**	**356 Days**

Current methods WR-ALC uses to determine the number of facilities needed to meet facility requirements are provided by Mr. Audley Swafford, Chief of the C-141 Production Division Engineering Team. The method involves a simple formula which depends only on the number of aircraft produced in a given time period and their flowdays at the facility of interest. The formula method is analyzed under two different scenarios the average flowdays ("Avg Flow"), and one standard deviation above the average actual flowdays ("85% Flow"). These approaches are called Scenarios 3 and 4 respectively.

The current methodology for induction scheduling is fluid at best. Currently, no firm schedules exist for fiscal years FY02-FY05. The 2001 fiscal year induction schedule remains in a constant state of flux. Consequently, mock induction schedules are developed for FY01- FY05. The schedules are developed using a deterministic integer linear programming model based on “Avg Flow” and “85% Flow,” both without releasing any facilities. These approaches are called Scenarios 1 and 2 respectively.

Deterministic Approach

The deterministic approaches are based on an integer linear program (ILP). The program simultaneously solves for the induction and release schedules. The objective function and constraint system formulations follow the formulation found in Section 4.2. The decision variables are the number of inductions in any given month by package (e.g. Mini PDM, PDM, PDM/998), and the number of facility releases in any given month by facility type (e.g. Ramp, Hangar, Functional Test). These decision variables are constrained to be nonnegative integers.

Integer programming problems, like the traveling salesman problem, are known to be in a non-polynomial class of problems, often referred to as NP-hard or NP-complete problems (Kikrpatrick, Gelatt, and Vecchi 1983) (Viana and Sousa, 2000). Practically, this means that trying to solve large integer problems may require more time or computing power than what is available. In this case, the study utilizes a divide and conquer approach. First, the model solves the problem one or two years at a time. If this fails to give a solution in a reasonable amount of time, the model solves for schedule and hangar facility releases. Then the model solves for the ramp and functional facility releases while holding the hangar releases constant.   The WR-ALC leadership considers hangar space as one of its most scarce and valuable resources.

Under the ILP the number of flowdays and the amount of resources consumed by an aircraft are considered fixed and known. Consequently, the impact of the flowday variance between aircraft of a given package does not affect the outcome of the model. The model runs against two sets of flowdays, "Avg Flow" and "85% Flow" for each work package. These approaches are called Scenarios 5 and 6 respectively.

Stochastic Approach

The stochastic approach is based on a computer simulation model of the flow of aircraft through the C-141 Production Division. A "greedy" heuristic determines the induction and release schedule. The model also writes the information necessary to determine the value of the objective functions and constraints to data files. These values are determined outside of the simulation model using Microsoft Excel. Each entity in the model represents an aircraft. The key parameters of flowdays and utilization are also output to a file for future comparisons.

Below is the "greedy" heuristic used to solve the stochastic scheduling problem:

A. Begin the simulation and release all entities representing aircraft inductions at the start of each fiscal year.

B. As soon as the facility capacity becomes available, release the aircraft into WR-ALC and begin work. (Note: the induction schedule for any year is the average time between when an entity is released for induction and its actual induction time. For example, a entity with an average wait time of 90 days for induction would be schedule for induction three months after the start of the fiscal year in which it was planned to be inducted.)

C. Compute the facilities utilization for each month and divide each fiscal year into quarters.

D. Compute the maximum utilization during each quarter.

E. Schedule the reduction in facilities resources, at the start of a quarter, based on when at least one whole unit of resource goes idle and remains idle for the remainder of the fiscal year.

F. Re-run the simulation model and check to see that no aircraft suffers an average induction delay of more than 365 days.

G. Repeat step E-F for the entire fiscal year.

H. Repeat step A-G for fiscal years FY01-FY05.

I. Save the results of the final simulation run for future analysis

The study follows this heuristic for two scenarios, Scenarios 7 and 8. The scenarios are based on computing Step C utilizing only 85% of excess facility availability, and then utilizing 100% of excess facility availability. The sequence in which the aircraft enter the depot is based on the induction schedule from the traditional approaches and deterministic approaches that has the shortest maximum average induction delay from the initial run of the model before facility releases.

<u>Cost Function Computations</u>

The study computes the cost function as the weighted average of the total number of months a facility is released between 1 October 2000 and 30 September 2005. The weighting factors are 10% for ramp space, 60% for hangar space, and 30% for functional test space. WR-ALC leadership considers hangar space as one of its most critical constrained resources.

The amount of facility capacity released is computed by first computing the maximum monthly facility capacity available without releasing any facilities: 600 for ramp space (10 ramp spots * 60 months), 540 for hangar space, and 240 for functional test space. The next step is to compute the total monthly facility capacity under a given release scenario. The difference between these two quantities becomes the amount of monthly excess facility capacity released back to the depot.

Study Scenario Summary

In all, eight scenarios are considered. The first two represent baseline comparisons of the "Avg Flow" and "85% Flow" without facility reductions. Then two runs are made at the "Avg Flow" and "85% Flow" for the traditional and deterministic approaches. Finally, two runs of the stochastic approach are made 85% excess facility availability and 100% excess facility availability. Table 4.2 contains a summary of the scenarios by scenario number.

TABLE 4.2 Scenario Summaries

APPROACH	SCENARIO	INDUCTIONS	RESOURCES	FLOWDAYS	OTHER
Baseline	**1**	**Mock Schedule**	**No Release**	**Fixed At Average**	
	2	**Mock Schedule**	**No Release**	**Fixed At Avg + Std Dev**	
Traditional	**3**	**Mock Schedule**	**Traditional Formula**	**Fixed At Average**	
	4	**Mock Schedule**	**Traditional Formula**	**Fixed At Avg + Std Dev**	
Deterministic	**5**	**Determined By Decision Variables**	**Determined By Decision Variables**	**Fixed At Average**	
	6	**Determined By Decision Variables**	**Determined By Decision Variables**	**Fixed At Avg + Std Dev**	
Stochastic	**7**	**Determined By Induction Delay**	**Determined By Greedy Heuristic**	**Determined By Simulation Model**	**85% Of Facilities Available To Release**
	8	**Determined By Induction Delay**	**Determined By Greedy Heuristic**	**Determined By Simulation Model**	**100% Of Facilities Available To Release**

Number Of Simulation Replications

Scenarios 1 – 6 are replicated 10 times across the simulation model. The half-width of the 95% confidence interval on the means are calculated for flowdays by package and utilization by facility type. The final number of replications is the maximum number of replications needed to obtain a half-width of 5 flowdays and 0.05 utilization points. Formula 4.1, found in Kelton, Sadowski, and Sadowski (1998 pp 182-187), is used to determine the final number of replications. The hangar utilization parameter for Scenario 3 drives the number of replications to 107 per scenario for all 8 scenarios.

$$n=n_0 * h_0^2 / h^2 \qquad (4.1)$$

n	number of replications needed to achieve desired half-width
n_0	initial number of replication runs
h	desired confidence interval half-width
h_0	initial confidence interval half-width

4.4 SYSTEM SPECIFICATIONS & MODEL FORMULATION (Steps 3 & 4)

Overall Data Availability

The most detailed level of data available for actual flowdays is found at Level 2, Dock Information. The four dock categories are Pre-Dock, Dock, Post-Dock, and Functional Test. In the simulation model the word "hangar" replaces "dock." Lower level modeling of the system would increase the number of activities that need measuring, as well as increase the amount of assumptions that need to be made to convert plan flowdays into actual flowdays.

The C-141 SPO maintains a list of critical data elements. These elements are excluded from the written portion of this study. Item #1 on the "C-141 Critical

Information List" restricts release of, "The number of aircraft that are in depot maintenance at Robins AFB." To protect this information, no induction schedules are displayed in the written portion of this report. Nor does the written report provide any specific statements or numbers of aircraft on station.

Manpower Assumptions

The actual manpower needed to do the work is not considered in this study. Actual manpower data at an operations level is not available do to union concerns. Manpower is frequently shifted from aircraft to aircraft and overtime is freely worked to keep aircraft on schedule. The error added and additional model complexity needed to emulate the flow of manpower at WR-ALC is not warranted for this study.

Flowday Estimates

Deterministic resource consumption times are developed using the flowday analysis discussed in Appendix A. Average flowdays for each dock and the average flowdays plus one standard deviation are used to create the resource consumption requirements.

Traditional Approach

The Chief of the C-141 Industrial Engineering Team, Mr. Audley Swafford, provides the following formula traditionally used to determine the number of facilities needed in any given year:

$$Fac_i = \sum_{j=1}^{t}(AoR_j * FlowD_{ij} \;/ \; CalD) \qquad (4.2)$$

Fac_i	number of facilities of type i required
AoR_j	number of aircraft (work packages) on the ramp of type j
$FlowD_{ij}$	number of flowdays required in facility i for work package j
CalD	number of calendar days in the year
i	type of facility 1=Ramp, 2=Hangar, 3=Functional Test
j	type of work package 1=Mini PDM, 2=PDM, 3=PDM/998; 1 to t

If the workflow does not vary significantly from year to year then formula 4.2 provides acceptable facility requirements. The formula has worked well in LJP for over 20 years. However, in the current drawdown environment the formula may not provide accurate enough information to meet study objectives. This formula depends on two key parameters that are often hard to precisely quantify, the number of aircraft on station and the flowdays requirements throughout a facility. Prior to this study, data was collected on flowdays through the facility but was not analyzed. The number of aircraft on station at any given time is another key formula input. However, LJP tracks no single metric for the number of aircraft on station. Nevertheless, when the workload does not vary significantly from year to year it is sufficient to use the annual induction schedules for each year. In essence LJP produces the same number of aircraft as are inducted each year.

Two important concepts need to be discussed. First, “carry-out” refers to the workload inducted in one fiscal year but the actual aircraft is produced in the following fiscal year. Likewise, “carry-in” refers to workload produced in the current fiscal year that was inducted during the previous fiscal year. To accurately project a facilities release schedule, the study must account for the carry-out and carry-in from year to year.

To accomplish this, the annual carry-out and carry-in numbers are adjusted such that the number of facilities needed in any fiscal year does not exceed the existing resources.

No formula for determining the induction schedule for current operations is readily available. However, to run the scenario through the simulation model a mock schedule is created using the following deterministic model:

$$\text{Max } \sum_{k=1}^{r} (Fac_{2k} / Avail_{2k}) \quad (4.3)$$

S.T.

$$Fac_{ik} <= Avail_{ik} \quad \forall\ i,k$$

$$Fac_{ik} = \sum_{j=1}^{3} \sum_{x=0}^{(s-1)} REQ_{ij(s-x)} * Induct_{j(k-x)} \quad \forall\ i,k$$

$$\sum_{k=f}^{(f+12)} Induct_{jk} = Work_{jf} \quad \forall\ j,f$$

$$Induct_{jk} >= 0 \text{ and integer} \quad \forall\ j,k$$

Fac_{ik}	number of facilities of type i needed in period k
$Avail_{ik}$	number of facilities of type i available in period k
$Induct_{jk}$	number of work packages inducted of type j available in period k
$Work_{jf}$	number of work packages required of type j required in fiscal year f, where f is the value of k at the start of each fiscal year.
REQ_{ijm}	number of units of facility i consumed by work package type j during workflow month m
i	type of facility 1=Ramp, 2=Hangar, 3=Functional Test
j	type of work package 1=Mini PDM, 2=PDM, 3=PDM/998
k	calendar month 1 to r
m	workflow month 1 to s

The model maximizes the hangar utilization by adjusting the induction schedule. REQ_{ijm} is constructed for both the "Avg Flow" and "85% Flow." Microsoft Excel Solver module is used to solve this deterministic model. AoR_j (formula 4.2) and REQ_{ijm} are adjusted to account for the facility requirements of the aircraft currently on station.

Deterministic Approach

Similar to formula 4.3, the deterministic approach develops an integer linear program to simultaneously solve for the induction and release schedules. The objective function and constraints in formula 4.3 are modified to account for the release of facilities. A coefficient of 100 is added to the facilities release schedule to make the value of releasing one facility much greater than a slight increase in facilities utilization. This represents a weighted average of to simultaneous objectives.

$$\text{Max } \sum_{i=1}^{3}\sum_{k=1}^{r} [(Fac_{ik} / Avail_{ik}) + 100 * Real_{ik}] \qquad (4.4)$$

S.T.

$$Fac_{ik} + \sum_{x=0}^{(k-1)} Real_{i(k-x)} <= Avail_{ik} \qquad \forall\ i,k$$

$$Fac_{ik} = \sum_{j=1}^{3}\sum_{x=0}^{(s-1)} REQ_{ij(s-x)} * Induct_{j(k-x)} \qquad \forall\ i,k$$

$$\Sigma_{k=f}^{(f+12)} Induct_{jk} = Work_{jf} \qquad \forall\ j,f$$

$$Real_{ik}, Induct_{jk} >= 0 \text{ and integer} \qquad \forall\ j,k$$

Fac_{ik}	number of facilities of type i needed in period k
$Avail_{ik}$	number of facilities of type i available in period k
$Real_{ik}$	number of facilities of type i released in period k
$Induct_{jk}$	number of work packages inducted type j available in period k
$Work_{jf}$	number of work packages required of type j required in fiscal year f, where f is the value of k at the start of each fiscal year.
REQ_{ijm}	number of units of facility i consumed by work package type j during workflow month m
i	type of facility 1=Ramp, 2=Hangar, 3=Functional Test
j	type of work package 1=Mini PDM, 2=PDM, 3=PDM/998
k	calendar month 1 to r
m	workflow month 1 to s

Microsoft Excel Solver module is used to solve this deterministic model. REQ_{ijm} is reduced to account for the facility requirements of the aircraft currently on station.

Stochastic Approach

The simulation model the study uses in all approaches breaks the workflow into its four docks processes: Pre-Hangar, Hangar, Post-Hangar, and Functional Test. In addition to these dock processes, logic was added to simulate aircraft inductions into the depot with any possible induction delay, and initializing the model for aircraft currently on station. The Student Version of Arena 3.01, is used to simulate the C-141 depot process. Microsoft Excel pivot tables are used to compute the maximum average induction delays for each aircraft inducted, and the monthly facility utilization for each facility type. Appendix B contains the Arena model for the simulation code. Figure 4.1 shows the overall logic for entities processing through the simulation models. The simulation collects data for each entity when it completes processing. The simulation also collects data on monthly depot workload. Table 4.3 contains the essential data elements collected during each replication.

TABLE 4.3 Data Elements Collected During Simulation

ENTITY DATA ELEMENTS COLLECTED (PER ENTITY)	MODEL STATE DATA COLLECTED (MONTHLY)
Production Unit Number (assigned at entry)	Replication Number
Work Package	Current Simulation Time
Time Inducted Into WR-ALC	Current Number of Aircraft At WR-ALC
Current Simulation Time	Number of Aircraft In Induction Queue
Induction Delay	Number of Aircraft In Ramp Queue
Flowdays	Number of Aircraft In Hangar Queue
Pre-Hangar Queue Time	Number of Aircraft In Functional Test Queue
Hangar Queue Time	Number of Aircraft On Ramp
Post-Hangar Queue Time	Number of Aircraft In Hangars
Functional Test Queue Time	Number of Aircraft In Functional Test
Replication Number	Maximum Number of Ramp Resources
	Maximum Number of Hangar Resources
	Maximum Number of Functional Test Resources

All simulation models use common random numbers (CRN) to assign processing times. This ensures the only flowday variance between paired replications in the different scenarios is a result of waiting for different resources, and not due to the randomly assigned processing times themselves. The intent of the study is to determine if the different induction and release schedules impact the flow, not to study the variation in actual processing times.

All simulation models select flowday parameters and distributions using Arena's Input Analyzer. The study uses raw data from the flowday analysis discussed in Appendix A in developing theoretical processing time distributions in each dock. The distributions with the smallest mean squared error and a p-value of greater than 0.15 are used. Where the p-values did not exceed the 0.15 threshold, the simulation used a triangular distribution centered at the planned processing time. The maximum and minimum of the triangular distributions are adjusted to yield averages and spreads consistent with the historic flowdays found in Appendix A.

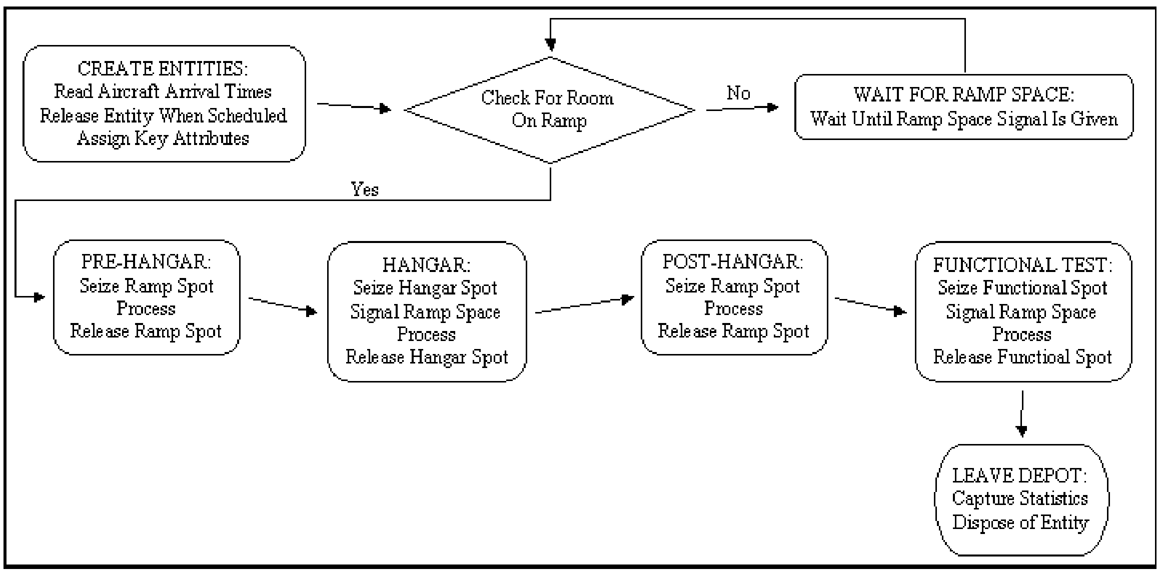

FIGURE 4.1 Simulation Process Flow Diagram

Scenarios 7 and 8 add special coding to the model to analyze Scenarios 1-6. This coding releases all aircraft inductions for each fiscal year at the beginning of the year. This allows for the implementation of the greedy algorithm that determines the induction schedule based on the average aircraft induction delay. This coding is also included in Appendix B with the Arena code files.

4.5 VERIFICATION & VALIDATION (Step 5)

Verification and validation are for the simulation models only. This is achieved by first running the model with fixed processing times for a limited number of entities to ensure the entities process through the model in the correct order and the output files collect the correct data. The models are then validated by comparing the average total flowdays with the historical averages and variations discussed in Appendix A. Also, the actual processing times for each individual entity are tracked to ensure the CRN perform as desired.

4.6 ANALYSIS & COMPARISONS (Step 6)

<u>Traditional Approach Scenarios 3 and 4</u>

The formula approach provides a quick and relatively easy means to compute a reduction schedule. The total time for the application of this approach takes less than half an hour after the mock schedules are generated. Generating the mock schedule using the ILP requires two weekends to run completely. As could be expected, the "85% Flow" resource consumption values require the retention of resources well beyond the release schedule generated by the "Avg Flow." The total resources that are released for Scenarios 3 and 4 are found in Table 4.5. The weighted average values are 132.3 and 56.1 for Scenarios 3 and 4 respectively.

One drawback to using the formula approach is that it does not specify monthly or daily facility requirements. The formula method only provides the average number of facilities required during the year. Analysts must develop a release schedule during the year. For this study the facilities are released halfway through the fiscal year to maintain the average availability the formula computes.

Deriving a release schedule using the formula does not require a detailed induction schedule. The formula only requires the number of aircraft inducted each year to generate a release schedule. However, the simulation model requires a mock induction schedule to run.

The difference in the average flowdays the simulation runs predict is 17.59 days across all the packages. This represents the largest average variance for scenarios using the same basic approach, 1.96 days for deterministic approaches, and 4.43 days for stochastic approaches.

Deterministic Approach Scenarios 5 and 6

The ILP the deterministic approach uses to simultaneously generate an induction and release does not find an optimal solution in an acceptable amount of time (ran 5 days without finishing). Consequently, the divided-and-conquer methodology is employed. With over 360 decision variables, all restricted to be nonnegative integers, it is unlikely that Excel could solve such a large NP-hard problem in a reasonable amount of time. The problem is solved recursively solved, starting in FY00 and proceeding to FY05 solving for the induction schedule and hangar release first. Then the hangar decision release variables are replaced by the functional test variables while the hangar release variables are held constant. This procedure continues for the ramp release variables.

Limiting the decision variables to 48 per run allows Excel to find a solution in five days total on a Pentium III 533Mhz PC.

The simulation runs using the deterministic schedules provide weighted averages for the facility release of 94.8 and 141.8 for Scenarios 5 and 6 respectively. The average predicted flowdays remains relatively close, 1.96 days. The slight increase in flowdays from Scenario 5 to Scenario 6 is of less concern than the 46.6 months of capacity difference between the computed release schedules.

Stochastic Approach Scenarios 7 and 8

The simulation model used to evaluate Scenarios 3 to 6 is modified to allow for direct construction of the induction and release schedules. The heuristic used to develop the schedules took less than an hour per scenario to finish. The induction schedule generated by Scenario 5 provided the lowest initial average induction delays and is used to run Scenarios 7 and 8.

Through direct manipulation of the release schedule, the study achieves the highest composite release capacity. Likewise, as an overall technique, the direct manipulation provides the best average composite value (see Table 4.5). Furthermore, the average flowday impact between Scenarios 7 and 8 is less than 5 days.

Paired Comparisons

The study uses the Arena Output Analyzer to conduct paired-t comparison test for the computed flowdays and the facilities utilization. Comparisons, at the 95% confidence level, are conducted for the 28 combinations of the scenarios. Tables 4.7 to 4.9 contain the results of these comparisons of the work package flowdays. Likewise, Tables 4.11 to 4.13 contain the results for facility utilization. The null hypothesis tested is the equality of the means. The paired-t comparison option in the Arena Output Analyzer is used to analyze the key parameters of flowdays and facilities utilization.

The differences in the means appear to be significant in almost all cases. However, from a flowday perspective, the magnitude of the differences, 26 days for Mini PDM, 24 days for PDM, 5 days for PDM/998, are relatively insignificant when compared to overall flow, 12% of Mini PDM, 9% for PDM, and 1% for PDM/998. However, for the facilities utilization there is no significant difference between Scenarios 5, 7, and 8. These scenarios all use the same induction sequence to generate their results suggesting that the sequence in which work packages enter the depot significantly impacts the optimal conditions. Initializing the heuristic with the schedule that provides the lowest maximum average induction delay also gives the heuristic the most flexibility in extending induction dates.

Average Facility Utilization

Arena computes the facility utilization as displayed in Table 4.10. The utilization is also computed from data output by the model. The facility utilization shown in

Table 4.4 is consistent with other WR-ALC analysis. This utilization is derived by computing the ratio of the number of entities in a resource divided by the maximum number of resources available. Under this type of utilization computation the center goal is 85% utilization. Across the board the hangars show the highest utilization rates.

Average Aircraft On Station

An average aircraft on station chart is developed to show how the different categories of scenarios, traditional, deterministic, and stochastic, balance the workload in the C-141 Production Division. WR-ALC experience shows that a level number of aircraft on station tends to balance the workload on the workforce and support functions. Since the C-141 SPO considers the number of C-141 on station a critical data element, no quantities are provided. The charts are provided to show the smoothness of the curves. The stochastic approach yields the smoothest lines while the formula approach provides erratic curves (see Figures 4.5 to 4.7).

Trade-Off Considerations

Three trade-offs are considered: speed, accuracy, and level of detail. Speed is the simplest measure to evaluate. Only the ILP of the deterministic approach gives great concerns over speed. The five days of dedicated computing time to provide an answer is not acceptable. Accuracy is judged by the additional flowdays the induction and release schedules cause. As a technique, the formula approach gives the greatest concern with an average of 20 additional flowdays. Level of detail is evaluated by the ability to provide a monthly induction and release schedule. Only the formula method does not deliver monthly schedules.

Scenarios 4, 6, and 7 all add additional restraints to the basic approaches, longer resources consumption requirements, or fewer facilities available for release. Naturally, this drove less aggressive resource release schedules, and provides shorter in-process delay times, less than 12% (20 flowday average) when compared to Scenarios 3, 5, and 8. However, the additional in-process delay appears acceptable when compared to the potential 50.1 months of composite facility capacity gains between the scenario with the best flowday performance (#6) and the greatest composite release score (#8).

Simulation Summary Results

The following tables show the results of the simulation runs of the different combinations of induction and facility release schedules. Figures 4.2 through 4.4 show the computed release schedules for ramp, hangar, and functional test facilities respectively. As mentioned earlier, no induction schedules are provided. As should be expected, scenarios employing the 85% flow released the facilities slower than schedules based on the average flow.

TABLE 4.4 Average Facility Utilization

			Traditional		Deterministic		Stochastic	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Ramp	29.34%	27.74%	71.69%	42.88%	55.04%	42.61%	58.48%	56.00%
Hangar	60.25%	60.13%	73.49%	63.90%	83.11%	73.30%	73.75%	78.76%
Test	40.36%	39.33%	67.35%	51.33%	46.22%	43.53%	56.46%	62.12%

TABLE 4.5 Equivalent Number of Resource Months Released

			Traditional		Deterministic		Stochastic	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Ramp	0	0	360	192	286	204	297	288
Hangar	0	0	110	32	170	113	122	153
Test	0	0	101	59	36	22	63	81
Composite	0	0	132.3	56.1	141.4	94.8	121.8	144.9

TABLE 4.6 Arena Predicted Average Flowdays By Package

			Traditional		Deterministic		Stochastic	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Mini	219	219	248	222	223	219	232	244
PDM	269	270	294	274	272	270	275	279
998	367	367	376	369	369	368	370	373

TABLE 4.7 Paired-t Comparisons: Mini PDM Flowdays (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	YES						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	YES	YES	NO	NO	NO		
7	NO	NO	NO	NO	NO	NO	
8	NO	NO	NO	NO	NO	NO	NO

TABLE 4.8 Paired-t Comparisons: PDM Flowdays (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	NO						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	NO	NO	NO	NO	NO		
7	NO	NO	NO	NO	NO	NO	
8	NO	NO	NO	NO	NO	NO	NO

TABLE 4.9 Paired-t Comparisons: PDM/998 Flowdays (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	NO						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	NO	NO	NO	NO	NO		
7	NO	NO	NO	YES	YES	NO	
8	NO	NO	NO	NO	NO	NO	NO

TABLE 4.10 Arena Predicted Utilization By Facility

			Traditional		Deterministic		Stochastic	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Ramp	3.20	3.08	2.72	3.04	2.81	2.97	2.78	2.78
Hangar	5.24	5.18	4.57	5.1	4.71	4.99	4.66	4.67
Test	1.61	1.59	1.41	1.57	1.45	1.54	1.44	1.44

TABLE 4.11 Paired-t Comparisons: Ramp Utilization (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	NO						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	NO	NO	NO	NO	NO		
7	NO	NO	NO	NO	YES	NO	
8	NO	NO	NO	NO	YES	NO	YES

TABLE 4.12 Paired-t Comparisons: Hangar Utilization (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	NO						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	NO	NO	NO	NO	NO		
7	NO	NO	NO	NO	YES	NO	
8	NO	NO	NO	NO	YES	NO	YES

TABLE 4.13 Paired-t Comparisons: Functional Test Utilization (Means Equal Yes or No)

Scenario	1	2	3	4	5	6	7
2	NO						
3	NO	NO					
4	NO	NO	NO				
5	NO	NO	NO	NO			
6	NO	NO	NO	NO	NO		
7	NO	NO	NO	NO	YES	NO	
8	NO	NO	NO	NO	YES	NO	YES

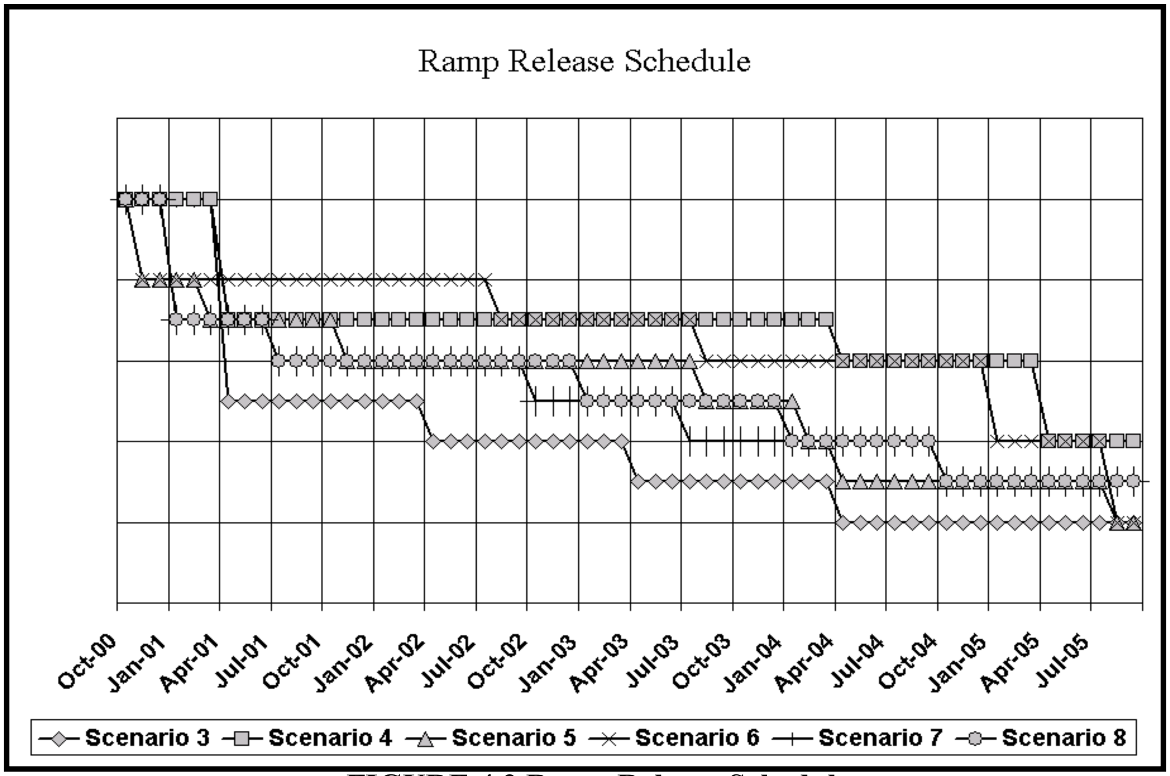

FIGURE 4.2 Ramp Release Schedule

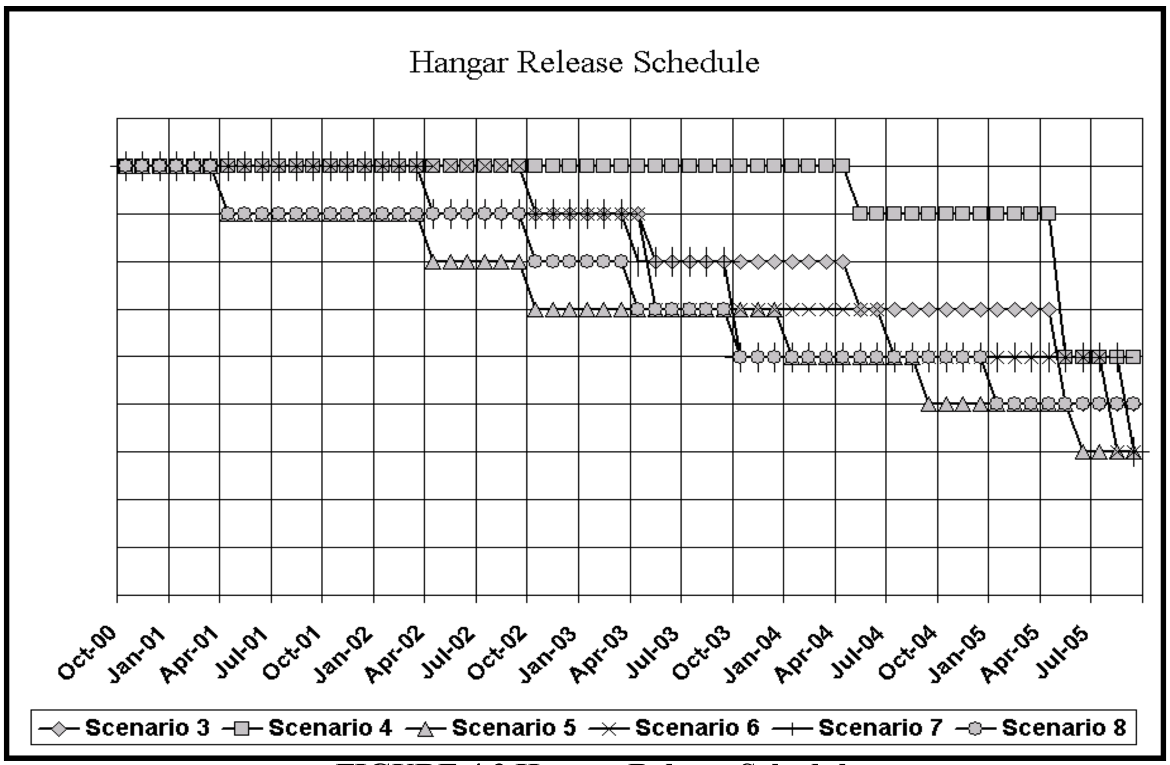

FIGURE 4.3 Hangar Release Schedule

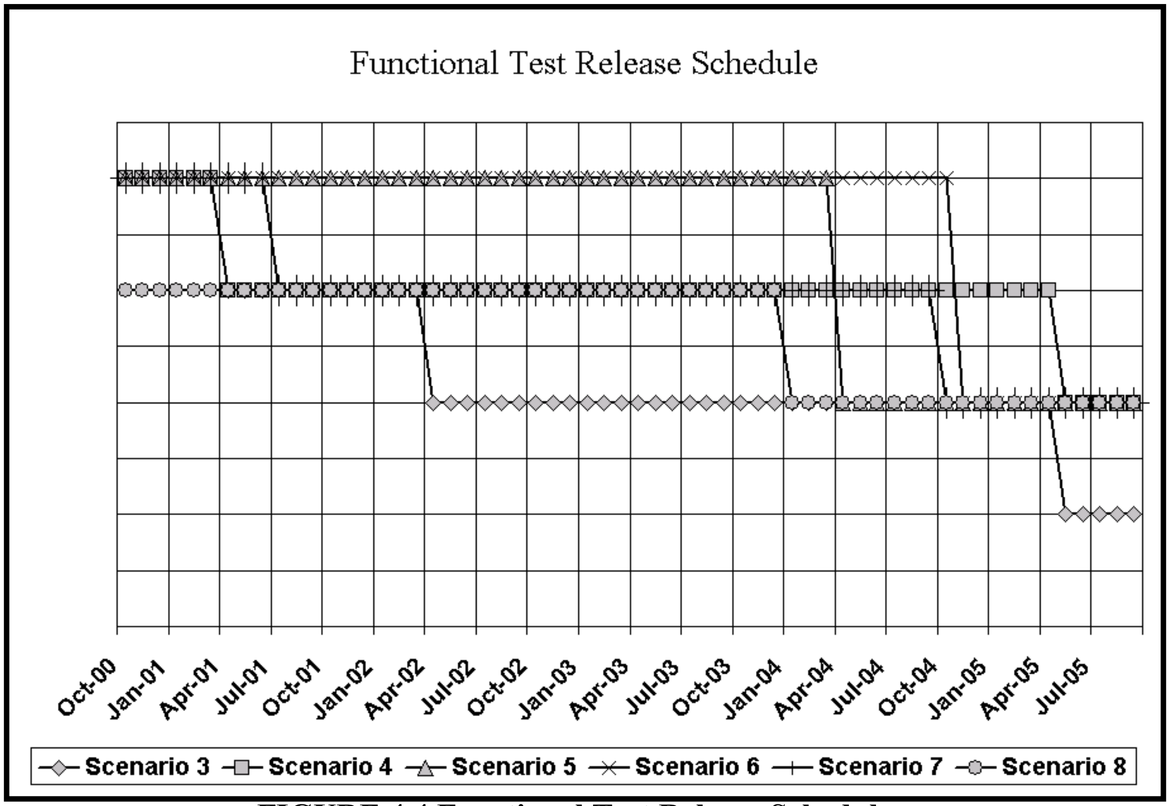

FIGURE 4.4 Functional Test Release Schedule

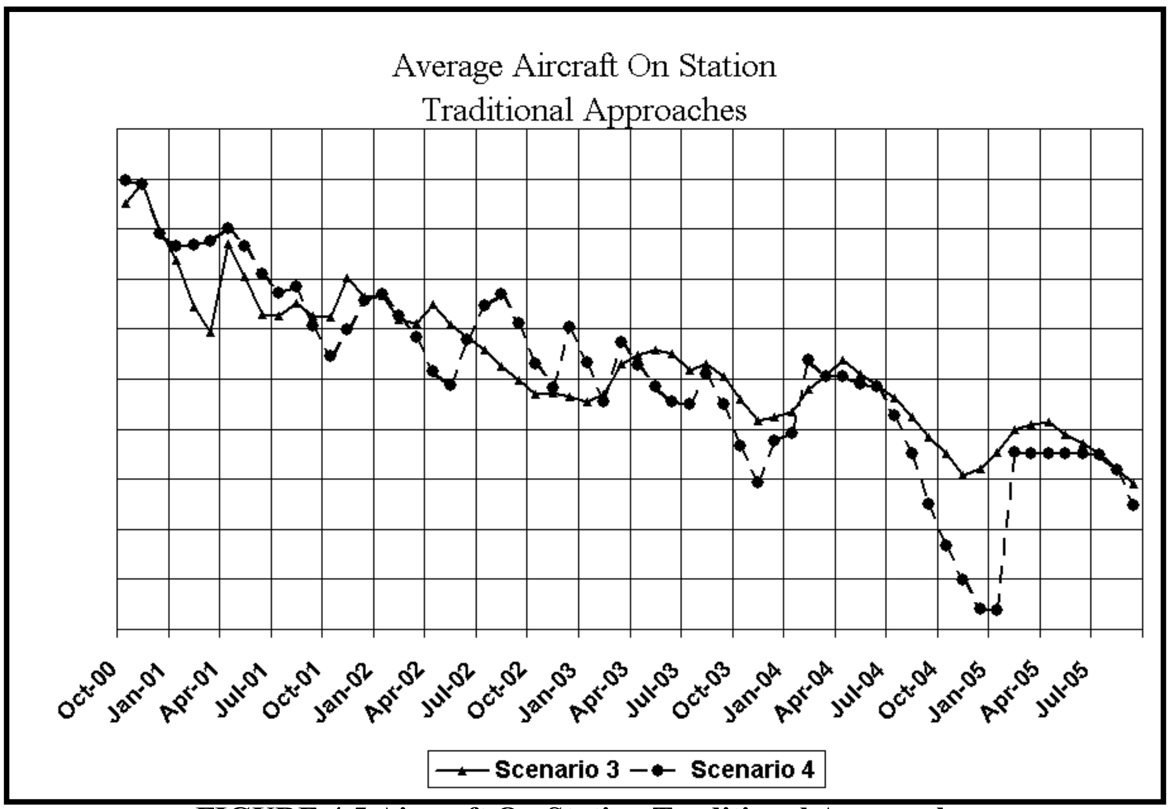

FIGURE 4.5 Aircraft On Station Traditional Approach

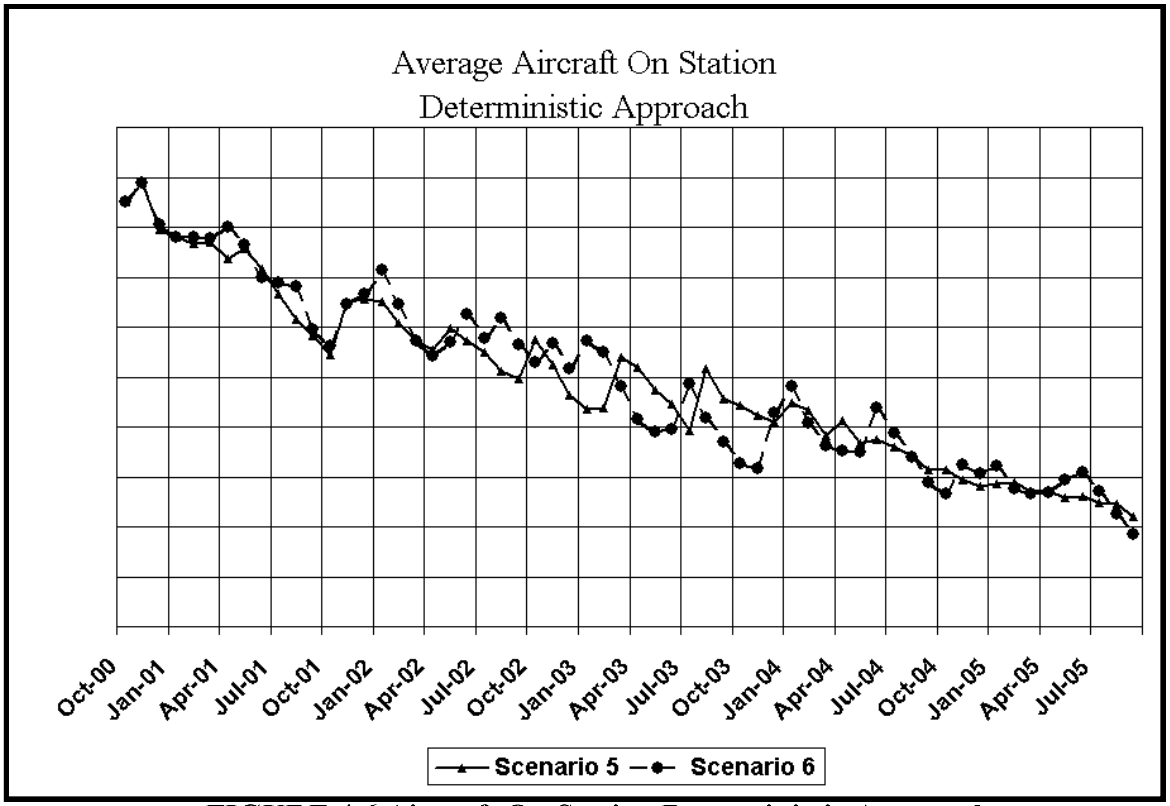

FIGURE 4.6 Aircraft On Station Deterministic Approach

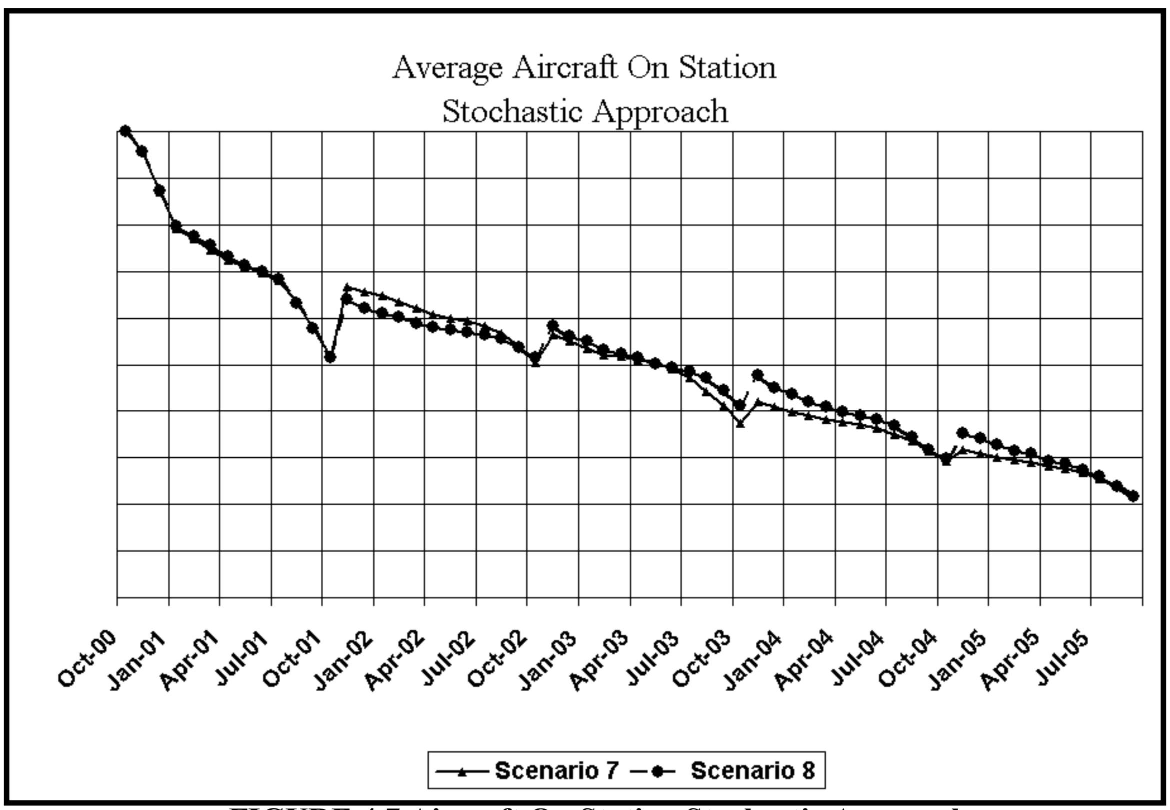

FIGURE 4.7 Aircraft On Station Stochastic Approach

4.7 RECOMMENDATIONS (Step 7)

As stated in the problem formulation, the study selects the scenario with the greatest value for the composite cost function as the best solution. Scenario 8, the stochastic heuristic optimization approach, which assumes 100% of the excess facilities are available for release, is selected as the best alternative. The stochastic approach also provides other signs of desirable performance. First, the induction schedule did not limit aircraft to arriving on the first of the month as in the deterministic approach. The procedure gives average induction delay in days. The delay is then converted into the induction date. Second, the stochastic approach provides the smoothest average aircraft on station curve. As stated earlier, WR-ALC experience shows that a level number of aircraft on station tends to level the workload in other areas such as production support shops and supply services. Finally, the overall speed of the algorithm helps the stochastic approach standout from the deterministic while the ability to simultaneously develop both the induction and release schedule enables the stochastic approach to standout from the traditional arithmetic approach. Table 4.14 is a summary of the release schedule for Scenario 8.

TABLE 4.14 Recommended Release Schedule

Resource	Release Quantity	Release Date
Ramp	3	1-Jan-01
Ramp	1	1-Jul-01
Ramp	1	1-Jan-03
Ramp	1	1-Jan-04
Hangar	1	1-Apr-01
Hangar	1	1-Oct-02
Hangar	1	1-Apr-03
Hangar	1	1-Oct-03
Hangar	1	1-Jan-04
Hangar	1	1-Oct-04
Functional Test	1	1-Oct-00
Functional Test	1	1-Jan-04

5.0 CONCLUSIONS

Analysts conduct optimization studies using many approaches including the arithmetic, deterministic, and stochastic approaches discussed here. The method that provides the "best solution," often depends on the nature of the system being studied and the trade-off characteristics. Trade-offs include study aspects such as, simplicity of application, modeling precision and realism, modeling versatility and flexibility, modeling speed, and economic considerations.

In this study of the C-141 depot maintenance process, the formula and deterministic approaches are both capable of generating feasible schedules. However, the variability of the process degrades the actual performance of the formula and deterministic schedules when the schedules are tested in a stochastic environment. The study confirms that optimizing the C-141 depot maintenance directly in a stochastic environment provides more desirable performance characteristics such as smoother aircraft on station curves, and quick computation speeds. The study recommends using the induction and release schedules the simulation heuristic approach generates which allow 100% availability of idle facilities for release back to WR-ALC (Scenario 8). The traditional methods for computing the induction schedules and facility requirements have worked well in the C-141 Production Division for over 20 years. However, in the current drawdown environment, these methods fail to account for the natural variability in the system thus degrading their performance under "real-world" conditions. Simulation analysis offers more desirable performance in the current C-141 production environment.

6.0 FUTURE ANALYSIS & APPLICATIONS

Ideally, the C-141 Production Division needs like a tool that can automatically conduct workload analysis and provide optimal induction schedules and facility requirements. Tools such as SimRunner provide one the answer. However, SimRunner is designed specifically to conduct design of experiments analysis in the PROMODEL simulation language, and does not necessarily optimize constrained resource schedules.

The simulation heuristic approach developed for this study performs better than the other approaches considered. However, it makes no promise of truly finding an optimal solution. The next logical step is to apply a true stochastic optimization technique to the induction and release scheduling problems.

A simulated annealing algorithm can be applied to the scheduling problem. The simulation can be used as a back box for the algorithm needed to evaluate the objective function. The neighborhood solution can be defined by randomly changing the induction work package sequence and the facility release schedule. Section 4.2, problem formulation, still applies when considering annealing algorithms. The "temperature" of the algorithm can be used to define the number of work package sequence swaps the algorithm makes and the number of facility releases it schedules at any given iteration. The stopping conditions can then include a fixed number of total simulation runs or a desired magnitude of change in the objective function. Park and Kim (1999) propose techniques for developing the other annealing parameters. Other approaches, such as genetic algorithms, also provide a rich collection of methods that are yet unexplored in the constrained resource scheduling domain.

BIBLIOGRAPHY

ACQ 201, "Intermediate Systems Acquisition Course (Class Notes)," *Defense Systems Management College,* September 1999, pp FM 1-13 to FM 1-14

Akbay, Kunter S. "Using Simulation Optimization to Find the Best Solution," *IIE Solution*, Vol 28, 5 May 1996, pp 24-29

Alexopoulos, Christos, Seila, Andrew F., "A Conservative Method For Selecting the Best Simulate System," *Operations Research Letters*, Vol 19, No. 3, September 1996, pp 143-150

Anderson, David R., Sweeny, Dennis J., Williams, Thomas A., *Statistics for Business and Economics Fifth Edition*, West Publishing Company, 1993

Anderson, David R., Sweeny, Dennis J., Williams, Thomas A., *An Introduction to Management Science Quantitative Approaches to Decision Making Seventh Edition*, West Publishing Company, 1994

Anonymous, "Depot Dueling," *Government Executive*, Vol 30, No. 6, January 1998, pp 6

Azadivar, Farhad, Tompknis, George, "Simulation Optimization With Qualitative Variables and Structural Model Changes: A Genetic Algorithm Approach," *European Journal of Operations Research*, Vol 113, 1999, pp 169-182

Gemmill, Douglas D., Edwards, Michelle L., "Improving Resource-Constrained Project Scheduling With Look-Ahead Techniques," *Project Management Journal,* Vol 30, No. 3, September 1999, pp 45-55

Gharbi, Ali, Pellerin, Robert, Villeneuve, "A New Constraint-Based Approach For Overhaul Project Scheduling With Work Place Constraints," *International Journal of Industrial Engineering,* Vol 6, No. 2, June 1999, pp 123-131

Glasserman, Paul, Yao, Davis D., "Some Guidelines and Guarantees for Common Random Numbers," Management Science, Vol 38, No. 6, June 1992, pp 884-907

Goldratt, Eliyahu M., Cox, Jeff, *The Goal Second Revised Edition*, North River Press, 1992

Haddock, Jorge, Mittenthal, John, "Simulation Optimization Using Simulated Annealing," *Computers & Industrial Engineering*, Vol 22, 1992, pp 387-395

Kelton, Davis W., Sadowski, Randall P., Sadowski, Deborah A., *Simulation With Arena*, WCB/McGraw-Hill, 1998

Khamooshi, Homayoun, “Dynamic Priority-Dynamic Programming Scheduling Method $(DP)^2SM$: a Dynamic Approach to Resource Constraint Project Scheduling,” *International Journal of Project Management*, Vol 17, No. 6, 1999, pp 383-391

Kirkpatrick, S., Gelatt Jr., C.D., Vecchi, M.P., “Optimization by Simulate Annealing,” *Science*, Vol 220, No. 4598, 13 May 1983, pp 671-680

Kleinman, Nathan L., Spall, James C., Naiman, Daniel Q., “Simulation-Based Optimization With Stochastic Approximations Using Common Numbers,” *Management Science*, Vol 45, No. 11, November 1999, pp 1570-1578

Kolonko, M., “Some New Results on Simulated Annealing Applied to the Job Shop Scheduling Problem,” *European Journal of Operations Research*, Vol 113, 1999, pp 123-136

Park, Moon-Won, Kim, Yeong-Dae, “A Systematic Procedure for Setting Parameters in Simulated Annealing Algorithms,” *Computers & Operations Research*, Vol 25, No. 3, 1998, pp 207-217

Phillips, Edward H., “Pentagon Eyes More Repair Depot Cuts,” *Aviation Week & Space Technology*, Vol 144, No. 17, April 1996, pp 52-54

Reynolds, A. P., McKeown, G. P., “Scheduling a Manufacturing Plant Using Simulated Annealing and Simulation,” *Computers & Industrial Engineering*, Vol 37, 1999, pp 63-67

Sankran, Jayaram K., Bricker, Dennis L., Juang, Shuw-Hwey, “A Strong Factional Cutting-Plane Algorithm For Resource-Constrained Project Scheduling,” *International Journal of Industrial Engineering*, Vol 6, No.2, 1999, pp 99-111

Sawaya, William J., Jr., Giauque, Willian C., *Production and Operations Management*, Harcourt Brace Jovanovich, Publishers, 1986

Viana, Ana, Sousa, Jorge Pinho de, “Using Metaheuristics in Multiobjective Resource Constrained Project Scheduling,” *European Journal of Operations Research*, Vol 120, 2000, pp 359-374

APPENDIX
A

FLOWDAY
ANALYSIS

APPENDIX A

FLOWDAY ANALYSIS

Overview

Aircraft flowdays are one of the major metrics Warner Robins Air Logistic Center (WR-ALC), C-141 Systems Program Office (SPO), and C-141 Production Division (LJP) track. Flowdays are essentially the number of calendar days an aircraft requires for overhaul. WR-ALC tracks three types of flowdays for Programmed Depot Maintenance (PDM) aircraft:

- Initial — Flowdays advertised to the customer based on historical data and planned workload.
- Planned — Flowdays negotiated with the customer after the aircraft is inducted into the depot. Additional flowdays are based on the amount of work an aircraft needs above the basic work package.
- Actual — Actual number of calendar days used to produce an aircraft.

Flowday variance is another key metric tracked at the center. It is the difference between the planned and actual flowdays. To center leadership, flowday variance is a measure of the production division's ability to predict and control their workload, as well as their ability to keep their promise to the customer.

Currently, LJP will induct aircraft requiring three different work packages between October 2000 and September 2005. The term "induction" refers to bringing an aircraft to the depot to begin its overhaul. Listed below are the five major work packages currently underway for the C-141:

- PDM — Basic package of inspections, repairs, and time change component replacements or overhauls.
- Inspect PDM — Inspect aircraft and repair as necessary
- Mini PDM — Scaled down basic package for aircraft retiring within three years.
- PDM/998 — Basic package with replacement of fuselage station 998 (FS998) frames.

- PDM/998/MODs Basic package with FS998 replacement and "glass-cockpit" avionics upgrades.

The physical location of an aircraft describes its flow through the center. Three major locations describe the flow of aircraft: on the ramp, in a hangar, or in functional test. The actual flow is described as Pre-Dock, Dock, Post-Dock, and Functional Test in that order (the term dock is interchangeable with the term hangar). Flowdays through the different docks vary from package to package.

Annually the center holds a Material Requirement Review Board (MRRB) where the customers and various SPOs negotiate flowdays, as well as the cost of each PDM work package. Preparation for these meetings takes place in December of each year. The actual meetings take place in the spring.

Study Objective

The objective of this study is twofold. First, establish new baseline initial flowday standards for the C-141 Mini PDM, PDM, and PDM/998 work packages. Second, establish new flowday standards for aircraft as they transition through each dock.

Problem Formulation

The traditional approach to setting flowday standards, as well and many other standards in the USAF, is to compute an average and standard deviation for the metric being studied. When the current flowday standards were set in 1997, the analysts had used the average and a standard deviation approach. When the standard is set one standard deviation from the average, 85% of the data will lie on the good side of the standard, assuming normality and no significant trend.

Data Gathering

Flowday data is gathered from both Mrs. Ann Ford's database of important aircraft dates, and the Programmed Depot Maintenance Scheduling System (PDMSS). The following data elements are collected form Mrs. Ford's database:

- Aircraft Tail Number
- Work Package
- Induction Date
- Functional Test Date
- Actual Output Date

The database lacks the information necessary to compute the flow of aircraft through the hangar. To complete the flow picture the dates the aircraft starts its major jobs, enters the hangar, and departs the hangar are colleted from PDMSS.

Data Analysis

Flowday history is collected for aircraft completed between October 1997 and September 2000. The data is tested for outliers by examining all data points whose values where more than two standard deviations outside the group average (another traditional and accepted USAF practice). Durbin-Watson Tests[1] are performed to test for serial correlation. No serial correlation is detected. Chi-Square[2] tests are performed to test for normality. Normality assumptions are not violated.

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1 Anderson, David R., Sweeny, Dennis J., Williams, Thomas A., *Statistics for Business and Economics Fifth Edition*, West Publishing Company, 1993, pp 633-638

2 Arena 3.01 Student Version Input Analyzer was used to perform Chi-Square Test

Results

Table A.1 contains the summary results for the "Avg Flow" (average flowdays) and the "85% Flow" (average flowdays plus one standard deviation). Figures A.1 and A.2 are graphic representations of the flowday computations.

TABLE A.1 Computed Flowdays By Dock

	MINI PDM		PDM		PDM/998	
	Avg Flow	85% Flow	Avg Flow	85% Flow	Avg Flow	85% Flow
Pre-Hangar	34	47	22	31	49	64
Hangar	112	134	155	181	205	231
Post-Hangar	34	46	54	84	68	100
Functional Test	34	44	36	51	46	59
Total	215	270	267	346	368	455

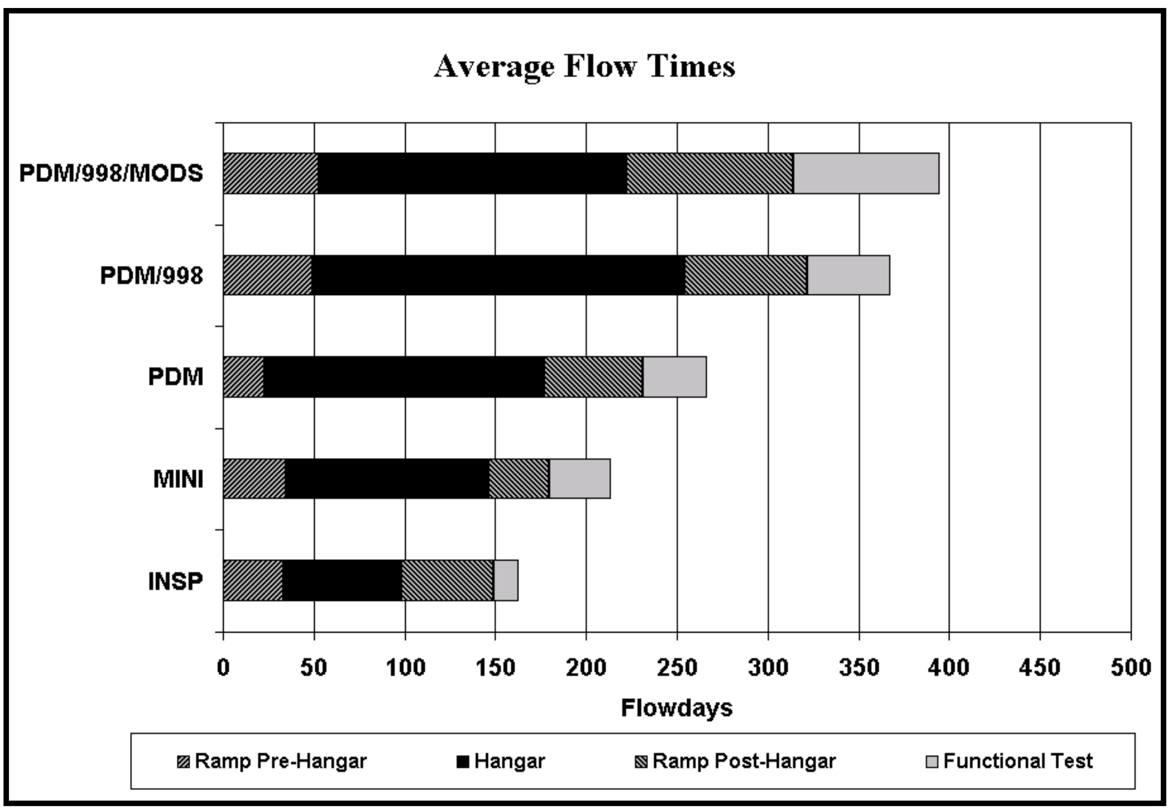


FIGURE A.1 "Avg Flow"

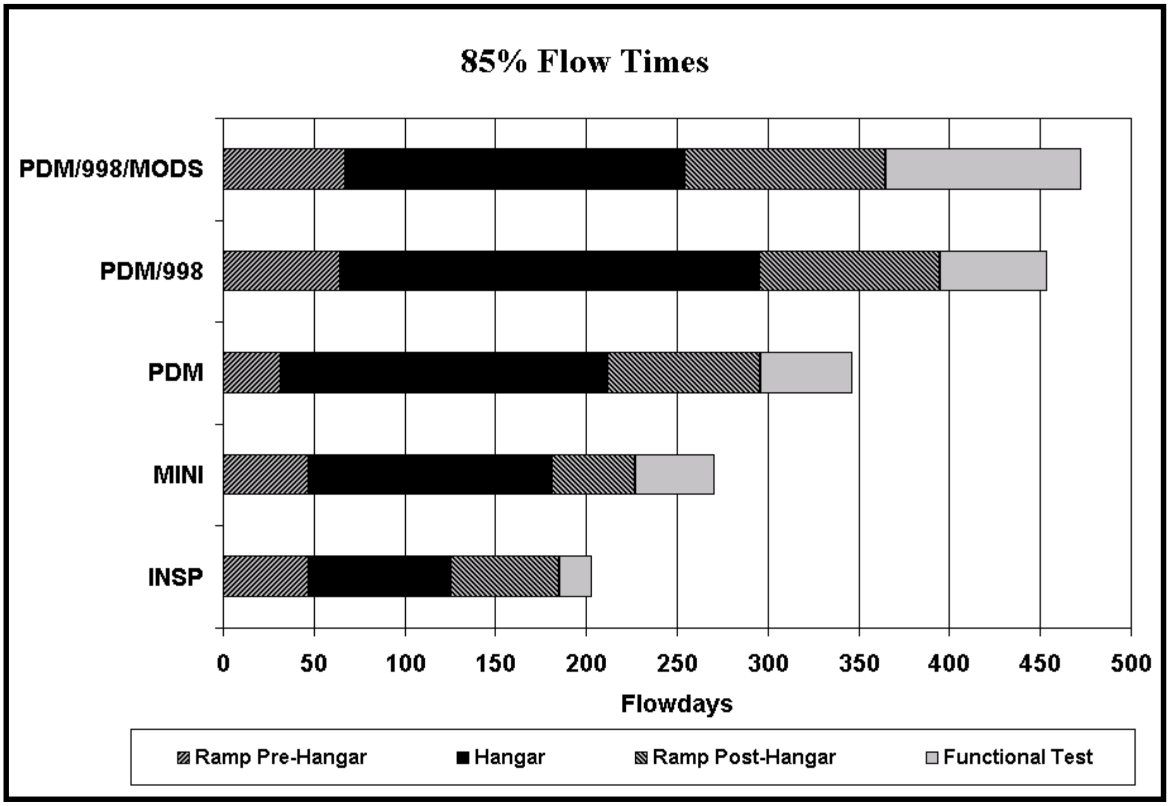


FIGURE A.2 "85% Flow"

<u>Conclusions</u>

The "Avg Flow" and "85% Flow" in Table A.1 will be used as the resource consumption rates and processing times for study in Chapter 4 of this document. The rates will also be used in the next MRRB to negotiate future flowday requirements.

APPENDIX
B

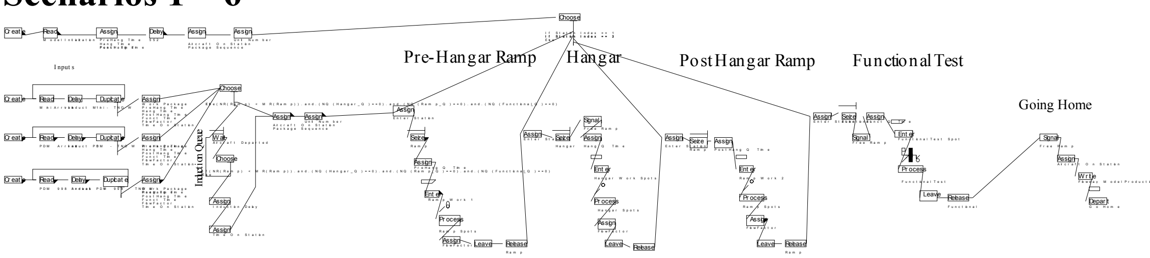
ARENA & SIMAN
SIMULATION
MODELS

Appendix B contains the basic simulation logic presented in its Arena model file, SIMAN experiment file, and SIMAN model files.

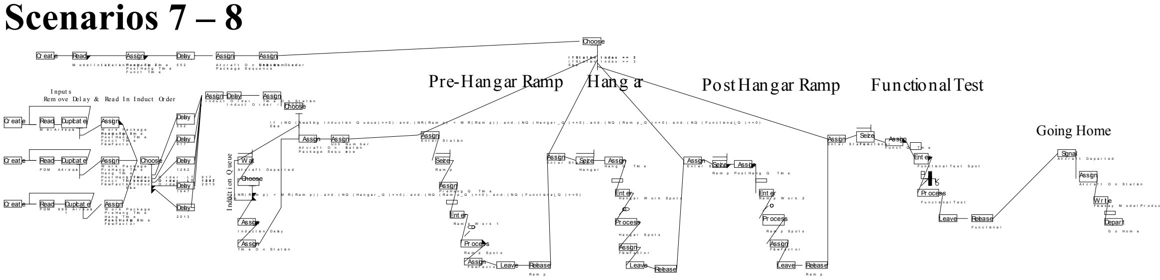
ARENA

BLOCK DIAGRAMS

Scenarios 1 – 6

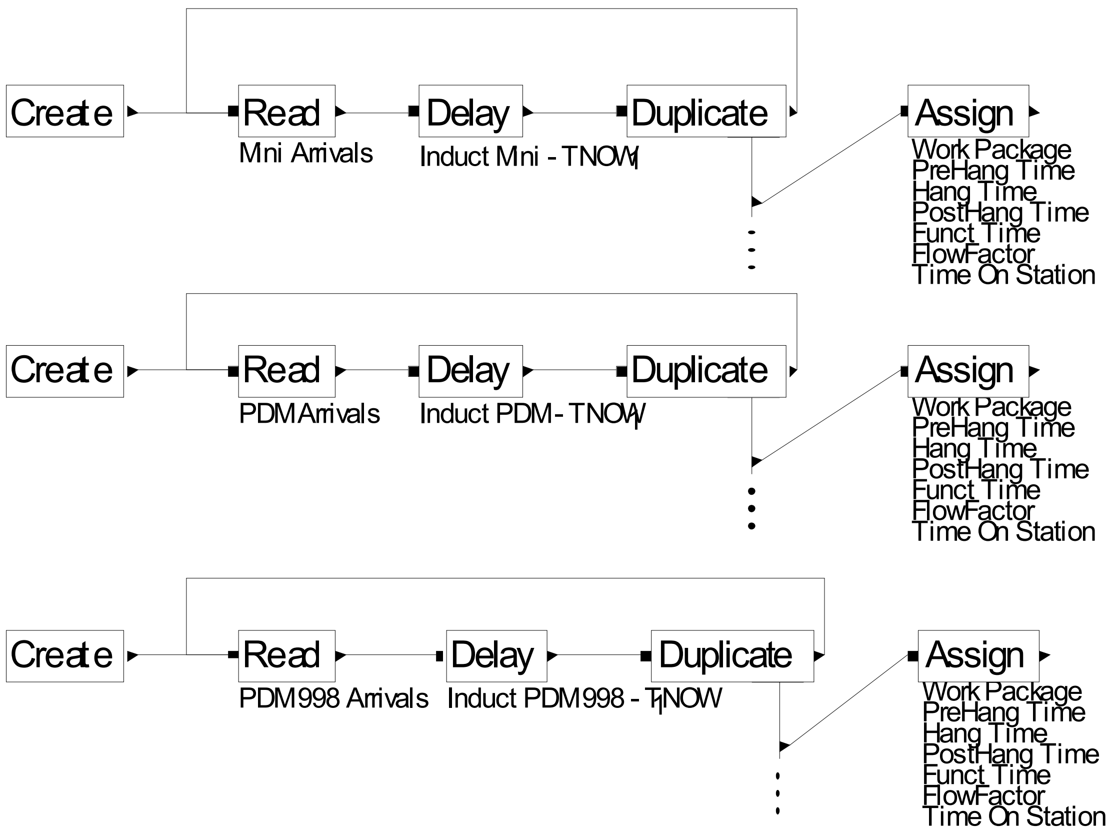


Scenarios 7 – 8



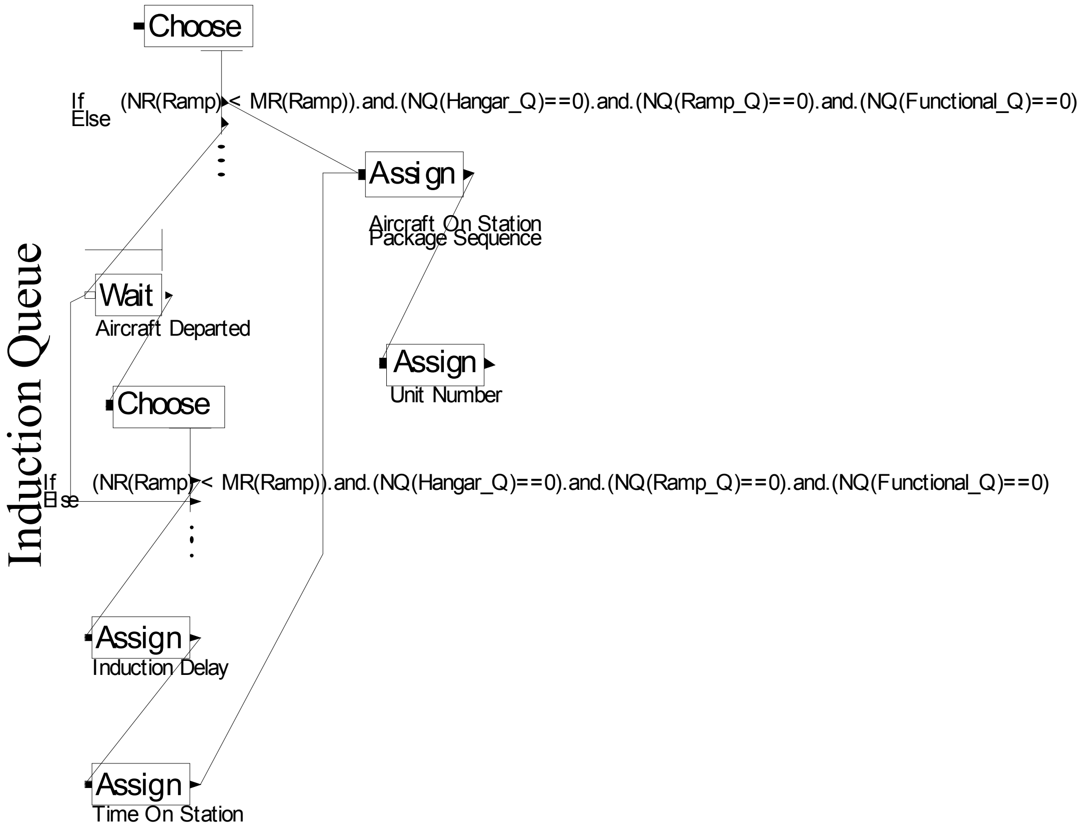
AIRCRAFT INDUCTION SCHEDULING LOGIC

Inputs



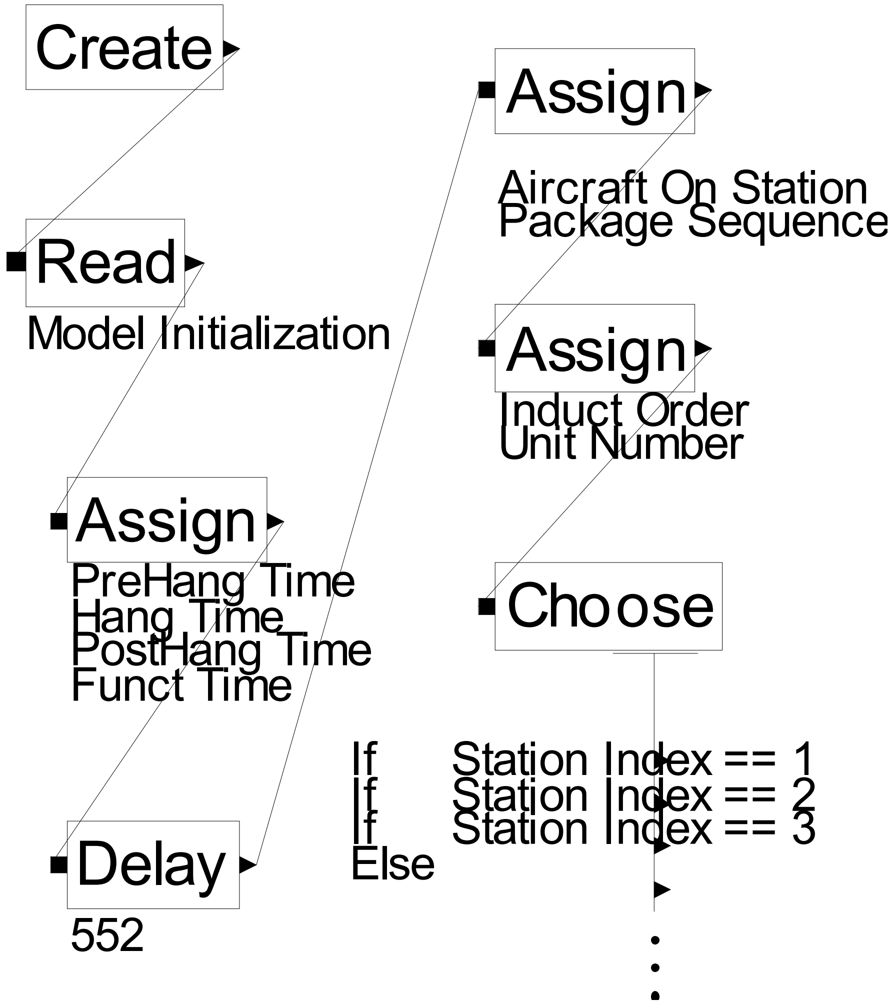
- Creates entity to read a data file containing induction dates.
- Entity delays until it's time to induct aircraft, it then sends a duplicate entity into the model before reading the next induction time. Duplicated entity now represents an aircraft.
- Assigns work package identifier, processing times (common random numbers), and time arrived on station (at depot). "Flow Factor" is used for the initialization of ramp population.

AIRCRAFT INDUCTION DELAY LOGIC



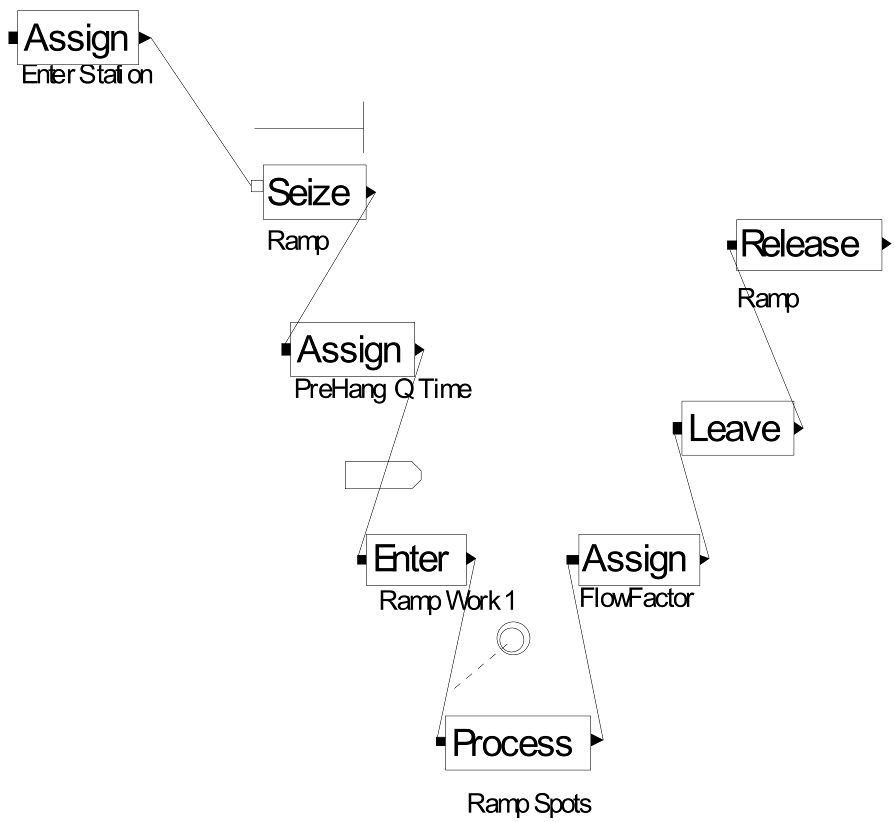
- Aircraft schedule to arrive on station may enter the depot.
  - If there is room on the ramp and no aircraft on station are awaiting a ramp spot.
  - Else the aircraft must wait in the induction queue until it get a signal that an aircraft has left the ramp.
    - However the aircraft still must check and see that no aircraft on station needs the ramp spot.
  - Once the aircraft in the queue is allowed to enter its induction delay is computed, and it will receive the actual time it enters the depot.
- Aircraft arriving on station are assigned a production unit number for later analysis, and number of aircraft on station is incremented.

RAMP POPULATION INITIALIZATION LOGIC



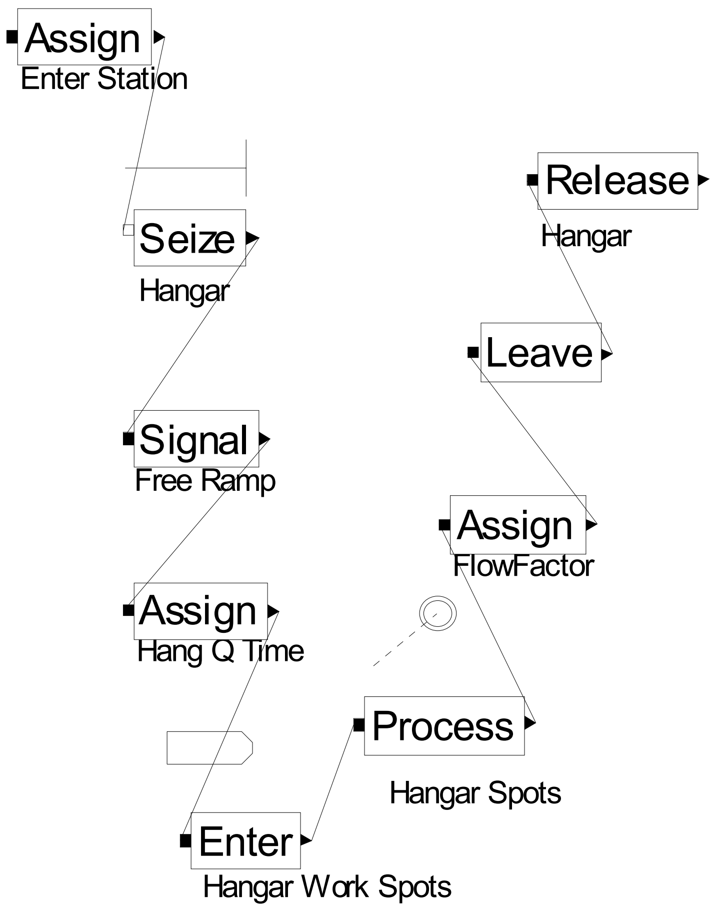
- Creates the number of entities necessary to read a data file containing information about the aircraft currently on station.
- Assigns work package identifier, processing times, and time arrived on station (at depot). "Flow Factor"(read in for the data file) is used to estimate the percentage of work the aircraft has completed at its current dock location (total dock times are still randomly assigned). Process times are common random numbers.
- Aircraft on station must wait until 1 Oct 00 (simulation time 552) to continue processing.
- Unit production number is assigned, number of aircraft on station is counted, and aircraft is routed to its current dock location at the depot.

Pre-Hangar Ramp



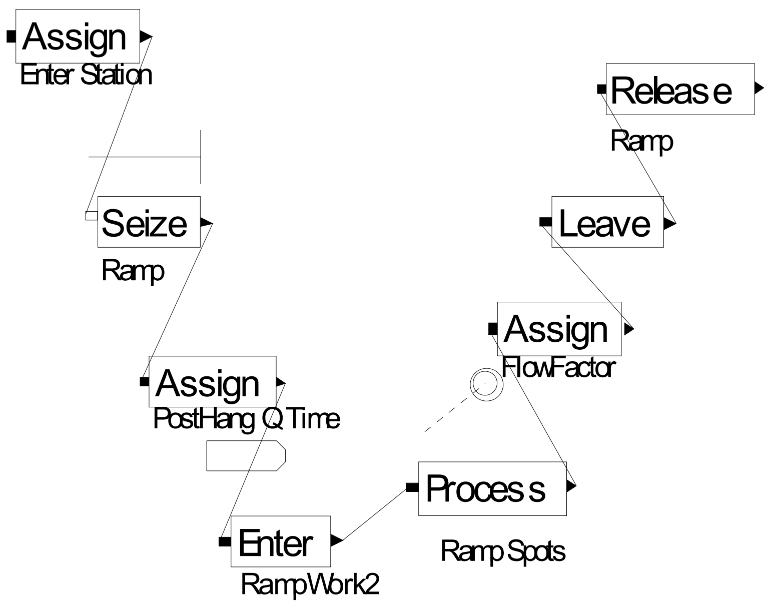
- Typical processing flow requires entity to seize a resource (ramp, hangar, or functional test) before processing. The time in the seize queue is the delay caused by limited resources. This time is captured when processing begins.
- The enter-process-leave could be replaced by a delay, but this would not allow animation.
- "Flow Factor" is set to one so aircraft that were initialized as being at this station at the start of the simulation will take their full processing time in subsequent stations.

Hangar



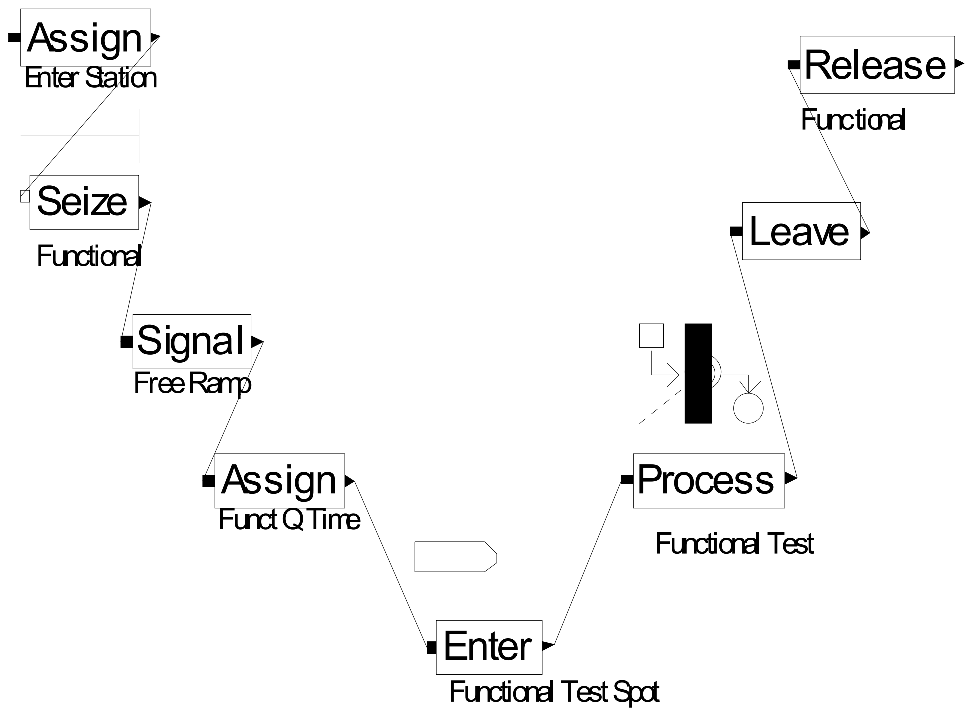
- Typical processing flow requires entity to seize a resource (ramp, hangar, or functional test) before processing. The time in the seize queue is the delay caused by limited resources. This time is captured when processing begins.
- The enter-process-leave could be replaced by a delay, but this would not allow animation.
- "Flow Factor" is set to one so aircraft that were initialized as being at this station at the start of the simulation will take their full processing time in subsequent stations.
- Aircraft entering a Hangar will signal that they have freed a ramp spot

Post Hangar Ramp



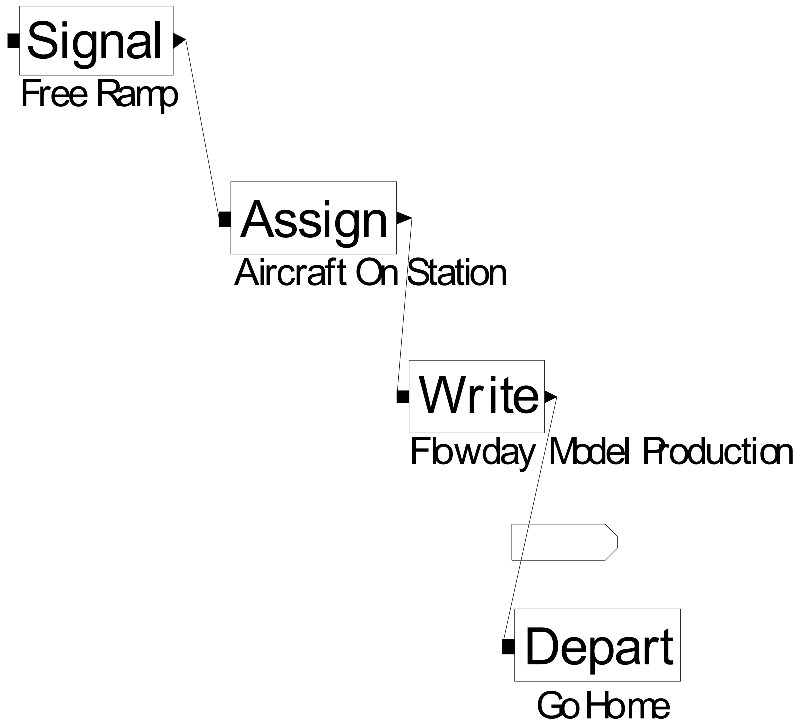
- Typical processing flow requires entity to seize a resource (ramp, hangar, or functional test) before processing. The time in the seize queue is the delay caused by limited resources. This time is captured when processing begins.
- The enter-process-leave could be replaced by a delay, but this would not allow animation.
- "Flow Factor" is set to one so aircraft that were initialized as being at this station at the start of the simulation will take their full processing time in subsequent stations.

Functional Test



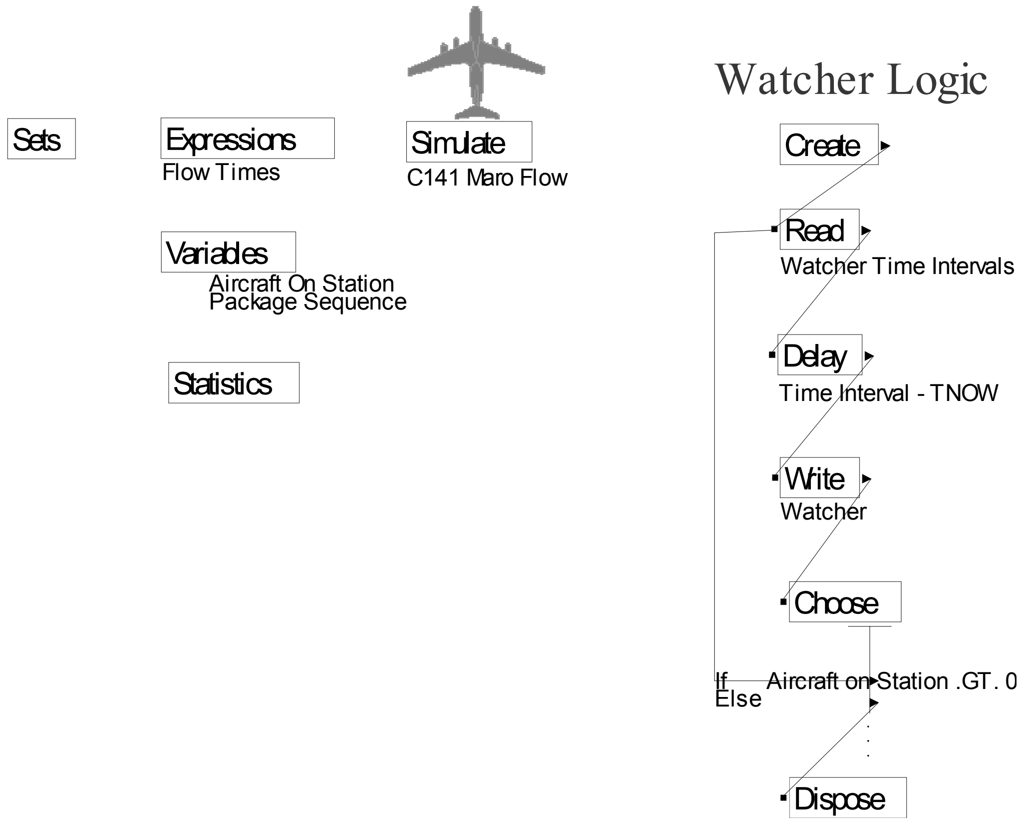
- Typical processing flow requires entity to seize a resource (ramp, hangar, or functional test) before processing. The time in the seize queue is the delay caused by limited resources. This time is captured when processing begins.
- The enter-process-leave could be replaced by a delay, but this would not allow animation.
- Aircraft entering Functional Test will signal that they have freed a ramp spot

Going Home



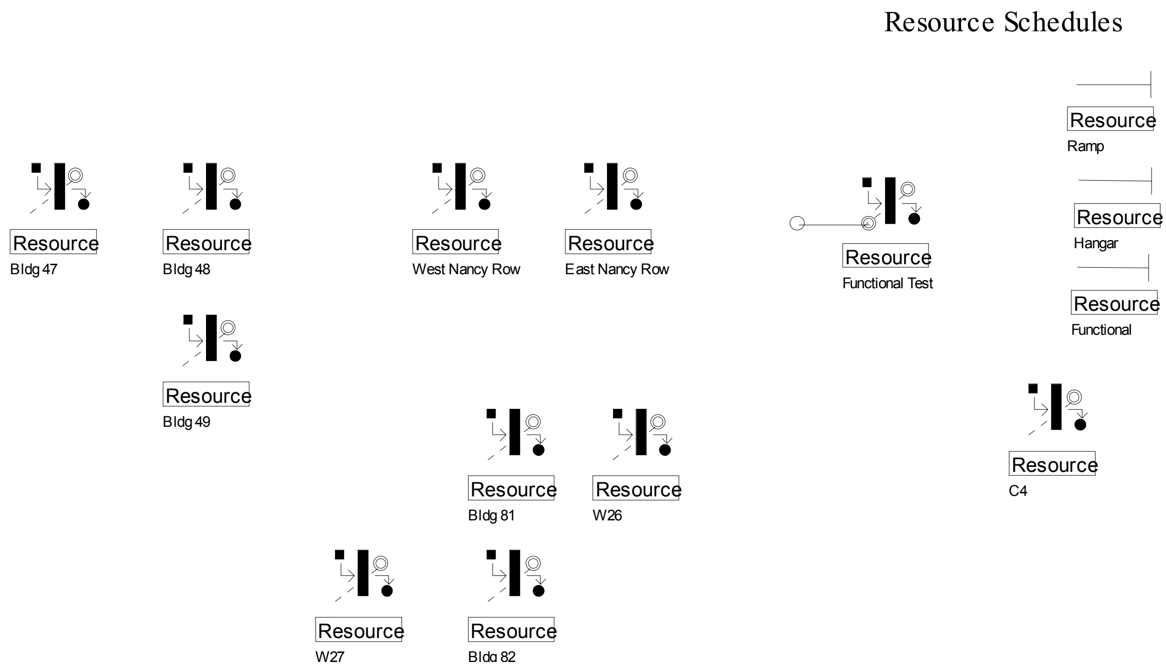
- Aircraft going home Test will signal that they have left.
- The number of aircraft on station is decremented.
- Information about the processing of the aircraft is capture.
- Statistics are collected and the entity is disposed of.

SIMULATION DATA & MONTHLY DATA COLLECTION LOGIC



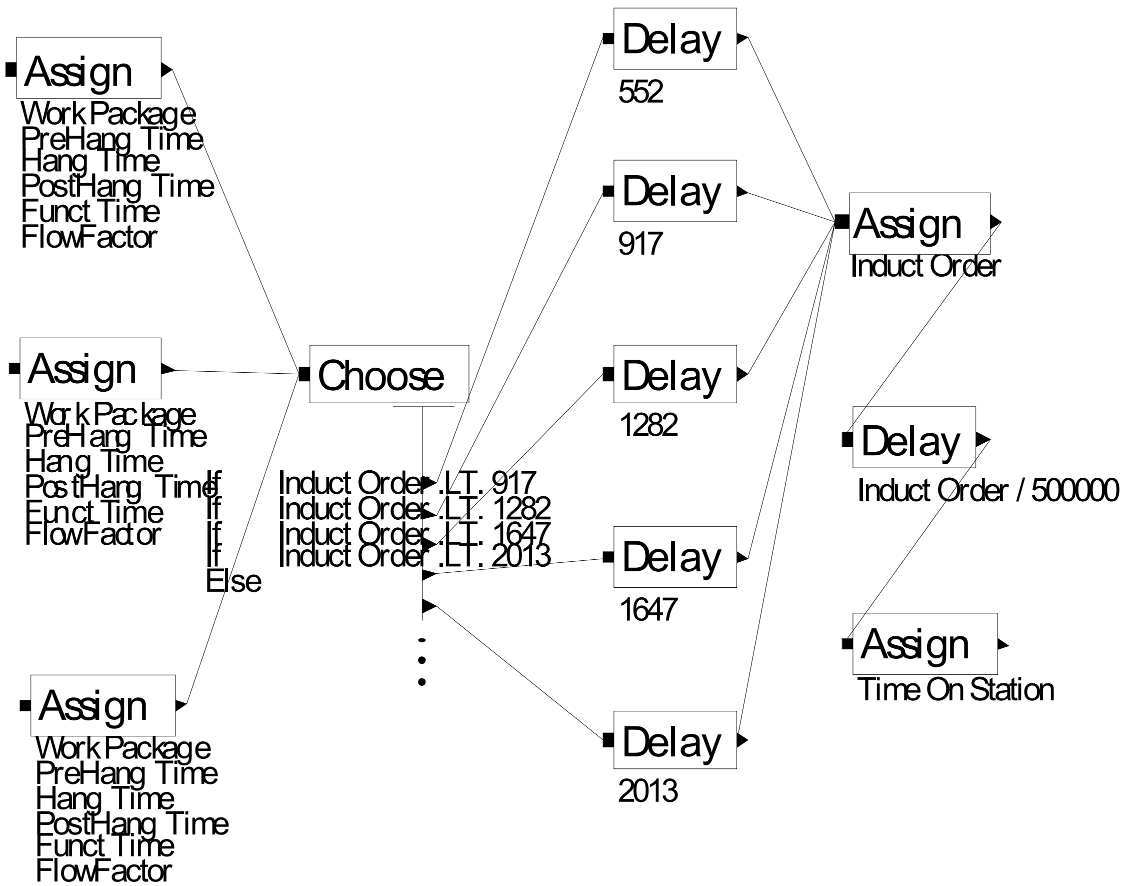
- "Watcher Logic" takes monthly statistics on the state of the depot/model.
- The remaining logic controls the simulation run and makes necessary model definitions.

SIMULATION ANIMATION AND RESOURCE SCHEDULING LOGIC



- The resource blocks on the right hand side of the model control the "release schedule."
- The remaining resource blocks are used for animation.

SPECIAL LOGIC TO ALLOW SCHEDULING AIRCRAFT AT START OF FISCAL YEAR



- All aircraft are read into the model at the start of the simulation.
- The delay blocks on page 3, Aircraft Induction Scheduling Logic, are removed and aircraft are routed to the appropriate delay block to await the start of the fiscal years. Induct order is the scheduled induction time read during the induction scheduling logic.
- A slight delay is added to each entity based on its scheduled time to ensure they arrive in the correct sequence.

SIMAN

EXPERIMENT FILE

```
PROJECT,      C141 Maro Flow,Ruben Bell;

ATTRIBUTES:   PreHang Q Time:
              PostHang Time:
              Unit Number:
              Induct PDM 998:
              Hang Time:
              Enter Station:
              Hang Q Time:
              PreHang Time:
              SetAttribute:
              Station Index:
              Induction Delay:
              Funct Time:
              QueueTime:
              Induct PDM:
              Time Interval:
              Funct Q Time:
              FlowFactor:
              Time On Station:
              Work Package:
              Induct Mini:
              PostHang Q Time;

FILES:        PDM 998 Arrivals,"a:998 Inducts.txt",(),Free Format,Dispose:
              Flowday Model Production,"e:\Thesis\Unit Production.txt",(),Free Format:
              Mini Arrivals,"a:MINI Inducts.txt",(),Free Format,Dispose:
              Model Initialization,"a:On Station Info.txt",(),Free Format,Rewind:
              Watcher Time Intervals,"a:Watcher Intervals.txt",(),Free Format,Dispose:
              Watcher,"e:\Thesis\Model Watcher.txt",(),Free Format:
              PDM Arrivals,"a:PDM Inducts.txt",(),Free Format,Dispose;

SCHEDULES:    Functional Schedule,4*2044,2:
              Ramp Schedule,10*583,8*638,7*365,6*519,4*212,2:
              Hangar Schedule,9*1282,8*212,6*427,5*396,3;

STATICS:      Aircraft Departed:
              Free Ramp;

STORAGES:     Functional Test Spot_S1:
              Ramp Work 2_S1:
              Ramp Work 1_S1:
              Hangar Work Spots_S1;

VARIABLES:    Package Sequence:
              Aircraft On Station,0;
```

```
QUEUES:   Bldg 81_Q:
          East Nancy Row_Q:
          Bldg 82_Q:
          Awaiting Induction Queue,LVF(Time On Station):
          West Nancy Row_Q:
          Hangar_Q,FIFO:
          Functional_Q,FIFO:
          C4_Q:
          Ramp_Q,FIFO(),Shared:
          W26_Q:
          Bldg 47_Q:
          W27_Q:
          Bldg 48_Q:
          Bldg 49_Q:
          Functional Test_Q,FIFO;

PICTURES:   Default;

RESOURCES:  Bldg 47,Capacity(1,),-,Stationary:
          C4,Capacity(1,),-,Stationary:
          Bldg 48,Capacity(1,),-,Stationary:
          Ramp,Schedule(Ramp Schedule,Ignore),-,Stationary:
          Hangar,Schedule(Hangar Schedule,Ignore),-,Stationary:
          Bldg 49,Capacity(1,),-,Stationary:
          W26,Capacity(1,),-,Stationary:
          W27,Capacity(1,),-,Stationary:
          Functional Test,Capacity(4,),-,Stationary:
          Bldg 81,Capacity(4,),-,Stationary:
          Bldg 82,Capacity(2,),-,Stationary:
          East Nancy Row,Capacity(4,),-,Stationary:
          Functional,Schedule(Functional Schedule,Ignore),-,Stationary:
          West Nancy Row,Capacity(3,),-,Stationary;

STATIONS:   Functional Test Spot:
          Go Home:
          Hangar Work Spots:
          Ramp Work 1:
          Ramp Work 2;

COUNTERS:   PDMs Produced,,Replicate:
          MODs Produced,,Replicate:
          MINIs Produced,,Replicate:
          PDM 998s Produced,,Replicate:
          INSPs Produced,,Replicate;
```

TALLIES: Functional_Q Queue Time:
MINI Flowdays:
Hangar_Q Queue Time:
Awaiting Induction Queue Queue Time:
Ramp_Q Queue Time:
INSP Flowdays:
MOD Flowdays:
PDM Flowdays:
PDM 998 Flowdays;

DSTATS: MR(Bldg 49),Bldg 49 Available:
MR(Bldg 48),Bldg 48 Available:
MR(Bldg 47),Bldg 47 Available:
NR(Ramp),Ramp Busy:
NR(C4),C4 Busy:
MR(Hangar),Hangar Available:
MR(C4),C4 Available:
NQ(Ramp_Q),# in Ramp_Q:
NR(Bldg 82),Bldg 82 Busy:
NQ(Hangar_Q),# in Hangar_Q:
NR(Bldg 81),Bldg 81 Busy:
MR(West Nancy Row),West Nancy Row Available:
MR(East Nancy Row),East Nancy Row Available:
NQ(Awaiting Induction Queue),# in Awaiting Induction Queue:
NR(Hangar),Hangar Busy:
NR(Functional),Functional Busy:
MR(Functional),Functional Available:
NR(West Nancy Row),West Nancy Row Busy:
NR(East Nancy Row),East Nancy Row Busy:
NQ(Functional Test_Q),# in Functional Test_Q:
NR(Functional Test),Functional Test Busy:
MR(Bldg 82),Bldg 82 Available:
MR(Functional Test),Functional Test Available:
NR(Bldg 49),Bldg 49 Busy:
MR(Bldg 81),Bldg 81 Available:
NR(W27),W27 Busy:
MR(W27),W27 Available:
NR(Bldg 48),Bldg 48 Busy:
NR(W26),W26 Busy:
MR(W26),W26 Available:
MR(Ramp),Ramp Available:
NQ(Functional_Q),# in Functional_Q:
NR(Bldg 47),Bldg 47 Busy;

OUTPUTS: DAVG(Functional Test Busy),"Functional Utilization.dat":
DAVG(Ramp Busy),"Ramp Utilization.dat":
TAVG(MOD Flowdays),"MOD Flowday Results.dat":
DAVG(Hangar Busy),"Hangar Utilization.dat":
DAVG(# in Functional Test_Q),"Functional Que No.dat":
TAVG(INSP Flowdays),"INSP Flowday Results.dat":
DAVG(# in Awaiting Induction Queue),"Induction Delay No.dat":
DAVG(# in Hangar_Q),"Hangar Que No.dat":
DAVG(# in Ramp_Q),"Ramp Que No.dat":
TAVG(MINI Flowdays),"MINI Flowday Results.dat":
TAVG(PDM Flowdays),"PDM Flowday Results.dat":
TAVG(PDM 998 Flowdays),"PDM 998 Flowday Results.dat";

REPLICATE, 107,0,,Yes,Yes,552;

EXPRESSIONS: Flow Times(5,4),tria(14,33,59,1),tria(5,21.8,45,2),19.5 + 76 * BETA(0.799, 0.752,3),0,0,TRIA(70,112.3,155,1),
103 + 88 * BETA(0.0875, 0.194,2),TRIA(152, 204.8, 258,3),0,0,tria(14,33.8,58,1),tria(14,54,94,2),
8 + 104 * BETA(0.452, 0.609,3),0,tria(45,60,90,5),TRIA(20,34.3,53,1),tria(21,36,65,2),
12.5 + 51 * BETA(0.932, 1.19,3),tria(30,60,120,4),tria(5,10,25,5);

SETS: Ramp Work Spots,Ramp Work 1,Ramp Work 2:
Production,MINIs Produced,PDMs Produced,PDM 998s Produced,MODs Produced,INSPs Produced:
Hangar Spots,Bldg 81,Bldg 49,Bldg 48,Bldg 47,Bldg 82:
Hangar Queue,Bldg 81_Q,Bldg 49_Q,Bldg 48_Q,Bldg 47_Q,Bldg 82_Q:
Ramp Spots,East Nancy Row,West Nancy Row,W26,W27,C4:
Ramp Queue,East Nancy Row_Q,West Nancy Row_Q,W26_Q,W27_Q,C4_Q:
Flowday History,MINI Flowdays,PDM Flowdays,PDM 998 Flowdays,MOD Flowdays,INSP Flowdays;

SIMAN

MODEL FILE

```
;    Model statements for module:  Create 1
;

80$        CREATE,      1;
87$        TRACE,       -1,"-Entity Created\n":;
84$        ASSIGN:      Picture=Default:NEXT(0$);


;
;
;    Model statements for module:  Read 1
;
0$         TRACE,       -1,"-Reading from Mini Arrivals \n":;
88$        READ,        Mini Arrivals:
                 Induct Mini:NEXT(1$);


;
;
;    Model statements for module:  Delay 1
;
1$         TRACE,       -1,"-Delaying for time Induct Mini - TNOW\n":;
89$        DELAY:       Induct Mini - TNOW:NEXT(2$);


;
;
;    Model statements for module:  Duplicate 1
;
2$         TRACE,       -1,"-Duplicating entities\n":;
90$        DUPLICATE:    1,60$:NEXT(0$);


;
;
;    Model statements for module:  Assign 30
;
60$        TRACE,       -1,"-Making assignments\n":;
91$        ASSIGN:      Work Package=1:
                 PreHang Time=Flow Times(Work Package,1):
                 Hang Time=Flow Times(Work Package,2):
                 PostHang Time=Flow Times(Work Package,3):
                 Funct Time=Flow Times(Work Package,4):
                 FlowFactor=1:
                 Time On Station=TNOW:NEXT(12$);
```

```
;;
;    Model statements for module:  Choose 1
;
12$          TRACE,        -1,"-Choosing from 2 options\n":;
92$          BRANCH,       1:
                       If,(NR(Ramp) <
MR(Ramp)).and.(NQ(Hangar_Q)==0).and.(NQ(Ramp_Q)==0).and.(NQ(Functional_Q)=
=0),11$,
                       Yes:
                       Else,9$,Yes;


;
;
;    Model statements for module:  Assign 6
;
11$          TRACE,        -1,"-Making assignments\n":;
93$          ASSIGN:       Aircraft On Station=Aircraft On Station + 1:
                       Package Sequence=Package Sequence + 1:NEXT(36$);



;
;
;    Model statements for module:  Assign 15
;
36$          TRACE,        -1,"-Making assignments\n":;
94$          ASSIGN:       Unit Number=Package Sequence:NEXT(48$);



;
;
;    Model statements for module:  Assign 24
;
48$          TRACE,        -1,"-Making assignments\n":;
95$          ASSIGN:       Enter Station=TNOW:NEXT(40$);



;
;
;    Model statements for module:  Seize 1
;
40$          QUEUE,        Ramp_Q:MARK(QueueTime);
96$          SEIZE,:       Ramp,1;
101$         ASSIGN:       j=j;
97$          TALLY:        Ramp_Q Queue Time,INT(QueueTime),1:NEXT(63$);
```

```
;
;
;    Model statements for module:  Assign 33
;
63$          TRACE,        -1,"-Making assignments\n":;
102$         ASSIGN:       PreHang Q Time=TNOW-Enter Station:NEXT(13$);


;
;    Model statements for module:  Enter 2
;

13$          STATION,      Ramp Work 1;
124$         TRACE,        -1,"-Arrived to station Ramp Work 1\n":;
104$         STORE:        Ramp Work 1_S1;
103$         DELAY:        0.;
118$         UNSTORE;
123$         DELAY:        0.000:NEXT(14$);


;
;    Model statements for module:  Process 2
;
14$          TRACE,        -1,"-Waiting for resource Ramp Spots\n":;
133$         SEIZE,        1:
                      SELECT(Ramp Spots,POR,SetAttribute),1;
220$         BRANCH,       1:
                      If,RTYP(Ramp Spots(SetAttribute)).eq.2,221$,Yes:
                      If,RTYP(Ramp Spots(SetAttribute)).eq.1,228$,Yes;
221$         MOVE:         ,m;
228$         DELAY:        0.0;
          TRACE,        -1,"-Delay for processing time PreHang Time*FlowFactor\n":;
144$         DELAY:        PreHang Time*FlowFactor;
152$         RELEASE:      SELECT(Ramp Spots,,SetAttribute),1;
195$         DELAY:        0.000;
205$         DELAY:        0.0:NEXT(18$);

;
;    Model statements for module:  Assign 8
;
18$          TRACE,        -1,"-Making assignments\n":;
229$         ASSIGN:       FlowFactor=1:NEXT(17$);
```

```
;
;
;    Model statements for module:  Leave 2
;
17$          DELAY:        0.00;
263$          TRACE,        -1,"-Delay for loading time 0\n":;
241$          DELAY:        0;
268$          TRACE,        -1,"-Transferred to next module\n"::NEXT(42$);


;
;
;    Model statements for module:  Release 1
;
42$          TRACE,        -1,"-Releasing resources\n":;
281$          RELEASE:      Ramp,1:NEXT(47$);


;
;
;    Model statements for module:  Assign 21
;
47$          TRACE,        -1,"-Making assignments\n":;
282$          ASSIGN:       Enter Station=TNOW:NEXT(43$);
;
;
;    Model statements for module:  Seize 3
;
43$          QUEUE,        Hangar_Q:MARK(QueueTime);
283$          SEIZE,:       Hangar,1;
288$          ASSIGN:       j=j;
284$          TALLY:        Hangar_Q Queue Time,INT(QueueTime),1:NEXT(72$);


;
;
;    Model statements for module:  Signal 5
;
72$          TRACE,        -1,"-Sending signal Free Ramp\n":;
289$          SIGNAL:       Free Ramp,1:NEXT(66$);


;
;
;    Model statements for module:  Assign 36
;
66$          TRACE,        -1,"-Making assignments\n":;
290$          ASSIGN:       Hang Q Time=TNOW - Enter Station:NEXT(20$);
```

```
;
;
;    Model statements for module:  Enter 3
;

20$         STATION,      Hangar Work Spots;
312$        TRACE,        -1,"-Arrived to station Hangar Work Spots\n":;
292$        STORE:        Hangar Work Spots_S1;
291$        DELAY:        0.;
306$        UNSTORE;
311$        DELAY:        0.000:NEXT(21$);


;
;
;    Model statements for module:  Process 3
;
21$         TRACE,        -1,"-Waiting for resource Hangar Spots\n":;
321$        SEIZE,        1:
                   SELECT(Hangar Spots,POR,SetAttribute),1;
408$        BRANCH,       1:
                   If,RTYP(Hangar Spots(SetAttribute)).eq.2,409$,Yes:
                   If,RTYP(Hangar Spots(SetAttribute)).eq.1,416$,Yes;
409$        MOVE:         ,m;
416$        DELAY:        0.0;
          TRACE,        -1,"-Delay for processing time Hang Time*FlowFactor\n":;
332$        DELAY:        Hang Time*FlowFactor;
340$        RELEASE:      SELECT(Hangar Spots,,SetAttribute),1;
383$        DELAY:        0.000;
393$        DELAY:        0.0:NEXT(25$);


;
;
;    Model statements for module:  Assign 11
;
25$         TRACE,        -1,"-Making assignments\n":;
417$        ASSIGN:       FlowFactor=1:NEXT(24$);


;
;
;    Model statements for module:  Leave 3
;
24$         DELAY:        0.00;
451$        TRACE,        -1,"-Delay for loading time 0\n":;
429$        DELAY:        0;
456$        TRACE,        -1,"-Transferred to next module\n"::NEXT(45$);
```

```
;
;
;    Model statements for module:  Release 2
;
45$          TRACE,        -1,"-Releasing resources\n":;
469$         RELEASE:      Hangar,1:NEXT(58$);


;
;
;    Model statements for module:  Assign 28
;
58$          TRACE,        -1,"-Making assignments\n":;
470$         ASSIGN:       Enter Station=TNOW:NEXT(55$);


;
;
;    Model statements for module:  Seize 4
;
55$          QUEUE,        Ramp_Q:MARK(QueueTime);
471$         SEIZE,:       Ramp,1;
476$         ASSIGN:       j=j;
472$         TALLY:        Ramp_Q Queue Time,INT(QueueTime),1:NEXT(67$);


;
;
;    Model statements for module:  Assign 37
;
67$          TRACE,        -1,"-Making assignments\n":;
477$         ASSIGN:       PostHang Q Time=TNOW - Enter Station:NEXT(49$);

;
;
;    Model statements for module:  Enter 5
;

49$          STATION,      Ramp Work 2;
499$         TRACE,        -1,"-Arrived to station Ramp Work 2\n":;
479$         STORE:        Ramp Work 2_S1;
478$         DELAY:        0.;
493$         UNSTORE;
498$         DELAY:        0.000:NEXT(50$);
```

```
;
;
;    Model statements for module:  Process 6
;
50$          TRACE,        -1,"-Waiting for resource Ramp Spots\n":;
508$         SEIZE,        1:
                         SELECT(Ramp Spots,POR,SetAttribute),1;
595$         BRANCH,       1:
                         If,RTYP(Ramp Spots(SetAttribute)).eq.2,596$,Yes:
                         If,RTYP(Ramp Spots(SetAttribute)).eq.1,603$,Yes;
596$         MOVE:         ,m;
603$         DELAY:        0.0;
           TRACE,        -1,"-Delay for processing time PostHang Time*FlowFactor\n":;
519$         DELAY:        PostHang Time*FlowFactor;
527$         RELEASE:      SELECT(Ramp Spots,,SetAttribute),1;
570$         DELAY:        0.000;
580$         DELAY:        0.0:NEXT(54$);


;
;
;    Model statements for module:  Assign 27
;
54$          TRACE,        -1,"-Making assignments\n":;
604$         ASSIGN:       FlowFactor=1:NEXT(53$);


;
;
;    Model statements for module:  Leave 5
;
53$          DELAY:        0.00;
638$         TRACE,        -1,"-Delay for loading time 0\n":;
616$         DELAY:        0;
643$         TRACE,        -1,"-Transferred to next module\n"::NEXT(57$);


;
;
;    Model statements for module:  Release 3
;
57$          TRACE,        -1,"-Releasing resources\n":;
656$         RELEASE:      Ramp,1:NEXT(46$);
```

```
;
;
;    Model statements for module:  Assign 20
;
46$          TRACE,        -1,"-Making assignments\n":;
657$          ASSIGN:       Enter Station=TNOW:NEXT(69$);


;
;
;    Model statements for module:  Seize 5
;
69$          QUEUE,        Functional_Q:MARK(QueueTime);
658$          SEIZE,:       Functional,1;
663$          ASSIGN:       j=j;
659$          TALLY:        Functional_Q Queue Time,INT(QueueTime),1:NEXT(73$);


;
;
;    Model statements for module:  Signal 6
;
73$          TRACE,        -1,"-Sending signal Free Ramp\n":;
664$          SIGNAL:       Free Ramp,1:NEXT(68$);


;
;
;    Model statements for module:  Assign 38
;
68$          TRACE,        -1,"-Making assignments\n":;
665$          ASSIGN:       Funct Q Time=TNOW - Enter Station:NEXT(27$);


;
;
;    Model statements for module:  Enter 4
;

27$          STATION,      Functional Test Spot;
687$          TRACE,        -1,"-Arrived to station Functional Test Spot\n":;
667$          STORE:        Functional Test Spot_S1;
666$          DELAY:        0.;
681$          UNSTORE;
686$          DELAY:        0.000:NEXT(28$);
```

```
;
;
;    Model statements for module:  Process 4
;
28$          TRACE,        -1,"-Waiting for resource Functional Test\n":;
695$         SEIZE,        1:
                        Functional Test,1;
781$         BRANCH,       1:
                        If,RTYP(Functional Test).eq.2,782$,Yes:
                        If,RTYP(Functional Test).eq.1,791$,Yes;
782$         MOVE:         ,m;
791$         DELAY:        0.0;
           TRACE,        -1,"-Delay for processing time Funct Time*FlowFactor\n":;
707$         DELAY:        Funct Time*FlowFactor;
714$         RELEASE:      Functional Test,1;
758$         DELAY:        0.000;
768$         DELAY:        0.0:NEXT(31$);


;
;
;    Model statements for module:  Leave 4
;
31$          DELAY:        0.00;
825$         TRACE,        -1,"-Delay for loading time 0\n":;
803$         DELAY:        0;
830$         TRACE,        -1,"-Transferred to next module\n"::NEXT(71$);


;
;
;    Model statements for module:  Release 4
;
71$          TRACE,        -1,"-Releasing resources\n":;
843$         RELEASE:      Functional,1:NEXT(33$);


;
;
;    Model statements for module:  Signal 4
;
33$          TRACE,        -1,"-Sending signal Free Ramp\n":;
844$         SIGNAL:       Free Ramp,1:NEXT(32$);
```

```
;
;
;    Model statements for module:  Assign 14
;
32$          TRACE,        -1,"-Making assignments\n":;
845$         ASSIGN:       Aircraft On Station=Aircraft On Station - 1:NEXT(37$);


;
;
;    Model statements for module:  Write 1
;
37$          TRACE,        -1,"-Writing to File Flowday Model Production\n":;
846$         WRITE,        Flowday Model Production:
                         Unit Number,
                         Work Package,
                         Time On Station,
                         TNOW,
                         Induction Delay,
                         TNOW - Time On Station,
                         PreHang Q Time,
                         Hang Q Time,
                         PostHang Q Time,
                         Funct Q Time,
                         NREP:NEXT(26$);


;
;
;    Model statements for module:  Depart 6
;

26$          STATION,      Go Home;
877$         TRACE,        -1,"-Arrived to station Go Home\n":;
847$         DELAY:        0.;
870$         COUNT:        Production(Work Package),1;
875$         TALLY:        Flowday History(Work Package),Interval(Time On Station),1;
884$         TRACE,        -1,"-Disposing entity\n":;
876$         DISPOSE;



;
;
```

```
;     Model statements for module:  Wait 1
;
9$           QUEUE,        Awaiting Induction Queue:MARK(QueueTime);
886$          WAIT:          Aircraft Departed,1;
887$          TALLY:         Awaiting Induction Queue Queue
Time,INT(QueueTime),1:NEXT(74$);


;
;
;     Model statements for module:  Choose 4
;
74$          TRACE,        -1,"-Choosing from 2 options\n":;
889$          BRANCH,       1:
                            If,(NR(Ramp) <
MR(Ramp)).and.(NQ(Hangar_Q)==0).and.(NQ(Ramp_Q)==0).and.(NQ(Functional_Q)=
=0),39$,
                            Yes:
                            Else,9$,Yes;

;
;
;     Model statements for module:  Assign 17
;
39$          TRACE,        -1,"-Making assignments\n":;
890$          ASSIGN:       Induction Delay=TNOW - Time On Station:NEXT(38$);


;
;
;     Model statements for module:  Assign 16
;
38$          TRACE,        -1,"-Making assignments\n":;
891$          ASSIGN:       Time On Station=TNOW:NEXT(11$);


;
;
;     Model statements for module:  Create 3
;

892$          CREATE,       1;
899$          TRACE,        -1,"-Entity Created\n":;
896$          ASSIGN:       Picture=Default:NEXT(3$);
```

```
;
;
;    Model statements for module:  Read 3
;
3$           TRACE,        -1,"-Reading from PDM Arrivals \n":;
900$          READ,          PDM Arrivals:
                             Induct PDM:NEXT(4$);


;
;
;    Model statements for module:  Delay 3
;
4$           TRACE,        -1,"-Delaying for time Induct PDM - TNOW\n":;
901$          DELAY:         Induct PDM - TNOW:NEXT(5$);


;
;
;    Model statements for module:  Duplicate 3
;
5$           TRACE,        -1,"-Duplicating entities\n":;
902$          DUPLICATE:     1,61$:NEXT(3$);


;
;
;    Model statements for module:  Assign 31
;
61$          TRACE,        -1,"-Making assignments\n":;
903$          ASSIGN:        Work Package=2:
                             PreHang Time=Flow Times(Work Package,1):
                             Hang Time=Flow Times(Work Package,2):
                             PostHang Time=Flow Times(Work Package,3):
                             Funct Time=Flow Times(Work Package,4):
                             FlowFactor=1:
                             Time On Station=TNOW:NEXT(12$);

;
;
;    Model statements for module:  Create 4
;

904$          CREATE,        1;
911$          TRACE,         -1,"-Entity Created\n":;
908$          ASSIGN:        Picture=Default:NEXT(6$);
```

```
;
;
;    Model statements for module:  Read 4
;
6$          TRACE,        -1,"-Reading from PDM 998 Arrivals \n":;
912$         READ,         PDM 998 Arrivals:
                           Induct PDM 998:NEXT(7$);


;
;
;    Model statements for module:  Delay 4
;
7$          TRACE,        -1,"-Delaying for time Induct PDM 998 - TNOW\n":;
913$         DELAY:        Induct PDM 998 - TNOW:NEXT(8$);


;
;
;    Model statements for module:  Duplicate 4
;
8$          TRACE,        -1,"-Duplicating entities\n":;
914$         DUPLICATE:    1,62$:NEXT(6$);


;
;
;    Model statements for module:  Assign 32
;
62$          TRACE,        -1,"-Making assignments\n":;
915$         ASSIGN:       Work Package=3:
                           PreHang Time=Flow Times(Work Package,1):
                           Hang Time=Flow Times(Work Package,2):
                           PostHang Time=Flow Times(Work Package,3):
                           Funct Time=Flow Times(Work Package,4):
                           FlowFactor=1:
                           Time On Station=TNOW:NEXT(12$);


;
;
```

```
;     Model statements for module:  Resource 6
;
;
;
;     Model statements for module:  Resource 5
;
;
;
;     Model statements for module:  Resource 4
;
;
;
;     Model statements for module:  Resource 3
;
;
;
;     Model statements for module:  Resource 2
;
;
;
;     Model statements for module:  Resource 11
;
;
;
;     Model statements for module:  Resource 10
;
;
;
;     Model statements for module:  Resource 9
;
;
;
;     Model statements for module:  Resource 8
;
;
;
;     Model statements for module:  Resource 7
;
;
;
;     Model statements for module:  Resource 12
;

;
;
;     Model statements for module:  Create 5
```

```
;

993$        CREATE,       ##; (aircraft on station number deleted)
1000$        TRACE,       -1,"-Entity Created\n":;
997$        ASSIGN:       Picture=Default:NEXT(34$);


;
;
;    Model statements for module:  Read 5
;
34$         TRACE,       -1,"-Reading from Model Initialization \n":;
1001$        READ,         Model Initialization:
                         Work Package,
                         FlowFactor,
                         Station Index,
                         Time On Station:NEXT(59$);


;
;
;    Model statements for module:  Assign 29
;
59$         TRACE,       -1,"-Making assignments\n":;
1002$        ASSIGN:       PreHang Time=Flow Times(Work Package,1):
                         Hang Time=Flow Times(Work Package,2):
                         PostHang Time=Flow Times(Work Package,3):
                         Funct Time=Flow Times(Work Package,4):NEXT(35$);


;
;
;    Model statements for module:  Delay 5
;
35$         TRACE,       -1,"-Delaying for time 552\n":;
1003$        DELAY:        552:NEXT(64$);


;
;
;    Model statements for module:  Assign 34
;
64$         TRACE,       -1,"-Making assignments\n":;
1004$        ASSIGN:       Aircraft On Station=Aircraft On Station + 1:
                         Package Sequence=Package Sequence + 1:NEXT(65$);
```

```
;
;
;    Model statements for module:  Assign 35
;
65$          TRACE,        -1,"-Making assignments\n":;
1005$        ASSIGN:       Unit Number=Package Sequence:NEXT(19$);


;
;
;    Model statements for module:  Choose 2
;
19$          TRACE,        -1,"-Choosing from 4 options\n":;
1006$        BRANCH,       1:
                       If,Station Index == 1,48$,Yes:
                       If,Station Index == 2,47$,Yes:
                       If,Station Index == 3,58$,Yes:
                       Else,46$,Yes;


;
;
;    Model statements for module:  Resource 13
;


;
;
;    Model statements for module:  Resource 14
;


;
;
;    Model statements for module:  Resource 15
;


;
;
;    Model statements for module:  Create 9
;

1028$        CREATE,       1,552;
1035$        TRACE,        -1,"-Entity Created\n":;
1032$        ASSIGN:       Picture=Default:NEXT(79$);


;
```

```
;
;    Model statements for module:  Read 7
;
79$          TRACE,        -1,"-Reading from Watcher Time Intervals \n":;
1036$        READ,         Watcher Time Intervals:
                           Time Interval:NEXT(75$);


;
;
;    Model statements for module:  Delay 9
;
75$          TRACE,        -1,"-Delaying for time Time Interval - TNOW\n":;
1037$        DELAY:        Time Interval - TNOW:NEXT(78$);


;
;
;    Model statements for module:  Write 4
;
78$          TRACE,        -1,"-Writing to File Watcher\n":;
1038$        WRITE,        Watcher:
                           NREP,
                           TNOW,
                           Aircraft On Station,
                           NQ(Awaiting Induction Queue),
                           NQ(Ramp_Q),
                           NQ(Hangar_Q),
                           NQ(Functional_Q),
                           NR(Ramp),
                           NR(Hangar),
                           NR(Functional),
                           MR(Ramp),
                           MR(Hangar),
                           MR(Functional),
                           NR(East Nancy Row),
                           NR(West Nancy Row),
                           NR(C4),
                           NR(W26),
                           NR(W27),
                           NR(Bldg 47),
                           NR(Bldg 48),
                           NR(Bldg 49),
                           NR(Bldg 81),
                           NR(Bldg 82):NEXT(76$);
```

```
;
;
;    Model statements for module:  Choose 6
;
76$          TRACE,        -1,"-Choosing from 2 options\n":;
1039$        BRANCH,       1:
                     If,Aircraft on Station .GT. 0,79$,Yes:
                     Else,77$,Yes;


;
;
;    Model statements for module:  Dispose 3
;
77$          TRACE,        -1,"-Disposing entity\n":;
1040$        DISPOSE;
```