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Examining EXPRESS with Simulation

David R. Williams

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Examining EXPRESS with Simulation

THESIS

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AFIT-OR-MS-ENS-12-27

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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EXAMINING EXPRESS WITH SIMULATION

THESIS

Presented to the Faculty
Department of Operational Sciences
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in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

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EXAMINING EXPRESS WITH SIMULATION

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//signed// 5 March 2012

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Abstract

The Execution and Prioritization of Repair Support System (EXPRESS) is a database tool used by the Air Force (AF) to prioritize depot maintenance of reparable spare parts in order to maximize responsiveness to warfighter need. Many studies have examined individual portions of EXPRESS, though few examine it as an entire system. This effort proposes a modeling approach for examining overall system behavior of EXPRESS using discrete event simulation. The emphasis of the model is to be flexible enough to provide useful insight into system performance, while also remaining open ended enough to provide a foundation for future expansion and analysis.

A case study involving three reparable parts managed by EXPRESS, based on six months of real world data, focuses on total Mission Capability (MICAP) hours as a measure of responsiveness to customer need. The model is validated using data on actual MICAP hours for the modeled period. The case study simulation is then used to study the impact on responsiveness and repair behavior resulting from running EXPRESS less frequently. Output data points to increases in total MICAP hours and variance in repair workload as run frequency decreases. The conclusion is that running EXPRESS less frequently negatively impacts system performance for both the maintenance and warfighter communities.

The God of the universe presents marvelous fingerprints of his glory throughout creation (Isaiah 6:3, Psalm 8:1). This study has been an incredible journey, every step of which has uncovered for me more reasons to worship him. I will seek him always.

This work would not be possible were it not for the continual support and encouragement from my wife. Thank you my dearest love.

To my son who was born in the middle of this project: may you one day learn of numbers, people, and of the God who created them both.

Acknowledgements

I would like to thank my thesis advisor, Dr. J. O. Miller, for his continual guidance and support throughout this effort. His continual leadership in my studies has been the driving force behind my research and time at AFIT. From the forklifts of Yellow Trucking Company, to the study of Air Force supply chains and depot maintenance, his mentorship and technical expertise have lead me to become a better student and analyst.

This thesis would not have been possible without the constant support from the staff of the Air Force Global Logistics Support Center. Thank you to Mark Fryman for introducing me to the Air Force supply chain and the issues surrounding EXPRESS and depot maintenance. To those fighting in the trenches at the Oklahoma City ALC (Steve Roberts, Lee Anna Coil, Sarah Hand), thank you for taking so much of your time to show me the real world. And for the week-by-week (and sometimes hour-by-hour) mentoring, education, expertise, and endless data collection, my biggest thanks go to Robert Walker and the EXPRESS program office. Without your support this effort would never have happened.

David R. Williams

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EXAMINING EXPRESS WITH SIMULATION

I. Introduction

1.1 Background

The United States Air Force (AF) manages one of the most complex supply chains in the world. The task of managing the AF reparable supply chain falls on one organization: the Air Force Global Logistics Support Center (AFGLSC). Founded in 2007 as an independent center within the Air Force Materiel Command (AFMC) the AFGLSC ensures AF expeditionary capabilities by providing supply chain planning and execution, operations support, and enterprise management solutions for the more than 100,000 different reparable parts in the AF inventory.

One of the critical facets of the AF reparable supply chain is depot maintenance. The repair of many reparable items requires rare skills or machinery. These skills are not always available at the locations where the AF operates and are normally managed at one of several centrally located depot maintenance facilities, or Air Logistics Centers (ALCs), operated by AFMC. The tracking and maintenance of reparable parts is a huge enterprise for the AF in terms of both budget and personnel. The skills, equipment, and facilities required to perform spares depot maintenance require more than \$2.8B per year to operate, and managing the reparable supply chain employs more than 1,200 people [35]. Despite the huge amount of resources allocated to depot maintenance, there is rarely enough capacity available to repair every item as it breaks. Thus what to repair, and where to send it once it is fixed, especially in a constrained maintenance environment, is a very important problem to the AFGLSC and ALC communities. In light of this, the Execution and Prioritization of Repair Support System (EXPRESS) was developed to prioritize which parts are repaired by the ALCs and where they are sent once they are done.

1.2 Problem Statement

The primary goal of this effort is to gain insight into the overarching system behavior of EXPRESS and the portion of the depot repair process that it manages. With hopes of beginning a larger movement of analytical study of EXPRESS as a system, the modeling strategy is twofold: first to structure a model in a way that is flexible enough to allow follow-on study to expand upon it in a variety of directions, and second to have enough resemblance to the real system that useful output can be generated. In specific, this study will use a discrete event simulation to examine the impact of running EXPRESS less frequently on the depot repair process's ability to respond to warfighter need.

1.3 Scope

This effort focuses on the portion of the reparable spares depot repair process managed by EXPRESS. Figure 1.1, adapted from [12] shows the overarching structure of the depot repair process and the different AF organizations involved. The portion to the right of the dotted line is the focus of this research.

EXPRESS uses current data on reparable asset positions, near-term warfighter scenarios, and ALC capabilities to prioritize distribution and inductions in a way that maximizes the likelihood of meeting Weapon System (WS) availability goals while also staying feasible to the ALCs constraints. The complex set of algorithms and data sources used to perform this task have historically been analyzed individually with the goal of optimizing a small portion of the system. This effort looks at the system

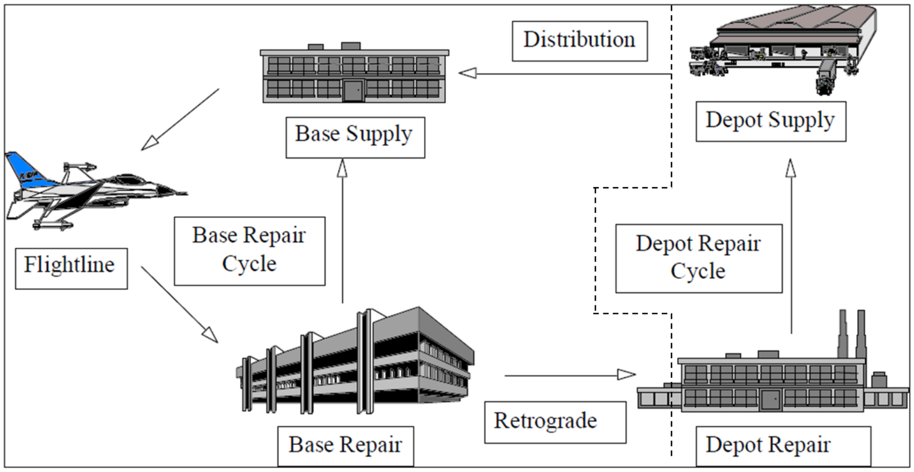

Figure 1.1. Repairable Pipeline, adapted from [12]

as a whole in an attempt to understand overarching behavior and configuration. This system includes the portion of the AF supply chain immediately flowing into and out of depot repair, the various modules within EXPRESS itself, and the ALC repair process. Those few reparable items EXPRESS does not manage are not considered here.

The incredibly complex nature of this system leads to simulation as the overarching modeling methodology. A discrete event simulation written in Arena® becomes the backbone that is flexible enough for future studies to expand on it while also measuring Customer Wait Time (CWT) and Mission Capability (MICAP) days.

1.4 System Background and Related Research

1.4.1 Development.

1.4.1.1 Quarterly Negotiations.

Prior to the 1980s, depot maintenance work levels were directed by quarterly negotiations between the supply and maintenance communities. Four times per year forecasts of reparable spares needs were conducted based on data that was six to nine months old in order to quantify demand for the next quarter. These figures were used to establish the working level of the depot for the next quarter, with minimal adjustment in response to changes in demand between meetings. The benefits of this method fell mainly to the maintainers, who were afforded the ability to plan their working schedules and tool usage well in advance. These efficiencies at the maintenance level, however, tied together with the age of the data used in the forecasts, resulted in a supply community that could not respond to the continually changing need of the warfighters they supported.

1.4.1.2 UMMIPS.

Department of Defense Directive (DoDD) 4140.1-R dictates, in section C8.8, the use of Uniform Materiel Movement and Issue Priority (UMMIPS) "for allocating materiel and other logistics resources among competing demands" [3]. The implementation of UMMIPS by the AF is regulated in Chapter 24 of the AF Supply Chain Manual, Volume 1, Part 1 [5]. Every unit with a need for spare parts is categorized with a force/activity designator as well as an urgency of need designator. UMMIPS gives AF Item Managers (IMs) overall guidance on requirement priority, and prior to the development of more rigorous tools was used to prioritize depot repair actions. Culosi and Eichorn describe UMMIPS as a "pull" mentality to allocating spares where units pull spares based on their need [25]. The system was used from its implementation in 1962 as the primary spares distribution tool until the AF received a waiver in 1993 to use the more comprehensive approach offered by the Distribution and Repair in Variable Environments (DRIVE) to prioritizing needs [9].

1.4.1.3 DRIVE.

In the 1980s it became clear that a better way of prioritizing reparable inductions into and distributions out of depot repair was needed [24, 23, 25]. Repair planning needed a more comprehensive and up-to-date supply chain perspective. It also needed to rely less on forecasted values for warfighter demand and focus on aircraft availability. A series of studies done under RAND's Uncertainty Project resulted in a new prioritization system called DRIVE [7, 29].

The logic behind DRIVE was the result of the Uncertainty Project's conclusion that forecasting demand of reparable parts in the volatile world of air power was impractical. In no way can the amount of uncertainty surrounding future part failures be forecasted in enough detail to result in affordable low-risk maintenance scheduling. Instead, over very short planning horizons, repair efforts should be tied to aircraft availability goals which are determined by a dynamic and ever-changing supply chain. As stated by Abell et al, this is accomplished when

> very current snapshots of the worldwide asset position, coupled with specified aircraft availability goals, are used by a computer based algorithm called [DRIVE] to prioritize component repairs and allocate the assets to locations worldwide in a way that maximizes the probability of achieving the availability goals. This approach contrasts sharply with the current component repair system in which component repairs are a matter of negotiation at the ALC based on estimated repair requirements... [7].

DRIVE used asset position data from the field that was only a couple of days old, along with warfighter scenario data for the near future, to output two lists: a repair list for the depots and an allocation list for the IMs to use for distribution [7]. Comparing this to the UMMIPS "pull" mentality, DRIVE becomes the "push" alternative in which the supply chain sends parts where they will be needed most. The computer algorithm employed ensures that the two output lists are sequenced in a way that maximizes availability while also minimizing cost. After successful demonstrations at the Ogden ALC, the AF slowly implemented DRIVE logic across its catalogue of reparable items beginning in 1993 [7, 20].

1.4.1.4 EXPRESS.

As seen in the AFMC Studies and Analysis Office annual report from 1995, the command had begun work on a single framework to determine which parts to put into repair and where to send them once they were serviceable [10]. This was accomplished by combining the best parts of several competing approaches used throughout the command: the Automated Induction System (AIS) used by Oklahoma City, and both DRIVE and the Supportability Module used at Ogden. The command was already implementing DRIVE logic to prioritize maintenance inductions for more and more weapons systems, and had begun using its prioritization scheme in the distribution of parts once they had been repaired. AIS was a system that generated maintenance requirements for a part if its status fell below the desired working level. Ogden's Supportability Module was designed to provide "an automated interface with depot management systems to examine whether or not the items needing repair were supportable for repair parts and other resources." The resulting single decision system for the command was to be called Execution and Prioritization of Repair Support System, or EXPRESS.

By 1996, the command began implementing the use of EXPRESS as a part of its Depot Repair Enhancement Process (DREP) initiatives (explained further in subsection 1.4.3), with full implementation starting in 1999 [36, 13]. AFMC dictates the implementation of EXPRESS in AFMCI 23-120 [4]. As well as the function adopted for prioritization from DRIVE, stock leveling from AIS, and constraint implementation from Supportability Module, EXPRESS uses an expansive data services module to capture a daily picture of the reparable supply chain positions as well as user scenario data. The different modules and data interfaces are described below. Minor changes have been made as analysis and best practices have pointed to better ways of doing business, but EXPRESS remains the primary way the AF manages the repair of parts to this day.

1.4.2 Structure and Execution.

The overarching structure of EXPRESS can be broken down into four processes: data services, prioritization, execution (supportability), and distribution [11, 13]. Figure 1.2 gives a top-level idea of the flow of information within EXPRESS from data gathering to the other modules. Current operations have EXPRESS run every day. One of the investigation points of this effort is to determine the impacts on customer responsiveness of running EXPRESS less frequently: something highly desirable to maintenance work planners attempting to maximize efficiency and load leveling. EXPRESS only prioritizes inductions for reparable parts. These inductions comprise only a portion of the work done at the depots, which also perform Programmed Depot Maintenance (PDM) on the aircraft in the fleet. This effort assumes reparable work happens independently from PDM.

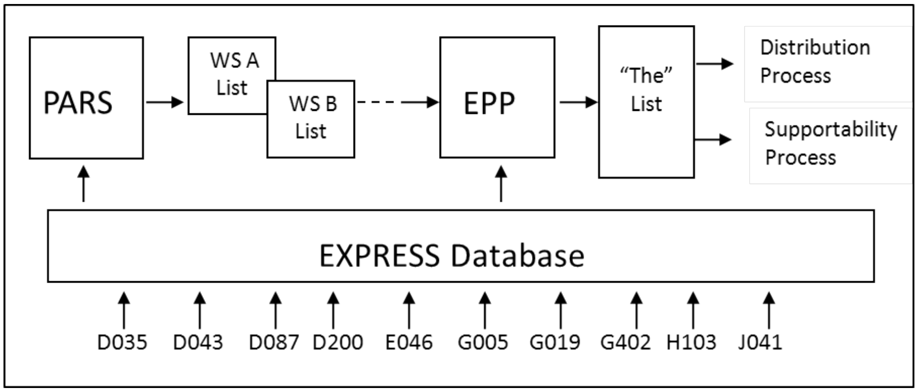

Figure 1.2. EXPRESS Data Flow

Data Services: The data services component gathers current position data daily from a variety of databases across the supply chain community. Modern computing systems allow EXPRESS access to data that is less than a day old for asset levels, backorder details, repair statuses, and projected warfighter needs. On a quarterly basis data is updated on item-unique information such as demand rates, applications of parts, and stock leveling goals. Once the current operating picture has been gathered, EXPRESS then proceeds to the prioritization process.

Prioritization and Distribution: Once data has been gathered, the next task for EXPRESS is to determine what needs to be repaired. This is accomplished by the Prioritization of Aircraft Reparable Spares (PARS) process: the portion of the EXPRESS logic that has evolved primarily from DRIVE. It uses a greedy marginal-analytic algorithm to create a prioritized repair needs list for each WS. These lists contain every requirement theoretically needed to meet availability goals for the given WS over the planning horizon, and consider both warfighter flying hour scenarios and current part position data. These lists usually total hundreds of thousands of items and are generated, due to the sensitivity of the warfighter scenario data, on a classified server. The details of the greedy marginal-analytic algorithm are considered beyond the scope of this effort. The global perspective taken by EXPRESS when prioritizing repairs dictates that modeling the logic would require an extensive model of the entire AF reparable supply chain: something not available at the time of this effort. For a detailed discussion of how parts are added to the output lists, refer to the series of RAND publications or AFMC working documents discussing the logic of DRIVE [7, 29, 30]. Details of the simplifying assumptions taken in the modeling strategy for this effort are detailed in chapter II.

Requisitions from the field, or Back Orders (BOs), with MICAP status (occurring when a base has more unmet BOs than its allowable holes) are given an AF level priority in the form of a Spares Priority Release Sequence (SPRS) designation derived from rules established at the June 1999 CORONA meeting. These rules dictate a SPRS mapping of 84 be given to the highest AF needs and a blank assignment given to the lowest. All requisitions are matched up with DRIVE-optimized requirements to create a list for each WS that is ranked by SPRS category, and then by DRIVE priority.

The Single Prioritization Across Weapon Systems (SPAWS) process joins the individual WS lists into a master list that balances the needs of the entire fleet. This is done by calculating the total repair cost for each WS costs and dividing by the fleet's total repair cost. This percentage is used as the repair portfolio proportion goal for that WS, and requirements are ranked within their SPRS designations in a way that gives the most bang for the buck under this goal (specifically, each additional part is assigned so that the mean square error from the portfolio mix goal is minimized).

The EXPRESS Prioritization Processor (EPP) puts on the finishing touches by factoring in requirements from Foreign Military Sales (FMS) and joint requisitions. Once all requisitions are on one list, FMS and joint requirements are added into their respective SPRS category, EPP then assigns a code to each requirement based on how it will be addressed by maintenance. A requirement can be satisfied by a fixed part on hand at the depot being shipped to fill the need, a part On Work Order (OWO) can be matched to it, or a new maintenance action can begin to fix a broken but fixable part (or carcass). Distribution actions are added to a list that is sent to the supply chain system used to distribute parts (D035A). Those requirements driving new maintenance actions are sent to the supportability module to assess if the induction is feasible.

Supportability: Requirements from prioritization that are not matched by on hand or OWO parts become the bill of labor for the depot maintainers. It is in the supportability process that the constraints from maintenance and individual shop supply are considered at four levels: carcass, capacity, funds, and parts consecutively. The master prioritization list is broken out to each ALC shop, and parts are inducted for maintenance down the list until one of the four constraints prevents it. Controls available to the maintenance supervisors allow their feedback on real-time shop capacities to tailor the supportability process to the day-to-day operations of their shop. The supportability constraints are based on the theoretical capability shop, given its full array of resources are available. But what if a worker is sick? What if a critical piece of equipment is down? There are several logic switches available to the maintenance schedulers that are designed to allow them to tailor the supportability process to further reflect current operational limitations. There are also ways of setting maximum values for induction based on the shop's ability to house and handle parts.

1.4.3 Measures of Performance.

If a part fails that cannot be fixed at the base, and the supply chain has not maintained an adequate available stock for it to be replaced, the mission capability of that war fighting unit is decreased. The Depot Repair Enhancement Process is an initiative to measure supply chain and maintenance success based on responsiveness to customer need [2]. This thesis effort will focus on two key metrics derived from the DREP process: CWT and MICAP hours. Customer Wait Time, the total amount of time spent waiting for parts to come from depot maintenance, is a key metric in measuring the responsiveness of the depot repair process to customer need [1]. Those failures that directly impact mission capability are given the special designation of MICAP, indicating that all base-level safety stock has been depleted and the WS is not able to operate until a replacement part is received. So an even more critical measure of responsiveness to customer need is the amount of time spent in MICAP status due to repair or unavailability of parts.

1.4.4 Previous Analysis.

An extensive amount of analysis has been conducted during the development and operation of EXPRESS, most having focused on its individual algorithms or informational flows. The cornerstone research done by RAND in its Uncertainty Project calling for and later developing the prioritization algorithms used in DRIVE are still the key papers backing the algorithms in EXPRESS [24, 23, 7, 29, 28, 30, 31]. During the implementation of DRIVE, several analyses, including student research at the Air Force Institute of Technology (AFIT), concluded that the AF would benefit by switching to DRIVE exclusively [25, 18, 20, 26].

Once AFMC moved to the structure of EXPRESS, which uses the already digested prioritization algorithms from DRIVE, research moved to asking higher level questions. One study done within AFMC examined what the impact would be on the ability of EXPRESS to meet warfighter need if there were a 30% increase in AF peacetime flying hours [17]. Another quelled ideas that a return to a UMMIPS-based prioritization scheme would be an improvement to the EXPRESS aircraft availability based scheme [16]. Another paper proposes the use of EXPRESS to redistribute reparable parts between Stock Record Account Numbers (SRANs) in order to address desperate needs [22]. Carter and London made the keen observations of a hole in the structure of EXPRESS logic when they wrote about AWP LRUs in the *Air Force Journal of Logistics* [21]. At the time, when requirements on the prioritization list were skipped over for induction due to a constraint on parts availability, no update to the ordering system for parts was ever made. Thus demand for parts was not updated despite demand, and many reparable parts were left awaiting parts for long periods of time. This has since been fixed, and EXPRESS now interfaces with ordering systems between parts vendors [6].

It is natural, when analyzing a large system such as EXPRESS, to search out examples of similar maintenance prioritization systems implemented in the commercial or defense sectors for comparison. As of the writing of this report, the Air Force Research Laboratory (AFRL) is attempting to seek out analogues of EXPRESS in the commercial sector for comparative study [35]. However, EXPRESS is unique in two ways: there are few examples of spares demand with greater variability than the AF depot repair process, and the mission of the AF demands a fleet with many WSs that are not profitable in terms of reliability. Both of these qualities point to EXPRESS filling a unique roll and make comparison to other maintenance systems difficult [15].

Though much investigation has surrounded portions of EXPRESS, very few efforts focus on modeling the system as a whole in order to study overarching system behavior or compare different system configurations. One key simulation by Stafford of AFMC focused on periodicity of EXPRESS runs and the results on aircraft availability [34]. A simulation referred to as the Supply Chain Operational Performance Evaluator (SCOPE for short) ran with different EXPRESS periodicities to produce prioritized lists. It also varied the amount of repair capacity reduced after each run due to reconfiguring the workshop, with 2%, 5%, and 10% as the design points. The study modeled 1,249 WSs, 49 SRANs, 598 parts, and ran for 250 simulation days after a 100 day warm-up period. The conclusion was that there may be potential gains in aircraft availability when running EXPRESS less frequently, depending on the impact from reconfiguration. Aside from this study, little has been done in simulating EXPRESS as a system, though AFMC has continued to pay attention to the periodicity issue [15]. This research attempts to bridge the gap for system-level analysis using simulation, while continuing to examine the impact of running EXPRESS less frequently.

1.5 Methodology

This effort models the EXPRESS system within the confines of a notional ALC as parts arrive needing maintenance, are repaired, and then leave to be distributed. The primary investigation focuses on the impact on CWT and MICAP hours (measured in days throughout this effort) resulting from running EXPRESS at different frequencies. In the real world, a large portion of the variance observed in these metrics is due to the complex behavior of the AF supply chain before and after the depot. However, in order to understand what portion of the total CWT and MICAP time is attributable to EXPRESS and ALC behavior, none of this surrounding supply chain is modeled.

The depot repair process is a very complex system that changes in response to variation in warfighter demand. The goal of understanding the inner workings of the system, as well as the desire to measure the impact on the behavior of such a complex system due to changes in performance settings, point to the use of simulation as a modeling tool [19]. The performance of the EXPRESS system changes over time and is driven by events occurring at discrete points. Kelton et al discuss that these characteristics are key signs that discrete event simulation would be an appropriate tool [27]. North and Macal's text on agent based modeling and simulation outlines when discrete even simulation is the most appropriate style of simulation [32]. They point out that it is most useful if the structure of the system does not change over time, and the process is fairly established and understood. Though other forms of simulation may be more appropriate in subsequent studies of EXPRESS, the central process is modeled here using a discrete event simulation in Arena.

1.6 Outline

The scope of this project is broken down as follows: Chapter 2, formatted as a standalone journal article, goes into detail on how the system is modeled and presents a case study of input taken from a set of repair shops, parts, and bases, comparing simulation output with real world behavior. Chapter 3, a conference paper, compares changes in system behavior due to changes in how often EXPRESS is run. Chapter 4 discusses key results, insights into the system gained from the modeling approach, as well as suggestions for further research.

II. Modeling EXPRESS: A Discrete Event Simulation Approach

2.1 Introduction

Prioritizing depot maintenance is a very important issue for the Air Force (AF). Nearly every weapon system in the inventory relies on depot maintenance to stay mission capable. Reparable parts that fail which cannot be fixed at their operating base are sent to be fixed at one of the Air Force Materiel Command (AFMC) Air Logistics Centers (ALCs). The constraints imposed at the ALCs by carcass availability, repair resource capacity, budget, and replacement parts require that maintenance be prioritized in order to most effectively address warfighter needs. This is accomplished by the Execution and Prioritization of Repair Support System (EXPRESS): a database tool managed by the Air Force Global Logistics Support Center (AFGLSC) that takes into account real time position data from the depot supply chain to produce a prioritized list of maintenance and distribution actions that maximize the likelihood that the fleet's availability goals are met for the least cost.

This effort examines the structure and performance of the EXPRESS-managed depot repair process using a discrete event simulation. With the goal of forerunning a larger movement of using simulation to study EXPRESS at the system-level, the modeling strategy here is twofold: first, to structure a model in a way that maximizes flexibility for follow-on study, and second to have enough resemblance to the real system that useful output can be generated. The primary measures for system performance are derived from one of the Depot Repair Enhancement Process (DREP) measures of meeting customer need: Mission Capability (MICAP) hours [2].

Modeling EXPRESS behavior is not a new science. The prioritization logic used in EXPRESS is derived from the Distribution and Repair in Variable Environments (DRIVE) system, a predecessor to EXPRESS also used to prioritize depot maintenance. The development of DRIVE was the result of a series of RAND studies on uncertainty in supply chain behavior [24, 23], and the mathematical model used for prioritization has itself been the subject of much study [7, 29, 28, 8, 31]. AFMC has continued, since the adoption of EXPRESS in 1995, to model and analyze different logic components of EXPRESS in order to assess and optimize their performance [17, 16, 21]. Very little research has been done on EXPRESS, and the depot repair process it manages, as a system. There have been a limited number of in-house AF studies, one using simulation to understand system performance as a function of running EXPRESS less frequently [34]. This effort seeks to bridge the gap and pave the way for future simulation study and further understanding of EXPRESS as a system.

The rest of this paper is comprised of a detailed description of the approach taken in modeling EXPRESS, a case study of a portion of the AF supply chain using the proposed model, as well as initial analysis of simulation output.

2.2 Scope of Study

There are two kinds of depot repair. The more commonly known is Programmed Depot Maintenance (PDM), which occurs for most aircraft in the AF on a periodic basis and involves deep inspection and repairs. The second type, which EXPRESS manages, is reparable Line Replaceable Unit (LRU) maintenance done at the ALCs to keep spares inventories filled across the fleet. As this effort focuses on EXPRESS, it is only concerned with the portion of depot maintenance it manages. All modeling done of the maintenance process assumes reparable work is performed independent of PDM.

The AF reparable supply chain consists of over 100,000 parts. Hundreds of different repair shops fix broken parts for more than eighty Weapon Systems (WSs), and the actual database handles more than 200,000 records every day. As EXPRESS is essentially a database with complex rules for gathering and ranking its records, the primary entity moving through the model is analogous to one of these records moving through the different tables. EXPRESS manages both those requirements generated from actual part failures (requisitions, or Back Orders (BOs) as this paper will refer to them) as well as those required to maintain adequate safety stock at the ALCs and throughout the supply chain.

For the purpose of this effort, the supply chain considered is reduced to the parts flowing immediately into and out of an ALC in order to focus on EXPRESS and not get distracted by other supply chain elements. What are often very complex logistics tails between the warfighter and the ALC are ignored along with the stock required to keep it flowing, essentially flattening warfighter demand directly adjacent to the ALC. Also, the model handles only single-level part indenture. In the real system, a reparable item, or LRU, may consist of several Shop Replaceable Units (SRUs), each with a different repair process. This indenture hierarchy may go on for several layers. The parts in this study are considered to be at their lowest level of indenture and are repaired individually. Additional assumptions and limitations are addressed in the subsequent sections.

2.3 Modeling Approach

The complex nature of EXPRESS and the depot repair process it manages requires flexibility from the model employed to study it. The goal of understanding the inner workings of the system, as well as the desire to measure the behavior of such a complex system due to changes in performance settings, point to the use of simulation as a modeling tool [19]. Since EXPRESS runs on a daily basis, and changes at discrete points in time, a discrete event simulation coded in Arena is the selected analysis tool [27, 32].

The first task when modeling EXPRESS is to understand the underlying data hierarchy for what is tracked and repaired. The heart of the constrained environment is the ALC workshop, or Production Shop Scheduling Designator (PSSD). It is within each PSSD that the constraints of carcass, capacity, funds, and parts are imposed. Thus data exploration most effectively begins at the PSSD and works back to the warfighter it supports. Each PSSD is responsible for fixing a unique set of reparable parts, or National Stock Numbers (NSNs). They arrive at the depot requiring repair, are fixed by the PSSD employees and equipment, and are distributed back to be reused on a WS. A given part may be used on a single WS, or may be common between several.

In the EXPRESS tables, the identification code given for a user organization is a Stock Record Account Number (SRAN). SRANs represent individual stocks at flying bases that are normally housed within maintenance squadrons or intermediate supply chain stockpiles. Requirement prioritization calculations in EXPRESS consider the levels of each NSN for every SRAN in the AF supply chain resulting in a global optimal ranking for the fleet. The resulting relationships of PSSDs, NSNs, and SRANs are generically visualized in Figure 2.1. This relationship structure is important later in the modeling of part failure rates and PSSD capacities.

The next task is to create a logic flow usable by a simulation language that mimics the flow of records through EXPRESS and the depot repair process. This needs to include the processes of generating repair requirements, prioritizing them, distributing repaired parts according to their priority rank, and repairing them in priority order according to supportability constraints.

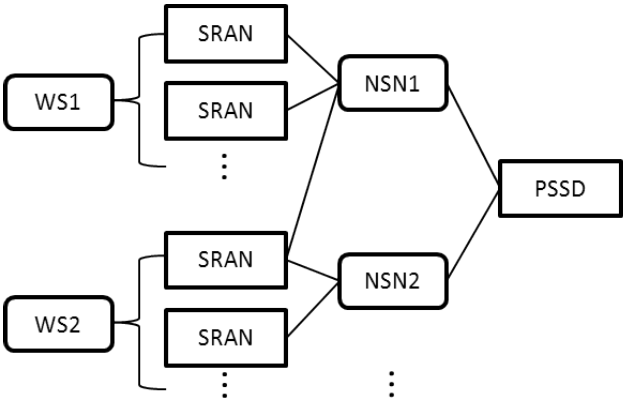

Figure 2.1. EXPRESS Data Hierarchy

To begin, part failures in the real world happen across the fleet and, as stated previously, EXPRESS considers every SRAN in the supply chain when prioritizing needs. Part failures are typically modeled for each SRAN,NSN combination using a negative binomial distribution–the average rate for which are tracked by the AF supply chain tool called D200. In order to scope the problem down for this study, failure generation is aggregated across SRANs into a smaller set of notional SRANs. This is done by summing the average daily failure rates of a subset of SRANs and using the sum as the average rate for the notional SRAN. Figure 2.2 summarizes this process. Since Arena does not have a built in function for generating negative binomial random variates, the failures in this study are generated using a Poisson distribution. This results in a reduction in variance from what is seen in practice, but allows for the demand aggregation since the sum of Poisson random variables is a Poisson random variable with mean equal to the sum of the individual means [33]. Use of a Poisson distribution here was considered a reasonable assumption by subject matter experts within AFMC and the AFGLSC [15, 35]. Additional abstractions of the real world system, and the accompanying assumptions described in the following sections, were also vetted with appropriate subject matter experts prior to implementation.

The Prioritization of Aircraft Reparable Spares (PARS) logic within EXPRESS considers both the safety stock at each base and the historic portion of failures handled by base repair units when deciding how many requirements to generate and prioritize. This model considers neither: every failure is considered to flow directly to the depot for repair without base repair attempting to fix it. And where there is normally a stock at each SRAN to mitigate demand variability, this effort assumes any part failing comes off of a WS, and any failure that causes too many non-mission capable WSs gains MICAP status.

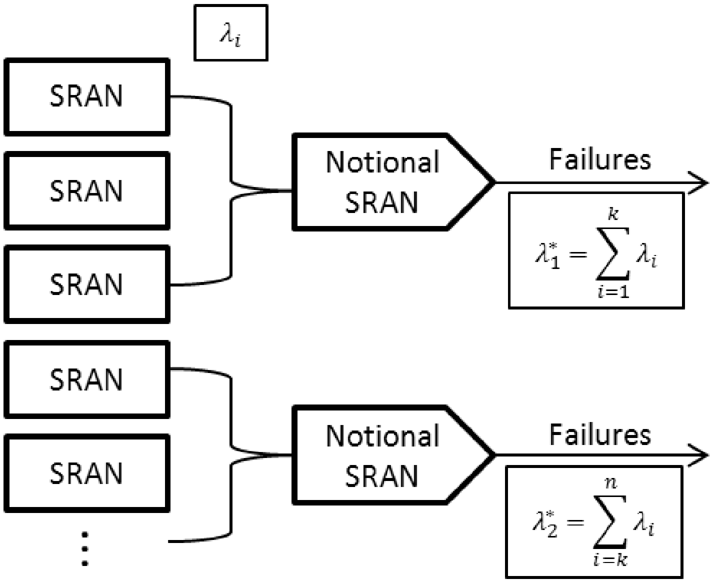

Figure 2.2. SRAN Parameter Aggregation

MICAP & SPRS: Those BOs that have MICAP status are given special priority in EXPRESS through Spares Priority Release Sequence (SPRS) categorization. Any failure that results in a total number of BOs more than the given SRAN's allowable holes is given MICAP status as can be seen in Figure 2.3 (this assumes parts are cannibalized in order to maximize WS availability).[1] Rules established at the 1999

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[1] Allowable holes outputs of calculations done during the PARS logic to determine each base's need. Since the supply chain has been reduced, and the prioritization logic has been simplified, allowable holes are set in a way that produces a representative portion of depot work going to MICAP requirements.

CORONA meeting determine which MICAP parts are most important based on mission priority, location, and depth of need using SPRS categories ranging from 10 to 84 [13]. We model this by stochastically assigning a SPRS attribute to MICAP BOs. In order to emulate the SPRS behavior of some bases receiving higher priority, our notional SRANs are each assigned an average SPRS value and the entities' SPRS attributes are drawn from an exponential distribution (with a ceiling of 84). In the simulation, after SPRS categories are assigned to MICAP BOs, the requirements are duplicated and the copies go on to perform two logical functions: one enters the EXPRESS process while the other waits in a queue representing the SRAN's outstanding needs. Those continuing join the rest of the requirements in the remaining fine-tune prioritization.

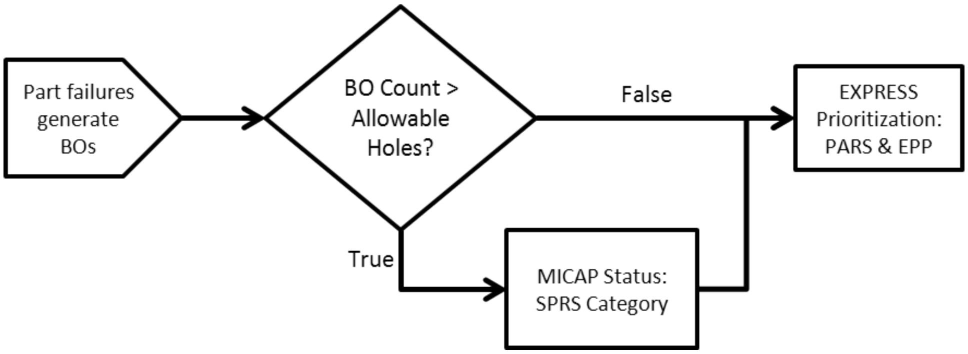

Figure 2.3. Decision logic for determining MICAP status

<u>Prioritization: PARS, EPP:</u> Within SPRS categories (non-MICAP BOs receiving a category of 00), EXPRESS prioritizes repair requirements using logic derived from DRIVE. This process begins with PARS: a math model that forecasts and prioritizes requirements needed to achieve aircraft availability goals over short planning horizons and matches them with any existing BO information. Additional processing follows within the Single Prioritization Across Weapon Systems (SPAWS) algorithm which balances fleet needs and consolidates all requirements into one list. And finally the EXPRESS Prioritization Processor (EPP) adds requirements for foreign military sales

and joint requirements to the list, and then matches parts on hand or On Work Order (OWO) at the depot to the highest priority items. The result is a master prioritized list of every requirement needed to meet the fleet's needs and the ways they are satisfied through the current repair positions. The downside for the modeler is the amount of supply chain resolution required to make calculations in the same way as these logic modules. For this study we forgo explicit modeling of EXPRESS prioritization within SPRS categories. Instead a uniform random number draw from zero to one is added to the SPRS rank attribute for each BO and PARS requirement to result in a final rank.

In order to explain how PARS requirements are generated in the model, it is first necessary to briefly outline how EXPRESS generates requirements. The DRIVE model implemented in EXPRESS seeks to maximize the likelihood that aircraft availability goals are met across the fleet. Mathematically it seeks to maximize

$$P[failures < on\_hand\_stock + allowable\_holes] \tag{2.1}$$

where we assume

$$failures \sim Poisson(avg\_daily\_failures * planning\_horizon\_days) \tag{2.2}$$

This is generally accomplished by calculating this probability for each base using current position data, and then calculating it again after adding one notional part. The base with the greatest marginal gain "receives" the part by having a requirement added to the master list, and a sort value is determined from a series of equations. This is accomplished until marginal gains go below a set threshold [30, 29].

Since on hand stock at the bases is not modeled, Equation 2.1 simplifies to maximizing $P[failures < allowable\_holes]$. And since the specific prioritization schemes are not important, only the number of requirements to generate, the model uses $P[failures < allowable\_holes + PARS] >= .95$, and solves for $PARS$ to determine how many requirements should be in the system, making .05 the effective threshold for marginal gain. The number of BOs has already already been determined when this algorithm is executed, so the model generates $PARS - BO\_Count$ requirement entities of type PARS. These PARS requirements are generated as separate entities and are assigned a rank attribute drawn from a uniform random variable between zero and one before they join the BO entities on the final prioritized list. This list is modeled using a queue ranked according to the rank attribute of each entity in line, highest released first.

<u>Distribution:</u> The next stop for our requirement entities is distribution. EXPRESS starts at the top of the final prioritized list and distributes any parts on hand according to priority order. The simulation accomplishes this by releasing the prioritized BO entities queued at the prioritized list node to see if there are parts on hand of the same type. If there are, a signal is sent to the SRAN of the BO to release the highest priority requirement waiting to be fulfilled. This entity's wait time is added to the total CWT variable (and to the total MICAP variable if applicable), the on hand stock is decremented, and BO and waiting requirement are both disposed of. PARS requirements are used to keep the depot pipeline charged and not, as in the real system, to maintain adequate parts at the bases and in the distribution pipelines. For this model they do not have a generating SRAN and are not considered for distribution. It is only during the matching of distribution that BO requirements are fulfilled and disposed.

The next step of EXPRESS execution is to match those requirements not fulfilled through distribution with parts currently OWO. These requirements are retained for subsequent runs until they are fulfilled with on hand parts. Requirements without a matching OWO part continue on to the supportability logic to attempt to be inducted for repair.

WL Requirements: EXPRESS ensures enough requirements enter supportability to maintain an adequate level of parts OWO and on hand by generating requirements with SRAN equal to the working level target for the explicit purpose of attempting supportability and repair. This level is calculated by different supply chain systems in the AF and is referred to in the EXPRESS tables as *w_level*. EXPRESS caps the number of considered requirements each day at $BO\_Count + w\_level$. Commensurate with EXPRESS rules, those requirements that are not matched with on hand or OWO parts are duplicated and passed on to the supportability module. The duplicates are assigned an entity type of WL to represent their fulfillment of working level need.

Supportability: The supportability constraints are processed in the following order: carcass, hours (capacity), funds, and parts (replacement components). The supportability module starts at the top of the prioritized list and checks to see if its PSSD can support the requirement in terms of the four constraints, and those that pass for all of them are inducted.

The only constraint explicitly modeled is shop capacity measured in labor hours available. Each PSSD has a fixed repair hour capacity which is decremented by the number of hours required to repair a part when it is inducted. Thus a part will pass the capacity constraint if there are enough remaining hours in the PSSDs capacity to induct it. Historically 45-48% of requirements meeting supportability pass for carcass. Carcasses are LRUs that failed previously at a base and have been shipped back to the depot for repair. Both the carcass and parts constraints represent complex supply chains that could be modeled in depth in future studies. Historically, those requirements passing for carcass pass for capacity 45-48% of the time. The fund constraint has largely not been a binding one in the past, though research into this aspect of the problem is of interest [35]. In the past, roughly 99% pass for funds; for this effort 100% pass during the supportability check (the 1% difference in incorporated into the parts check as seen below). Finally, of those passing for carcass, capacity, and funds, roughly 30% pass for parts. In order to roughly mimic the stochastic nature behind the carcass and parts constraints, the number of a given NSN allowed to pass each supportability constraint is calculated by:

$$Allowed_{NSN,t} = Count_{NSN,t} * X \tag{2.3}$$

where $X \sim Exponential$ with mean of .45 for carcass, and $(.45)(.5)(1)(.3) = .07$ for parts. Requirements meeting supportability are processed in priority order one at a time. If a requirement passes for all constraints, it is inducted for maintenance and the depot's resources are decremented appropriately. Thus once a requirement fails, all subsequent requirements fail since the shop is now full.

Repair: Once a requirement passes supportability it enters a delay representing maintenance. It is assumed that repair will behave according to historic trends, and the case study in section 2.4 parameterizes the distributions for three actual parts for use in the simulation. Repair could be modeled in much higher fidelity, with concern given to back-shop processes and delay times. However this study simplifies the process to a simple delay. Once the part has completed its repair, it enters the depot's on-hand stock and can be used for future distribution. Like those matched with OWO, the requirements driving new repair actions are not fulfilled until they are matched for distribution. Thus they initiate a repair action and then, if they are a BO, return to be processed the next day. PARS and WL entities are disposed of at this point since they are generated new each day. The complete modeled process, from requirement generation to prioritization to distribution, supportability, and maintenance, is summarized in Figure 2.4. Screen shots of the Arena simulation can be found in Appendix A.

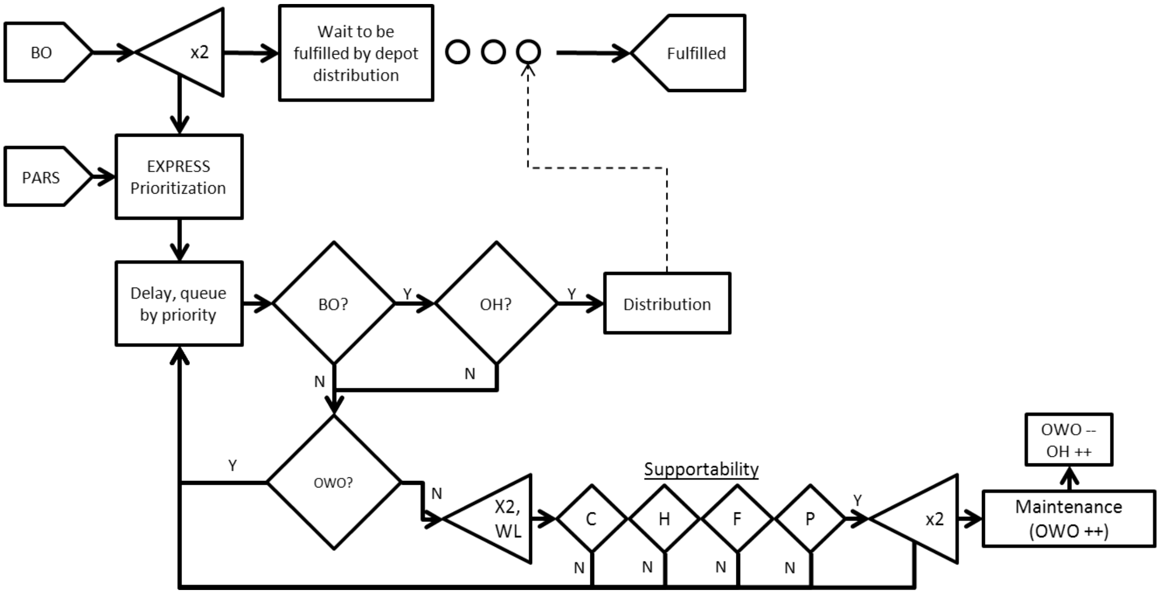

Figure 2.4. Overall Model Logic Flow

System Performance Metrics: This thesis effort focuses on one key metric derived from the DREP process for measuring system performance: MICAP hours [2]. Customer Wait Time (CWT), a related system performance metric, is defined as the total amount of time spent by the user waiting for parts to come from depot maintenance [1]. Those failures that directly impact mission capability are given the special designation of MICAP, indicating that all base-level safety stock has been depleted and WS is not able to operate until a part is received. So an even more critical measure of responsiveness to customer need is the amount of time spent in MICAP status due to depot maintenance. In the simulation, CWT is measured for every BO and begins at the time it is generated. It ends when the BO is fulfilled by distribution. MICAP hours is the CWT for those BOs that have MICAP status. Instead of hours, since this model steps through time in days, CWT and MICAP hours are measured in days; the conversion back into hours is performed by multiplying by 24.

2.4 Case Study

This case study applies the modeling approach presented above to a set of real world data from the EXPRESS process. Simulation parameters are based on data for a subset of the NSNs repaired by two PSSDs at the Oklahoma City ALC. Requirement generation is based on a set of notional SRANs aggregated from those actually supported by the NSNs. Real world EXPRESS data on the workload of the repair shops, daily system performance, and MICAP days are used to validate simulation output. All data, unless otherwise specified, comes from the six month period between 3 January 2011 and 30 June 2011.

One of the many complicating dimensions of the EXPRESS system is the behavior of repair across all PSSDs. Some parts have short repair times, or Shop Flow Days (SFD), while others require long periods of time to fix. Additionally each part requires a specified number of labor hours to repair as calculated by engineering estimates at the shop. In order to represent the breadth of this spectrum, the two shops selected for this study are MTAA9D and MTBB9F. MTAA9D (referred to in the model as PSSD 1) repairs small components for the F-16 that require only a few labor hours to repair, while MTBB9F (PSSD 2) is a structures shop that repairs large items, requiring many hours to complete, for the KC-135. These shops are selected based on subject matter expert opinion [6]. Data for the selected PSSDs from the *SptResults* table (daily supportability results for every requirement) was concatenated over the six months and the resulting data tables were used to generate several parameters. Table 2.1 summarizes data for each National Item Identification Number (NIIN) repaired by the selected shops.[2] Outlined are statistical values on SPAWS rank (final prioritization value, highest priority has value of 1), the total number that passed supportability, average capacity and fund costs, as well as the hours inducted per part (equal to the number inducted times the part's cost in hours) and the percent of the total work inducted accounted for by the given part (part hours divided by total shop hours).

Table 2.1. Selected PSSD Statistics by NSN

PSSD	NIIN	Count Req	Avg SPAWS Rank	Min SPAWS Rank	Count Passing	Avg Hours	Avg Cost	Hours Inducted	% Hours
MTBB9F	**1095725**	**2562**	**101151**	**67795**	**38**	**773**	**$172,639**	**29374**	**0.8927**
MTBB9F	3367412	99	65446	33302	0	10	$1,291	0	0.0000
MTBB9F	6317598	83	84420	71106	32	110	$24,508	3530	0.1073
MTAA9D	11479116	284	73737	33329	29	15	$7,023	431	0.0749
MTAA9D	11479117	65	38781	32790	0	26	$11,043	0	0.0000
MTAA9D	11493168	156	74283	37162	9	18	$7,445	166	0.0288
MTAA9D	11780487	1467	90411	43904	31	67	$22,337	2074	0.3600
MTAA9D	11922637	2341	58603	41432	0	19	$9,056	0	0.0000
MTAA9D	12267238	1900	115241	37715	13	21	$8,672	273	0.0474
MTAA9D	12276669	13	69812	51074	5	22	$6,818	109	0.0190
MTAA9D	13079079	858	99171	89376	0	26	$5,377	0	0.0000
MTAA9D	**13130343**	**3315**	**47695**	**43**	**81**	**21**	**$16,760**	**1662**	**0.2886**
MTAA9D	13633031	27	82739	12036	0	7	$1,134	0	0.0000
MTAA9D	**13903690**	**2953**	**54268**	**18**	**50**	**21**	**$18,453**	**1045**	**0.1814**

The parts selected from among those repaired by these PSSDs were chosen based on a combination of the portion of the work they represent for the given shop and their average SPAWS rank. For MTAA9D, the selected parts are NIINs 13130343 and 13903690 and for MTBB9F, NIIN 1095725 (referred to as parts 1, 2, and 3 respectively). These parts, bolded in Table 2.1, account for the majority of their respective shop's labor, and tend to be the highest priority items. Table 2.2 outlines, over the studied period, the average desired working levels, the aggregated failure rates, the portion of the total hours inducted for the part's PSSD, the planning horizon

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[2] NIIN and NSN are considered synonymous. A NSN is a 13-position alpha/numeric field assigned to each item of supply under the federal catalog system. The NSN is composed of the applicable four-position Federal Supply Classification (FSC) plus the applicable nine-position NIIN [14].

in days (equal to the average of the maintenance delay distribution), and the fitted distribution for the delay for maintenance taken from D200 over the studied period. The aggregated failure rates are calculated by averaging the *daily_demand_rate* field from the *PartBase* table for any SRAN with rate greater than zero over the model's time frame, and then summing these averages to represent the fleet's average total demand for the given part. Due to the fact that only a subset of the parts repaired for each selected repair shop are modeled, the capacities for the PSSDs must be scaled down in order to achieve an appropriately constrained repair environment. This is accomplished by summing up the total number of each part for the given PSSD that passed supportability (and is assumed to have been inducted), multiplying these counts by the number of hours they cost, and calculating the portion of the total of these hours represented by each part. Table 2.3 shows the resulting modeled PSSD capacity parameters.

Table 2.2. Part Parameter Summary

NIIN	Model Part #	w_level	Failure Rate	Workload Portion	Planning Horizon	Maint. Distribution
13130343	1	13	0.123	89%	74	1 + EXPO(73.4)
13903690	2	7	0.071	29%	92	1 + EXPO(91.1)
1095725	3	18	0.292	18%	94	1 + GAMM(62.6,1.49)

EXPO - Expression draws values from the Exponential distribution with the given mean

GAMMA - Expression draws values from the Gamma distribution with given the parameters

Table 2.3. PSSD Capacity Breakdown

PSSD	Model #	Capacity (Hrs)
MTAA9D	1	94
MTBB9F	2	4500

Another axis of the EXPRESS problem is prioritization behavior. Those parts with higher prioritization are repaired more often, which should result in the part accounting for a higher percentage of the PSSD workload and lower MICAP times. In order to exhibit a variety of prioritization behaviors, the aggregated parameters for 13130343 and 13903690 are divided into two notional F-16 SRANs, both needing the two parts. The first notional SRAN is considered to be a small forward operating base close to combat. It has a high average SPRS rank (used in an exponential random draw to assign MICAP BOs a SPRS category), modeling the tendency for this base's MICAP requirements to take priority in the supply chain. It's parameters account for 30% of the fleet. The other 70% are aggregated into the second notional SRAN, with a lower average SPRS ranking. This SRAN represents a larger state-side base taking lower priority due to its non-combat mission. Parameters for NIIN 1095725 are aggregated into a single notional SRAN with a very low average SPRS category inspired by the real world data for this part, for which the SPRS category was always blank over the modeled period. Table 2.4 displays the modeled values for these notional SRANs. For BO generation the simulation uses a part's average aggregated rate multiplied by the SRAN percentage as the parameter for a Poisson distribution for each SRAN, NSN combination.

Table 2.4. Notional SRAN Parameters

Model SRAN	WS	% Fleet Modeled	Avg SPRS	Allowable Holes
1	F-16	30%	15	3
2	F-16	70%	3	3
3	KC-135	100%	0.001	6

The real system, though highly volatile in its behavior, is theoretically steady state in nature. Thus a set of ten initial runs over very long periods of time were used to determine that, on average, 400 days were required to reach a roughly steady state in the simulation's state variables. Figure 2.5 verifies this from the plots of BO and OWO counts for part 3 (longest SFD, and therefore the last to become stationary) settle out by the 400th day.

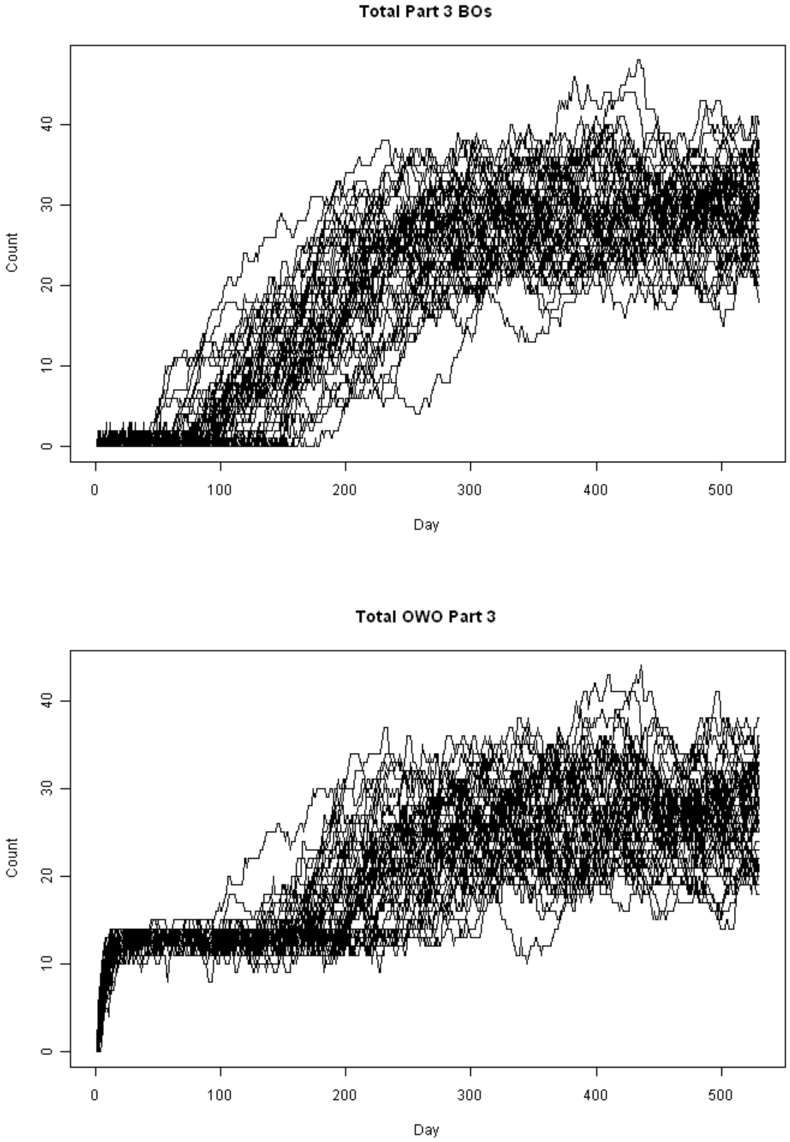


Figure 2.5. Long Run Steady State Behavior

2.5 Results

Prior to the exercising and analysis of the simulation described above, the code was reviewed by an array of subject matter experts from AFMC to verify its representation of EXPRESS. Given the assumptions made about the supply chain outside of the depot, and the generalizations made for prioritization, the model was found to be adequate.

Since all input parameters come from a 6 month period, the simulation is only measured for 6 months, or 130 days, after the initial 400 day warm up period. The simulation code executes quickly on a standard desktop computer, requiring less than a second per run. Thus data was collected on 50 runs for analysis to insure approximately normal output with acceptable standard errors. This output data will be used to validate the model in two ways: time-phased system behavior will be compared with the positions of the actual system, and final totals will be compared with summary data from the AF supply chain.

Figure 2.6 shows the daily positions of the modeled parts over the studied period. The plots for 13130343 and 13903690 indicate there may be problems with the steady state assumption of the model. Shop workload appears to increase, starting halfway through the period, to address high numbers of requirements meeting supportability. A swing this drastic in shop behavior would be unexpected in a steady state system. The plot for 1095725 indicates less variability in shop behavior, indicative of shop behavior closer to that expected by the model. It is reasonable to assume the early differences between the number meeting supportability and the number OWO for parts 1 and 2 would lead to inflated CWT and MICAP times for those months. Indeed this appears to be the case from real world data on MICAP hours (divided by 24 to convert to days) by part in Figure 2.7.

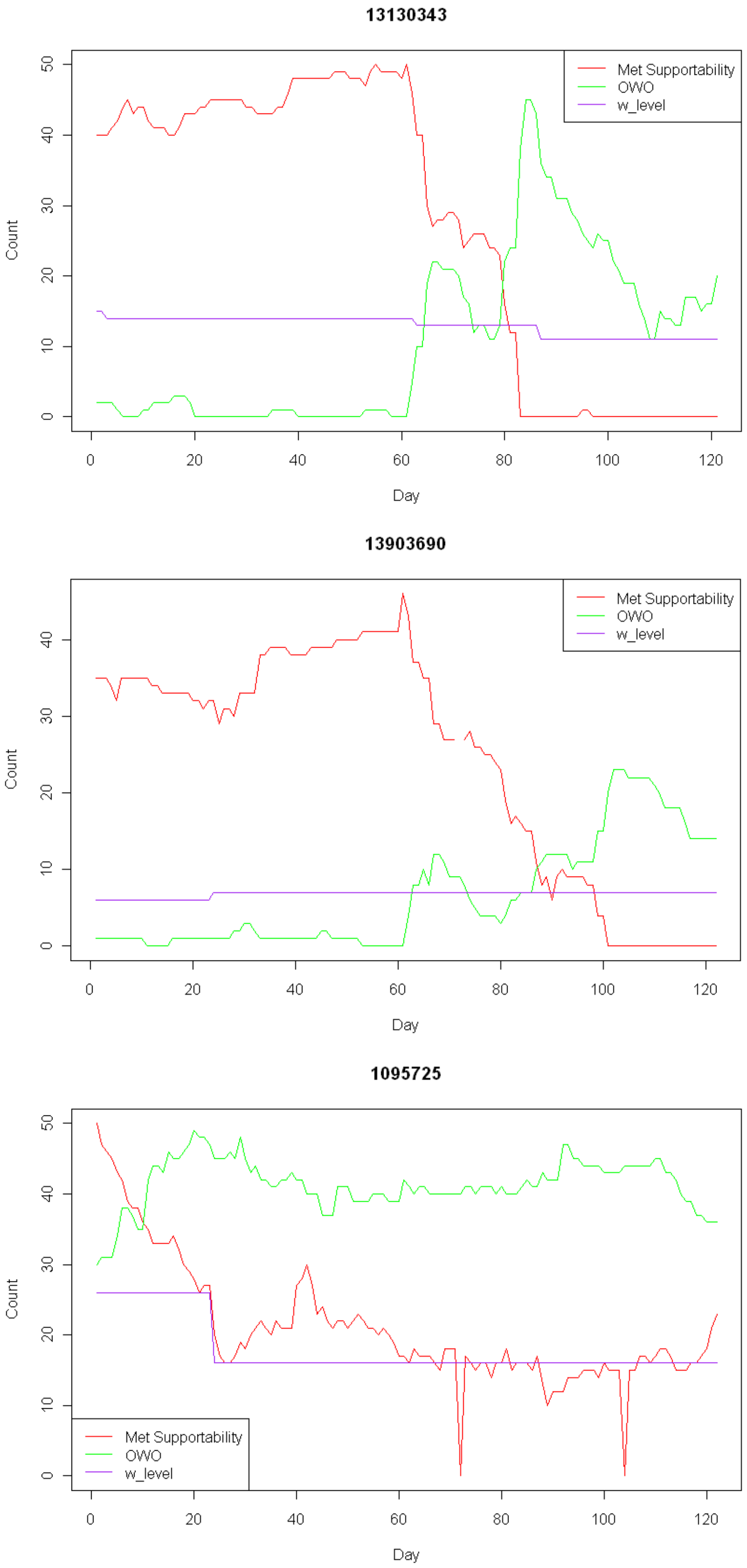


Figure 2.6. Daily Position Plots

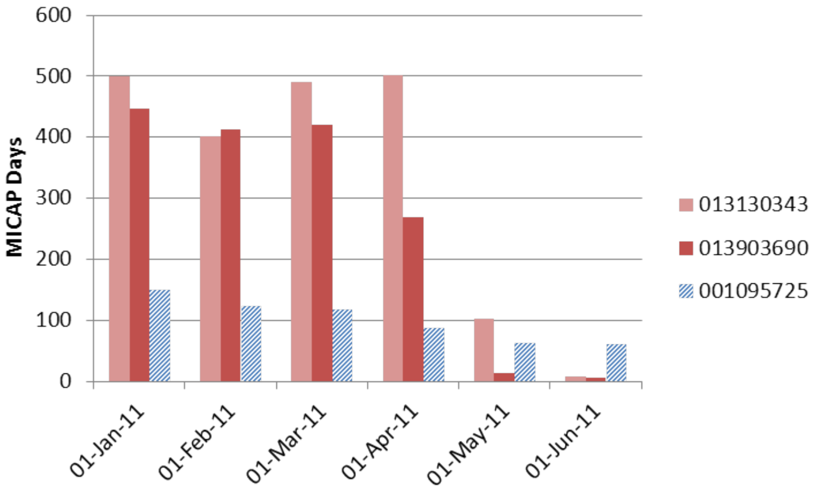


Figure 2.7. Actual MICAP Days by Month

It is assumed that standard shop behavior, and in the resulting MICAP hours while at the depot, is reflected more accurately in the last three months than in the first for MTAA9D. Thus the value used to compare with simulation output for parts 1 and 2 is twice the sum of the MICAP hours observed in the last three months. The stability in MICAP hours and daily behavior of MTBB9F leads to the sum of all six months of data admitted as valid. Simulation output for MICAP days broken down by part is shown in Figure 2.8, with the observed six month total (calculated per above) indicated by the red arrow at the top of each plot.

The strongest validation would come from the observed value falling within two quantiles of the mean if the observed values are not themselves outliers. This appears to be the case for parts 2 and 3. However, the simulated totals for part 1 do not encompass the observed total in any of the 50 runs. This points to strong statistical evidence that the model does not adequately describe the behavior of the system for this part. Figure 2.9 shows the total across all three parts for MICAP days. When considered as an overall system, the simulation appears to produce, on average, total MICAP times lower than the actual result. There is a chance that the observed totals

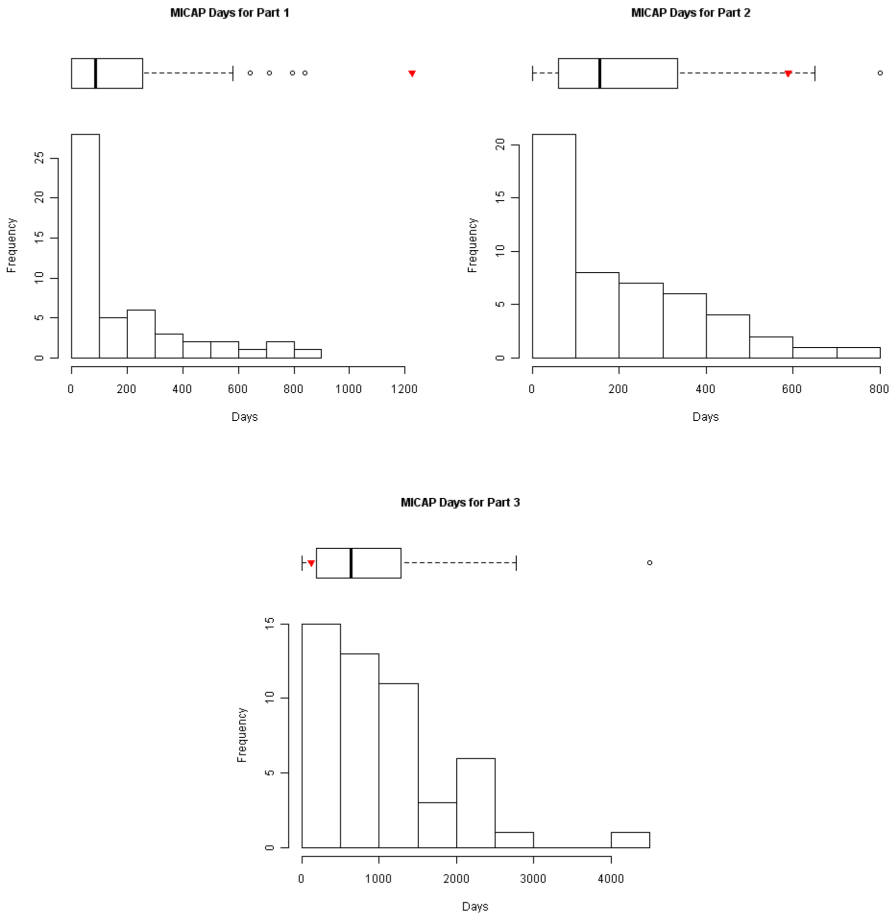


Figure 2.8. Total Simulated MICAP Days by Part vs Actual

were outliers, especially given the non-stationary behavior of MTAA9D. In either case, the simulation output appears to be approximately valid, if not slightly optimistic.

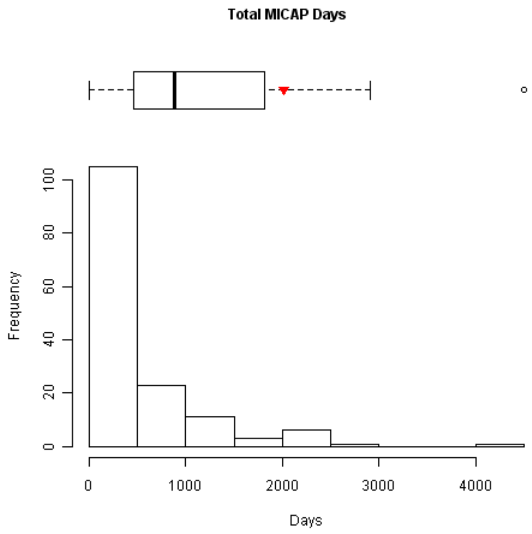


Figure 2.9. Total Simulated MICAP Days vs Actual

Another validation point for the simulation is daily OWO behavior. Though we wouldn't expect the daily positions of a single simulation run to mirror the actual systems, especially considering the non-stationary behavior seen in the data for parts 1 and 2, we would expect the overall distribution of all simulation data to be similar to the distribution of real world data. Figure 2.10 shows a side-by-side comparison of these distributions. Notice that the simulation's distributions are tighter due to their more stationary behavior, but also that they overlap with the observed values for parts 1 and 2. The overlap is not quite as close for part 3, an effect assumed to be attributed to the simplification of this part's repair pipeline. This indicates the simulation produces similar daily behavior as the real system.

2.6 Conclusions

In order to understand a complex system like the EXPRESS managed depot repair process at the system level, it is necessary to break it down to the important processes and structures. EXPRESS considers a massive array of supply chain input

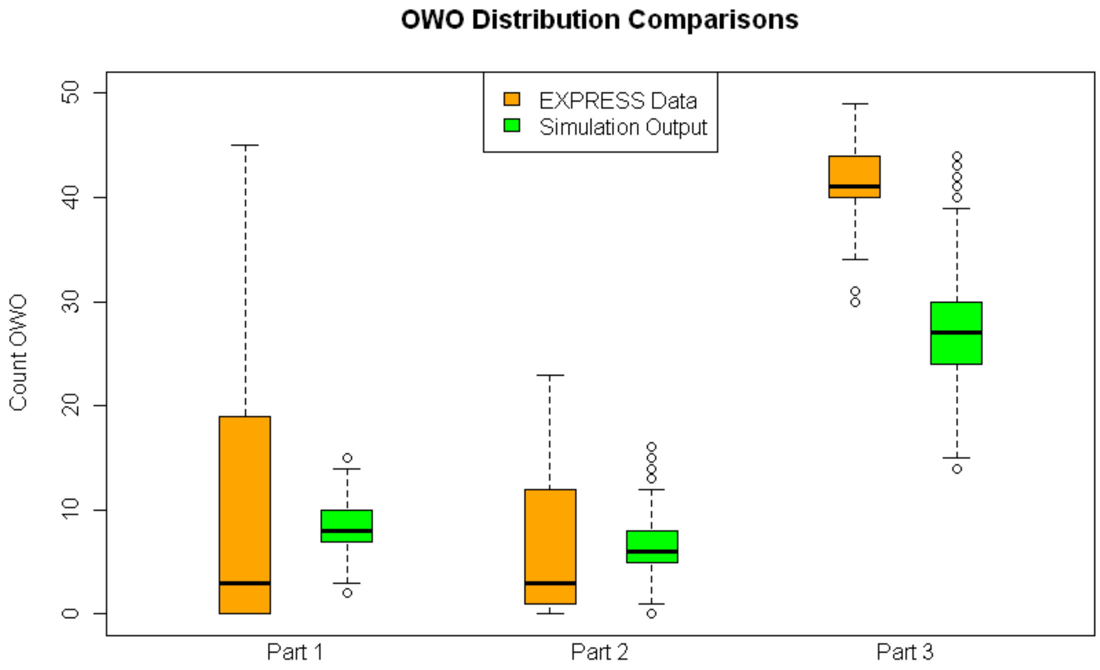


Figure 2.10. Comparison of EXPRESS and Simulation OWO Distributions

data processed through complicated mathematical calculations to bring the workload of depot repair shops closer to the need of the warfighter. This effort is by no means an end product examining EXPRESS at a detailed level. Instead it focuses on beginning to understand the primary logic flows of requirements going through in the database, and how parts are repaired and shipped to satisfy them, from the perspective of a discrete even simulation in order to gain insight into overall behaviors.

The simulation outputs reveal our simplifications of the prioritization logic, along with the flattening of the logistics tail to and from the depot, still allow the simulation to capture the average daily positions found in EXPRESS. The assumptions of a steady state workload and aggregated supportability constraints do detract from the model's ability to describe behavior at the part level. However, when considered as a system, the simulation output does resemble aggregated EXPRESS behavior. Large steps toward model adequacy may be gained from even simple modeling of carcass movement through the logistics tail, and tying this with the supportability constraints and are left as suggested future study.

III. Impact of Periodicity in EXPRESS Runs

3.1 Introduction

Prioritizing depot maintenance is a very important issue for the Air Force (AF). Nearly every weapon system in the inventory relies on depot maintenance to stay mission capable. Reparable parts that fail which cannot be fixed at their operating base are sent for repair to one of the Air Force Materiel Command (AFMC) Air Logistics Centers (ALCs). The constraints imposed at the ALCs by carcass availability, repair resource capacity, budget, and replacement parts require that maintenance be prioritized in order to most effectively address warfighter needs. This is accomplished by the Execution and Prioritization of Repair Support System (EXPRESS): a database tool managed by the Air Force Global Logistics Support Center (AFGLSC) that takes into account real time position data from the depot supply chain to produce a prioritized list of maintenance and distribution actions that maximize the likelihood that the fleet's availability goals are met for the least cost.

In current operations, EXPRESS runs every day. This research effort tries to determine the impact on the depot repair process' ability to respond to warfighter need due to running EXPRESS less frequently: something highly desirable to maintenance planners attempting to maximize efficiency and load leveling at the ALC. A discrete event simulation written in Arena, modeling the general flow of information and parts through the depot repair process, is used to determine the effect of the frequency of EXPRESS runs on Mission Capability (MICAP) hours.

3.2 Background

EXPRESS is a combination of several supply chain management tools that were merged into a single hierarchy in the 1990s [10, 11]. It employs a prioritization algorithm derived from the Distribution and Repair in Variable Environments (DRIVE) model developed by AFMC and the RAND Corporation in the 1980s [24, 7, 23, 29]. Its objective function is to maximize the likelihood that aircraft availability goals, based on warfighter scenarios over short planning horizons, are achieved given the highly variable nature of part failures [30]. EXPRESS also uses logic from the supportability module developed at the Ogden ALC to “examine whether or not the items needing repair were supportable for repair parts and other resources” [10]. Additionally, several tasks previously requiring manual input were automated within EXPRESS by incorporating logic from the Automated Induction System (AIS) developed at the Oklahoma City ALC [11]. Together these functions allow EXPRESS to serve as the single AFMC process for determining which items to put into repair.

The motivation for EXPRESS comes out of the Depot Repair Enhancement Process (DREP) which focused on streamlining repair processes and more closely aligning them with warfighter needs [2]. One of the key measurements of logistics performance highlighted by DREP is Mission Capability hours. Customer Wait Time (CWT) is a measure of total wait time for a customer from the time they submit a need until it is fulfilled [1]. MICAP hours is a special subset of CWT reserved for requirements that represent a mission capability need (i.e. an aircraft is grounded until the requirement is fulfilled). MICAP hours is the primary measure of system performance studied by this effort.

The AF has often questioned what the impact would be if EXPRESS were run less often [15]. Several practical studies have been executed at different ALCs with a subset of shops running EXPRESS weekly instead of daily [6]. No rigorous analytical output was produced during these studies, and subject matter experts could not determine that the resulting increase in shop efficiency outweighed the reduction in responsiveness to customer demand. AFMC has previously studied this question using a computer simulation, with the results pointing to potential gains in aircraft availability due to less frequent runs [34]. Inconclusive evidence, along with continued debate between the two EXPRESS-user communities of depot maintenance and supply chain managers, leaves the periodicity of EXPRESS runs a point of debate. This effort attempts to shed light on the debate by revisiting the problem with a computer simulation.

3.3 Methodology

3.3.1 Modeling Strategy.

A discrete event simulation was developed to model the flow of requirements through EXPRESS, and the resulting parts that are maintained and distributed. In order to limit the scope of this study to a manageable size, the boundaries of the model are limited to the walls of a notional ALC. Within these walls two repair shops are modeled, along with a subset of the parts they repair. The shops were selected based on subject matter expert opinion of examples representing the spectrum of supportability constraint behavior. Thus the first notional shop represents one repairing small parts for the F-16. These parts require only a few hours of labor to complete and repairs demand little from the ALC budget. The other represents a structures shop repairing large parts for the KC-135, each requiring many hours of labor and many days to fix.

Of the parts repaired by these shops, only three are modeled: two from the small parts shop and one from the structures shop. Data was collected from archived EXPRESS tables from 3 January 2011 to 30 June 2011. Queries on average rank value and portion of shop labor were used to map simulation parameters to real world parts. The three modeled parts represent National Item Identification Numbers (NIINs) 13130343 (F-16 assembly), 13903690 (F-16 assembly), and 1095725 (KC-135 refueling boom). Table 3.1 summarizes the parameters found during data collection over the modeled period for each part.

The number of individual bases operating F-16s and KC-135s, and therefore using the three modeled parts, number in the hundreds. Instead of individually modeling each base, demand and priority behavior were aggregated across the fleet and broken into three notional user bases. Table 3.2 outlines these notional bases and their demand rates.

Entities in the simulation model three types of requirement. The first represent requisitions from the field generated by actual part failures, or Back Orders (BOs). BOs are assumed to arrive according to a Poisson distribution with average daily rate equal to the notional base demand rate. Once all BO entities have been generated on a given day, the difference between their count and the inverse Poisson cumulative distribution function (with average rate equal to the part's average daily failure rate

Table 3.1. Part Parameter Summary

NIIN	Model Part #	w_level	Failure Rate	Workload Portion	Planning Horizon	Maint. Distribution
13130343	1	13	0.123	89%	74	1 + EXPO(73.4)
13903690	2	7	0.071	29%	92	1 + EXPO(91.1)
1095725	3	18	0.292	18%	94	1 + GAMM(62.6,1.49)

EXPO - Expression draws values from the Exponential distribution with the given mean

GAMMA - Expression draws values from the Gamma distribution with given the parameters

Table 3.2. Requirement Generation Parameters by SRAN and NSN

Notional SRAN	NIIN	Model Part	Aggregated Rate	% Fleet Modeled	Modeled Rate
1	13130343	1	0.0708	0.3	0.021
1	13903690	2	0.1233	0.3	0.037
2	13130343	1	0.0708	0.7	0.050
2	13903690	2	0.1233	0.7	0.086
3	1095725	3	0.2920	1	0.292

multiplied by the average repair time for that part) evaluated at .95, becomes the count for the number of PARS entities generated. These entities mimic the requirements generated by the primary EXPRESS prioritization algorithm, Prioritization of Aircraft Reparable Spares (PARS), that attempts to generate and rank repair requirements above and beyond BOs from the field in order to maximize aircraft availability across the fleet [30]. The third type of entity models additional requirements generated in EXPRESS to ensure enough requirements are in the repair pipeline to keep adequate safety stocks at the depot. These working level target requirements are called WL entities.

Since the supply chain between each base and the depot are not modeled, the prioritization logic used by EXPRESS is simplified to two random number draws. The first, coming from an exponential distribution, is reserved only for those BOs with MICAP status (occurring when the notional base currently has more unmet BOs than its allowable holes value). This number emulates the Spares Priority Release Sequence (SPRS) categorization of MICAP parts. Each notional base has a different average value for the random number draw, representative of higher priority given to different bases due to their mission. The second is a uniform random number draw between zero and one. This value is assigned to every entity (added to the SPRS number for those that have one) and represents final fine tuning rank given by EXPRESS to each requirement.

Several assumptions were made when modeling supportability logic. The only constraint explicitly modeled is shop capacity measured in labor hours available. Each Production Shop Scheduling Designator (PSSD) has a fixed repair hour capacity which is decremented by the number of hours required to repair a part when it is inducted. Thus a part will pass the capacity constraint if there are enough remaining hours in the PSSDs capacity to induct it. Historically 45-48% of requirements meeting supportability pass for carcass. Carcasses are Line Replaceable Units (LRUs) that failed previously at a base and have been shipped back to the depot for repair. Both the carcass and parts constraints represent complex supply chains that could be modeled in depth in future studies. Historically, those requirements passing for carcass pass for capacity 45-48% of the time. The fund constraint has largely not been a binding one in the past, though research into this aspect of the problem is of interest [35]. In the past roughly 99% pass for funds, but for this effort 100% pass during the supportability check (the 1% difference in incorporated into the parts check). Finally, of those passing for carcass, capacity, and funds, roughly 30% pass for parts. In order to roughly mimic the stochastic nature behind the carcass and parts constraints, the number of a given National Stock Number (NSN) allowed to pass each supportability constraint is calculated by:

$$Allowed_{NSN,t} = Count_{NSN,t} * X \tag{3.1}$$

where $X \sim Exponential$ with mean of .45 for carcass, and $(.45)(.5)(1)(.3) = .07$ for parts. Requirements meeting supportability are processed in priority order one at a time. Those requirements passing all supportability constraints move on to maintenance.

Repair is modeled by a simple delay based on fitted distributions of total shop flow days by part type. Table 3.1 outlined these distributions for each part, and Table 3.3 shows the cost of inducting each part to the shops capacity and budget. The number of parts currently being repaired are reported by the On Work Order (OWO) variable. Once repair is complete, the number of parts OWO are decreased and the number of parts on hand are increased. Parts on hand are shipped to fulfill the highest priority need waiting to be met at the notional bases. The overall flow of the simulation

Table 3.3. Modeled Part Costs and Parameters

NIIN	Avg Rank	Avg Cost (Hrs)	Avg Cost ($)
1095725	101151	773	$172,639
13130343	47695	21	$16,760
13903690	54268	21	$18,453

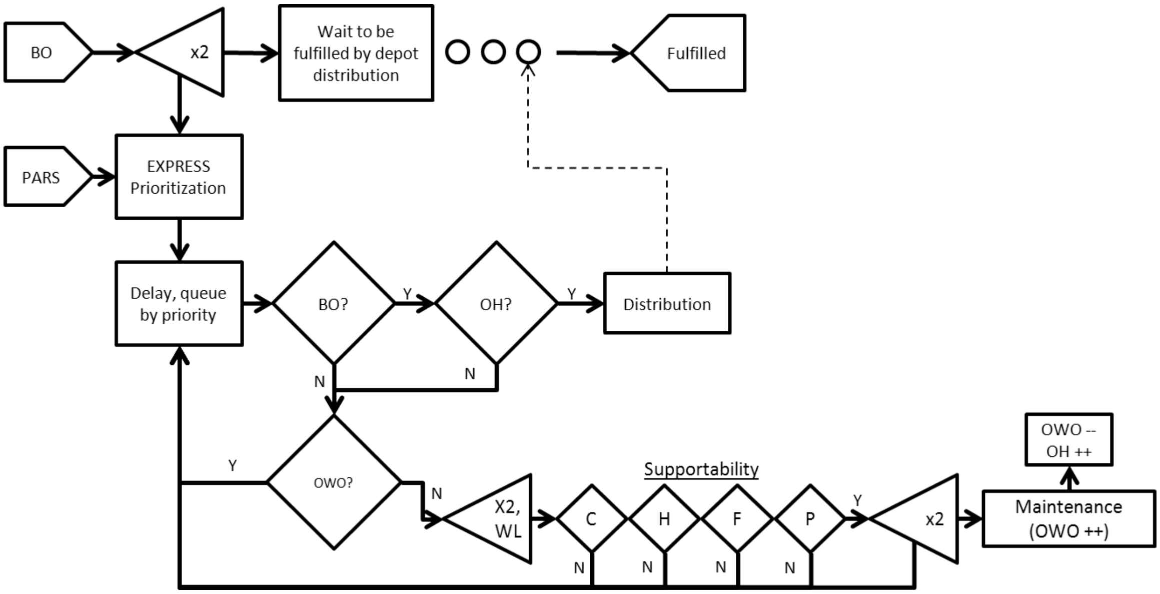


Figure 3.1. Overall Model Logic Flow

logic is shown in Figure 3.1. Screen shots of the Arena simulation can be found in Appendix A.

The modeled system performance is tracked by total CWT and MICAP days, which are convertible to hours by multiplying by 24. CWT is tracked by measuring the total time between when a requirement is generated by a notional base, and when it is matched by the distribution process in EXPRESS. The delay time of those parts that have MICAP status are tracked by a second variable. These totals are recorded after each run, and serve as the primary measure of the system's ability to address user need. Additionally, daily counts of parts OWO, along with a myriad of system variables, are recorded for use in analysis and diagnostics.

3.3.2 Periodicity.

The run frequency of EXPRESS is controlled by setting a variable that determines how many days elapse between runs. BO generation happens every day regardless of whether EXPRESS runs, while PARS entities are generated only as a part of prioritization when it does. The primary assumptions regarding system behavior as a function of run frequency include:

- EXPRESS runs in its entirety according to the frequency variable, and only then. Distribution is included in this, and requirements are only matched during runs.
- Notional Stock Record Account Number (SRAN) behavior does not change with run frequency.
- Prioritization logic does not change.
- Workshop capacity limits used in the supportability logic are multiplied by the number of days between runs.
- The average portion of requirements meeting supportability that pass for either carcass or parts does not change.

It is also assumed the depot repair process is, in general, a steady state system. A warm-up period of 400 days was used to bring the simulation to a near steady state prior to collecting performance metrics. This was determined by plotting system behavior over several runs and observing when performance appeared to have roughly leveled out. Since the input parameters were taken from a 6 month period of time, output data was only measured for 6 months (130 days) after the warm up period in order to avoid extrapolating outside observed system behavior. Subject matter experts on the logic flow of EXPRESS verified the model's layout and assumptions prior to implementation. The simulation was then validated against real world data for OWO daily positions and total MICAP hours while in its daily run configuration.

3.4 Results

The primary investigation point of this effort is to shed light on the potential impacts of running EXPRESS less frequently. The simulation was configured to run every 1, 2, 5 (weekly), 10 (every other week), and 20 days (monthly), and output data was gathered for each. Fifty runs for each system configuration were executed. Since the most important performance factor is responsiveness to customer need, total MICAP days is the first topic of analysis. The sum of total wait time for MICAP requirements was recorded for each individual part, as well as the collective sum for all three. Figure 3.2 shows the distributions of the collective sum for the different configurations.

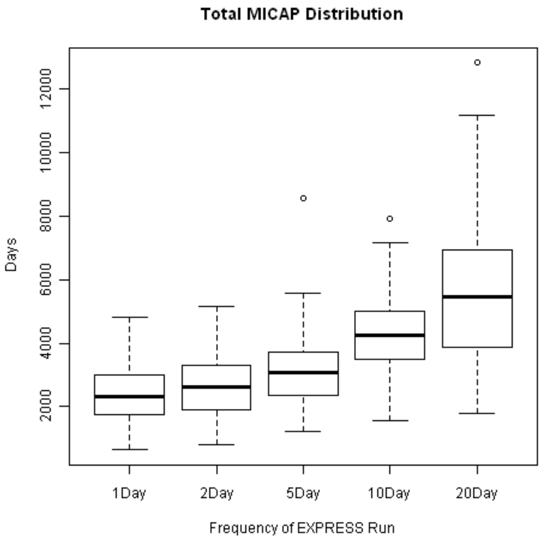


Figure 3.2. Distribution of Total MICAP Days

A Wilcoxon Signed Rank Test is used to non-parametrically compare the results of the different configurations. In an attempt to isolate the variance between configurations for comparison to just the variance attributed to run frequency, the simulation was configured using common random number seeds. Thus the paired comparison of the Wilcoxon test was used to determine the treatment effect of running EXPRESS less frequently. The results are outlined in Table 3.4. Since the plots in Figure 3.2 indicate increasing the number of days between EXPRESS runs increases the median, each p-value comes from the one-sided test checking to see if the output from the higher frequency (Freq 1) is less than the lower frequency (Freq 2).

Table 3.4. Comparison of Mean MICAP Days by Run Frequency: Wilcoxon Signed Ranked Test P-values

		p-values			
Freq 1	Freq 2	Part 1	Part 2	Part 3	Total
1	2	0.000001	0.009546	0.000533	0.000005
2	5	0.000000	0.000000	0.000063	0.000000
5	10	0.000025	0.000000	0.000009	0.000000
10	20	0.009495	0.013150	0.006916	0.000284

Both the generally increasing quantile plots from Figure 3.2, and the low p-values (all less than .05) of the pairwise comparisons, indicate that decreases in EXPRESS run result in statistically higher MICAP times. The Wilcoxon Signed Rank Test does not reveal the size of the difference, just whether there is statistical evidence of one. There appears to be only a small shift between the 1, 2, and 5 day outputs in terms of the median response, with a much larger shift at the 10 and 20 day configurations. Additionally, the variance appears to increase with the number of days between runs as outlined in Table 3.5. This would be expected due to a reduction in the frequency of times workshop labor distribution can be adjusted to match changes in demand. These patterns appear to hold across the quantile plots of individual parts' MICAP times seen in Figure 3.3. These outputs are from a mathematical abstraction of the problem and offer only evidence of a change in behavior. The decision of how much

Table 3.5. Summary Statistics on Total MICAP Days By Configuration

Days Between Runs	Median	Mean	StdDev	Max	Range
1	1180	1374.70	712.33	3341	2950
2	1440	1678.34	802.76	3720	3118
5	2416	2537.38	1096.21	5194	4475
10	3752	3761.92	1226.93	6768	5697
20	4362	4839.02	2063.25	10176	9043

of a shift in output distribution and increase in variance is acceptable remains the task of the EXPRESS user community.

The other important system behavior that is tied to run frequency is repair workload and distribution. In actual operations it is arguable that shop behavior would compensate for some of the reduction in responsiveness with gains in efficiency due to scheduling. For this effort shop capacity is left constant across runs in order to focus analysis on the raw change due to the structure of EXPRESS. Figure 3.4 shows how shop workload was distributed for the different run periodicities.

Clearly, across both shops, the variance on workload increases with the number of days between runs. This would be undesirable to a maintenance planner attempting to keep consistent workloads in order to maintain a trained and efficient workforce. Additionally, drastic swings in workload distribution across the parts repaired by a shop could result in the need to retrain and redistribute employees or equipment within the shop. Figure 3.5 shows the distribution of the portion of labor in shop 1 used to repair part 1 over the different configurations (calculated by $OWO\_Part1/(OWO\_Part1 + OWO\_Part2)$ since these are the only two parts modeled for this shop).

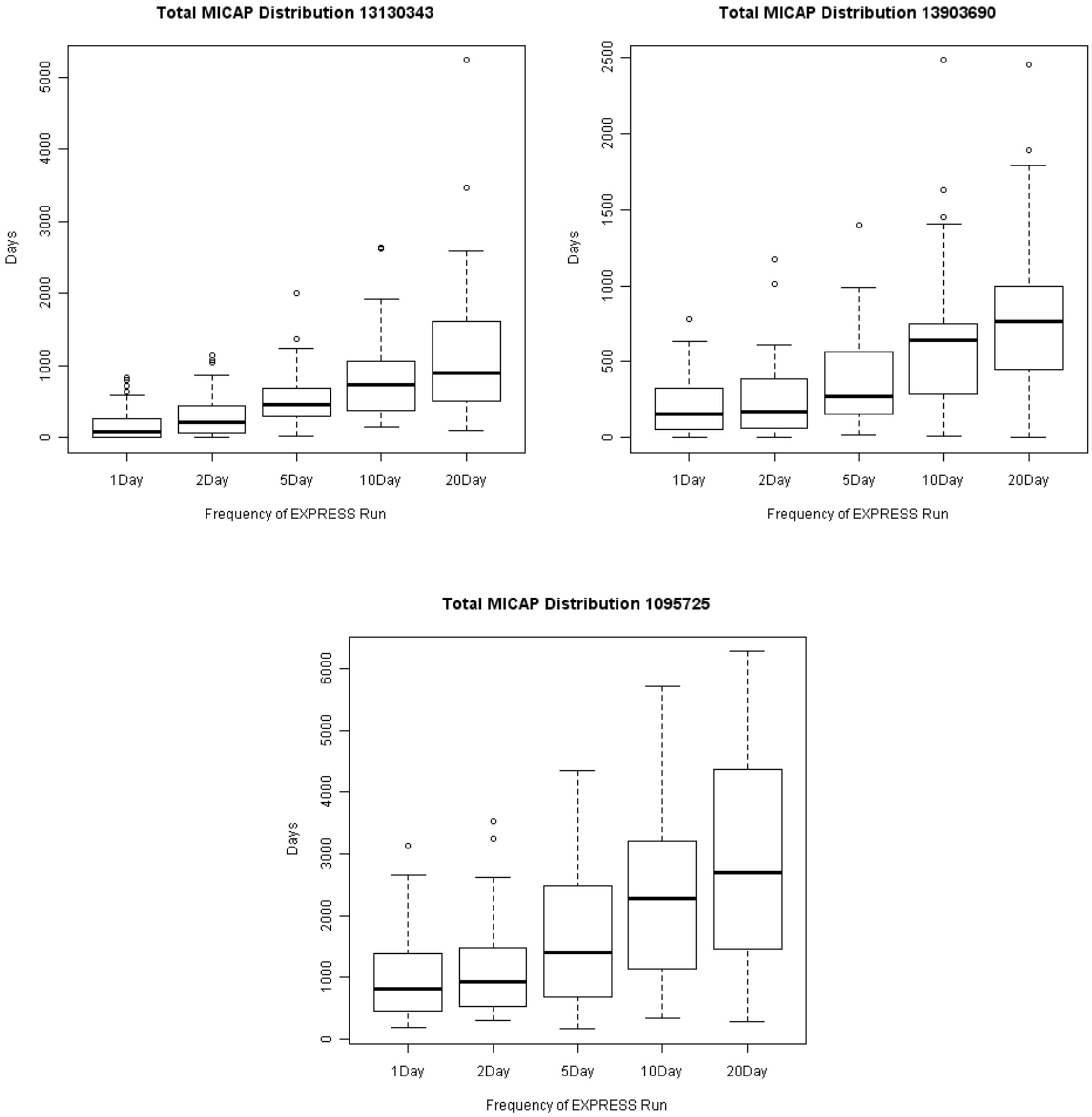


Figure 3.3. Distribution of Total MICAP Days by Part

The general trend here is for the range of this portion to increase as run frequency decreases. There does appear to be an unexpected benefit found by running weekly as the range is less for this configuration, which may be an interesting focal point of future study. But the increase in range points towards a trend undesirable to the maintenance community.

3.5 Conclusions

The model used here captures adequate database behavior to produce interesting insights into the question of how often EXPRESS should be run. Output data points to an increasing trend in total MICAP days over the modeled six month period as run frequency is decreased. In general this trend is highly undesirable to the AF under its DREP goals of maximizing responsiveness, however the amount of change is neither quantified nor mapped to any decision criteria in this study. Similarly, there is statistical evidence that repair shop behavior is also negatively impacted, with shop workload becoming more volatile (both overall and between parts repaired within the shop) as the amount of time between EXPRESS runs increases. Given the assumptions used in data collection and model creation for this effort, the statistical evidence indicates that running EXPRESS less frequently negatively impacts the depot repair process's effectiveness, both for the maintainers and the supply chain managers. The interpretation of these impacts, along with how they influence actual system configuration decisions, are left to the EXPRESS user community.

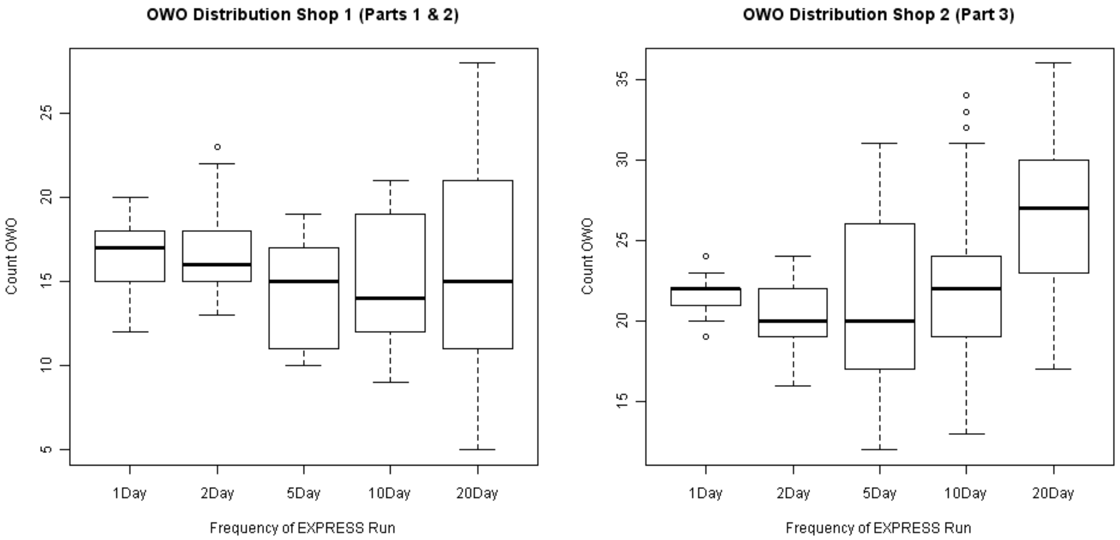


Figure 3.4. Distribution of OWO By Repair Shop

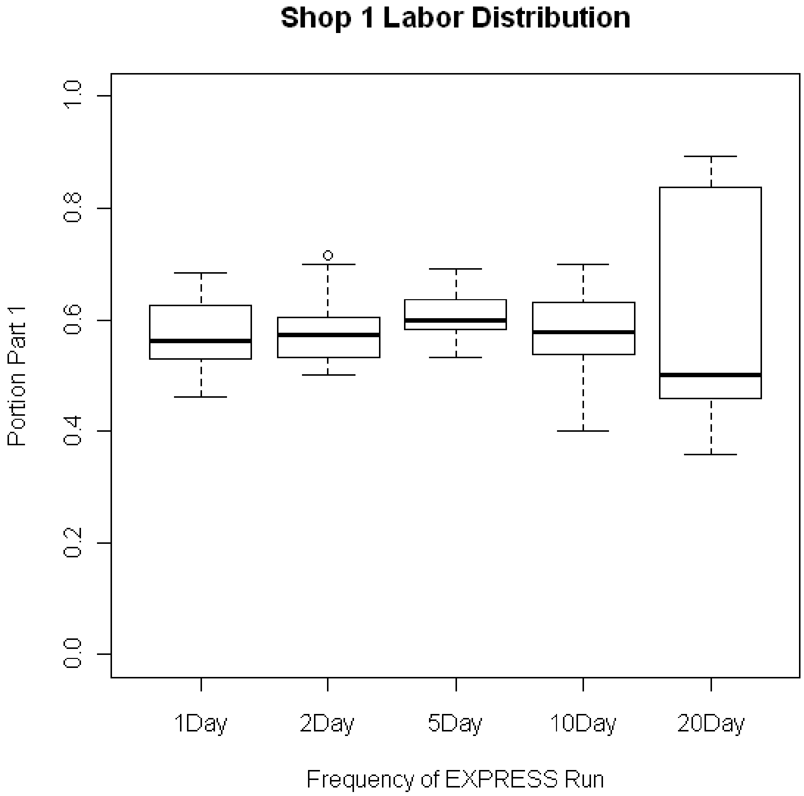


Figure 3.5. Portion of Shop 1 (PSSD MTAA9D) Used for Part 1 (13130343)

IV. Conclusion

4.1 Research Summary

EXPRESS is a complex system designed to accomplish a difficult task: to prioritize depot repair actions in a way that maximizes the likelihood that aircraft availability goals are met in light of a constrained maintenance environment. Equally difficult is the task of modeling EXPRESS in a way that allows for valuable insight into overall system behavior. The vast amount of data collected daily by the system to make prioritization and distribution decisions, along with the complicated algorithms used to rank repair actions and determine their supportability, result in a modeling landscape difficult to capture and analyze. The questions facing the AF supply chain and maintenance communities who rely on EXPRESS to execute their day to day mission require an overarching system understanding to answer, as it is in the interactions of the entire system that the understanding needed lies.

This thesis accomplishes the task of both modeling overarching system behavior and offering insights into the effect of running EXPRESS less frequently. The model implemented here focuses on only three parts as they move through the depot repair process. But the structure of the approach would easily allow a larger portion of the reparable supply chain to be represented. Flexibility is the key design characteristic of the model, which is intended to be the backbone of a vast future of examining EXPRESS at the system level using simulation.

4.2 Future Study

The model could be expanded in several directions to increase its bearing on reality and hone the provided insights into system behavior. The first is scope. In order to scale the problem down to a manageable size for this initial effort, the supply chain between the warfighter and the depot was ignored. An excellent first step in bolstering this model would be to include higher resolution models of base supply, base repair, and the shipping activities for parts being sent to and from the depot for repair.

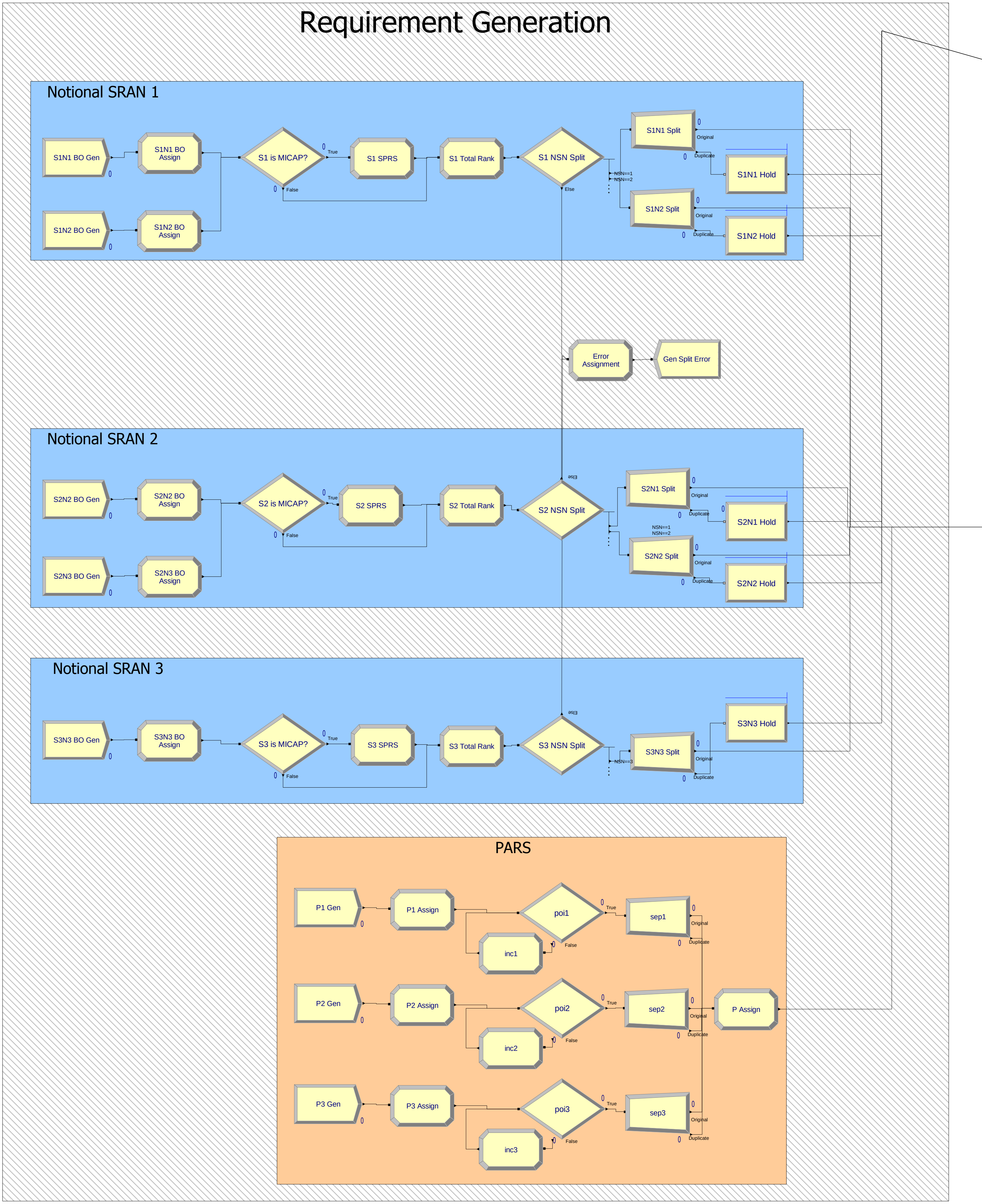
The second is depth. Once more detail has been included on base and shipping activity, finer representations of the prioritization logic used in EXPRESS could help the behavior of requirements moving through the database mirror reality. The PARS and EXPRESS Prioritization Processor (EPP) algorithms require data from the bases and the supply chain to generate, rank, ship, and repair requirements. Supportability checks involve the availability of actual carcasses and parts at the depot. Instead of tying pass rates for carcass and parts to historic passing percentages of the requirements meeting supportability, future work should focus on tying this logic to the actual supply of the items offered by increasing the scope per above. Maintenance activities could also be modeled at higher resolution, as data is readily available on delay times at different stages of repair. This effort combined what can amount to be very complex part indentures and back shop repair processes into a single delay. Additional attention should focus on these details.

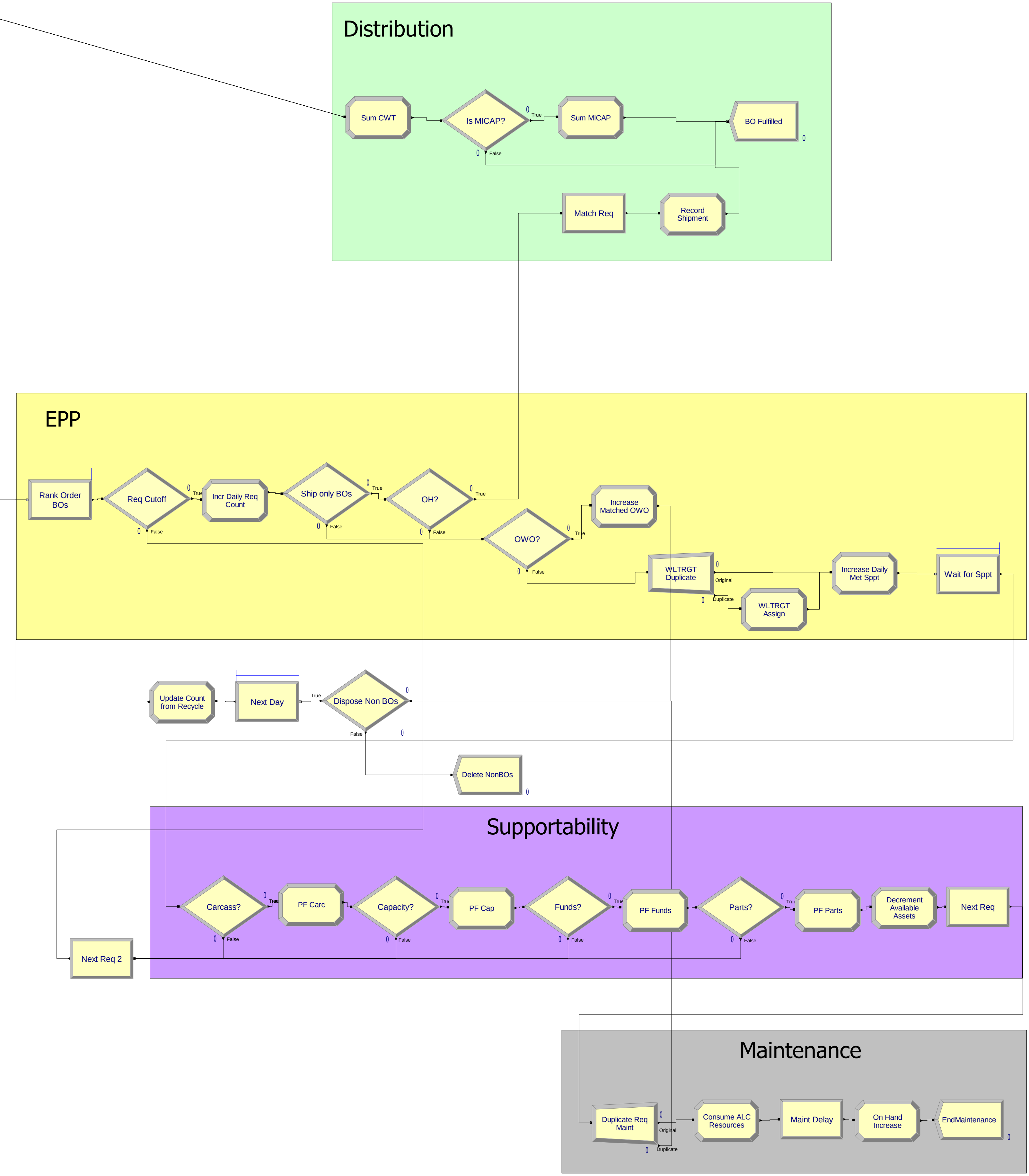
Once more of the supply chain has been modeled, and the EXPRESS algorithms have been modeled in greater detail, the model could easily be expanded to include more of the reparable parts in the AF inventory. Fleet dynamics are very important to the Single Prioritization Across Weapon Systems (SPAWS) algorithm, and the system's ability to address the warfighter need across all airframes is essential to understanding system performance.

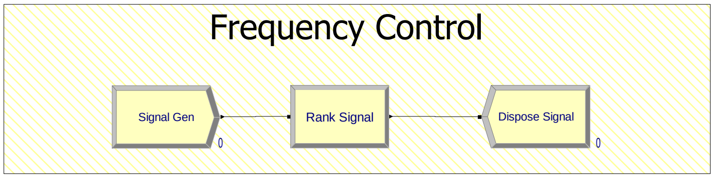
The final recommendation for future study is in overall modeling dialect. Many of the questions being asked about EXPRESS are in regards to the people it involves. Many different people have the ability to adjust how the system performs based on their data inputs and control settings, and different groups of users have different criteria for what a successful outcome looks like. Long run system performance could be tied to the objectives of these stakeholders by modeling the problem using an agent based approach. The discrete event strategy taken by this effort was selected based on its ability to address process oriented questions regarding systems that do not change in response to an environment. An agent based approach would allow for addressing the higher level questions that involve the environment in which EXPRESS operates: a largely human one where user behavior can indeed change both the process and the outcome.

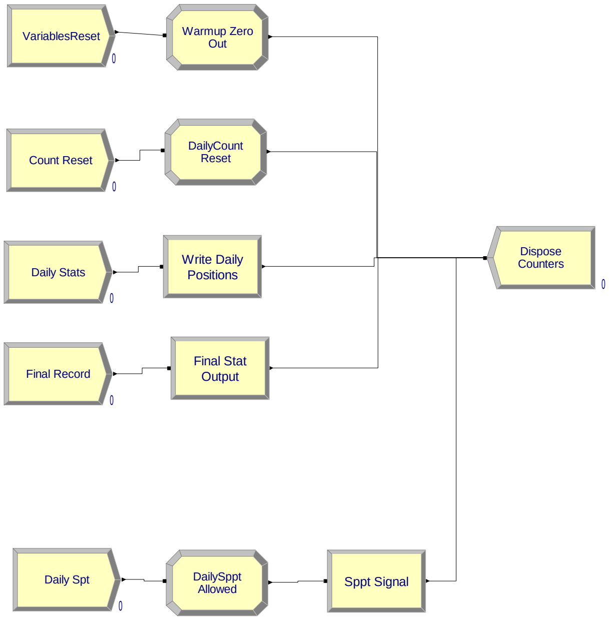
Appendix A. Arena Screen Shots

The following are screen shots of the Arena simulation coded to model EXPRESS as outlined in Chapters 2 and 3.


Requirement Generation
Notional SRAN 1
S1N1 BO Gen
S1N1 BO Assign
S1N2 BO Gen
S1N2 BO Assign
S1 is MICAP?
True
False
S1 SPRS
S1 Total Rank
S1 NSN Split
NSN==1
NSN==2
Else
S1N1 Split
Original
Duplicate
S1N1 Hold
S1N2 Split
Original
Duplicate
S1N2 Hold
Error Assignment
Gen Split Error
Notional SRAN 2
S2N2 BO Gen
S2N2 BO Assign
S2N3 BO Gen
S2N3 BO Assign
S2 is MICAP?
True
False
S2 SPRS
S2 Total Rank
S2 NSN Split
Else
NSN==1
NSN==2
S2N1 Split
Original
Duplicate
S2N1 Hold
S2N2 Split
Original
Duplicate
S2N2 Hold
Notional SRAN 3
S3N3 BO Gen
S3N3 BO Assign
S3 is MICAP?
True
False
S3 SPRS
S3 Total Rank
S3 NSN Split
Else
NSN==3
S3N3 Split
Original
Duplicate
S3N3 Hold
PARS
P1 Gen
P1 Assign
poi1
True
False
inc1
sep1
Original
Duplicate
P2 Gen
P2 Assign
poi2
True
False
inc2
sep2
Original
Duplicate
P Assign
P3 Gen
P3 Assign
poi3
True
False
inc3
sep3
Original
Duplicate


Distribution
Sum CWT
Is MICAP?
True
False
0
Sum MICAP
BO Fulfilled
0
Match Req
Record Shipment
EPP
Rank Order BOs
Req Cutoff
True
False
0
Incr Daily Req Count
Ship only BOs
True
False
0
OH?
True
False
0
Increase Matched OWO
OWO?
True
False
0
WLTRGT Duplicate
Original
Duplicate
0
WLTRGT Assign
Increase Daily Met Sppt
Wait for Sppt
Update Count from Recycle
Next Day
True
Dispose Non BOs
False
0
Delete NonBOs
0
Supportability
Carcass?
True
False
0
PF Carc
Capacity?
True
False
0
PF Cap
Funds?
True
False
0
PF Funds
Parts?
True
False
0
PF Parts
Decrement Available Assets
Next Req
Next Req 2
Maintenance
Duplicate Req Maint
Original
Duplicate
0
Consume ALC Resources
Maint Delay
On Hand Increase
EndMaintenance
0


Frequency Control
Signal Gen
0
Rank Signal
Dispose Signal
0


VariablesReset
0
Warmup Zero Out
Count Reset
0
DailyCount Reset
Daily Stats
0
Write Daily Positions
Final Record
0
Final Stat Output
Dispose Counters
0
Daily Spt
0
DailySppt Allowed
Sppt Signal

Appendix B. List of Acronyms

AF	Air Force
AFGLSC	Air Force Global Logistics Support Center
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AIS	Automated Induction System
ALC	Air Logistics Center
AWP	Awaiting Parts
BO	Back Order
CDF	Cumulative Distribution Function
CWT	Customer Wait Time
DoDD	Department of Defense Directive
DREP	Depot Repair Enhancement Process
DRIVE	Distribution and Repair in Variable Environments
EPP	EXPRESS Prioritization Processor
EXPRESS	Execution and Prioritization of Repair Support System
FMS	Foreign Military Sales
FSC	Federal Supply Classification

IM	Item Manager
LRU	Line Replaceable Unit
MICAP	Mission Capability
NIIN	National Item Identification Number
NSN	National Stock Number
OWO	On Work Order
PARS	Prioritization of Aircraft Reparable Spares
PDM	Programmed Depot Maintenance
PSSD	Production Shop Scheduling Designator
SC	Supply Chain
SFD	Shop Flow Days
SPAWS	Single Prioritization Across Weapon Systems
SPRS	Spares Priority Release Sequence
SRAN	Stock Record Account Number
SRU	Shop Replaceable Unit
UMMIPS	Uniform Materiel Movement and Issue Priority
WL	Working Level
WS	Weapon System

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Examining EXPRESS with Simulation

Capt David R. Williams

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Reader: Daniel Mattioda, Maj, USAF, Ph.D
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Background:

The EXecution and Prioritization of REpair Support System (EXPRESS) is the single decision framework used by the Air Force to prioritize repairable spares depot maintenance actions. It is responsible for maximizing aircraft availability by prioritizing the repair pipeline and distribution for more than 100K unique items every day.

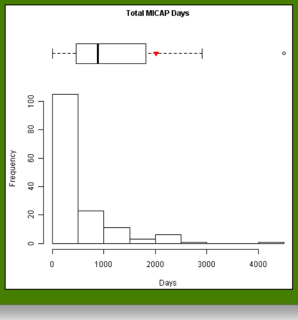
Research Goals:

- Gain insights into EXPRESS as a whole system
- Flexible methodology allowing for follow on study
- Study impacts of run frequency on system's responsiveness to customer need (measured in MICAP hours)

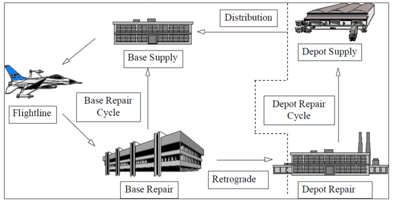
Verification & Validation:

- Subject Matter Experts verify model logic
- Model validated against historic MICAP data

(red marker = total MICAP hours from input period)



Model Scope: Only within depot walls
(right of dotted line)



Flattens reparable supply chain

Input Parameters:

Taken from 3 Jan to 30 June 2011

Depot Shops Modeled

PSSD	Modeled Shop #	Description	Capacity (Hrs/Day)
MTAA9D	1	Small, F-16	94
MTBB9F	2	Large, KC-135	4500

Parts Modeled

NIIN	Modeled NSN #	Avg w_level	Aggr. Failure Rate	Planning Horizon	Maint Delay Dist.
13130343	1	13	0.123	74	1 + EXPO(73.4)
13903690	2	7	0.071	92	1 + EXPO(91.1)
1095725	3	18	0.292	94	1 + GAMM(62.6,1.49)

EXPO: Exponential distribution, GAMM: Gamma distribution

SimulationEntities:
BO: Back Orders from field
PARS: Forecasted requirements
from PARs prioritization logic
WL: Working Level requirements

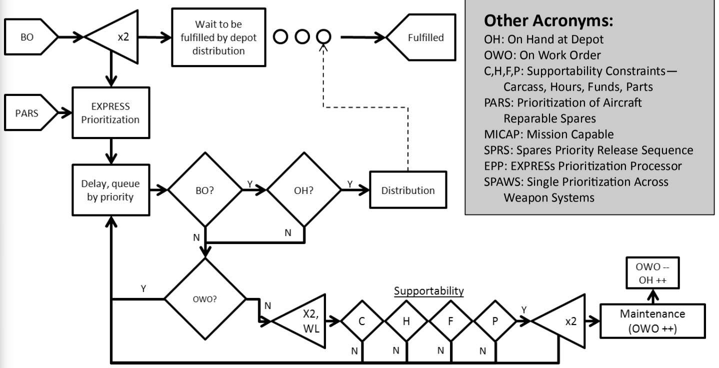
Methodology:

- Discrete-event simulation modeling requirements passing through database
- Software: Arena
- System performance metric: Total MICAP hrs over run

Key Assumptions:

- BO generation comes from Poisson, aggregated over user bases
- Prioritization simplified to random number draws
  - SPRS from Exponential distribution
  - PARS/EPP/SPAWS from Uniform(0,1)
- Supportability tied to historic rates for the portion meeting supportability passing for each constraint

Overall Model Logic:



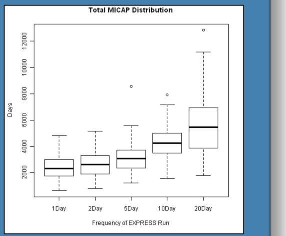
Other Acronyms:
OH: On Hand at Depot
OWO: On Work Order
C,H,F,P: Supportability Constraints—
Carcass, Hours, Funds, Parts
PARS: Prioritization of Aircraft
Reparable Spares
MICAP: Mission Capable
SPRS: Spares Priority Release Sequence
EPP: EXPRESs Prioritization Processor
SPAWS: Single Prioritization Across
Weapon Systems

Effects of Run Frequency:

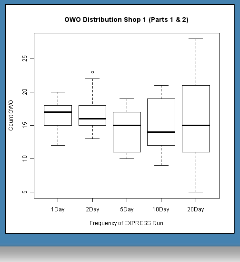
Responsiveness Effect: Wilcoxon Signed Rank test shows statistically significant higher total MICAP times for lower run frequencies

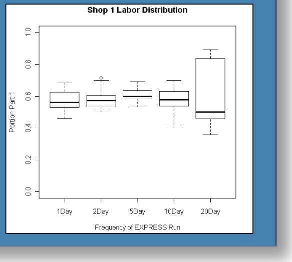
Comparison of Mean MICAP Days by Run Frequency: Wilcoxon Signed Ranked Test P-values

		p-values			
Freq 1	Freq 2	Part 1	Part 2	Part 3	Total
1	2	0.000001	0.009546	0.000533	0.000005
2	5	0.000000	0.000000	0.000063	0.000000
5	10	0.000025	0.000000	0.000009	0.000000
10	20	0.009495	0.013150	0.006916	0.000284



Shop Behavior Effect: Overall shop workload more variable as run frequency decreases, increase in variance in workload distribution within shops as frequency decreases





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Conclusions: Statistical evidence that less frequent EXPRESS runs results in a shift towards a less responsive and more volatile system.

Practical impact of run frequency on AFGLSC mission requires additional research.

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14. ABSTRACT

The Execution and Prioritization of Repair Support System (EXPRESS) is a database tool used by the Air Force to prioritize depot maintenance of reparable spare parts in order to maximize responsiveness to wafighter need. Many studies have examined individual portions of EXPRESS, though few examine it as an entire system. This effort proposes a modeling approach for examining overall system behavior of EXPRESS using discrete event simulation. The emphasis of the model is to be flexible enough to provide useful insight into system performance, while also remaining open ended enough to provide a foundation for future expansion and analysis.

A case study involving three reparable parts managed by EXPRESS, based on six months of real world data, focuses on total Mission Capability (MICAP) hours as a measure of responsiveness to customer need. The model is validated using data on actual MICAP hours for the modeled period. The case study simulation is then used to study the impact on responsiveness and repair behavior resulting from running EXPRESS less frequently. Output data points to increases in total MICAP hours and variance in repair workload as run frequency decreases. The conclusion is that running EXPRESS less frequently negatively impacts system performance for both the maintenance and warfighter communities.

15. SUBJECT TERMS

EXPRESS, depot repair, prioritization, supply chain, supply chain management, discrete event simulation, responsiveness, MICAP hours, periodicity,

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