# MODEL-BASED OPTIMIZATION FOR PILOT TRAINING

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## ABSTRACT

Pilot training in the Air Force is modeled as a supply chain where each step in the process is seen as the "supplier" of the next step. We use a model-based approach for optimizing the cost of pilot training while improving the war-fighting capability of the Air Force. A linear programming model that synchronizes and balances the flow of pilots through the various stages of the supply chain is developed. The model includes constraints such as capacity and manpower flows reflecting hiring and training of pilots.

## INTRODUCTION

Air Force pilots go through a lengthy and difficult training process in order to become qualified fighters. The pilots have a tiered training progression that moves them from one qualification to another. There are seven steps in this process and it takes as long as eight years to attain the highest level. The pilots spend most of their time in training, in order to be ready whenever their service is needed. In fact, the main objective of the operational squadrons is to maintain readiness to deploy and operate in wartime, contingencies, and other engagements.

With a complex and lengthy training process, the number of available pilots and the readiness level of these pilots today are the result of the hiring and training decisions that were made many years ago. Therefore, it is very important to develop an anticipatory decision making model for hiring and training of pilots so that pilots are ready with required capabilities when they are needed.

The pilot training process is very similar to a traditional manufacturing supply chain process, where outputs of one step are the inputs for the next step. The pilot training supply chain has two major challenges. The first one is having the right number of trained pilots of different capabilities available when needed. The second challenge is maintaining a smooth flow of pilots through the various stages of the supply chain. In addition to achieving optimal levels of trained pilots, lowering the costs and investments is another important goal.

The main objective of this research is to design a model for the pilot training supply chain, in order to achieve a desired readiness level with the least possible cost. This will be achieved by 1) formulating an optimization model that best represents the pilot training supply chain; and 2) testing the model under different scenarios that will show the nature of tradeoffs associated with strategic decisions in optimizing the supply chain. We choose to model the training process of F-16 pilots and its specific requirements. However, due to the richness and flexibility of the model, it is possible to make small modifications and use it for the training processes of pilots of other types of aircrafts in the Air Force as well as in other branches of the DoD.

## Literature Review

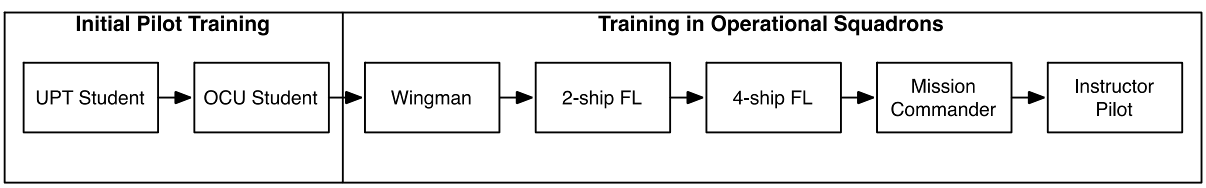
Previous authors have used operations research and supply chain optimization models for military workforce planning. For example, [9] provides an excellent review of Markov chain, simulation, optimization, and system dynamic models while [6] solves a linear program and employs a simulation. Linear and dynamic programming is used in [4] for military manpower systems, while [7] looks at a more detailed manpower scheduling problem. Markovian models, such as in [5] and [10], are also useful in modeling manpower supply chains.

## DESCRIPTION OF SUPPLY CHAIN

We model the organizational structure of the F-16 squadrons and training process of their pilots. The F-16 pilots have a tiered training progression that moves them from one qualification to another. The training regimen can be broadly separated into two categories: Initial Pilot Training (IPT) and Pilot Training in Operational Squadrons. Though our model begins with IPT, any processes that feed into IPT (e.g. Initial Flight Screening—a one month course required before starting IPT) can be taken into account by adjusting the flow of pilots into the supply chain.

The IPT is the initial training before pilots are assigned to their operational squadrons. There are two stages in the IPT: Undergraduate Pilot Training (UPT) in the first year and Operational Conversion Unit (OCU) training in the second year. Once the IPT is completed, the pilots are assigned to their first operational squadrons. In an operational squadron, there are five stages of progression: 1) Wingman, 2) 2-Ship Flight Lead, 3) 4-Ship Flight Lead, 4) Mission Commander, and 5) Instructor Pilot. The pilot training process as a supply chain is depicted in Figure 1.

**FIGURE 1: Supply Chain**




The seven-stage path of F-16 pilot training, starting from UPT up to IP takes eight years on average. While some pilots climb it faster, it takes more time for others. Some highly talented pilots can be assigned as a 4-ship flight lead right after completion of wingman training. In this study, it is assumed that each stage in the training progression takes exactly one year and the whole process is completed in seven years in total.

## Training

Pilot training in operational squadrons can be divided into two broad categories: *continuation training* that ensures that pilots maintain and sustain the skills required to perform the squadron’s assigned missions; and *upgrade training* that prepares pilots for the next level in their career path, from wingmen to instructor pilots, as per the Ready Aircrew Program (RAP). The process of upgrading in the operational squadrons can take up to six years under normal conditions. It is assumed in this study that each upgrade takes exactly one year.

The determination of sortie requirements that allow all of the pilots to keep their Combat Mission Ready (CMR) status is in fact a very complex procedure. Each squadron is required to have a minimum number of different types of pilots (e.g., wingman, flight leads, instructor pilots, etc.) who have been trained for different special skills. There are many issues that are considered during calculation of the sortie requirements, such as experience levels of the pilots, jobs of the pilots in the squadron, sortie profiles and versions, skill acquisition of the pilots, etc. Hence, the annual flight hour program of each squadron is customized to that unit.

Bigelow, et al. [2] show that 13 sorties per month per pilot are enough to gain all the skill sets and meet the mission requirements for any type of pilot in an operational squadron. Considering that the duration of a sortie is 1 hour 40 minutes on average, the flight requirement for each pilot sums up to 260 flight hours annually (= 1.66 hours/sortie x 13 sorties/month x 12 months/year). This number can be used as the quality constraint that ensures that all pilots keep their CMR status at all times. It should also be noted that there exists some variation in the annual flight hour requirement for pilots at different stages. For example, UPT students are required to fly about 240 hours per year while OCU students are required fly about 200 hours per year (20 hours in the Introduction to Fighter Fundamentals course plus around 180 hours in the B-course). In our optimization model, we use the parameter $A_j$ to indicate the flight hour requirement for a pilot at level *j*.

Given that each pilot must fly at least 260 hours, or 156 sorties annually, the supervision requirement is equal to 44.2 flying hours, or 17% (26 sorties/156 sorties per year) of all sorties flown in a particular year. The supervision requirement in an operational squadron is enforced for the wingman, 2-ship flight leads and 4-ship flight leads only. The supervision requirement—defined in our model as $S$ hours of supervision per year—is the most critical constraint in the training capacity of a squadron and is taken into account during model formulation.

Although the instructor pilot is part of the pilot training supply chain, he is the key element in determination of training capacity of a squadron. Therefore, the number of instructor pilots in a squadron determines the training capacity of that squadron and also the readiness levels of the pilots. However, the instructor pilots are typically allowed to fly only one sortie per day. Note that although this is not an everyday event, at times instructors do fly two sorties per day while still remaining within safety limits and regulations. We incorporate this reality through the use of a multiplier. For example, if we assume that only 5% of the time the instructors fly two sorties per day, the multiplier to be used is 1.05. In this case, the training capacity of an instructor pilot is 455 flight hours/year (= 1.66 hours/sortie x 1.05 sortie/day x 5 days/week x 52 weeks/year). In our model, we use the parameter K to indicate the training capacity of an instructor pilot.

The attrition rates are relatively higher in the Air Force as compared those in the commercial enterprises. The Air Force typically experiences an 8-10% attrition rate for the student pilots. The attrition rate among pilots gets even higher once their mandatory service is over. In addition, pilots get assigned to different aircraft throughout their training process, and thus in effect leave the training supply chain for F-16 pilots. The combined effect of attrition and assignment to different aircraft type are taken into account through an aggregate attrition rate, defined as the parameter $\delta_j$ in our model. In this study, an attrition and turnover rate of 10% is used for the first four steps of pilot training progression. For the next three steps, an attrition rate of 30% is used in the model.

## OPTIMIZATION MODEL

The pilot training supply chain will be modeled as a multi-period Linear Programming (LP) model. This will be accomplished by developing a set of equations representing the stocks and flows of manpower (see [1], [3], and [8]). Since the Air Force Command is able to increase the number of pilots in a particular year, $P_j(t)$, by hiring new pilots, the basic decision variable facing the management is the number of new pilots to be hired in time period $t$, $h(t)$. Therefore, a set of equations should be developed for the manpower system in Pilot Training Process (PTP) that captures the relationship between new hires, $h(t)$ and numbers of pilots, $P_j(t)$ over time.

As mentioned before, there are seven stages in the pilot supply chain. From the beginning of the Undergraduate Pilot Training until becoming an Instructor Pilot, the pilot must undergo approximately seven years of training and upgrading. This time delay makes the relationship between $h(t)$ and $P_j(t)$ even more important in nature. There are two other factors that add more complexity to this relationship. First, the promotion of pilots over time to higher levels and second, the common phenomenon of attrition and turnover among pilots. The notation used in the model is given in Table 1.

**TABLE 1: Model Parameters and Variables**

| | |
|---|---|
| $P_j(t)$ | The observed number of pilots of level *j* in time period *t* |
| $InvP_j(t)$ | The inventory of pilots of level *j* left after attrition at the end of time period *t* |
| $h(t)$ | Number of new pilots being hired in time period *t* |
| $\beta_j$ | The ratio of pilots at level *j* who are promoted to a higher level |
| $\delta_j$ | The turnover and attrition rate for pilots at level *j* |
| $C_{FH}(t)$ | Cost of a flying hour in time period *t* |
| $C_j(t)$ | The annual composite cost of a pilot at level *j* in year *t* |
| $REQ_j(t)$ | Required number of pilots of level *j* for time period *t*, in order to achieve the readiness level for time period *t* |
| $K$ | The training capacity of instructor pilots, in flight hours in each time period |
| $S$ | The hours per year that pilots must be supervised by instructors, for $j=3,4,5$ |
| $A_j$ | Required flight hours per year for pilots of level *j* to maintain CMR |
| $MIN_j(t)$ | Minimum number of pilots of level *j* required for time period *t*, in order to achieve a continuous flow in the supply chain |
| $MAX_{ins}(t)$ | Maximum hours that instructors can fly in time period *t* |
| $Hours(t)$ | Total flying hours flown by all levels of pilots in time period *t* |
| $SI_j$ | Starting Inventory for level *j* pilots in year 1, for $j = 2,3,...,7$ |

Note that this is a stylized supply chain, but it is flexible enough to handle actual Air Force practices through minor adjustments. For example, in reality, students enter the pilot training supply chain approximately every three weeks. Hence, the system flow is closer to being continuous. However, we have chosen to discretize the training process into seven stages of year-long durations to capture the strategic decisions involved in the process. If in case greater granularity is needed, it would be straightforward to use stages of shorter duration and to formulate the model using essentially the same conceptual framework. Also, at times pilots leave the program for certain duration for non-flying assignments, and then return to resume their training. This can also be incorporated by adding sojourn states in which a certain percentage of pilots remain for a set time period.

**Objective Function and Constraints**

The objective function in this optimization model is formulated to minimize the total cost of achieving a desired number of seven different types of trained pilots for a seven-year time period. The total cost for the seven-year period is composed of two different costs. First is the cost of training. As described earlier, in order to achieve the maximum level of readiness and preserve the CMR status, the pilots on hand must fly a certain amount of sorties each year. Therefore, the training cost will be equal to the number of flying hours flown by the pilots during each year in total, multiplied by the cost of a flying hour. The second cost in the objective function is the cost of carrying the inventory of pilots. Each pilot carried in the inventory costs the Air Force a composite rate. Therefore, the inventory carrying cost will be equal to the numbers of pilots of different types, multiplied by the composite rates. The optimization model, including objective function and constraints, is given below.

$$\min \sum_{t=1}^{7} Hours(t) * C_{FH}(t) + \sum_{j=1}^{7}\sum_{t=1}^{7} C_j(t) * P_j(t) \tag{1}$$

$$\text{s.t. } P_1(t) = h(t) \quad \forall t = 1,2,\ldots,7 \tag{2}$$

$$P_j(1) = SI_j \quad \forall j = 2,3,\ldots,7 \tag{3}$$

$$InvP_j(t) = P_j(t) * (1-\delta_j) \quad \forall j = 1,2,\ldots,7 \text{ and } \forall t = 1,2,\ldots,7 \tag{4}$$

$$P_j(t) = \beta_{j-1} * InvP_{j-1}(t-1) + \left(1-\beta_j\right) * InvP_j(t-1) \quad \forall j = 2,3,\ldots,7 \text{ and } \forall t = 2,3,\ldots,7 \tag{5}$$

$$InvP_j(t) \geq REQ_j(t) \quad \forall j = 1,2,\ldots,7 \text{ and } \forall t = 1,2,\ldots,7 \tag{6}$$

$$InvP_j(t) \geq MIN_j(t) \quad \forall j = 1,2,\ldots,7 \text{ and } \forall t = 1,2,\ldots,7 \tag{7}$$

$$Hours(t) \geq \sum_{j=1}^{7} A_j P_j(t) \ \forall t = 1,2,\ldots,7 \tag{8}$$

$$S \sum_{j=3}^{5} P_j(t) = K\, P_7(t) \ \forall t = 1,2,\ldots,7 \tag{9}$$

The objective of the model in (1) is to minimize the training and inventory costs. Constraint (2) captures our model's decision variable—how many inexperienced pilots to hire in each period. In the first period of the model, the each level of the manpower supply chain has starting inventory of pilots; this is expressed in constraint (3). As the model moves from one period to another, we must take into account the attrition—in (4)—and promotion—constraint (5). In order to maintain readiness, there is a minimum number of pilots required in each period at each echelon; (6) reflects this. Meanwhile, as requirements change over time, the smooth flow of pilots through the system is essential; thus, (7) prevents extended periods where no pilots are hired. CMR requirements are taken into account through (8), while the instructor pilot's capacity on flying hours—*K* hours—along with the requirement that *S* hours per pilot per year are supervised by an instructor are represented in (9).

Although the number of aircraft and the total flying hours that the aircraft can fly are also critical constraints in the pilot training process, they were excluded from the scope of this study. The main reason for this is the fact that the capacity of the aircraft is much higher than the capacity of the instructor pilots. Therefore, adding another constraint that has no binding effect on the solution would be of no use. Also note that, since we are considering yearly decisions, the long run average effects of weather and maintenance can be taken into account by suitably adjusting the numerical values of the parameters. We also consider that the money spent on the aircraft is a sunk cost that does not change among different scenarios in the short run. The decision to buy new aircraft or decommission them is a very long-term strategic decision and it is not possible to procure or decommission aircraft annually as a result of yearly threat level changes. Therefore, the calculation of the right number of aircraft in a squadron is outside the scope of this study and it is assumed that there are enough aircraft in the squadron for the adequate training of the pilots.

## PLANNED ANALYSIS & CONCLUSIONS

We have collected the necessary data regarding parameter values and have successfully solved the model described above. The next step in analyzing this problem is to perform numerical experiments through simulation. We plan to create different threat-level scenarios based upon recent American history; next, we will simulate the next seven years based upon our probability distribution for threat-level. For each simulation run, we will solve the above optimization problem, resulting in a distribution of costs over many scenarios. This will allow us to test the sensitivity of the total costs in our model to various possible future threat levels.

### Conclusion

The purpose of this study was to develop a model-based approach for generating an optimal training plan for F-16 pilots. The model developed is suitable for analysis and provides a good understanding of the pilot training progression using a manpower supply chain to model the movement of pilots through the training sequence. As this model is employed, we will understand how optimal costs change as we vary future threat scenarios.

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