AIRCREW TRAINING SYSTEM LIFE CYCLE COST MODEL

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ABSTRACT

The C-17 Aircrew Training System (ATS) Life Cycle Cost (LCC) model was constructed around the approved Wright Patterson AFB, Aeronautical System Division Work Breakdown Structure (WBS) for Aircrew Training Systems as modified for the C-17 ATS program. Structuring the LCC model around this established WBS provided the framework so that the model is generic enough to fundamentally analyze any integrated training system. In addition the use of this approved WBS allows the model predictions to be easily integrated and compatible with a prime contractor's accounting system used to perform cost accumulations, cost reporting, budgeting, and cost tracking.

Rather than make the C-17 ATS LCC model a pure accounting type of LCC model, a decision was made to integrate the functional parameter algorithms of each WBS element with the cost element relationship algorithms of each WBS element. This caused the model to be more of an engineering type of model in which the predicted outputs of the model are sensitive to input data, and changes in the input data to the model (i.e. program and pragmatic data changes). As a result, the model can be used to make early predictions for program development and acquisition decisions and can then be re-used during the operations and support phase to make continuing economic decisions based on actual annual operational decisions.

Because of the automated capability of the model, the vast array of integrated cost analysis tools embedded within the model, and the complete on-line documentation features of the model, the information necessary to understand what elements within the system are cost drivers, why these cost drivers exist, and which LCC inputs have the greatest influence on these cost drivers is readily available to the analyst. The complete on-line documentation provides different analyst using the model the ability to easily adapt the model to their specific needs, and provides program management with a quick and flexible method of preparing required program cost and budget reports.

ABOUT THE AUTHORS

Mr. Raymond Moore is a Systems Engineering and Life Cycle Cost Analyst subcontracted to General Technology Corporation, under contract with McDonnell Douglas Training Systems to develop an automated life cycle cost modeling tool for the C-17 Aircrew Training System. Mr. Moore has also developed Reliability and Maintainability, Models, predictions, program plans, and integrated logistic support analysis reports for numerous defense related programs. As a member of the Society of Automotive Engineers (SAE) G11 review committee, he provided subject matter expert review for sections of the SAE Reliability, Maintainability and Supportability (RMS) Handbook. Mr. Moore also publishes "The 8A Connection", a quarterly listing of Small Disadvantaged Businesses qualified to meet Government Prime Contractor's SDB set aside subcontracting requirements. Mr. Moore’s formal academic education is in Business Administration from Sam Houston State University and the University of Texas at Arlington.

Mr. Gerrit K. Spieker is the C-17 ATS Training System Support Center Manager with McDonnell Douglas Aerospace. During the development phase of the C-17 Aircrew Training System, Mr. Spieker led the System Engineering effort to define, develop, and deploy the integrated system that now provides C-17 aircrew training for the United States Air Force. Mr. Spieker has over thirty years of experience designing, developing, and supporting aircrew training systems for commercial airline and military applications. Mr. Spieker holds a B.A. degree in Government from the University of Texas at Arlington and a Master of Arts degree in Human Resources Development from Webster University.

Ms. Joan E. Hendrix is employed by Simms Industries, Inc. as the C-17 ATS Courseware Product Assurance Manager. In this capacity, Ms. Hendrix performs Independent Verification and Validation Services for the C-17 Aircrew Training System. Ms. Hendrix has been instrumental in the design and implementation of all C-17 ATS Formative, Summative, and (currently) Operational Evaluation activities. Ms. Hendrix is a Ph.D. candidate in the Instructional Psychology and Technology program at the University of Oklahoma.

AIRCREW TRAINING SYSTEM LIFE CYCLE COST MODEL

Introduction

The need for an Aircrew Training System (ATS) life cycle cost (LCC) model was realized after reviewing the applicability of traditional LCC models, and assessing their capability to predict the life cycle cost for the C-17 Aircrew Training System. This analysis revealed that the traditional LCC modeling tools available are centered around a hardware end item that is being defined as an "Operating System". As a result, the traditional LCC analysis is focused around the major hardware end item operating system. Due to this "hardware" focus, cost drivers within the traditional LCC modeling tools are hardware oriented. With an Aircrew Training System, or any integrated training system, the "hardware" items of the "operating system" play only a supporting role to the major objective of producing trained students. Therefore, the focus of a "training system" LCC analysis, or model, must center around the functional systems and elements required to produce a trained student. The first question then must be, "What functional systems, or elements, comprise a training system?" A general review of a training system from a cost analysis perspective indicates that a training system will be comprised of a Training Program, Training System Hardware, and a Training System Support System. Here we should point out a unique common feature of "training systems" verses "hardware oriented operating systems". A training system always produces a trained student as the output product from the system. In order to produce this product, the training system will employ a training program. The training program is a process consisting of the correct combination of courseware, instructional curriculum, and training delivery media used to instill learning objectives in order to transform a training candidate (i.e., a student) into a proficiently trained student. This continuing process requires certain support resources and resource management in order to accomplish the goal of a proficiently trained student. Figure 1 shows a high level common architecture of a "training system" with the "training program" as a element to the training system. An analysis of these functional systems, or elements, that comprise a training system clearly demonstrates the sharp contrast in the needs of an Aircrew Training System LCC model to those in the traditional hardware oriented LCC models.

By generally analyzing the Training Program element of a training system it was determined that a Training Program is the integration of training resources, processes, and people. The training resources are the courseware, instructional curricula, and training media through which academic knowledge can be transferred from static "book" information to dynamic human cognitive intelligence. The training processes are the methods by which training resources are integrated in order to effectively and efficiently accomplish the training objectives established for the training program. The people are those human resources required to develop and maintain the training program, manage the operation of the training program, deliver and administer training instruction, and ensure the operational capability of the training system hardware and training delivery media.

Training System Hardware are all of the hardware elements within a training system that will place a demand upon support system resources. This hardware includes all of the hardware from training system administrative equipment to training device support equipment and classroom training equipment.

The division of training system hardware from the training program's training media requires special attention. Training Media are those mediums used in the training program to instill learning, or task proficiencies, enhance long term knowledge retention capabilities, and provide a bi-directional avenue that is not only used for transference of academic knowledge, but to also demonstrate that the desired knowledge has been successfully learned. Training Media in a training system ranges in depth from Instructor/Classroom Based Training equipment to delivery of training through the use of sophisticated high-tech training devices such as interactive computer based training and weapon system training simulators. While the training media May represent a large portion of the hardware acquisition cost in a training system, it is obvious that these elements have only a supporting role in a training system as a part of the training program. For cost analysis efforts we must make a distinction between these hardware elements as training media and training system hardware due to the fact that each category has very different cost driving factors.

The Training System Support System again breaks from the traditional definition of a support system. Here the support system is all of those elements that are non- training program resources that are needed in order to meet the training system's goal of producing a trained student. The Training System Support System elements include all of those hardware items, processes, and personnel needed to perform such functions as training system personnel and asset management, program or project administration, training system resource management and coordination, student data collection and student records management, training media support requirements identification, acquisition and management, quality assurance functions, and other system support related activities. These support system elements consist of operational functions combined with hardware items, operational processes, and people to form an integrated operational entity whose purpose is to support the training system and/or training program. In a hardware oriented operating system; the "support system" deals primarily with the logistics and supportability aspects of the hardware components of the hardware end item. Such items as the resources needed to perform quality assurance tasks for instructional curriculum changes and resources needed to perform continuing maintenance of courseware materials do not fit into the traditional categories of a hardware oriented logistics support system.

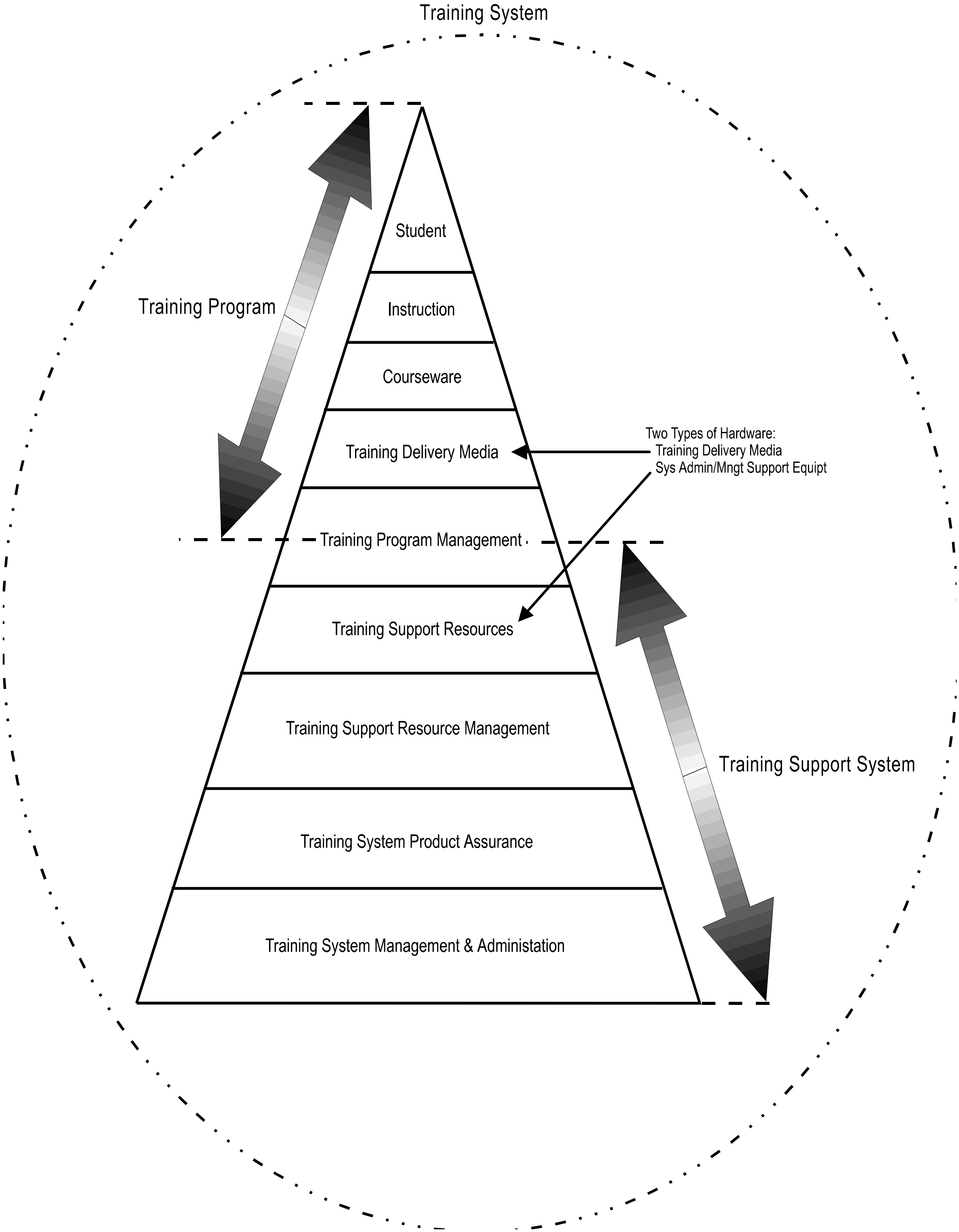


Figure 1 Common Training System Elements

By analyzing the elements that comprise a "training system", it is apparent that a training system LCC model must be focused on analyzing the functional and operational sub-elements that make up a training system and not be centered around a hardware end item which is being defined as an "operating system". This analysis and the subsequent training system LCC model must consider such ambiguous sub-elements as courseware, instructional curriculum, student remediation, and other non-hardware elements that affect the quality of the training system's output product (i.e. a proficiently trained student). Not only must these non-hardware elements be recognized as operational entities within the training system model which affect the output product of the training system, but the non-hardware inputs to the training system that affect these sub-elements must also be recognized and analyzed. Additionally, the training system model must possess the capability of identifying and assessing the impacts from both external input variations and internal sub-element relationship variations which affect these non-hardware elements and the associated impact, or risk that these variations have on the training system's output product and overall life cycle cost. Student remediation is a good example of a non-hardware sub-element within a training system. Excessive student remediation requirements in a training system are not normally an acceptable condition. Excessive student remediation either requires additional consumption of training system resources such as training device operational time and instruction time, or necessitates a change in how the student is being trained. If the cause of the need for student remediation is not identified, nor the impacts of excessive student remediation on other elements within the training system are not properly analyzed, the ability to adequately predict a training system's life cycle cost is in question. Therefore, the training system LCC model must be capable of addressing the ambiguous sub-element of student remediation by:

> Identifying and defining what causes the need for student remediation, and/or what minimizes the need for student remediation.
>
> Identifying the operational and cost influences that student remediation has on the training system and other sub-elements within the training system.
>
> Defining what is acceptable remediation both in the terms of training, training system product output, and cost.
>
> Identifying the elements within the training system and those elements external to the training system that drive or influence the requirement or non-requirement for remediation, and that determine the associated varying amounts of student remediation needs.

Training System Modeling Requirements

According to reference books on life cycle cost analysis, or modeling, the first requirements for an LCC model are that the model must be:

> A simplified representation of a real-world situation about which future operational and cost information is imperative for operational and cost decisions to be made today.
>
> An analytical tool that generates data in a timely manner which can then be evaluated and employed in the operational and cost investment decision making process associated with the real-world situation.

Therefore the major purpose of the LCC model must be to provide adequate information about the system being modeled in order to allow today’s decisions affecting tomorrow’s outcomes to be made with some confidence regarding the level of risk associated with that particular decision. Applying the above two LCC model requirements to a training system LCC model reveals that one of the major requirements of a training system LCC model must be its ability to continuously predict and re-predict cost based upon uncertain and very dynamic input data.

The hardware oriented LCC model's output cost estimate is usually bound by a pre-defined set of input parameters which have minimum and maximum boundaries defined by hardware design constraints and hardware operational usage profile constraints. The training system LCC model needs to be capable of dealing with situations where the input boundaries are contingent upon:

> The three element input characteristics of training candidate population size, training candidate population demography composition, and the training candidate population’s inherent academic knowledge and skill attributes.
>
> The mix of these characteristics within the inputs to the training system
>
> The dynamics of these characteristics over time

In the analysis of training systems and training system requirements, it was revealed that these items are rarely completely known and established during the design and development of a training system. Additionally, the analysis revealed that these items cannot be established as a constant over time, and the ability to predict these items with a high level of confidence for more than one or two fiscal periods is usually very low.

As stated earlier, the output product of a training system is a trained student. How the trained student is obtained is defined by the construct of the training program and the capability of the training system. The construct of the training program is developed by identifying:

> A student target population.
>
> What knowledge and skill attributes currently exist within that target population
>
> The knowledge and skill attributes that the graduating student population must have
>
> A viable set of learning objectives that can be achieved through a set of progressive learning steps

The capability of a training system is generally predicated based upon the assumptions that the:

> Volume of trained students output by the system has a definitive relationship to the number of training candidates entering the system
>
> Composition of the training candidate population demography and the segment mix of the training candidate population demography will remain within some predefine boundaries
>
> Academic and learning characteristics of the training candidate population will always match those identified in the target student population used to establish the construct of the training program

Understanding the elements that drive the construct of the training program, and the dynamics in the assumptions that define the capability of the training system confirm that the major requirement of a training system LCC model must be its ability to constantly re-estimate output cost based upon the:

> Dynamic changes in the size of the training candidate population entering the training system
>
> Demography segment composition of the training candidate population, and consideration of the continuing shifts or changes in these population demography segments as well as the magnitude, or rate of change within these demography segments.
>
> Variance and the direction of the variance of the training candidate population's academic knowledge, skills attributes, and learning characteristics as compared to the academic knowledge, skills attributes and learning characteristics identified for the training program's target population.

Thus the training system LCC model must not only be responsive to these input changes when predicting an output cost, but must provide the information for a decision-maker using the model to understand how the dynamics of these input characteristics will affect not only cost, but also how the training system must be functionally operated in the future. Therefore a training system LCC model must be capable of producing a non-hardware oriented output based on future assumed input data which predicts training candidate population size, demography composition, and inherent attributes, and then again re-producing an output based on actual known data regarding these input element characteristics. In addition, the training system LCC model must consider the unique sub-elements of courseware, instructional delivery, and the support resources associated with these elements which are driven by the characteristics of the training candidate population as inputs to the training system.

Another major requirement of a training system LCC model is that the training system LCC model predictive output must not be just a single point estimate providing an estimated set of "out year" annual cost, but rather a dynamic tool that could initially produce an estimated set of out-year annual cost based on assumed input data and then re-predict this set of estimated out year annual cost based on sporadic known input data. As an example, in an aircrew training system the yearly Program Flying Training (PFT) for an aircrew training system is rarely known prior to the start of any one fiscal year. The actual PFT for an aircrew training system contains the information regarding the training candidate population's size and demography composition. The PFT's demography segment composition contains information regarding the academic knowledge and skills attributes of the training candidate population entering the training system. While the PFT for a training system can be predicted based on the assumptions of aircraft delivery schedules, crew ratios, crew compositions, etc., and a subsequent LCC cost estimated formulated, the actual cost for annual budget establishment should be accomplished based on the known PFT, and the characteristics or attributes of that known PFT, for the up-coming fiscal year.

Training System LCC Modeling Objectives

Once the needs for an aircrew training system LCC model were established, a set of general modeling design criteria was developed. This modeling design criterion was established not only to ensure accomplishment of the identified needs, but also to prevent the resulting model from only providing a "single point-in-time" estimate, or becoming a program specific modeling tool. A review of training systems in general revealed that "training systems" of all types have similar elements that comprise the training system (i.e., a training program and training system support elements) and that fundamentally the input and output requirements for training systems are generally the same (i.e., inputs are a training candidate population, the resources needed to manage and support the training program and support certain elements of the training system; outputs are the cost of producing a trained student to a prescribed level of academic knowledge and repeatable skills proficiency). Taking into consideration the commonalties among training systems, the following criteria and objectives were set for the C-17 ATS LCC modeling design and development effort:

> Must be capable of modeling all elements of an integrated aircrew training system as a single operational entity
>
> Must be capable of accepting aircrew training system types of input data
>
> Must be capable of utilizing existing input data available and must minimize the need for creation of new input data
>
> Must be dynamic and reactive for continuing usage to assess potential future program changes and evaluate the impacts of these changes
>
> Must be a reusable modeling tool and not just a point estimate for the C-17 ATS program LCC. Reusability is defined by the ability of the tool to accept changes in the input data without requiring a re-examination of the modeling tools algorithms or infrastructure in order to produce a new set of LCC output estimates. This requirement is driven by the dynamics within input data from one fiscal year to the next, as well as, the need to use the tool for periodic re-competitive assessments and budget establishment.
>
> Must be transportable and flexible. Transportability means that the tool must be capable of modeling and assessing the LCC of other integrated training systems. This requires the tool to use somewhat generic elements; however these generic elements share common traits among integrated training systems. Flexibility means that the LCC modeling of other integrated training systems only requires the selection or non-selection of input data in order to perform an LCC estimate for that integrated training system and not a restructuring or modification to the modeling tool's element cost estimating, functional or operational relationships, algorithms, or infrastructure.
>
> The modeling infrastructure must be designed around the current Wright Patterson AFB Aeronautical System Division approved Work Breakdown Structure (WBS) for Aircrew Training Systems in order to promote future LCC Tracking and Estimate to Actual Cost Analysis efforts.
>
> Modeling documentation must be of sufficient nature to support cost estimate auditing during Estimate to Actual Cost Analysis efforts in order to determine the detailed causes of variances. The outputs from the model used during the performance of Estimate to Actual Cost Analysis efforts must be compatible with the current approved WBS and the current capabilities of the contractor's accounting and reporting system.
>
> The model should employ a modular design concept so that modules that perform specific functions can be used, or not used, dependent upon the design of the training system being analyzed or modeled. The use or non-use of a specific module should not require a reconstruction of the algorithms in the model (nor the algorithms in the modules within the model) but merely a modification to the interface points between model modules.

Model Development Approach

The C-17 ATS LCC model was developed using the Automated Cost Estimating Integrated Tool (ACEIT) modeling environment. This environment was selected primarily because of the flexibility and functional capability that it could supply to an LCC model. As a result, the model is a tool which can be continuously employed to manage the life cycle cost of an integrated training system and is not just a single point LCC estimate.

The ACEIT modeling environment contains an integrated set of standard cost analysis tools needed in the performance of a life cycle cost analysis, or an economic cost analysis. This set of integrated tools has a user-friendly interface between the tools which allows the tools to be employed in the model when, and as, necessary. The integrated tools also provide the analyst with the capability to perform statistical and risk analyses functions from within the model, apply learning and beta curves as required, and perform out year estimates in both base year dollars or inflated dollars. Additionally, this environment provides an easy avenue for the analyst to perform sensitivity studies and "what if" comparisons without disruptions, or changes to the basic model infrastructure. The ACEIT modeling environment allows the analyst to concentrate on compiling data and building the estimate, rather than spending time ensuring that the model is inter-faceable with the analytical tools needed to perform an estimate. In addition, this modeling environment contains all of the necessary cost reporting aids that will allow an analyst to develop and perform a complete cost or economic analysis program and develop the required periodic cost reports.

The ACEIT modeling environment was developed by an integrated team of Tecolote Research, Inc., the Air Force Electronic Systems Center (ESC), and the Army Cost and Economic Analysis Center (CEAC). This modeling environment has been field proven by both governmental and commercial entities. This modeling environment provides the analytical tools which will allow the fully developed integrated training system LCC model to be automated, flexible enough to accommodate potential future modeling change needs, and easily transportable for use by either government, or contractor analyst, with minimal cost impact to both. The automated capability and flexibility provided by the ACEIT modeling environment ensures that the integrated training system LCC model will have the dynamic ability to be continuously used throughout the life of a program, not only to assess the life cycle cost of the program, but to provide the necessary information for program management to make cost effective and efficient operational decisions.

The decision to use the ACEIT modeling environment for development of the C-17 ATS LCC model was made after an extensive research of the currently available LCC modeling tools. This research and subsequent conclusions were documented as a part of the C-17 ATS LCC program. During the research, thirty-two (32) LCC models and/or modeling tools were identified and evaluated for their ability to:

Perform an LCC analysis for the C-17 ATS program

Meet the LCC program requirements as contained in the C-17 ATS system specification

The ACEIT modeling environment was selected not only because of its vast array of integrated cost analysis tools, but also due to the fact that the modeling algorithms, along with the modeling algorithms' documentation, could be easily saved independent of the modeling environment, and reused in other cost analysis modeling efforts without manual re-entry of the algorithm, the algorithm's documentation, or the input data interface to the estimating algorithm. As a result, any cost analysis developed in the ACEIT environment for one program could be easily transportable for use in another program's cost analysis efforts.

A secondary reason for selection of the ACEIT modeling environment was the minimal cost impact to both contractor and the government. Because the ACEIT modeling environment was developed by the government, it is available to both government users and prime contractors. Additionally, since the cost analysis algorithms can be saved independent of the modeling environment, the cost analysis model and estimate supporting data/documentation could become a program deliverable item without concern about who owns the model operating program. Also, model algorithms delivered by a prime contractor could be easily modified by government analysts to fit the different needs of a government program analyst verses the needs of a contractor program analyst, without requiring programming skills or operating system source code. Additionally, because the estimate's documentation is embedded with the modeling algorithms and subsequent estimate, an entire program's cost or economic analysis estimate could be developed and delivered in a paperless medium.

Model Development Methodology

The C-17 ATS LCC model encompasses all of the hardware, operational, and functional entities that comprise an integrated training system. The principle structure of the C-17 ATS LCC model was constructed around the Work Breakdown Structure (WBS) for the C-17 ATS program. This approved WBS is a modified version of the Wright Patterson AFB, Aeronautical System Division WBS for Aircrew Training Systems. Because the program approved WBS elements are used to collect and track program cost, this approach enhances the ability to directly compare model predictions to actual cost incurred. Additionally, this approach enhances the ability to perform variance analyses and to understand why, and what caused, the variance between the actual cost incurred and the predicted cost. This information can then be used by program decision makers to control and manage a program's cost, as well as to enhance their ability to realistically establish achievable future budgets.

Since the program approved WBS provided the fundamental baseline from which the C-17 ATS LCC model was formulated, it also provided the frame work for the LCC Tracking System. Structuring the LCC model around the established WBS (i.e. the modified Wright Patterson AFB, Aeronautical System Division WBS for Aircrew Training Systems) allows the model to be integrate-able and compatible with a prime contractor’s accounting system used to perform cost accumulations, cost reporting, budgeting and cost tracking. Additionally, the capability to perform a predictive cost to actuals incurred variance analysis is enhanced by the model's ability to predict a cost for each of the approved WBS elements.

For modeling purposes, the C-17 ATS LCC modeling effort deviated somewhat from tradition by expanding the approved WBS in order to allow for the discrete identification of cost elements at the lowest possible level. Because the expansion of the WBS was performed inside of the ACEIT environment, cost at lower levels could be estimated and then rolled up to and reported at one of the approved program WBS levels. The expansion of the WBS for modeling purposes allows the contractor to identify the necessary cost elements needed to perform a complete LCC without disruption to the established WBS cost accounting, reporting, and traceability system established early in a program. This approach allows a cost analyst to go down to a level where simple discrete cost estimates can be formulated and then rolled up to a common reporting level. As a result, a complete predictive cost audit trail can be established for the cost estimated. Because the documentation for each cost estimating algorithm can be developed on-line and embedded with the cost estimating algorithm, the necessary information needed to support an estimated to actual cost variance analyses is readily available. In addition, this embedded on-line documentation for each algorithm enhances the ability of multiple users to easily modify the model, or the model's algorithms to meet their specific needs.

Because of the need for the LCC model structure to be compatible with the WBS cost accumulation system, the C-17 ATS LCC model is primarily an accounting type of LCC model, however not totally. Rather than make the model a pure accounting type of LCC model, a decision was made to integrate the functional parameter algorithms of each WBS element with the cost element relationship algorithms of each WBS element. This caused the model to be more of an engineering type of model in which the predicted outputs of the model are sensitive to input data and changes in the input data to the model (i.e. program and pragmatic data changes). As a result, the modeling algorithms for each WBS element were developed using combined operations research, systems engineering, and accounting analysis methodologies.

Initially each WBS was analyzed using an operations research cause and effect analysis methodology to break the WBS element down and identify the smallest component parts that comprise that WBS element, and that influence, or drive that WBS element. The results of this analysis provided information about the integral element relationships of each WBS element component and the integral relationships between WBS elements. (For example, the total number of instructors needed has a direct relationship to the number of instructional hours to be delivered during a single period of time. The number of instructional hours to be delivered has a direct relationship to the number and types of students to be trained during that single period of time, etc.).

Figure 2 shows the basic infrastructure of the C-17 ATS LCC model built around the C-17 ATS program WBS. Figure 3 shows a sampling of how the operations research analyses methodology was used to breakdown and identify the component parts of each WBS element. Also shown in Figure 2 and 3 is a sampling of the results from the operations research cause and effects analysis. (For example, the total number of instructors required at a training site is determined by the total number of instructional hours to be delivered at that training site. The instructional hours to be delivered at a training site is determined by what training is to be accomplished at that training site and the number of students scheduled to receive that particular type of training.) The operations research analysis fundamentally determined the structure and foundation of the LCC model by defining the type of integral relationships between WBS elements and WBS element components. These integral relationships provided the baseline information to identify and define detailed element relationships (ERs) for the operational, functional, and physical (hardware) elements of the training system. The dependent variables between the ERs were then identified and analyzed to define how the integral relationships within each ER function. The integral relationships between the ERs were then used to develop estimating equations for the ERs and subsequently used to develop the modeling element equations for each element in the model.

Once the WBS element component parts were identified and the basic integral element relationships established, a systems engineering functional analysis was conducted to define the parameters within the element relationships and the sensitivity factors within these element relationship parameters. The results from this analysis provided the critical information needed to understand the integral relationships between WBS elements and element components, as well as, the influence that each element parameter has on other element parameters. This analysis established the heart of the LCC model by identifying and defining the dynamics within the WBS elements and their associated relationship parameters. The detailed functional analysis also provided the necessary information about the sensitivity factors within each element relationship parameter, the dynamics of these sensitivity factors, and the integral relationships that influence these sensitivity factors. The element relationship parameters and sensitivity information were then used to determine cost drivers and cost driver factors in the model. Additionally, this analysis provided the information needed to understand why these cost drivers exist, and which LCC inputs have the greatest influence on these cost drivers.

The systems engineering analysis also provided the information necessary for integration of data from other analysis tools being utilized on the C-17 ATS program. Interface points were identified within applicable WBS elements where data from these other modeling/prediction tools could be integrated with the C-17 ATS LCC model. Data from these other modeling/prediction tools in most cases function as an input to the LCC model. In some cases this data is an integral variable within a WBS element algorithm. In either case, the data from these other tools is combined with data either generated within the model, or supplied by other inputs to the model, and eventually used to calculate WBS element cost estimates.

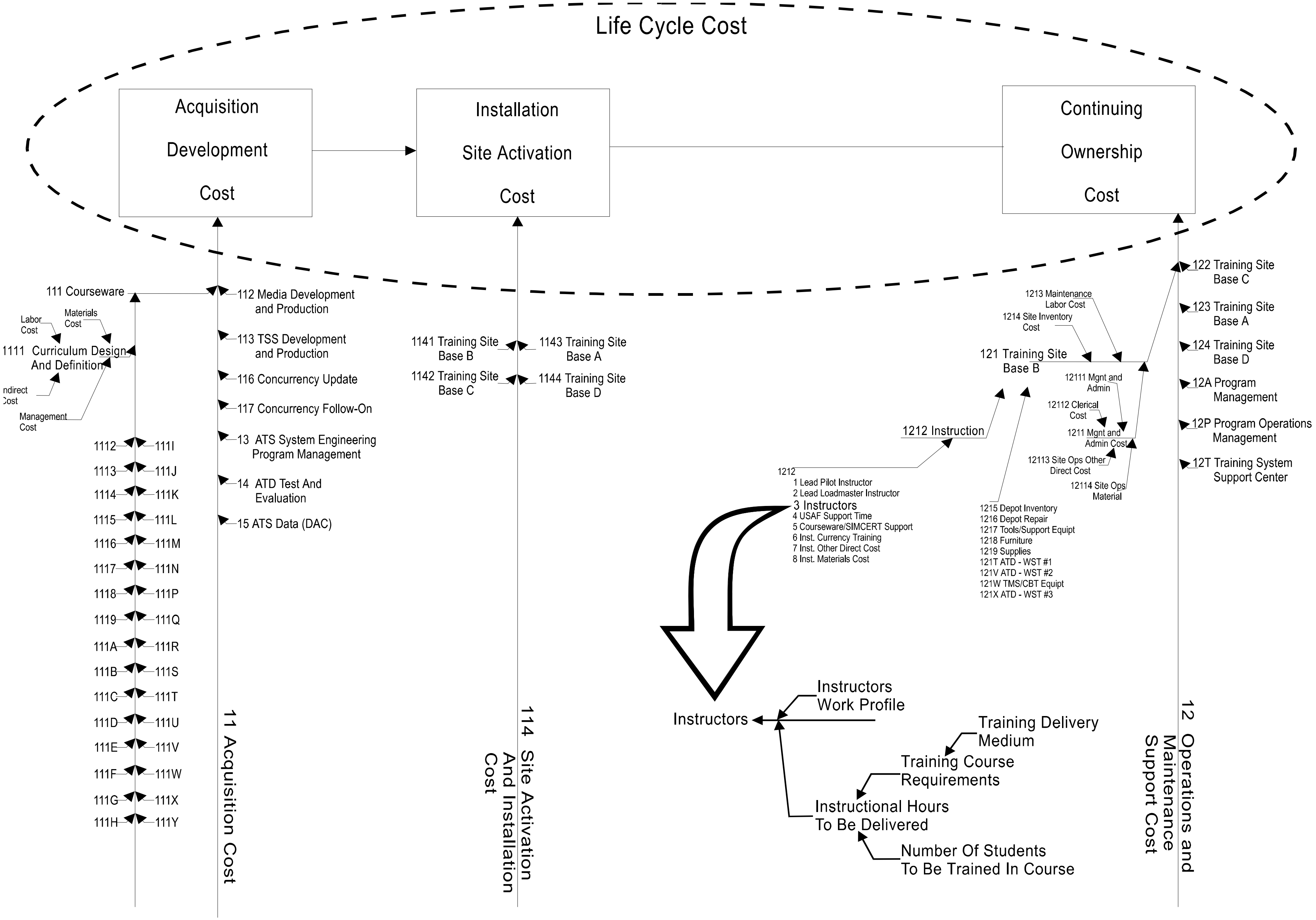


Figure 2 C-17 ATS LCC Model Infrastructure

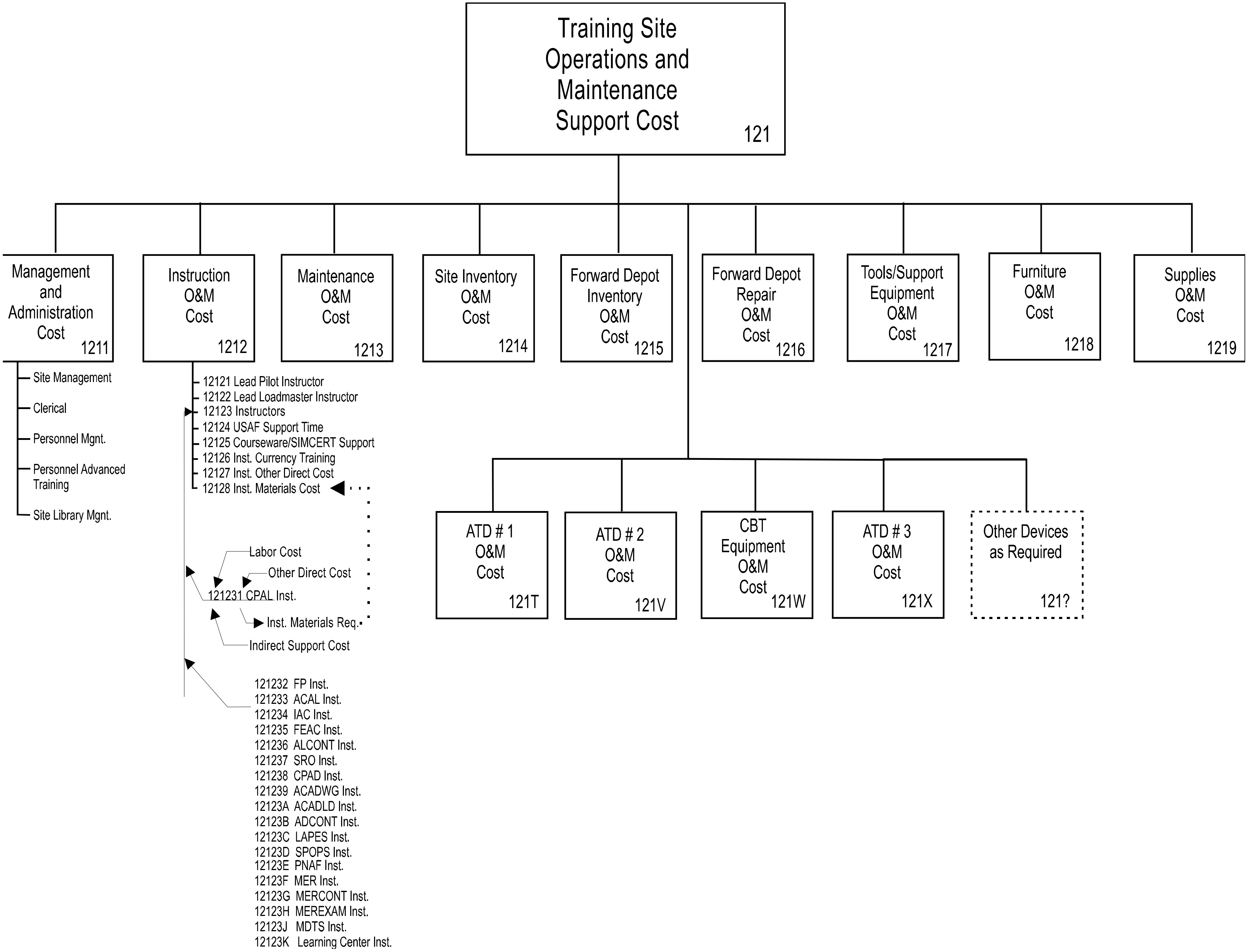


Figure 3 Program Structure

Figure 4 shows the top level center piece of the C-17 ATS LCC model established by the system engineering functional analysis. This part of the model is basically comprised of five major modules. These major modules are comprised of interrelated sub-modules which possess integral functional relationships. Each of the five main modules also possess integral functional relationships between each other. (For example, the number of instructional hours to be delivered is identified by the outputs of the Student Training Throughput Determination Module and the Instructor/Staffing Requirements Determination Module. The types and quantities of training devices needed to adequately deliver the required instructional hours are determined by the Operational Training Equipment Determination Module. The necessary instructional support resources needed to deliver the required instructional hours with the selected training devices is determined by the Instructional Support Requirements Determination Module. The Training System Support Requirements Determination Module identifies the training system and training delivery support resources, such as the number of courseware personnel needed to support updates and maintenance to the training program's courseware, and the number of maintenance personnel and spare parts needed to maintain the training delivery devices in an operational condition. Please note that the input data shown in dotted boxes in Figure 4 is only representative of the types of data that feed in to each module and is not all inclusive. Each of the main modules in the Functional Element Relationship Definition Model provide multiple inputs and multiple types of input data to the other major sections of the model.

The Student Training Throughput Determination module is used to process dynamic program input data, assess input data influences, and assess impacts from changes in the input data such as aircraft delivery, aircraft crew ratios, and numbers of additional students needed to be trained in order to achieve a desired student throughput goal. This module is used to identify such elements as student training throughput requirements and instructional hours that must be delivered. Fundamentally this module uses a Queuing theory approach to accept raw data inputs, process these inputs, and then provide the necessary processed input data to the other modules in the model.

The Instructor Staffing Requirements Determination and Operational Training Equipment Determination modules were identified as being the center piece of the C-17 ATS LCC Model. These two modules are where most of the pragmatic types of data and engineering design data influences are identified, defined and processed. As a result, these two modules control most of the training system's operational influence information (i.e. how the ATS should be operated, the quantities of instructors and support personnel that should be utilized to deliver the most cost effective training, what quantities and types of training medium will be needed to adequately deliver training, etc.). These two modules are the core to the C-17 ATS LCC model.

The Instructional Support Requirements Determination Module receives inputs primarily from the Instructor Staffing Requirements Determination Module and processes this input data with instructional support requirements data, training system operational support data and other program support data to identify and assess support element functional relationships and the influences that these relationships have on determining the unique support resources for an operational training system. This module also receives some input data from the Operational Training Equipment Determination Module which is used to process support requirements for the operational equipment used to support operational and functional systems within the training system.

The Instructional Support Requirements Determination Module gives the C-17 ATS LCC model its unique difference over "hardware oriented" LCC models. This module recognizes that a "training system" has operational and functional entities that must be accounted for as separate independent elements which are not necessarily hardware driven. These operational and functional entities have different characteristics and, as a result, different modeling requirements than those used for the hardware elements in a training system. (For example, the Training Management System is an operational entity comprised of operational procedures, hardware, software, personnel, and training site interfaces. The TMS as an operating system has specific support requirements as a functional entity within the training system which are not hardware driven. Additionally, the TMS is not directly tied or associated with a specific hardware end item, but is an operational entity needed within the training system in order for the training system to be a viable entity capable of accomplishing the desired output, or goal of the training system.) The Instructional Support Requirements Determination Module accounts for all of the unique support requirements of an "integrated training system" as the end item and allows the model to estimate a more realistic LCC that is not totally hardware driven.

The Training System Support Requirements Determination Module receives inputs from the Operational Training Equipment Determination Module and processes this input data with logistics support analysis data, and other program support data, to identify and assess hardware and support system element functional relationships, and the influences that these element relationships have on determining the support resources for the C-17 ATS as an operating system. This module is more hardware oriented than the Instructor Support Requirements Determination Module. This module takes the more traditional approach in LCC modeling in the sense that most of the functional element relationships and associated modeling parameters are identified and driven by specific hardware elements in the C-17 ATS. This module is where most of the other modeling/analytical tools used by C-17 ATS logistics engineering center are integrated into the overall C-17 ATS LCC model. This module functions primarily like typical LCC models currently available on the commercial market in that it will assess and determine Supportability functional element relationships that are mostly driven by hardware WBS elements.

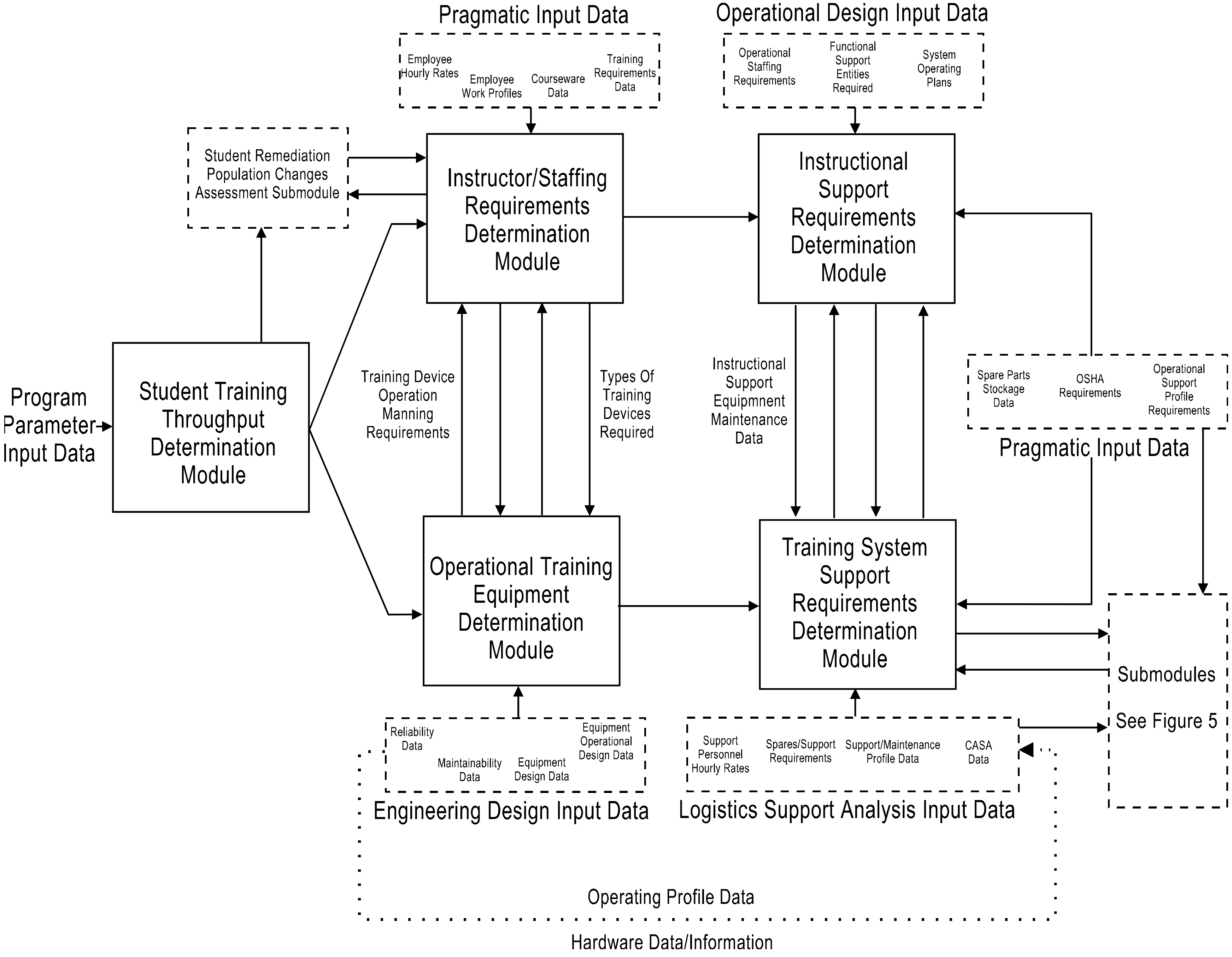


Figure 4 Functional Element Relationships Definition Model

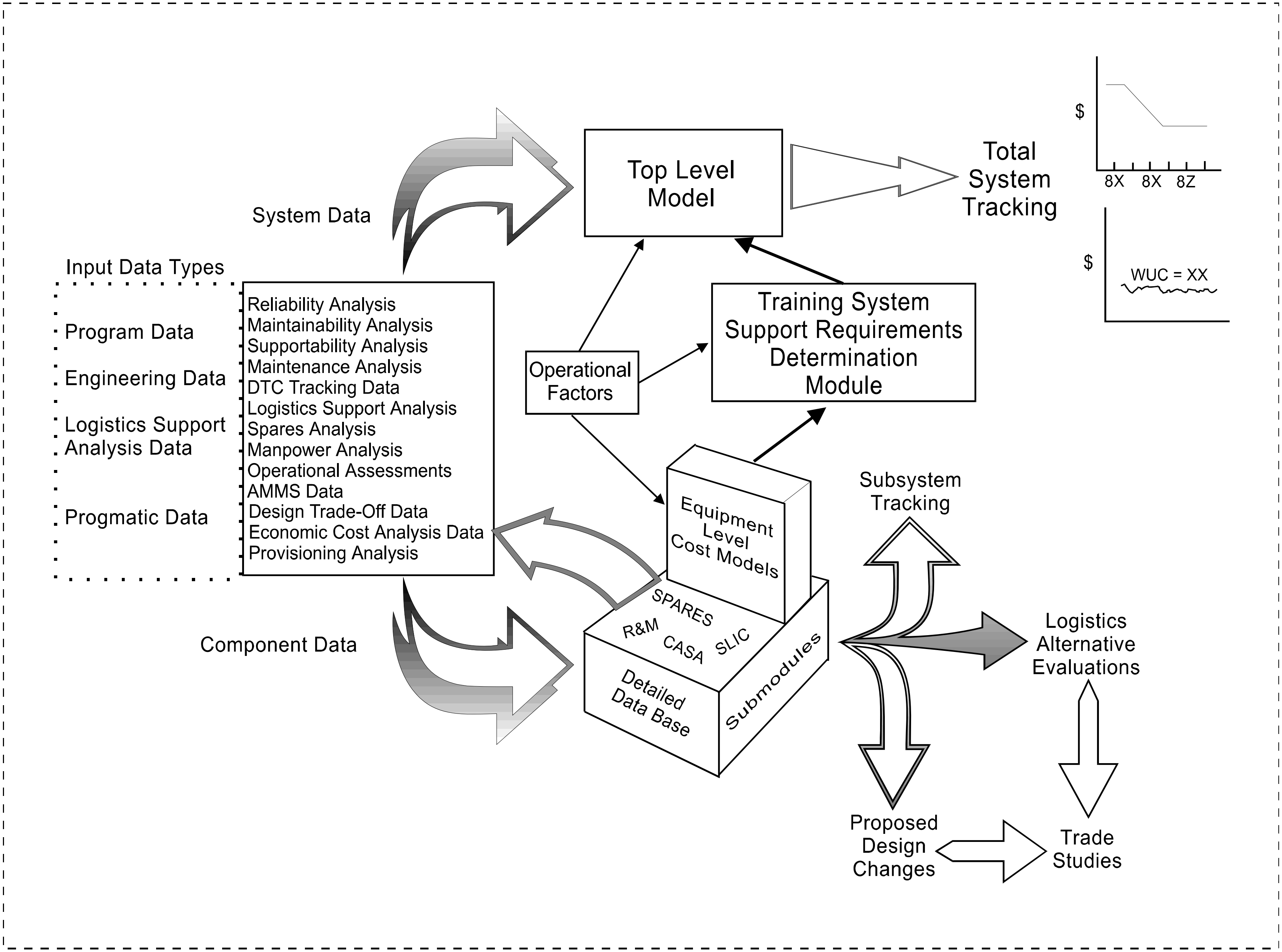
This module is basically comprised of several sub-modules integrated together as shown in the example in Figure 5. For the most part, these sub-modules consist of external analytical tools such as the CASA model, SLIC (a logistics support analysis tool), reliability and maintainability (R&M) prediction models, and various other logistics and design analysis tools. Most of these analytical tools were used during the initial design phase to provide LCC data and design assessment information for the various training hardware devices utilized in the C-17 ATS. These external analytical tools become sub-modules to the LCC model as they are integrated / interfaced with the applicable WBS element algorithms within the LCC model.

Combining together the resulting outputs from the five modules of the Functional Element Relationship Definition Model provides an identification of all the functional relationships between the WBS elements and WBS element components identified by the operations research and systems engineering analysis. These functional relationships provide the model with the necessary dynamics that allow the C-17 ATS LCC model to be a useful predictive tool for estimating future program resource needs and cost based on the dynamics of constantly changing program input data.

Results of the operations research and systems engineering analyses formulated the foundation for development of the model's detailed cost element relationships (CERs). Development of the detailed CERs was achieved by using a cost accounting analysis process. Initially, accounting models were established for each WBS element following the WBS structure as shown in Figure 6. This was accomplished by using the results of the operations research and systems engineering functional analysis, and developing an accounting type of model for each WBS element and WBS element component down to the lowest WBS cost element structure. (For example, Instructor materials needed for the Copilot Airland Training Course plus instructor materials needed for the Aircraft Commander Airland Training Course plus etc.,.. etc., equals the total instructor materials needed at the training site. Instructor training materials needed at training site #1 plus instructor training materials needed at training site #2 plus etc. ... etc., equals the total instructor training materials needed by the C-17 ATS.) These accounting relationships were then analyzed to identify CER factors to integrate with each operational and functional element relationship identified by the results of the operations research and systems engineering analyses. The results of this analysis were used to create a baseline for development of the detailed CERs for each model element. This was accomplished by defining and determining the functions of the accounting model algorithms for each of the WBS elements and associated WBS element components and then adding unit of measure and unit cost data to these functions (e.g., Instructor Materials Safety Shoe Annual Replacement Cost Total = total number of instructor safety shoe replacements required annually multiplied by the unit cost for a single pair of instructor safety shoes.).

The detailed cost element relationship algorithms for each WBS element and associated WBS element component were then developed by integrating the accounting model algorithms with the operational and functional WBS element algorithms defined by the operations research analysis and systems engineering analysis efforts. (For example, The total number of Copilot Airland instructors requiring safety shoe replacements plus the total number of Loadmaster Airland instructors requiring safety shoe replacements plus etc. ... etc., equals the total number of safety shoe replacements required at training site A. The total number of safety shoe replacements required at training site A multiplied by the unit cost for safety shoe replacements equals the total cost of safety shoe replacements at training site A. The total cost of safety shoe replacements at training site A plus the total cost of other instructor materials at training site A equals total cost of instructor materials for training site A. Annual cost of instructors at training site A plus annual cost of instructor materials for training site A plus etc. ... etc. equals annual Instruction Operations and Maintenance Support Cost for WBS Element No. 1212 (see Figure 3 and 6). Combining the cost element relationships with the operational and functional element relationships for each WBS element and WBS element component allows the model to produce cost estimates that are driven by dynamic operational and functional relationships which are influenced by programmatic inputs such as the number of students to be trained based on number of aircraft to be delivered.

Figure 7 shows the high level integration of the operations research analysis (Program Structure Model), the systems engineering analysis (Functional Element Relationship Definition Model) and the cost accounting analysis (Accounting Structure Model). It should be noted that each of these analysis efforts were not independent efforts undertaken as a single task, but rather were performed simultaneously as a cohesive modeling effort. (Note: The output lines from the Functional Element Relationship Definition Model feeding into the Program Structure Model in Figure 7 are only sample representations of the integral functional relationships between the two models. Each of the main modules in the Functional Element Relationship Definition Model provide multiple inputs and multiple types of input data to both the Program Structure Model and the Accounting Structure Model shown in Figure 7).



Submodule For Training System Support Requirements Determination Module

Figure 5 Integration of Hardware Sub-modules To System Level Model

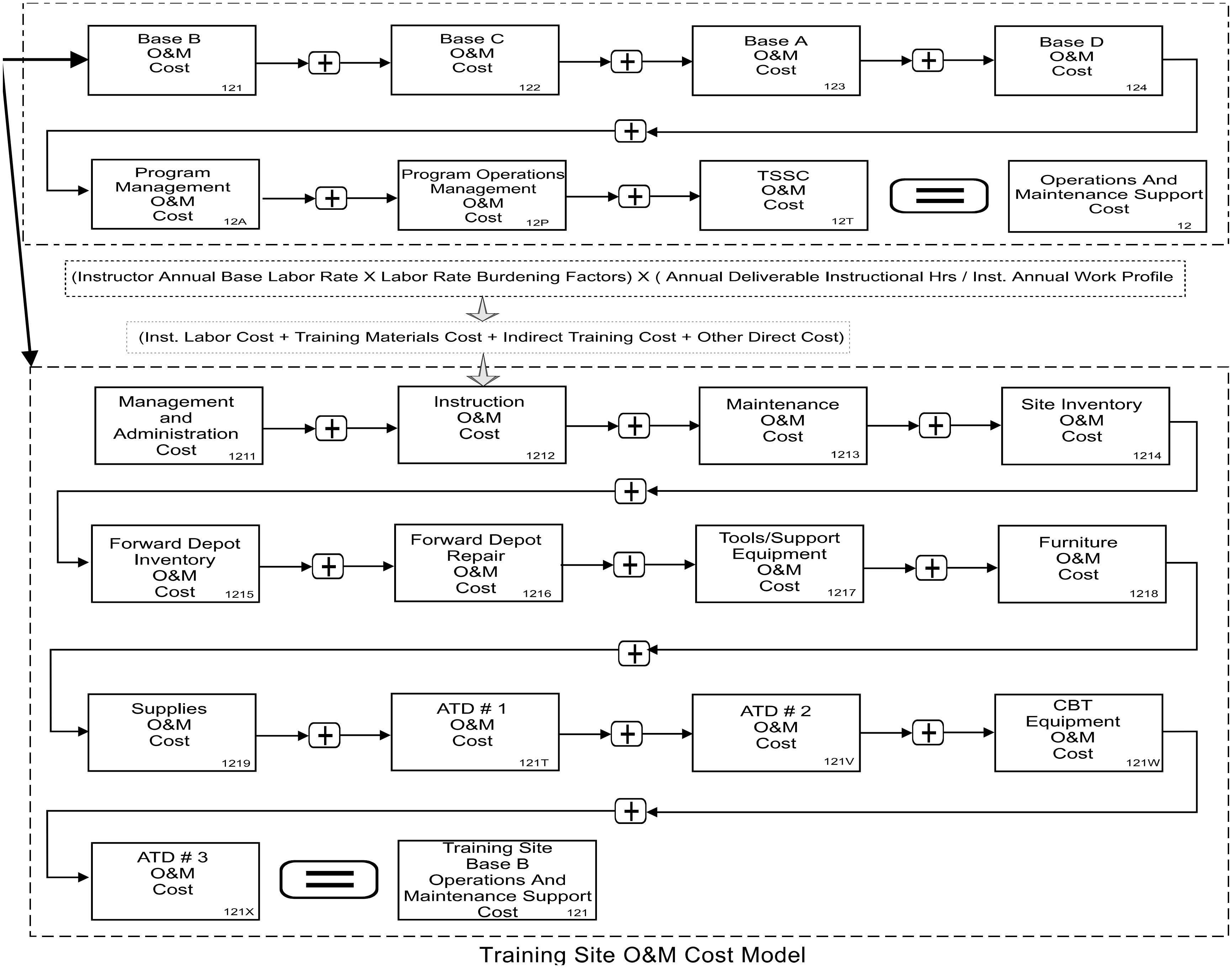


Figure 6 Accounting Structure Model

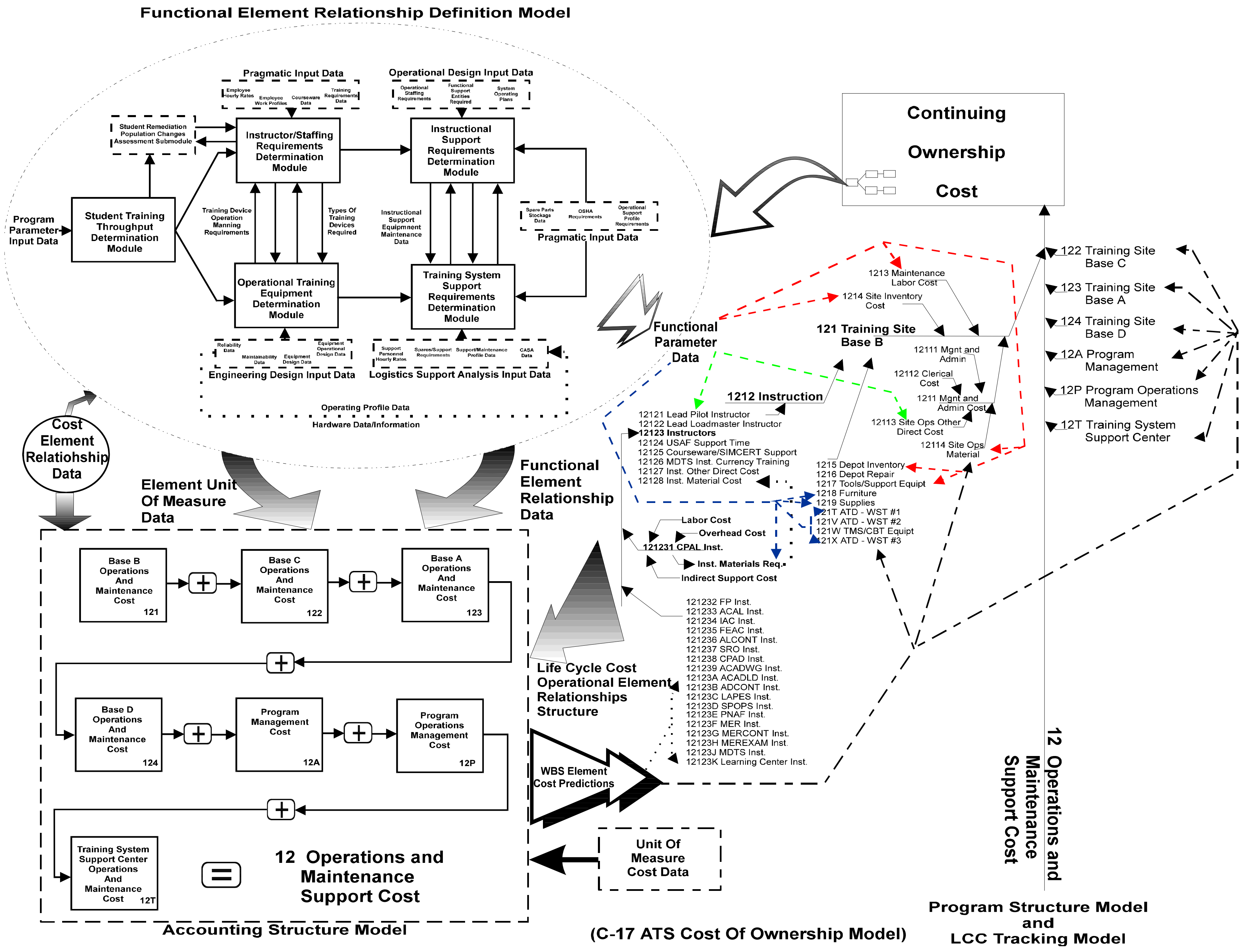


Figure 7 Integration Of Modeling Analysis Approaches

While the element relationships within the C-17 ATS are somewhat unique to aircrew training systems; the algorithms used in the element relationships at the lowest WBS element levels, or component parts, were selected (when possible) from proven sources such as the CASA manual, M. E. Earles' book, Factors Formulas, and Structures for Life Cycle Costing, R. D. Stewart's book, Cost Estimators Reference Manual, B. S. Dhillon's book, Life Cycle Costing Techniques, Models and Applications, W. J. Fabrycky and B. S. Blanchard's book, Life Cycle Cost And Economic Analysis, MIL-HDBK-276-1, and from the modeling libraries included with the Automated Cost Estimating Integrated Tools (ACEIT) modeling environment used to develop the C-17 ATS LCC model. In addition to the proven element relationships and cost element algorithms selected from these established sources, the C-17 ATS LCC model development team is currently reviewing many of the validated modeling tools available on the commercial market that perform unique, or specific functions (such as spares determination, reliability attributes predictions, etc.) for either inclusion into the C-17 LCC modeling effort or interface development with the C-17 LCC model for future use. This approach of using commercially available unique or specific modeling tools has held down development time and development cost for the model.

Currently, two commercially available models have been tentatively identified for inclusion in the C-17 ATS LCC model, in addition to some sections of the CASA model. Other available commercial models may still be utilized as integral sub-modules to the main modules of the C-17 LCC model. It is recognized that a good hardware end item level reliability, maintainability and availability model(s) will be needed. Additionally, a more flexible spares determination model is needed. Currently a spares prediction module using a Poisson distribution formula has been tentatively selected and is being evaluated for inclusion in the C-17 ATS LCC model. As specific sub-modeling needs are identified, commercially available models are researched and evaluated prior to engaging in the development of sub-models for the C-17 ATS LCC model. The intent for all sub-models or lower tiered modeling tools will be to integrate stand-alone sub-models as embedded plug-in sub-modules to the main ATS LCC model.

LCC Documentation and Tracking

During the development of the C-17 ATS LCC model, each WBS operational, functional, and cost element relationship rationale, element algorithm and estimating methodology, along with other relevant data and information denoting how an element is modeled, was recorded and documented. At the conclusion of the modeling effort, this documentation will provide the necessary traceability information and auditing data to verify and validate the model's predictive capability. This documentation is being developed on-line as an integral part of the definition and development of the operational, functional and hardware cost element relationships for each WBS element and associated WBS element component parts

Here we should point out an important fact regarding LCC model estimates (predictions), documentation, tracking, and estimates to actual variance analysis. A model's estimate for each WBS assumes that the WBS element is comprised of certain elements and element components which have a predefined set of operational, functional, and cost factors. This predefined set of factors are established by algorithms with dynamic inter-relationships which provide an estimate based on a specific set of input information. As a result, the model estimating world is fundamentally a rigid environment, unlike a real world accounting cost collection and reporting system. The major differences are the subjectivity of the human interfaces with the real world accounting systems which refine the structural rules for what is collected and reported for an item, as necessary to accommodate real world situations, versus the rigidly structured modeling world bound by the rules and constraints of inanimate algorithms. In summation, this means that there may always be differences between what a model estimates, or predicts for an item, versus the actual costs incurred for, or collected against, that item. Therefore, some amount of variance analysis should always be considered a part of the LCC program. As a result, part of the LCC tracking and LCC goal attainment assessment should be to determine if the variance of the estimated cost from the actual cost reported is a true deviation due to operational or functional problems in the system being modeled, or whether the deviation is merely due to the subjective inclusion of a cost component in the accounting system which was not originally considered or planned for inclusion with that element during modeling development. The LCC modeling documentation therefore becomes an important part of the LCC program. This documentation provides the necessary and critical information needed to truly assess, identity, and understand the reasons for variances between estimates to actual costs reported for an item. The key is to understand why the variance exists and whether the variance is due to a problem within the operational and functional elements of the model, or the subjective inclusion of cost by the accounting system which was not originally planned for inclusion at that element, or due to an actual operational problem within the training system being modeled.

Because the documentation for each modeling element, functional and cost relationship, and relationship algorithm is embedded within the aircrew training system model, the necessary information to make immediate program cost and operational decisions, to perform estimate-to-actual variance analysis, and to perform sensitivity analyses and "what if" comparisons, is readily available to the analyst. In addition, the model allows the analyst to record input data information on-line within the model. This input data can then be saved with the estimate and estimating model for future assessment and use. "What if" studies can also be accomplished without destroying the original input data or causing any disruption to the infrastructure of the model.

Problems, Challenges, And Solutions - A C-17 ATS LCC Modeling Side Benefit

The modeling development approach selected was focused around establishing a sound understanding of the component elements that comprise a WBS element, the parameters that bound each of these component elements, and the sensitivities within these parameters and their respective interrelationships. It is also important to understand the integral relationships of these items with other WBS element components and other WBS elements within a training system LCC model. As a result of the development approach selected, some side benefits were realized. Some of these benefits have direct relationships to the total LCC program goals, while some provide benefits in other areas such as risk identification and cost driver analysis. An example of these side benefits in the C-17 ATS LCC modeling effort was discovered during the development of the Student Remediation sub-module (shown in Figure 4 as an integral part of the overall LCC model and in Figure 8 as a stand-alone Student Remediation Model). This module processes the anticipated impacts from student remediation needs and uses the anticipated impacts to influence student throughput factors and support system resource requirements.

Prior to the development of the LCC model, the amount of anticipated instructor resources to deliver the required instructional hours to meet student throughput goals was predicted by calculating basic manpower resources needed and then modifying these resource needs with a student remediation factor. Due to the lack of sufficient data available needed to perform a parametric analysis to derive this factor, the student remediation factor had been developed as an experienced guesstimate. Research confirmed that neither the Air Force, nor any other integrated aircrew training program, had ever collected sufficient data regarding student remediation that could be used adequately in a parametric analysis to support a remediation factor for modifying instructor manpower and other associated resources. The first question then was, "Is student remediation an important factor?". The initial answer is yes, because student remediation places additional demands on two prime resources: instructor manning and operational time on the training devices. The second question was, "If student remediation is important, why is there a lack of historical information associated with student remediation?" The initial research revealed that the Air Force, other DoD entities involved with training, and other prime contractors that operate integrated training systems, are concerned with student remediation, especially with:

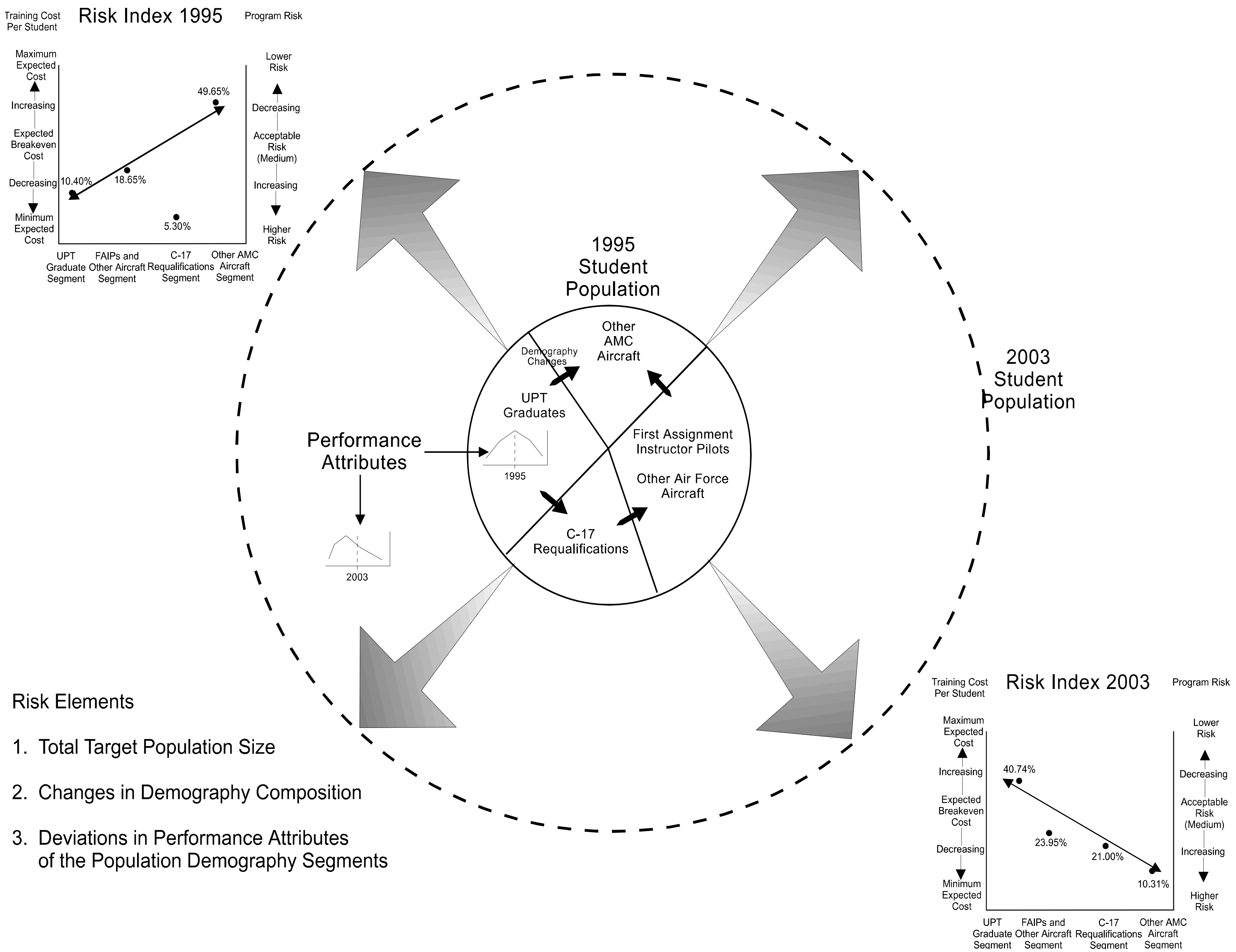
> How it should be measured
>
> How to predict its effect on the training program
>
> How to control the amount of remediation needed in a program

The research also revealed that the lack of data regarding student remediation was specifically due to the lack of a system to adequately collect, document, and analyze student remediation data. As a result, most integrated aircrew training system prime contractors only guesstimated a student remediation factor, or anticipate remediation hours based on their personnel's past experiences and a "good gut feel" for student remediation. Realizing that a guesstimate or "good gut feel" may not be sufficient to provide a supporting rationale, or other supporting traceability evidence for predictive modeling audits, a decision was made to develop a mini-model to predict the number of anticipated student remediation hours required based on student throughput requirements. Due to the C-17 program's requirement to produce a guaranteed student output, the contractor developed and implemented a system to collect, analyze, verify, and validate student remediation information. The information from this system will provide the data needed to verify and validate a student remediation model or student remediation factor; however to date, insufficient time has elapsed to collect adequate data to develop a student remediation factor using a parametric analysis approach.

During the development of the student remediation model, two significant facts were discovered while analyzing the elements that control student remediation. First, student remediation requirements have three primary influence drivers, and second, these three primary influence drivers are also primary drivers associated with overall program cost and risk factors and program data inputs. These three primary drivers are:

> Student Population Size
>
> Student Population Demography
>
> The academic knowledge, skills, and performance attributes associated with each segment of the student population demography.

Figure 8 shows these three drivers and their associated relationships. The Student Population Size factor is straight forward. An increase in the student population means an increase in the probability of student remediation activities. However, the other two factors are not so straightforward, and have some complex interactive inter-relationships that affect student remediation requirements, as well as, training system cost and risk factors.



Risk Elements

1. Total Target Population Size
2. Changes in Demography Composition
3. Deviations in Performance Attributes of the Population Demography Segments

Figure 8 Student Remediation And Program Risk Elements

The Student Population Demography Segments that comprise a total student population can be viewed similar to student experience/performance categories which have filtered out some of the need for remediation. As an example, the Student Population Demography Segment categories in Figure 8 are:

UPT Graduates

First Assignment Instructor Pilots (FAIPs) and Other Air Force Aircraft

Other AMC Aircraft Qualified

C-17 Requalifications

A comparison of the student population demography segments indicates that the UPT Graduates have the least amount of experience and training, and therefore will require the most amount of training in order to attain the predetermined performance goals of a C-17 ATS graduate. Due to this lack of experience and the maximum need for training, this category would be expected to have a higher remediation requirement in relationship to its proportional demography segment size than the other demography segment categories. A review of the other demography segment categories, and comparison of experience and performance attributes among the demography segments, indicates that the Other AMC Aircraft Qualified and C-17 Re-qualification students would have the advantage of having the most experience and training (C-17 Re-qualification students are aircrew members who have been in staff positions and are now re-assigned back to an aircrew position). As a result of these student's past experiences and training, these demography segment categories would be expected to have the lowest remediation factor, or requirements. If the largest demography segment of the student population to be trained were either AMC Other Aircraft Qualified students or C-17 Re-qualification students, and the smallest demography segment of the student population to be trained were comprised of UPT Graduates, then the potential need for student remediation should be at its lowest possible requirement level. This condition would also possess the lowest program risks in terms of cost and the ability to achieve guaranteed student throughput goals. This is because the learning rate for AMC Other Aircraft Qualified students would be significantly higher than the learning rate for the UPT Graduate, simply due to previous exposure to the training objectives and flying experiences. A review of the student input population demographics provided by the Air Force for the C-17 ATS program indicates that this will be the case in the early years of the C-17 ATS program. The phenomena of having a more qualified candidate student population entering the training system in the early years of a training system, and a less qualified candidate student population during the later years of a training system's existence, appears to be true for most types of integrated training systems.

As the demography segment proportional sizes begin to shift (i.e., the UPT Graduate segment gets larger and the other segments get smaller), the probability for remediation also increases, as does the program risk factors associated with the cost to train a student and the cost to operate the training system. It should be noted that the increase in student remediation requirements and program cost and risk factors are not proportionally linear with incremental increases in demography segment size. As the demography segment size changes, the increase in student remediation requirements and program cost and risk factors increase at some order of magnitude larger than the proportional change in the demography segment size. This fact is compounded in complexity when both the student population size is changing and there are shifts in the proportional sizes of demography segments at the same time. A review of the Air Force student populations that are planned inputs to the C-17 ATS indicates that this will be the case in the out-years of the C-17 ATS program. Not only will the student population size be increasing, but there will be shifts in the student population demography segments from a small UPT graduate segment in 1995 to a larger UPT graduate segment in 2003.

The third element affecting student remediation requirements and training program risk factors concerns the specific academic knowledge, skills, and performance attributes of each student population demography segment. This third element has two important fundamental parts which are somewhat independent, yet both have an inter-dependency which is affected by the specific academic knowledge, skills, and performance attributes of each student population demography segment. The first fundamental part is the effect that a demography segment's average academic knowledge level, skill level, and performance attributes have on student remediation. The second fundamental part is the potential impact that the demography segment's average academic knowledge level, skill level, and performance attributes have on training program risk factors. This third element (student population academic knowledge, skills, and performance attributes) affecting student remediation has some hidden factors which are the key components that drive the unique requirements of an integrated training system LCC model.

These hidden factors that affect student remediation and program risk, and which cause student remediation needs and program risk to be non-linear in relationship to changes in the student population size and inter-related shifts in demography sizes, are associated with the training concept employed. In the current C-17 ATS training program two strategic training concepts are being employed in the training program. These strategic training concepts are Student Pair Training and Mastery Training. Both of these training concepts provide benefits to the training program, however from a program management and program cost analysis perspective, some very important risk factors may be overlooked.

In the Student Pair Training concept, students are trained in pairs or sets. An attempt is made to pair a potentially more knowledgeable, more experienced student (e.g., AMC Other Aircraft Qualified or C-17 Re-qualification student) with a potentially less knowledgeable, less experienced student (e.g., UPT Graduate). By doing this, the potential need for student remediation and the risk of increased demands on training system resources from remediation requirements is minimized (e.g., less time required of the instructors to adequately deliver the training, lower demand for the instructors to perform remediation efforts, less time required on the training devices to accomplish training objectives, less time required on the training devices for student remediation, etc.). However as the demography segment size of less experienced/lower performance attribute students increases above the demography segment of more experienced/higher performance attribute students, the ability to adequately pair students is decreased. As a result, at some point two less experienced/lower performing attribute students must be paired together, thus increasing the training program cost and risk factors driven by remediation needs or requirements.

The Mastery Training concept utilizes a set of systematic processes to ensure that the trained student exiting the training system meets all of the objectives and goals established for the training program. The training program baseline design and development criteria established by the Instructional System Development (ISD) Front-End Analysis (FEA) is based on an expected average level of academic knowledge, skills, and performance attributes identified for the expected student population submitted to the training system for training. During the development of the training baseline design criteria, certain assumptions were used regarding the expected student target population. These assumptions were compiled by analyzing the magnitude and types of training and experience that the expected student population (training candidate) entering the training system would have been exposed to prior to entering the training system.

The intent of the ISD process is to accurately identify training requirements based on the assumptions about the target population, and then to cost effectively build a training program. The intent of a Mastery Training Program is to ensure that the output from a training program accomplishes the goal of producing a qualified student. The ISD process monitors the status of this goal accomplishment through the use of systematic evaluations which assess the effectiveness of the training program, and systematically initiates corrective actions for implementation when potential training deficiencies are identified in the output product (e.g. the proficiency trained student).

The Mastery Training concept assumes that the knowledge, skills, and performance attributes of the student training candidate population entering the training system each fiscal year remains relatively constant, and that the student training candidate population attributes closely match those identified for the target population during the Front-End Analysis phase of the training program. If the attributes of the student population supplied to a training system are not comparable to those identified for the student target population during Front-End Analysis, the Mastery Training program's systematic ISD evaluation process may identify this variance in population attributes as a need for changes in the training program element of a training system. (Figure 9 illustrates this concept.) However, the cause for deficiencies in the training program may be due to fundamental contractual issues associated with the training system as an operating business unit (i.e., the student training candidate population submitted to the training system does not exhibit the same attributes which were identified during the FEA phase of the program), rather than due to an actual deficiency in the instructional curriculum. This situational phenomena of a conflict between the student population attributes identified in the FEA phase of development and the actual attributes of the student population entering the fully developed and implemented training system, currently exists in the C-17 ATS program. This conflict phenomena can be illustrated by reviewing the current situation in the C-17 ATS program. The initial squadron that comprised the C-17 ATS student population entering the training system possessed academic knowledge, skill, and performance attribute levels above those projected for the true student target population anticipated for the C-17 ATS as the system reaches a steady state training condition. Therefore, current remediation requirements are not as extensive as might be expected for the true target population. As the average attribute levels for the student training candidate population move closer to the baseline design criteria attributes determined for the true target population, there will be an increase in the probability of having to remediate more students. An increase in student remediation activity means that more demand is placed on instructor resources, operational time in the training devices, and on the support resources associated with these two items. These are fairly typical conditions which can be expected for a newly fielded training program/system that is reaching design maturity, or a steady state condition. As the system matures, the average attribute levels for the training candidate student population entering the system should come in alignment with those assumed for the target population during the FEA process.

If the training candidate student population's average attribute levels entering the training system are not as anticipated during the FEA process and if these attributes begin to move below those established during development of the baseline training design criteria, the need for remediation begins to exceed the anticipated amount of remediation that would normally be expected. The real conflict arises when the students being trained under the Mastery Training concept are required to reach the predetermined student proficiency level goals set for the training program. The proficiency goals must be met either by changes implemented within the normal training design, or by whatever additional remediation is needed for the students to obtain the student proficiency goals. If the true root cause driving the need for changes in the training program, or driving the need for student remediation, are not determined, the training system will incur operational costs that were not planned for, or anticipated during the design and development of the training system. The root cause analysis must identify whether the need

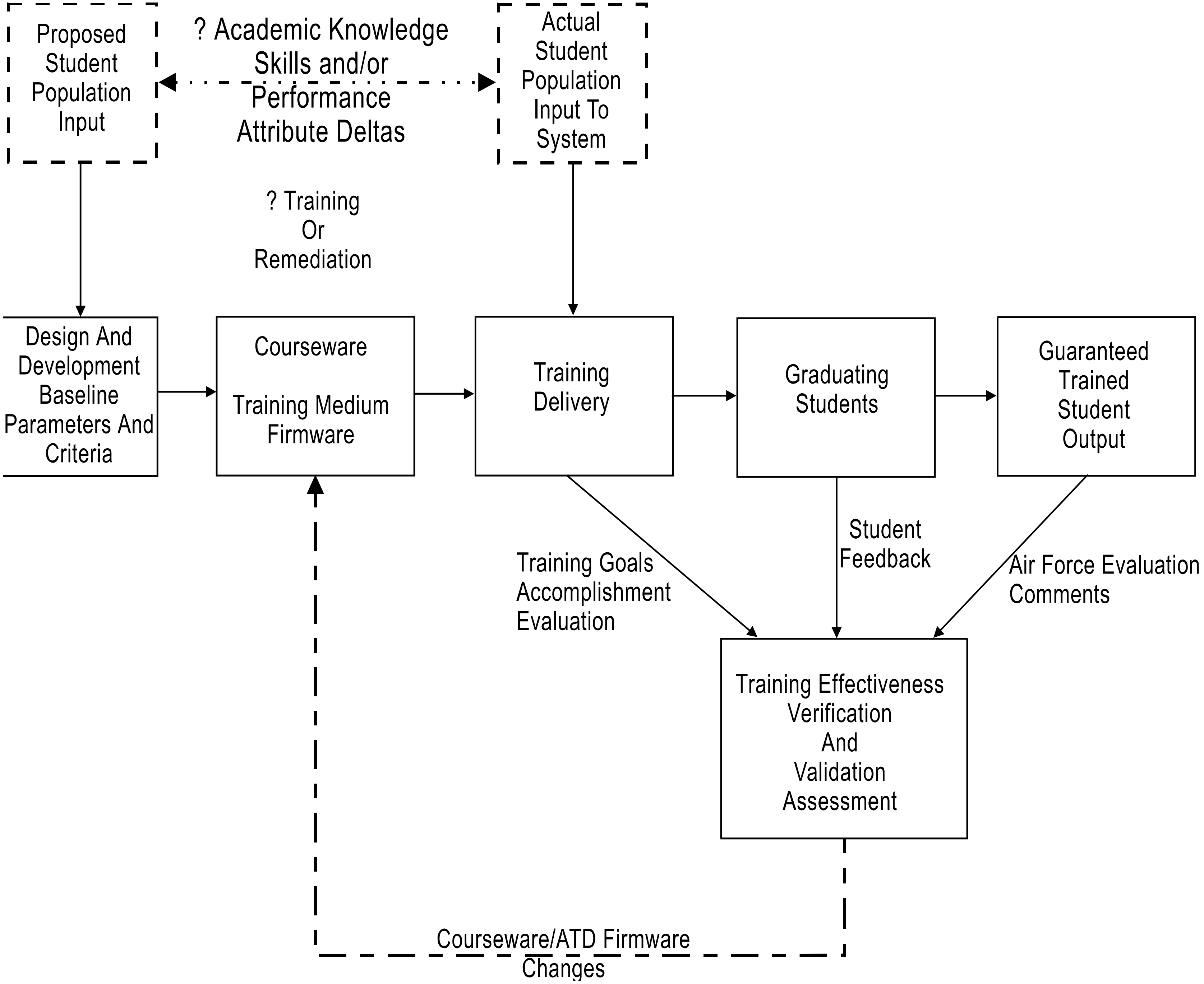


Figure 9 Mastery Training Program Concept/Remediation Risk

for changes or additional remediation stems from training program deficiencies, or are simply due to training system business unit contractual conflict issues.

Thus one of the most interesting discoveries resulting from the Student Remediation analysis was that the three characteristics which drive the need for student remediation are also the three characteristics which are the fundamental cost drivers within an integrated training system. As the training candidate population entering the training system increases, and/or shifts in the training candidate population demography segments occur, and/or the training candidate population's attributes deviate below those identified for the training program's true target population, corresponding increases in the cost of operating the training system will be incurred. Because of the complex interactions of these three training candidate population characteristics, and their association to the training system's operating cost, the following issues should be addressed when determining the capability of the training system and training system model:

> What is the maximum size of training candidate population that the system is capable of accepting and processing during any single period of time?
>
> What is the maximum rate of change in the sizing of the training candidate population that the system is capable of accepting and what are the time span parameters in which this rate of change can occur without causing a detriment to the training system?
>
> Is the training candidate population's demography composition similar to the true target population demography composition used during development of the training program?
>
> What is the maximum delta between the expected and actual segment sizes of the training candidate population's demography composition that the training system is capable of processing while still obtaining the desired attribute goals by the students graduating from the training system.
>
> What is the maximum rate of change in the training candidate population's demography segments that the training system is capable of accepting, and what are the time span parameters in which this rate of change can occur without causing a detriment to the training system?
>
> Do the academic knowledge and learning characteristics of the current training candidate population match those of the student target population around which the training program was developed? If not, what is the magnitude of the deviation, and in which direction is this deviation from the academic knowledge, skills, performance attributes, and learning characteristics identified for the training program's target student population?

In summation, the combinations of deviations in inputs to the training system which result from the impacts due to the changes in population size, shifts in demography segments of the student population, and/or deviations in the average academic knowledge, skills, and performance attributes of the student populations being submitted to the training system, create a complex set of variables which have the potential to affect not only student remediation factors and program risk factors, but the life cycle cost for the system, as well.

The C-17 ATS LCC model is being developed based on the design assumptions and resulting baseline design criteria initially established for the C-17 Aircrew Training System and training program. Like the training system, if the baseline design criteria changes due to changes in the attribute levels of the training candidate student population being supplied to the training system, the ability of the C-17 ATS LCC model to accurately predict the training system's possible LCC would be questionable. The LCC model normally would not have the capability to analyze input variances that may be due to programmatic or contractual issues. The C-17 ATS program has integrated a set of training program data collection and evaluation processes with the C-17 ATS LCC model's Student Remediation model to assess the potential root causes for student remediation and monitor the cost associated with these student remediation drivers.

The Student Remediation model development for the C-17 ATS LCC model was designed specifically to identify the impacts that potential student remediation has on the C-17 ATS LCC. This model considers the complex variables and interrelationships of changes in overall student population size, changes in demography compositions, and deviations in performance attributes within each demography segment. This model fundamentally requires only three inputs. Changes in population size and demography composition are measured from annual period to annual period based on data provided by the Air Force (e.g., the anticipated Program Flying Training (PFT) training candidate student populations). Performance attributes for each of the demography segments can be assessed similar to collegiate grade point averages for graduating classes each annual period and assessed against a benchmark as specified by the original baseline criteria used in the initial design and development of the training system. The output of the Student Remediation model was designed to be consistent with data collected by the contractor's training effectiveness verification and validation assessment system (Summative and Operational Evaluations). This allows model predictions to be compared to actual data being collected from the training system to aid in variance analysis of estimate predictions to actuals incurred and to identify the "true root cause" of this variance. In addition, we have found that since the same elements that affect student remediation also affect overall program risk and cost, the outputs of the Student Remediation model can be converted into a metric which could provide an early indicator of the direction that program risk and cost factors may be moving. This concept is shown Figure 8. These early indicators are predicted based on inputs to the C-17 ATS LCC model. While the model does not quantify program risk in cost, schedule, or technical factors, it associates a correlation between unplanned demand on program resources and an impact upon program risk factors.

Current Status of the LCC Model

The LCC model currently being developed for the C-17 ATS program could more accurately be titled the C-17 ATS Cost Of Ownership model. Referring back to Figure 2; note that the C-17 ATS LCC model consists of an Acquisition/Development Cost portion, Installation/Site Activation Cost portion, and a Continuing Ownership Cost portion. This indicates that an LCC model for the C-17 ATS would be comprised of three separate program phase models where the output results of each program phase model would be summed together to identify the total life cycle cost for the C-17 ATS program. Due to the status of the C-17 ATS program, only the Continuing Ownership Cost modeling portion is currently being developed. This portion of the model will use program input data to predict continuing ownership cost. Historical (sunk) cost data will be collected for each of the WBS elements for the Acquisition/Development Cost and Installation/Site Activation Cost portion of the LCC model. These historical or sunk costs will be summed with the predicted cost estimates from the Continuing Ownership Cost portion of the model to provide a LCC estimate for the C-17 ATS. Upon completion of the Cost of Ownership model, the contractor will evaluate the feasibility and need for development of the other program phase cost estimating models.

Model Benefits/Advantages

The C-17 ATS LCC model construct is comprised of multiple cost estimating modules. These modules can be plugged-in or removed from the estimating model as needed without disrupting the fundamental frame work of the estimating model. This was done to provide the model with the maximum amount of flexibility possible in order to model other types of integrated training systems and to enhance the reusability of the modules. As an example, the module that predicts the number of instructors required could be plugged-in to any aircrew training system model to predict the number of instructors required for that system by simply interfacing this module with the module that identifies the number of instructional hours to be delivered during an annual period. The module that predicts the number of maintenance personnel required can be removed and plugged-in to any maintainability model that identifies the number of possible maintenance actions and the general types of maintenance actions to be performed during an annual period. This advantage was achieved by employing the "divide and conquer" approach outlined in MIL-HDBK-726-1 (Life Cycle Cost for Defense Material Systems, Data Collection Workbook). Logical groups of element and cost relationships were combined into independent modules. These modules were then interfaced at well-defined points to develop an estimating structure. The interface points define input and output data points for the module. As a result, by understanding the data outputs that each module produces, the modules can be plugged together to formulate different estimating structures. (Note: The approach of plug-in modules follows the same fundamental principles as the Cost Estimating Relationship Library function in the ACEIT modeling environment.)

The modular concept not only enhances reusability aspects and reduces the time span required to perform future program, or other program cost estimating efforts, but also allows the analyst the freedom to select any mixture of cost estimating functions appropriate for the analysis effort being undertaken. This freedom also allows the analyst to select the appropriate estimating structure which can be flexible enough to accommodate the data available for the estimate and the time available for performing the estimate. This modular design allows the model to accomplish the design objectives of reusability, transportability, and flexibility to the maximum extent possible.

Because the model is built with algorithms based on the operational, functional, and cost relationships within, and between the WBS elements identified for the C-17 ATS program, the resulting LCC model will be capable of achieving all of the design criteria and objectives outlined in the Training System LCC Model Objectives as discussed previously.

Currently, the model provides a tool to assess the expected annual recurring cost of ownership for an aircrew training system. This cost of ownership model was developed in an automated medium which allows the execution of the model to be performed on a personnel computer using the DOS operating environment. The intent of building this model in an automated medium was to ensure the flexibility, adaptability, and reusability of the model to continually assess the annual cost of ownership of an integrated training system. The automated capability of the model allows the C-17 ATS to meet the intent of Air Force Regulation AF173-15 and AFI 65-501 which requires programs with recurring cost commitment to perform an annual economic analysis. This model was designed as a stand-alone estimating model with the appropriate necessary documentation to support the fundamental cost estimating and economic analysis principles embedded within the estimating structure of the model. Additionally, this documentation provides traceability to the most basic inputs, estimating equation relationships, and units of measure, so that the resulting anticipated cost of ownership estimates can be assessed with a high level of confidence and certainty regarding their relative accuracy.

Part of the reusability design objective in this estimating model was to ensure that at model maturity, the model could be transformed from a cost of ownership estimating tool to a Program Evaluation (PE) economic analysis tool used to assess not only on-going operations for the C-17 ATS throughout its useful life, but also to assess other on-going integrated training systems that exhibit similar inherent design characteristics or attributes. The PE economic analysis portion of the model allows early estimates to be compared to actual performance cost once incurred.

Because the basic model is constructed with semi-generic modules, the C-17 ATS LCC model can be used to model any integrated training system, or any operational entity (non-hardware end item) that produces a product, i.e. a manufacturing system or process. Some of the unique capabilities and advantages of the C-17 ATS LCC model to both the C-17 program, and other integrated training system programs that must perform recurring cost analysis efforts are cited below.

Unique Capabilities -

> Ability to plug-in annual Program Flying Training (PFT) numbers into annual fields without destroying the models infrastructure, algorithms, or the ability to predict the PFT for other annual periods for which the PFT is yet unknown.
>
> Ability to plug-in training device quantities and training device mixes in annual periods to fit program budget constraints without destroying the models infrastructure, algorithms or ability to predict the future training device needs for other annual periods for which the training device quantities are yet unknown.
>
> Ability to predict student throughput and program resources either on the models predicted PFT and Training Device quantities or on the plugged-in PFTs or training device quantities.
>
> Not centered around hardware or a hardware end item, but rather around an operating process which has the output product of a trained student and predicting the resources needed in order to produce this particular product. Some of the major resources considered are courseware, training delivery media and associated support requirements, training processes, instructional support system, operational elements (i.e. training program management, student management, student records management, and training systems management), and student throughput based on aircraft delivery schedules, aircraft crewing decisions, placement location of aircraft, and the impacts of placement upon training system resource utilization rates.
>
> Changes to the model do not require programming skills, only mathematics and cost analysis skills.

Cost Savings Advantages -

> Reduced cost due to use of ACEIT Environment (ACEIT is available to government analysts through the Air Force Electronic Systems Command and can be obtained by Prime Contractors either as Government Furnished Property or direct purchase from Tecolote Research, Inc.).
>
> ACEIT is designed so that it operates like a common spreadsheet using a column and rows approach which reduces usability learning curves for the analyst.
>
> ACEIT is a cost estimating tool containing all of the standard cost analytical tools integrated into a single automated package.
>
> Models can be separate from the operating environment which allows delivery of the estimating model without concern of copyright infringements to the operating environment or system.
>
> Model modules can be built independently and then linked together to model various types or configurations of operating systems.
>
> Model modules can be easily modified for multiple program applicability.
>
> Model modules can be built, verified, and validated once and used many times on multiple programs.

Examples of Other Potential Uses -

> "Should Cost" modeling/predictions and continuing Program Evaluation economic analysis efforts.

Comparing competing projects/contractors by identifying the major cost drivers and risks when selecting among competing projects or bids.

Long-range planning and budgeting for on-going operations.

Controlling on-going projects/programs by changing input data on a continuing annual bases and identifying the impacts of program pragmatic changes upon annual budgets and resulting program costs.

Identifying impacts upon the program due to training device selection constraints, training device mixes, and annual budget constraints for training device acquisition.

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