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**INTEGRATED WORKFORCE MODELING SYSTEM**

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**ABSTRACT**

There are several computer-based systems, currently in various phases of development at KSC, which encompass some component, aspect, or function of workforce modeling. These systems may offer redundant capabilities and/or incompatible interfaces. A systems approach to workforce modeling is necessary in order to identify and better address user requirements.

This research has consisted of two primary tasks. Task 1 provided an assessment of existing and proposed KSC workforce modeling systems for their functionality and applicability to the workforce planning function. Task 2 resulted in the development of a proof-of-concept design for a systems approach to workforce modeling. The model incorporates critical aspects of workforce planning, including hires, attrition, and employee development.

# INTEGRATED WORKFORCE MODELING SYSTEM

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## 1. INTRODUCTION

Workforce planning, alternatively referred to as workforce forecasting or manpower planning, refers to predicting the size and mix of a pool of workers for some future time period [1]. According to Gass [2], it is determining "the number of personnel and their skills that best meets the future operational requirements of an enterprise".

There are three primary workforce planning strategies: transaction, event-driven, and process-driven workforce forecasting [3]. The transaction-based strategy is the most widely accepted. It monitors the flow of human resources through the organization over time. This strategy utilizes one or more views of the future that are driven by choices under the control of the organization. (Niehaus [3] refers to these as internal demand-driven business strategies.) The analytical tools associated with transaction-based workforce planning are categorized into two groups. The bottoms-up review reflects the perspective of project or functional department managers, regarding their human resource needs for a given planning horizon. These managerial inputs are summed into a consolidated workforce projection for the entire organization. These bottoms-up transaction forecasts are useful when incremental organizational growth is expected. However, top-down strategic organization changes are often required to address declining workforce situations [3]. These strategic resizing situations are usually estimated by using mathematical "flow" models, incorporating transition rate data, manpower requirements, and an existing population profile.

The objective of workforce planning is to define the future human resource needs of an organization in relation to the availability of suitable personnel, organizational goals, and budgetary constraints. A number of approaches are available for management to achieve this objective [4]. Traditionally, workforce planning has been accomplished based on judgement and experience. However, with the increase in workforce composition, complexity, and organizational competition, many mathematical models and computer-based information systems have been applied to this problem area. Decision support systems (DSS) are information systems that incorporate such sophisticated mathematical models. They can provide the opportunity to project workforce requirements across a defined planning horizon, as well as evaluate the alternatives in order to find the optimal solution to sub-problems.

## 2. TASK 1

There are several computer-based systems currently in various phases of development at Kennedy Space Center. These systems may offer redundant capabilities, and/or have incompatible interfaces. A systems approach to workforce modeling was requested by the client. The initial task in this approach was to assess current and proposed KSC workforce modeling systems for their functionality and applicability to workforce planning. Systems

identified for review include the Integrated Management System (IMS), the Project Resource Management System (PRMS), the Integrated Financial Management System (IFMP), the Expert Workforce Modeling System, and Expert Seeker (for corporate knowledge). It was also requested that this review provide recommendations for possible integration of these initiatives.

## 2.1 DESCRIPTION OF THE CURRENT PROCESS

The Workforce Planning group (designated HM-E), within the KSC Administration Office (HM) directorate, is responsible for Center-wide workforce planning. The overall processes associated with KSC workforce planning, and subsequent workforce development, are consistent with ISO documentation requirements. This process of workforce planning follows an overall transaction-based strategy, such as that described in the Introduction section of this research report. This transaction-based strategy combines aspects of both the bottoms-up and top-down approaches described.

Workforce Planning receives inputs with regard to future needs over the next five year planning horizon, from each of the individual programs/projects, as well as the functional departments, at KSC. These inputs frequently take the form of an Excel spreadsheet. Five-year KSC workforce thresholds, normally based on Agency budgetary limits, are provided to Workforce Planning by Mr. Roy Bridges (KSC Center Director). This guidance may also contain specific skill level targets.

These future needs and constraints are then compared to the existing baseline. The current workforce profile is identified at the center-level as well as at the program/project/functional department level. Again, these are represented as Excel spreadsheets. The Center-wide skills inventory describes present employee competencies and subordinate skills. The skills inventory was compiled during Fall 1998, via the Project Resource Management System (PRMS). The skills inventory is available as an Access file downloaded from PRMS. In addition to comparing these existing baseline profiles with the objective requirements and constraints, other factors (e.g. hires and attrition) are considered. The output of this effort is a time-phased workforce plan across the Center, for a five-year horizon, showing both prospective FTE (Full Time Equivalents) and headcounts. These outputs are also generated in the form of Excel spreadsheets, with breakdowns available at the program/project/functional department level.

One important aspect of the workforce plan is to identify the skills mix required to meet Center missions and roles, over the given forecasting horizon. Any projected skills imbalances are determined by manual inspection. Employee development plans are then established in order to relieve any skills mix constraints.

To-date, this process at KSC has been accomplished on a primarily manual basis, via the judgement and expertise of the Workforce Planning group. This approach has been sufficient in a relatively stable environment, or one experiencing incremental changes [1]. The Kennedy Space Center workforce is undergoing a major restructuring. This process involves a transition from operations to a focus on research and development [5]. This changing environment requires new computer-based tools to more effectively support KSC workforce planning.

## 2.2 CONCLUSIONS AND RECOMMENDATIONS OF REVIEW

The functionality of several current/proposed computer-based systems was reviewed. Based on this functional assessment, neither IMS nor Expert Seeker are either applicable or even relevant for Center-wide workforce planning. Both systems are merely concepts at this point, with far different objectives than those of the KSC Workforce Planning group.

As noted previously, the Expert Workforce Modeling System also does not meet these requirements. Although it could conceivably roll up workforce projections and associated skill requirements to the Center level, the level of detailed data required to conduct this analysis would be prohibitive. The skills identified in the system would have to be recrafted to align with those currently in the KSC skills inventory. IFMP focuses on the correct organizational level, and plans to conduct workforce analyses consistent with the current HM-E processes. However, due to schedule slippages, IFMP is still only in the early stages of design. Its Budgeting module is particularly ill-defined at this point.

PRMS has the most applicable functionality of the systems investigated. It has the potential to provide a consistent source of workforce requirements, in much the same way that it was utilized to compile the skills inventory. These future requirements could be input by the functional departments as well as the programs/projects. (However, procedures would have to be carefully established to insure consistent use across the Center.) Utilization of PRMS might provide more structure than the present Excel-based inputs.

However, PRMS has significant limitations with regard to the use of these future requirement inputs. It supports the bottoms-up aspect of the transaction-based strategy, but cannot apply the top-down constraints. Although new hires may be considered, there is no facility to address attrition. Finally, PRMS treats each project's set of inputs in isolation, although it appears to be able to roll-up or summarize across multiple input sets. There is no capability to avoid potential "double-counting" the same project, or identifying which KSC projects have not provided inputs. Some types of commercially-available project management software provide a facility for linking roles (using the PRMS term) to a given organization. These may then be related in a hierarchy to reflect the overall organizational structure. (The application software "Project Scheduler", marketed by Scitor, is one such example.) Incorporating analogous functionality into PRMS would address this last limitation.

Since these systems do not adequately support Center-wide workforce planning, Task 2 of this research must be initiated. This task will provide a functional systems design to better meet the needs of the Management Planning group. This proof-of-concept design may then be implemented either on a stand-alone basis or incorporated into either IFMP or PRMS.

## 3. TASK 2

Due to the cited limitations of the current/proposed systems at KSC, the second major task within this project was to develop a proof-of-concept design for a systems approach to workforce planning.

### 3.1 LITERATURE REVIEW:

Based upon the documented requirements and nature of the data sources, an extensive literature search was conducted. Keyword searches of the internet (Using the Net Search, Yahoo, and Alta Vista search engines) were conducted, as well as engineering and business databases. The literature documents a variety of mathematical modeling techniques applied to workforce planning. However, Edwards [6] notes that beyond a certain level, "the models currently available are sophisticated enough for the needs of most organizations, and that greater use of simple models would be more effective than looking for ever-increasing (mathematical) refinement". He further notes that the current trend is to use variations on one of three widely accepted modeling approaches: Markov chains, network flow models, or optimization models. Surveys conducted by both Verhoeven [7] and Gass [2] confirm this opinion.

According to Verhoeven [7], the purpose of a Markov chain model for workforce planning is to forecast the number of employees in each of the specified categories at equidistant points in time (i.e.,  $t = 0, 1, 2, \dots$ ). In a Markov chain model, the number of employees who make a transition from one category to another in a given period is assumed to be a constant fraction of the size of the first mentioned category at the beginning of the period. These fractions are called transition fractions. The actual number of employees in all categories, the transition fractions, and the future recruitment in all categories have to be given. Formulas exist to estimate the transition fractions [7]. The future number of employees in all categories (i.e. the future workforce distribution) is forecasted.

Network representations of personnel problems are extensions of the classical operations research assignment problem. For these problems, the basic form of the network is that of the more general minimal cost transshipment (or flow) network [2]. In the network, the arcs represent the flow of personnel, the source nodes represent initial personnel inventories, and the sink nodes represent the final inventories. Intermediate nodes may be established to force inventories to meet specific grade and skill goals.

Optimization models (e.g. linear programming, goal programming) are the third category of mathematical models. The model is formulated to either maximize (or minimize) the objective function (depending upon the purpose of the model) within the context of available resources and constraints.

### 3.2 APPROACH SELECTED FOR THIS PROJECT

NASA KSC provides a unique environment in which to conduct workforce planning. It comprises both project-oriented elements as well as those associated with functional departments. This situation complicates the selection of the mathematical modeling approach. For example, network flow models have proven to be effective forecasting tools, but only in a project-oriented environment [2]. Further, the proposed transition from operations to R&D negates the usefulness of such tools as linear regression, which are dependent on the relevance of historical data.

In general, the Markov model is preferred due to its flexibility [7]. In a Markov chain model, the categories can be defined such that several characteristics of the employees are included (e.g. critical skills). Attrition is reasonably assumed to be a push flow (i.e. the future workforce distribution is determined by the transitional fractions, thus employees are "pushed through the system as a result of attrition). Although optimization models can be crafted to include these additional characteristics, the size of these models becomes very large very quickly. This impacts the computational efficiency of the resulting DSS.

Like NASA, the U.S. Department of Defense has been undergoing a period of organizational restructuring, as well as a reorientation of mission, with the end of the Cold War. Case studies associated with military workforce planning were found to be very applicable to KSC's situation. Although both network models [8] and optimization models [9] have been used, the case study by Gass et al. [10] appears to be the most relevant. Here, a combination Markov chain/linear programming-based system was constructed to address Army long-range manpower planning. This integrated approach appears to support the KSC Management Planning (HM-E) group's requirements, and will be used as the basis for designing this Integrated Workforce Modeling System.

### 3.3 PROPOSED SYSTEM REVIEW

#### 3.3.1 SYSTEM OVERVIEW

The purpose of the Integrated Workforce Modeling System (IWMS) is to support Center-wide workforce planning with regard to headcount, FTE, and skills requirements. A combined bottom-up/top-down transaction-based approach to workforce planning is utilized, consistent with existing methods. It will be capable of calculating the workforce requirements per year, over a five year planning horizon, at both the Center-level and for individual programs and projects. The skills profile will be optimized within these projections. Markov chain and linear programming mathematical modeling techniques are incorporated into the system's processing to provide these results. The capability to conduct "what-if" analysis, in order to facilitate the decision-making processes, is also included.

The nature of the inputs (i.e. Excel and Access) to the current Center-wide workforce planning process infers a microcomputer-based approach to developing and deploying the system. One objective of this functional systems design is to utilize existing KSC hardware, software, and communications assets to the extent possible. Continuing the use of Excel and Access inputs also suggests the use of a Microsoft Windows-based operating environment to support software compatibility and interoperability.

The recommended Markov chain and linear programming analyses may be conducted using Excel. An initial design of the IWMS Markov module was developed by employing a combination of Excel's Solver and Growth functions. Further investigation indicated that the volume of input data was too large, and the necessary mathematical models were too complicated, for Excel to adequately support.

A more powerful modeling solver engine is needed. Lindo version 6.1, marketed by Lindo Systems Inc., is such a software application. Lindo provides an interactive

modeling environment for building various types of optimization problems, including linear, integer, and quadratic programming problems [11]. It provides extensive documentation and help facilities, and can be used to construct Markov chain models. Lindo is a relatively easy software package to learn, and is frequently used in undergraduate operations research classes. Due to this functionality, as well as the fact that it executes in an MS Windows microcomputer environment, it is recommended for this project.

However, one drawback to Lindo is that it provides a limited user interface. In order to better customize the IWMS system to HM-E needs, a Visual Basic (VB) shell is suggested. This VB interface will guide the user through the system by using a series of customized displays and facilities. VB can seamlessly integrate with the Lindo solver engine into a Windows-based application [11]. In this project, VB will be used to retrieve input from the data sources, prepare Lindo model files, activate `lindo.exe` files, and import initial data and constants into the Lindo model. Further, it can facilitate report generation through the use of the Crystal Reports module, incorporated in the VB development software.

Projected workforce requirements by the programs/projects/functional departments, the current workforce profile, and the current skills inventory are read from their current media by the VB interface, and merged. Center workforce and skills thresholds, as well as factors for hiring and attrition, are entered via VB input screens. The Lindo software utilizes this combined input to support the mathematical modeling processes. Results are stored in an Access database, for later use by VB's Crystal Reports facility. Access was selected as the storage medium since it allows for easier manipulation by Crystal Reports, to support subsequent formatting of the system output displays and reports.

Three modules are envisioned for the IWMS system: System Inputs, Workforce Quantity Planning, and Skills Optimization. Upon system initiation, the user will be able to identify the source of the input data (or in the case of user-specified inputs, data can be entered directly). These data are then read, merged, and stored in a temporary Access file (TMP1). TMP1 provides the input to the Markov chain analysis, upon initiation of the Workforce Quantity module. TMP1, like the other temporary files, is overwritten the next time that the supplying module executes. The results stored in TMP2 (i.e. adjusted workforce requirements in terms of headcount and FTE). TMP1 similarly provides the input to the linear programming algorithms in the Skills Optimization module. Here, the profile of critical skills is optimized based on the constraints provided by the previous module. Output is sent to the TMP3 Access file. TMP1, TMP2, and TMP3 are then accessed by Crystal Reports to provide the user-requested output. Upon completion of processing, the user will be provided with the opportunity to either exit the system, or to initiate another processing iteration. This additional iteration will support "what-if" analysis, where the user may modify certain input criteria (e.g. changes in hires, or attrition) to determine the impact on the workforce projections.

#### 4. CONCLUSIONS

According to Blanchard and Fabrycky [12], "Every system is developed in response to a need or to fulfill some anticipated function. The effectiveness with which the system fulfills this function is the ultimate measure of its utility and its value to the customer". In Task 1 of this research, a series of current and proposed systems at Kennedy Space Center were reviewed with regard to their applicability to Center-wide workforce planning.

Due to the cited limitations of these systems, Task 2 was initiated. Task 2 encompassed the development of a functional design specification for the Integrated Workforce Modeling System, which is intended to better meet the needs of the KSC Management Planning group (HM-E). Inputs, processing considerations, and resulting outputs are identified, as well as the necessary hardware and software assets. These specifications are consistent with the KSC Chief Information Officer's guidelines.

It is recommended that the IWMS be constructed and implemented as designed, as a stand-alone system. This will allow the opportunity to prove out its functionality, as well as providing the Workforce Planning group with a tool to support KSC's transition to an R&D-based organization over the near-term. It is further recommended that, in subsequent years, IWMS should be incorporated into either IFMP or PRMS discussed in Sections 2.3 and 2.4, respectively). These two "supersystems" are currently under development at KSC. They are independently developing their own standardized linkages to other Center information systems and databases (and sometimes replacing them). Assimilation will reduce the number of redundant/conflicting systems and interfaces, as well as improving long-term maintenance of the IWMS functionality.

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