Presented May 1991 at the Thirteenth Annual Conference of the
International Society of Parametric Analysts

MODELING PERSONNEL TURNOVER IN THE PARAMETRIC ORGANIZATION

by
Edwin B. Dean
NASA Langley Research Center

BACKGROUND

A primary issue in organizing a new parametric cost analysis function is to determine the skill mix and number of personnel required. The skill mix can be obtained by a functional decomposition of the tasks required within the organization and a matrixed correlation with educational or experience backgrounds. The number of personnel is a function of the skills required to cover all tasks, personnel skill background and cross training, the intensity of the workload for each task, migration through various tasks by personnel along a career path, personnel hiring limitations imposed by management and the applicant marketplace, personnel training limitations imposed by management and personnel capability, and the rate at which personnel leave the organization for whatever reason.

Faced with the task of relating all of these organizational facets in order to grow a parametric cost analysis (PCA) organization from scratch, it was decided that a dynamic model was required in order to account for the obvious dynamics of the forming organization. The challenge was to create such a simple model which would be credible during all phases of organizational development. The model development process was broken down into the activities of determining the tasks required for PCA, determining the skills required for each PCA task, determining the skills available in the applicant marketplace, determining the structure of the dynamic model, implementing the dynamic model, and testing the dynamic model.

TASKS REQUIRED FOR PARAMETRIC COST ANALYSIS

Analysis of the tasks required for PCA revealed the following. PCA has three primary functions. The first function is to obtain equations relating cost to parameters. The second function is to apply equations by tailoring parameters to the specific situation and using these instances to predict cost. The third function is to report the results both through presentation and archival documentation.

Obtaining the equations includes two primary tasks. The first task is the development and maintenance of a system including a data base of technical information, data, and equations. The second task is applying a tool set for manipulating the data base to obtain desired outputs.

Applying the equations to make estimates includes three primary tasks. First, the estimator must understand the system to be estimated. This includes the requirements, the implementation, and the programmatics. Second, the estimator must intelligently determine instances of the parameters which describe the system to be estimated. This includes both interviewing project personnel and applying personal knowledge. Third, the estimator must perform the estimate. This includes application of various models and integration of the results.

Reporting the results includes two primary functions. The first task is to organize and summarize the information into a form acceptable to each presentation audience. This includes determining the audiences, determining the most desirable presentation form for each audience, and preparing the presentation. The second task is to prepare archival documentation. This includes a complete detailed description of all applicable assumptions, data, equations, model inputs, model outputs, and result determination and integration.

SKILL MIX REQUIRED FOR PARAMETRIC COST ANALYSIS

Analysis of the skills required for PCA revealed a need for an organization which provides a broad and interdisciplinary coverage. Of particular importance within the aerospace environment is the ability of the PCA organization to cover the knowledge required to understand all aspects of an aerospace system over its complete life cycle. Thus system engineering and system management skill requirements are dominant. Of equal importance is the ability of the PCA organization to cover the knowledge required to implement all PCA tasks. A failure in either system perspective or task implementation can be disastrous for the organization.

System perspective requires general and broad knowledge of the engineering disciplines, the sciences, mathematics, statistics, operations research, economics, systems theory, and management.

PCA task implementation requires specific knowledge of least squares, linear and nonlinear optimization, statistics, computer applications, computer programming, PCA model development, PCA model application, risk analysis, accounting, public speaking, writing, project management, and project politics.

SKILLS AVAILABLE FOR PARAMETRIC COST ANALYSIS

An analysis of the skills required within a PCA organization led to the conclusion that it was impossible to look for all of the skills in a single individual. The skills must be derived from specialization and extensive cross training within the PCA organization. The hiring strategy implemented was to develop an interview to determine both the breadth and depth of applicant system perspective and PCA implementation skills. This interview lasted between one and two hours and tested each desired skill by asking increasingly difficult questions in each category until the level of depth within the category was determined. No applicant was expected to "pass" the interview. Those that showed a reasonable degree of breadth and depth were considered from the perspective of how their strengths would enhance the net organization skill. The interview guideline was over seven pages long in outline form and covered the primary engineering disciplines, the primary sciences, the primary mathematical disciplines, statistics, the primary operations research disciplines, system theory, economics, accounting, project management, and PCA specific disciplines.

Because of the interdisciplinary nature of the skills, no single discipline was determined to be most desirable.

DETERMINING THE STRUCTURE OF THE DYNAMIC MODEL

Given time constraints and considering that experience in developing PCA organizations was not available, it was impossible to develop a model to include all skills and all tasks. The model had to be simple and dynamic. Analysis led to the concept of personnel being hired, trained, and transferred to specializing in a few of the many tasks. Consequent cross training would broaden skills, support increasing generalization, and permit eventual transfer to management. The existence of these states led naturally to the state variable diagram for a system of linear differential equations. Since many different systems could be generated from different perspectives, the problem became to develop a model structure with a minimum number of states which provided a useful description of the PCA organization. Useful here meant the ability to guide the development of the organization and to answer questions by management which would certainly be asked if additional resources were requested of them.

The particular model chosen defines states for trainee (T), support analyst (SA), cost estimator (CE), model developer (MD), advanced trainee (AT), manager, and attritor (A). An attritor is defined here to mean a person who leaves the parametric organization for any reason. The model assumes that a person may be simultaneously performing in multiple states. For example, the initial workload often required the manager to perform as a support analyst, a cost estimator, a model developer, and a manager, simultaneously. Similarly, as trainees progressed, they were called upon to fill the full duties of a cost estimator or model developer simultaneously with the performance of training tasks. As cost estimators and cost modelers progressed, they required advanced training simultaneously with current duties.

A trainee is defined as a new entrant in the field of PCA who does not yet have the skills required to perform required tasks as a support analyst, a cost estimator, or a model developer. A support analyst is trained to perform tasks required to support a cost estimator, a model developer, or a manager and is performing a support task. A cost estimator is trained to perform cost estimates and is performing a cost estimate. A model developer is trained to develop PCA models and is developing a PCA model. An advanced trainee has already been trained as a support analyst, a cost estimator, a model developer, or a manager and is now improving their skills through cross training. A manager is trained in managing a PCA organization and is performing management tasks within the PCA organization. An attritor no longer performs a task in the PCA organization. Note that these definitions permit performance in multiple categories as was desired for the model. Under these definitions a support analyst may still be in training to support a particular performing state while performing a support task for another performing state. A cost estimator, a model developer, and a manager may also be an advanced trainee. A cost estimator may also be a model developer or a manager. A model developer may also be a cost estimator or a manager. A manager may also be a cost estimator or a model developer. An attritor may simultaneously be partially in any of the other states since tasks may also be performed outside the PCA organization. Overtime may permit an individual to perform more than one unit of effort. In essence, the model measures person-effort units by state which are to be allocated to actual individuals within the PCA organization.

IMPLEMENTING THE DYNAMIC MODEL

The first challenge in implementing the model is to obtain the coefficients representing the behavior of the state transitions. The second challenge is to provide the input data which drives the model.

The principle of linear superposition for linear systems permits us to consider the transition from state i to state j as an equation which is independent of all other transitions. Consider the transition from state i to state j. Suppose there were n people in state i at time 0 and that k of those people were in state j at time τ. Then n-k of those people would still be in state i. Considering the flow out of state i only, the solution to this equation is

$$x_i(\tau) = x_i(0)\ e^{-a_{ii}\tau}$$

where $x_i(\tau)$ = n-k is the value of state i at time τ, $x_i(0)$ = n is the value of state i at time 0, and a_{ii} is the transition coefficient from state i to state i. Isolating states i and j as the only states of a closed linear system,

$$a_{ij} = \frac{1}{\tau} \ln((n-k)/n)$$

also determines the the total flow

$$x_j(\tau) = (x_i(\tau) - x_i(0)) - x_j(0)$$

from state i to state j over duration τ.

The values n and k were initially obtained through the analysis of discussions with managers of parametric organizations, personnel managers, and other managers in both industry and government. The process of defining all required coefficients was performed through the systematic process of heuristically deriving the value of personnel outflow k, given the initial number of personnel n in state i, from each state i to each state j over the seven states identified for the model.

The initial set of equations was derived about 1985 and did not represent the personnel turnover experienced by the relatively new cost estimating organization at LaRC. The LaRC turnover rates at that time were much lower than those suggested by managers in the initial interviews; thus the coefficients were adjusted on a trial and error basis through the end of 1987. At that time, the new coefficients seemed to represent the dynamics of the LaRC Cost Estimating Office rather well. However, between early 1988 and late 1990 many personnel and organizational changes occurred. The outflow values (k) in Figure 1 and the associated coefficients in Figure 2 are the result of another heuristic adjustment in late 1990 to reflect the functional spread and number of personnel, now spread over three organizations, at LaRC who were performing parametric cost analysis at that time. This set of coefficients provides attrition rates between those of the initial interviews and the more optimistic 1987 analysis.

The rows of Figure 1 are interpreted as follows. If there are twenty trainees today, then three years from now 1 will still be a trainee, 1 will be a support analyst, 5 will be cost estimators, 1 will be a model developer, and 12 will have left the parametric function as attritors. By definition, personnel can not move directly from trainee to either advanced trainee or manager. Other rows are interpreted analogously.

In Figures 1 and 2 there are no rows for the attritor state since it goes to no other state. In Figure 1, Tau (τ) is the standard attrition time in years chosen for each state in order to calculate the individual decay coefficients. In Figure 2 the rows sum to 0 since the flow out of the state is equal to the flows to the other states. The columns of Figure 2 are the coefficients for the state associated with the column from the states associated with the rows.

	T	SA	CE	MD	AT	M	A	n	Tau
T	1	1	5	1	0	0	12	20	3
SA	0	3	0	0	1	0	6	10	3
CE	0	0	4	0	1	1	4	10	5
MD	0	0	1	3	1	1	4	10	5
AT	0	0	2	2	1	4	1	10	3
M	0	0	1	1	1	3	4	10	4

Figure 1. Outflow Values (k).

	T	SA	CE	MD	AT	M	A
T	-0.4355	0.0171	0.0959	0.0171	0.0000	0.0000	0.3054
SA	0.0000	-0.3406	0.0000	0.0000	0.0351	0.0000	0.3054
CE	0.0000	0.0000	-0.1443	0.0000	0.0211	0.0211	0.1022
MD	0.0000	0.0000	0.0211	-0.1654	0.0211	0.0211	0.1022
AT	0.0000	0.0000	0.0744	0.0744	-0.3542	0.1703	0.0351
M	0.0000	0.0000	0.0263	0.0263	0.0263	-0.2067	0.1277

Figure 2. Linear Dynamical System Coefficients (a_{ij}).

From Figure 2 the linear dynamical system can be seen to be

$$\frac{dT}{dt} = -.4355\ T + U_T$$

$$\frac{dSA}{dt} = .0171\ T - .3406\ SA + U_{SA}$$

$$\frac{dCE}{dt} = .0959\ T - .1443\ CE + .0211\ MD + .0744\ AT + .0263\ M + U_{CE}$$

$$\frac{dMD}{dt} = .0171\ T - .1654\ MD + .0744\ AT + .0263\ M + U_{MD}$$

$$\frac{dAT}{dt} = .0351\ SA + .0211\ CE + .0211\ MD - .3542\ AT + .0263\ M + U_{AT}$$

$$\frac{dM}{dt} = .0211\ CE + .0211\ MD + .1703\ AT - .2067\ M + U_{M}$$

$$\frac{dA}{dt} = .3054\ T + .3054\ SA + .1022\ CE + .1022\ MD + .0351\ AT + .1277\ M$$

where U_T, U_{SA}, U_{CE}, U_{MD}, U_{AT}, and U_M are the hiring functions for the associated states. The equations, as implemented in STELLA ™ (Richmond, Vescuso, and Peterson ,1987) and shown in Figure 3, represent the latest interpretation of the LaRC distributed parametric organization experience. In the function PULSE(X,Y,Z), X represents the fraction of a unit volume pulse applied first at time Y with repetition rate Z.

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A = A + dt * ( dA )
INIT(A) = 0
AT = AT + dt * ( dAT )
INIT(AT) = 0
CE = CE + dt * ( dCE )
INIT(CE) = .8
M = M + dt * ( dM )
INIT(M) = .2
MD = MD + dt * ( dMD )
INIT(MD) = 0
SA = SA + dt * ( dSA )
INIT(SA) = 0
T = T + dt * ( dTr )
INIT(T) = 0
Cum = TP+A
dA = .3054*T +.3054*SA +.1022*CE +.1022*MD +.0351*AT +.1277*M
dAT = .0351*SA +.0211*CE +.0211*MD -.3542*AT +.0263*M +PULSE(.5,83.5,100)
+PULSE(.5,87,100) +PULSE(.5,88,100) +PULSE(.15,87.7,100)
dCE = .0959*T-.1443*CE +.0211*MD +.0744*AT +.0263*M +PULSE(.1,83.5,100)
+PULSE(.25,87,100) +PULSE(.25,88,100)
dM = .0211*CE +.0211*MD+.1703*AT -.0267*M +PULSE(.3,83.5,100)
dMD = .0171*T -.1654*MD +.0744*AT +.0263*M +PULSE(.1,83.5,100)
+PULSE(.2,87,100) +PULSE(.2,90.5,100)
dSA = .0171*T -.3406*SA +PULSE(.4,84.5,100) +PULSE(1,85,100)
+PULSE(.5,87,100)
dT = -.4355*T +PULSE(1,83.5,100) +PULSE(1,85,100) +PULSE(2,86,100)
+PULSE(.75,87,100) +PULSE(.25,88,100) +PULSE(.2,89.5,100)
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Figure 3. LaRC Distributed Parametric Organization Model

Hiring has been assumed either to occur in January or in July, whichever more closely approximates actual hiring dates. Personnel hired were allocated in fractional values of initial full time effort to the various states. This was heuristically based upon both their experience at the time of hire and the initial tasks they had to perform. This was implemented by adding fractions of a unit volume pulse at assumed time of hire. U_X is thus the sum of these time phased fractional unit volume impulses. Initial conditions were taken as the values of the states at the beginning of 1983.

REFINING AND TESTING THE DYNAMIC MODEL

The model was tested during implementation by adding the equations one state at a time. During this phase all initial conditions were set to zero except for the state for which the equations were being added and all hiring functions were held at zero. The initial condition of the state for which the equations were being added was set to 10. A variable was added to ensure that the sum of the states remained at a value acceptably close to 10 over the simulation time span between 1983 and 1999.

Two additional tests were performed. Both had initial condition settings of 5 for trainee, 1 for cost estimator, and 1 for manager. For the first test, all hiring functions were held at zero. For the second test, hiring functions for all except the trainee were held at zero while the trainee hiring function was adjusted to a level which seemed to provide a stable organization. Coefficients for the model were iteratively adjusted until these simulations, as well as the LaRC model, seemed to be reasonable. These models were monitored to ensure that the correct number of personnel was obtained over the simulation period.

The final test of the LaRC model was to ensure that the correct number of personnel was available at all points over the simulation period.

MODEL RESULTS AND SUGGESTED IMPROVEMENTS

Figure 4 is a tabulation of the results by year of the simulation of the LaRC distributed organization model. TP is the estimated total number of LaRC and LaRC support contractor personnel performing parametric cost functions, and Cum is the total number of personnel hired since 1983 plus the sum of the initial conditions or A+TP.

As of 1 January 1991, the actual number of LaRC and LaRC support contractor personnel performing parametric cost functions is approximately 4.5 which compares with the estimated 4.330. The actual peak was 7 in the 1987-1988 time period compared with the estimated peak of 6.730 in January 1987. As to the actual distribution of duties, each of the parametric cost personnel would probably see the distribution a little differently. The distribution shown is an approximation of the author's perception. Note that no hires have been included in the simulation past January 1991, so this represents a prediction, given no additional hires.

Note that the management function never exceeded one. This is in keeping with the observation that the high workload dictated that management functions be performed extremely efficiently so that more effort could be applied to the technical functions of cost estimating. Many of the administrative management functions were delegated to a support analyst. Though probably not a wise move for the trainees to move to cost estimator faster, an increase in that transition rate would represent actual occurrence better. Enhanced transitions from advanced trainee to model developer and manager as well as from support analyst to advanced trainee would probably more accurately represent LaRC experience. A more accurate representation should also include overtime since large amounts of actual overtime/compensatory time are not included in the inputs to this model. Training periods were shortened by specializing personnel in areas such as software or life cycle, thus decreasing τ for the training states would probably improve the representation.

Date	T	SA	CE	MD	AT	M	A	TP	Cum
1983	0.000	0.000	0.800	0.000	0.000	0.200	0.000	1.000	1.00
1984	0.787	0.008	0.859	0.127	0.436	0.489	0.295	2.700	3.00
1985	1.490	1.330	0.846	0.156	0.343	0.476	0.762	4.640	5.40
1986	2.920	0.965	0.886	0.186	0.302	0.456	1.690	5.710	7.40
1987	2.620	1.210	1.270	0.426	0.760	0.442	2.870	6.730	9.60
1988	1.940	0.893	1.600	0.454	1.100	0.501	4.110	6.490	10.60
1989	1.260	0.658	1.620	0.489	0.842	0.595	5.140	5.460	10.60
1990	0.970	0.484	1.580	0.498	0.658	0.638	5.980	4.820	10.80
1991	0.628	0.356	1.500	0.673	0.527	0.650	6.670	4.330	11.00
1992	0.406	0.260	1.410	0.626	0.430	0.642	7.230	3.770	11.00
1993	0.263	0.190	1.300	0.578	0.357	0.619	7.690	3.310	11.00
1994	0.170	0.138	1.190	0.530	0.301	0.588	8.080	2.920	11.00
1995	0.110	0.100	1.090	0.485	0.256	0.552	8.410	2.590	11.00
1996	0.071	0.073	0.989	0.441	0.221	0.514	8.690	2.310	11.00
1997	0.046	0.053	0.896	0.401	0.192	0.476	8.940	2.060	11.00
1998	0.030	0.038	0.810	0.364	0.168	0.438	9.150	1.850	11.00
1999	0.019	0.027	0.731	0.330	0.148	0.402	9.340	1.660	11.00

Figure 4. LaRC Distributed Parametric Organization Model Simulation Results

Improved fidelity, particularly in the distribution of effort by function, could have been obtained by more meticulous bookkeeping of time by function and the application of system identification techniques (Sage and Melsa, 1971) to that data.

During the 1985-1987 period, this model, then on a spreadsheet, was used to determine how many trainees would be required to bring the number of cost estimators up to desired levels at given points in time. This was performed by increasing hiring inputs to a level which predicted that the desired levels would be met at the desired times. Management was informed of the results, but constraints on hiring kept the number of trainees below the level predicted by the model as necessary to generate desired cost estimator levels. Salary constraints also limited the prospects for hiring experienced estimators. As a result, the organization was always short of cost estimators fully qualified for the tasks at hand.

Ongoing reorganizations of the distributed parametric cost organization at LaRC indicate the need for this type of analysis again. This could be performed in the "what if" mode as was done previously. However, modern control theory tells us we can move a controllable system, such as the model presented, to any desired state at a desired time (Chen, 1984). The optimal control for this system would provide the optimal hiring profile to meet desired objectives.

CONCLUSIONS

This model, parameterized by the likelihood of job function transition, has demonstrated the capability to represent the transition of personnel across functional boundaries within a parametric organization using a linear dynamical system. It has also demonstrated the ability to predict required staffing profiles to meet functional needs at the desired time. Techniques exist which, if applied, can improve the fidelity of organizational representation and provide optimal hiring profiles to meet desired functional needs at the desired time. This model can also be extended by revisions of the state and transition structure to provide refinements in functional definition for the parametric and extended organization.

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