Summer 1996

An Artificial Life Model of Engineering Attrition Contemplation: Why do Federally Employed Civilian Engineers Think of Quitting?

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Recommended Citation

Herweg, John W.. "An Artificial Life Model of Engineering Attrition Contemplation: Why do Federally Employed Civilian Engineers Think of Quitting?" (1996). Doctor of Philosophy (PhD), dissertation, Engineering Management, Old Dominion University, DOI: 10.25777/z33x-v862
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AN ARTIFICIAL LIFE MODEL OF ENGINEERING ATTRITION CONTEMPLATION: WHY DO FEDERALLY EMPLOYED CIVILIAN ENGINEERS THINK OF QUITTING

by

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A Dissertation submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

DOCTOR OF PHILOSOPHY

ENGINEERING MANAGEMENT

OLD DOMINION UNIVERSITY
August 1996

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ABSTRACT

AN ARTIFICIAL LIFE MODEL OF ENGINEERING ATTRITION CONTEMPLATION: WHY DO FEDERALLY EMPLOYED CIVILIAN ENGINEERS THINK OF QUITTING?

John William Herweg
Old Dominion University, 1996
Director: Dr. Laurence D. Richards

The research objective is, using engineer turnover, to develop an Artificial Life (A-Life) model and simulation methodology useful for studying behavioral variables of individuals in an organization.

One consequence of work stress is burnout, and its extreme expression is quitting or turnover. Various models have been used to explain and predict this behavior. Behavior models are useful tools to explore the ability of organizational policies to reduce stress levels and turnover. Advancing the usefulness of models is a goal which assists all research on human behavior. A-Life offers a new and different methodology for this purpose. It provides an ability to model large numbers of individuals where the individuals are modeled truly as individuals rather than as statistical condensations. A-Life models also allow modeling large numbers of individuals simulating an organization. This modeling, in preserving the individual, allows the observation of holistic dynamics of the system. It also provides an ability to model multi-generational effects so that extremely long-term simulations can be performed.

Modeling human behavior represents a challenge to the degree of adaptation that can be made in A-Life models. This study uses engineer turnover and thinking of

quitting as a test case for developing , exploring, and expanding A-Life techniques. Data appropriate for A-Life models was collected to use for the simulation.

The utility of this research is twofold: first, it can produce a standard methodology and off-the-shelf tools to model and simulate individuals' behavior in an organizational setting and second, it offers the prospect of a tool by which future policy decisions can be formulated and simulated before implementation to lower turnover and consequently its cost.

FRONTISPIECE

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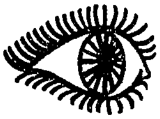
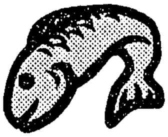
 +  +  +al

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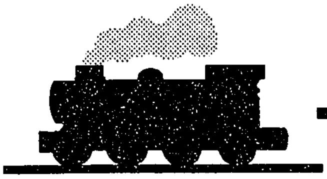
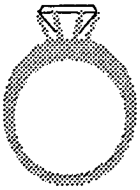
 +  + 

DEDICATION

To Liisa my wife

You accomplished the same

I don't have to tell you that it's done

But I will anyway

We's done it!

ACKNOWLEDGEMENTS

During this endeavor, much was learned, but yet something was lost. The friendship of a mentor who is not here to enjoy with me, the finishing of this task. He lived his life to the fullest and yet always had time for communications. Transcending the theory, of which he was the master, he was always a practitioner. The nights after classes when the carafe of wine and pound of shrimp were finished in the early hours of the next day can never be forgotten. Conversations, or rather just listening to stories and tales from the early days of Cybernetics by one who was there with those, long since departed, of whom I can only read their works, filled me with reverence. When I saw you last, you were getting into your taxi after we had dined together at The Athenaeum Club. Wearing your cape, as usual, you departed into the mist of a late London night. Gordon Pask, I'll never forget you. The frontispiece is for you!

In the beginning, Larry started the Engineering Management program. And it was without faculty. Then Larry said "Let there be faculty." And there was Barry and Fred. And they were good. Many thanks to all three; professors, mentors, and friends. You guided me through my journey and made this work possible.

To my advisor Barry, and the members of my committee Larry, Derya, and Irwin, who provided guidance in this endeavor and had faith in my ability.

For Gerri and Venetia who always had kind words of encouragement and assisted in many ways to ease the burden.

Finally for Liisa, my wife and co-student. Your help in being a listener for my thoughts and a reader of my work made it possible to finish this task. I owe you a big kiss. Together, we did it.

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CHAPTER 1

INTRODUCTION

Basic Problem

The ability to study an aspect of human behavior such as turnover is important. In studying human behavior, models are formulated to represent mental constructions of a phenomenon. These models are often used to perform experiments which would not be possible in the real world. Advancing the usefulness of models is a goal which assists all research on human behavior. Artificial-Life offers a new and different methodology for this purpose. It provides an ability to model large numbers of individuals where the individuals are modeled truly as individuals rather than as statistical condensations. It also provides an ability to model multi-generational effects so that extremely long-term simulations can be performed. My purpose in doing this research was to investigate the utility of Artificial-Life in studying human issues.

My example question was turnover, because turnover is expensive for the individual, employer, and society. As quitting represents a non-trivial state of affairs, this structural inefficiency has an effect on all members of society. It represents the goods, services, and quality of life that are not built, used, or achieved by all. Turnover has implications for the individual, the organization, and for society in general. By immersing myself in the question of turnover, I ensured that the Artificial-Life simulation engine was appropriate for this arena. However, the use of turnover, per

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The style manual followed for this work is Kate L. Turabian's "A Manual for Writers of Term Papers, Theses, and Dissertations."

se, as the research question was incidental (other appropriate questions could have been used to ground the research). The key point was to build and explore the Artificial-Life simulation engine that would handle human issues.

To test this new technique, data gathered through a survey soliciting responses to questions addressing the propensity of engineers to think of quitting was used. The themes of this research are further explored in the following sections.

Implications for the Individual

Quitting is an emotionally stressful time for an employee. The act of leaving the familiar and going into the unknown is a stressor. Even simple reasons, such as leaving for a higher paying job, involve stress as one ponders why the old employer would not pay as much as the new employer is willing to pay or why one did not get a promotion. Senger (1980, 181-3) discusses a "Social Readjustment Rating Scale" developed by Holmes and Rahe. This scale uses a maximum value of 100 to indicate the stress level resulting from the death of a spouse and decreasingly lower values for lesser stressors. Some selected work related values, together with two other events which serve as high and low end reference points, are given in table 1.

TABLE 1

SELECTED SOCIAL READJUSTMENT RATING SCALE VALUES

Event	Value
Death of a spouse	100
Being fired from work	47

Event	Value
Retirement from work	45
Major business readjustment	39
Changing to a different line of work	36
Major change in responsibilities at work	29
Troubles with the boss	23
Major change in working hours or conditions	20
Minor violations of the law	11

An aspect of these stressors is that they tend to act in a cumulative manner. A slightly metaphoric rewording is that they have a gestation period. During the period prior to quitting, the individual is thinking about quitting. Research into the thinking of quitting has significance for both the employee and employer, as actions could be taken by either one or both parties to avoid the actual quitting and thus help to reduce the overall stress in the work environment.

Implications for the Organization

Any individual acting in an employed capacity represents an investment by the organization. Many jobs have long learning curves associated with them, particularly in the federal work place. Often years in a specific job are needed to learn all the rules and regulations one needs to know in order to function at an acceptable level of performance. Often this knowledge is arcane in nature and is not the general knowledge possessed by an applicant from the outside. During the time this knowledge is being acquired by the employee, the reduced efficiency represents an indirect cost.

This is the situation for those positions where the learning takes place as on-the-job-training. For those positions which have a formal training period or classroom training, the cost is more direct. Worthy of mention also is another type of knowledge which, while not specifically required for the position, is necessary to accomplish the tasks of the position. This type of knowledge involves learning how to really fill out a form, who to call to obtain something, how to navigate through all the rules which say you can't do that, etc.. If, for example, the proper buzz words are not present in a proposal, then the proposal is likely to linger for eternity in the limbo of in-baskets. This knowledge is essentially process oriented. Both types are lost when an employee quits.

Another cost is the recruitment cost of a replacement. As the position becomes more difficult to fill, ranging from a replacement within the same group, division, department, or facility to someone off the street, the cost increases due to the increase in effort necessary to fill the position. If a replacement can't be found and assigned to the position with an appropriate turnover period being provided, a disruption cost occurs due to the position not being filled. In an extremely controlled job environment, such as the officer corps of the military, a replacement is detailed to the position and the incumbent has a few weeks to turn over the job to the incoming individual thus reducing disruption to a minimum. A ship at sea where the new navigator received a turnover which did not include the fact that a certain navigational instrument has some quirks, might run aground. Here cost can be construed as not being able to fulfill the mission.

Many organizations seem to be ambiguous in their attempts to reduce the turnover rate. Some view a continual turnover as a weeding mechanism which rids the organization of the troublemakers. Hirschman discusses a balance between exit and voice (1970, 76-105). If a dissatisfied employee remains in the company (no exit), the only recourse to vent the dissatisfaction is to vocalize the discontent (voice). Some organizations, in an attempt to reduce the exit option and at the same time not to have to deal with a griping employee, will attempt to buy loyalty. This can be undertaken in a number of ways. Some dissatisfied employees are promoted beyond their competence levels, locking them into a health benefit, pension, or retirement plan, given extra privileges, and other perks. Regardless of this self-deception, if the dissatisfaction remains for long enough or reaches high enough, exit can still occur.

If a reduction in the turnover rate and attendant costs can be achieved, this would be of significant value for the organization.

Implications for Society in General

As management attempts to reduce turnover, a dichotomy occurs; if there is a genuine attempt to address the causes of the discontent, they could be successful and reduce the turnover. On the other hand, if management either erects barriers to exit or does nothing, the underlying problems will not go away. Eventually they will resurface and often be more severe than before. All during this time, turnover costs are occurring and often increasing. At some point management will (though not for this factor only) realize that perhaps it might be more cost effective to accept and perhaps foster the turnover. Companies operating in this mode will view an employee as a consumable machine to be used and discarded. Companies practicing this burn out technique will often hire contract or temporary workers without paying fringe benefits or else foster quitting before an employee is vested in a retirement system. Companies which practice this policy soon become known to potential employees through the grapevine. This represents a negative goodwill for the company. Acceptance of employment in one of these companies is predicated on the implicit scheme to "Take them for what I can get before they burn me out"!

The unfortunate implication is that there seems to be a movement toward this mode of operation by more and more companies. As more companies put this into practice, there are fewer jobs which have good benefits. Competition is created within the labor pool of available workers to land a permanent job which has decent benefits. This often translates into newly hired employees accepting fewer benefits for a permanent job. This seems to be an apt description of the job market of today, particularly regarding health or retirement benefits subsidized by the employer. An inherent characteristic of shifts, such as this, is that they often span decades. As such, they represent a paradigm shift and thus present a different environment for business and employee alike. The implications thus become applicable to society as well as to a collection of individuals and separate firms.

Implications for Modeling

The usefulness of exploring an Artificial-Life approach as performed in this research must be addressed. An efficient way to face this issue is using a question and answer dialogue concerning Artificial-Life.

1. Why is this an interesting approach? While this approach is interesting for many reasons, one single factor stands out above all others. This approach allows the building of a model which can be used for experimenting with human behavior in which the individual is modeled as an individual. The three second conversation, the split-second decision to buy a Coke rather than a Pepsi, and deciding which TV channel to watch using the process of channel surfing (clicking through the channels for second or two on each one) are examples of individuals doing individual things. Yet the totality of all individuals can have large consequences. Hertz is "Number One" while Avis "Tries Harder" (a Madison Avenue euphemism for being number two, second best, or an also-ran) is the result of individuals making choices. Thus the ability to model and simulate the individual is more than interesting.
2. What questions can this technique answer? and How would you tell if you had answered the question? This technique can or has the potential to answer any

question which can be represented as a model of individual human behavior. If a question can be transformed into a model, this technique can be used. As with any simulation technique, the ability to tell if you have answered a question is often difficult. This technique does have a self-checking ability or a reality check inherent in its formulation. While simulation data for a single individual is not predictive and really cannot be mapped to an individual, the collective output should be indicative of the population being simulated. If the collective output varies too far from real life, then one must examine and redesign the model.

3. What is the payoff? The payoff can be construed to encompass the ability to build models of human behavior within the context of an organization or society and perform experiments. The ability to change a policy, foster or stifle actions or preferences, or alter environmental factors and then run a simulation to observe the effects of these changes is the payoff.

4. How do you tell that this constitutes significant work in Artificial-Life? As in any scientific inquiry, the significance of any work cannot be determined a priori. Significance is determined often long after the work has been performed. In a new field, such as Artificial-Life, many directions are being explored at the same time. This is a direct result of the multi-disciplinary aspect of this field. A blessing of this approach is that, for the time being, all work is considered significant.

5. What questions can you ask? and What answers would you get? With this Artificial-Life type model and simulation, one has the ability to ask questions concerning the formulation of models for investigating individual human behavior occurring within a large group. Questions concerning causality, determinism, variable relations, feedback loops, learning and memory within the individual, and group behavior are representative of what can be asked. For answers, one can observe and analyze the dynamic behavior of the simulation to gain insight for improving a specific model formulation.

6. How do you draw a distinction between being a user or a creator of a simulation engine? Using a spreadsheet program as an analogy, the emphasis of the creator is that the program works properly. If you put numbers into cells and have the program add them and write the result to a certain cell, the program must perform these processes without error. The specific internal construction which allows these operations to be performed is the domain of the creator. Hardware and software problems have existed in the past and will exist in the future. This points out the fact that the creator and designer must be concerned with testing to ensure reliability of an engine. The user expects that the program will flawlessly perform the operations specified on the data entered. The actual specific algorithms to accomplish these tasks by-and-large are not the concern of the user. To perform trigonometric calculations, computers perform iterative calculations for series expansions which converge rapidly. Details

> about how to have a computer accomplish this via hardware and software is a black box question for the creator. A trust that it is performed accurately is the concern of the user.

Thus it can be seen that exploring and extending Artificial-Life techniques offer vast potential for aiding research on human behavior.

Conclusion

For the reasons enumerated in the preceding sections, this study will investigate the use of Artificial-Life techniques to study an aspect of human behavior. The investigation uses turnover and thinking of quitting as a test case to ground the simulation using data gathered through a survey. The model simulates turnover within an organizational grouping of individuals using an Artificial-Life computer program developed by the researcher specifically to support this research.

CHAPTER 2

LITERATURE REVIEW

Background and Key Literature Review

This literature review surveys the literatures on turnover and artificial life. As this review is rather diverse and wide-ranging as to the topics covered, it is divided into the following sections: motivation, financial motivation, work force stress, turnover, modeling, cellular automata, genetic algorithms, and artificial life techniques. Each of these sections is covered in detail.

Motivation

"Motivation at work, defined as effort at work, will be obtained when work is the process by which incentives can be obtained. The more work is seen as the means toward need satisfaction, the higher motivation will be" (Joint Engineering Management Conference 1967, 85). Table 2 presents a survey performed for the Department of Labor which gives the ranking in order of importance for some aspects of work (Health, Education, and Welfare 1981, 13). It is interesting that good pay and job security (hygiene factors) are ranked fifth and seventh respectively in the list. Moreover, three aspects are directly controlled by management which, if provided, allow or facilitate the performance of work.

TABLE 2

RANK ORDER OF SOME ASPECTS OF WORK

Rank Order	Aspect of Work
First	Interesting work
Second	Enough help and equipment to get the job done
Third	Enough information to get the job done
Forth	Enough authority to get the job done
Fifth	Good pay
Sixth	Opportunity to develop special abilities
Seventh	Job security
Eight	Seeing the results of one's work

Likewise Thompson (1961, 31) makes the point that satisfaction will be greater when jobs have the following characteristics:

1. The job requires a high level of skill.
2. The job requires the use of a number of different programs rather than one or a few.
3. The work role is compatible with employee's self-image and non-work role.
4. The job is considered to be a career.
5. There is considerable autonomy in decisions.
6. Work relations are predictable.
7. The organization has less control over the job (that is to say, the job is less organizationally defined).

These seem to demonstrate that workers have a desire to manage their own jobs, be responsible for their actions, and obtain a sense of importance and recognition from work.

In his research, Herzberg (1959) noted that professional employees and engineers in particular tend to correlate time periods of high performance and positive attitude with work itself. Sense of achievement, recognition, responsibility, advancement, and satisfaction with work itself are a class of factors referred to as motivators. Motivation is the process of creating the link between effort (work) and the achievement of goals. "If the accomplishment of work becomes the only way to satisfy a need and reach a goal, the motivational consequences are obvious" (Joint Engineering Management Council 1967, 85). This fact has been obvious to management in the past and still is as management has attempted to control the goal definition process. It becomes self serving for management to have the worker's goals be the accomplishment of work. The result has been the rise of the organization or company man. Many professional jobs have had their contents mechanized through the introduction of labor saving automated systems and with the rise of the large modern corporation, individual goals as set jointly by the professional and his or her personally known manager become supplanted by distant corporate goals which could very well have been promulgated on another continent. The result is that the goals are alien in nature and appearance. This seems to lead to a decoupling of motivation from goals at the individual level. This has lead to more "power management" as workers are coerced, prodded, forced, impelled, and extolled to do more to achieve the corporate goals.

In many surveys of employee satisfaction, workers report that they are satisfied in the job environment, but it can be postulated that these responses really mean that the workers are not dissatisfied in terms of Herzberg's framework. Their work, while providing pay and security, is often not considered intrinsically rewarding.

Financial Motivation

Unfortunately, many organizations have defined motivation in terms of financial incentive only. In its ultimate conception, piece rate wages are the result. Many blue collar workers are paid via this scheme, but it has not found extensive utilization in the engineering profession. A limited example would be engineering consultants paid by the project. The obvious assumption by the management is that money is a motivator for the employee. The link between a reward system (money) and performance is designed as a motivator; hence to increase the performance, the organization increases the reward. However in many circumstances for professionals, the performance of the group, division, department, or the entire organization is often used as a substitute for the performance of the individual. Thus the determination of individual performance has become unlinked from the reward system and often loses its intended effectiveness as a motivator and can even create stress by its perceived unfair application.

Another type of unlinking is the application of different reward criteria for individuals high in the organization. As an ultimate example of irony, witness the many CEOs who receive large bonuses while massive downsizing the company or for reorganizing them to leverage the liabilities onto others. The perception of this being unfair is not lost on the work force. In addition, when financial reward is viewed as the dominant or only motivator by the organization, sight is often lost of the appropriate nature of other motivational forces. Moreover, as management hones in on the use of a single motivator, less emphasis is given to the maintenance of lower level motivators (often referred to as hygiene factors).

Work Force Stress

Herzberg (1966) has also found that there exists another class of factors which he terms "dissatisfiers" or "hygiene factors" that are associated with periods of dissatisfaction. Some of these factors are supervision, company policy and administration, salary, and working conditions. The employees' perception or fear that low level needs might not be met negates the effect that any high level motivator used by management is designed to have. The uncertainty of satisfying low level needs causes stress. When these dissatisfiers are present, their effect is often evident in the employees' actions.

These actions have both internal and external effects upon organization. Internal effects can be described by employee actions such as reduced work output, reduced attention to job details, antagonism and hostility toward supervision, absenteeism, and many others. External effects can be described by employee actions such as whistle blowing to regulatory agencies, bad mouthing the organization to outsiders, and quitting the organization. "The large number of engineers who seek out an advanced degree in business each year is evidence of the conflict," (Joint Engineering Management Conference 1967, 86). Switching or being promoted to management is a metaphor for not wanting to be an engineer anymore. Again the question must be asked, why?

An underlying thread in the literature concerning work place stress is the notion that there is consistency among individuals. The individual is conceived as a simple mass-produced windup toy or machine without purpose or memory. Von Foerster (1984) relates the attributes of a trivial or simple machine using concepts of cybernetics (a particular input state is coupled deterministically with a specific output state). His description of a simple machine is not too dissimilar from these implicit descriptions of the individual. An aspect of the turnover problem is that "engineering managements are frequently more concerned with new methods, systems or designs and they lose sight of their real job--people" (Joint Engineering Management Conference 1976, 127). Employees are just another machine to be replaced when broken or worn out. Machines are viewed as being predictable in their operation. For the machine, overload it by fifty percent and you will shorten its life. For the employee, make a change in the level of stress (hygiene factors) and the individual will respond in a similarly predictable fashion. The same logic holds true also for changes in the motivation factors. This implies a simple deterministic view of the employee and ignores any humanistic consideration. This lack of humanistic consideration ensures that high level motivators won't come into play.

In many companies, a common symptom of problems is turnover, but the problem is management. Warnecke (1993, 66) states "Hiring and firing does no-one any good, least of all the company." This can further be illustrated by the relevant shortcomings of management which are listed below (Joint Engineering Management Conference 1967, 124-7):

1. Lack of an opportunity for self-expression
2. Assignment to the wrong position
3. Ineffective organizational manpower planning
4. Insecurities of the industry or organizational climate
5. Management aloofness

The solution is simple to narrate but it requires an adjustment in thinking by management. A common phrase used by managers of today when dealing with employees is "You need to be recalibrated." However, the situation is just the opposite.

> If engineering management spent more time working with and through their people than they do in the more technical and tangible parts of their jobs, they might become lesser engineers and better managers. As better managers they may get more and better engineering work accomplished and therefore might become more effective contributors to the engineering function within the organization. Rather than being a vicious circle; it's a constructive circle. It optimizes turnover from everyone's vantage point and produces constructive results (Joint Engineering Management Conference 1967, 127).

Thus stress in the work place, generated within the working environment, can be seen as having a large impact on turnover.

Turnover

Turnover is the degree or measure of individual movement across the membership boundary of a social system (Price 1977, 1-10). This definition can be used for membership within any organization. Restricting this definition to the working environment, Price discusses seven types of turnover:

1. Interfirm movement: from one firm to another or a change of employer
2. Occupational movement: from one occupation to another
3. Industrial movement: from one industry to another
4. Geographic movement: from one local area to another
5. Employment movement: from an unemployed to an employed state
6. Unemployment movement: from an employed to an unemployed state
7. Working movement: into and out of the labor force

While this breakdown does provide a division that is useful for statistical purposes, any of these categories could apply to a person who quits his or her job. From the viewpoint of the company, a consequence of quitting is the loss of an employee; there is no need to differentiate as to the subsequent state of the ex-employee. Where the ex-employee is or what he is doing does not impact the organization any more. Moreover, as the cause and effect relation is taken to be that quitting is the cause of the effects that can be seen in the ex-employee afterward, there is a rationale to study the act of quitting rather than the effects of quitting.

Another aspect of turnover is the stipulation of its being voluntary or not. Quitting implies turnover initiated by the individual while firing implies turnover initiated by the company. For quitting, the reasons will be thought out and decided by the individual who quits. No one else can think of quitting, make the decision to quit, or quit for you. At the other end of the spectrum, the decisions involved in involuntary turnovers (firings) can be made for many reasons and at varied levels in the organization. Today many firings are made with no reflection upon the work quality of the individual. A causal link between the performance of the individual and being let go is often missing. Working hard in a plant which is being shut down, still means that you will be out in the street without a job. Downsizing is often a lottery in which a few win and most lose.

To discuss turnover, one must be able to measure it. Many measures of turnover are expressed as ratios, but it is important to remember that the quantum level is a single individual who leaves the organization. As the phenomenon of turnover is dynamic, most measures of turnover focus on the rate rather than the event.

Price (1977) examined three codifications containing jointly thirty-four measures of turnover. A subset of these measures is listed as follows:

Average Length of Service

$$\text{Stayers} = \frac{\text{sum of length of service for each member}}{\text{number of new members}}$$

$$\text{Leavers} = \frac{\text{sum of length of service for members who leave}}{\text{number of members who leave}}$$

Crude Turnover Rates

$$\text{Accession Rate} = \frac{\text{number of new members added during the period}}{\text{average number of members during the period}}$$

$$\text{Separation Rate} = \frac{\text{number of new members leaving during the period}}{\text{average number of members during the period}}$$

Stability and Instability Rates

$$\text{Stability Rate} = \frac{\text{number of beginning members who remain during the period}}{\text{number of members at beginning of period}}$$

$$\text{Instability Rate} = \frac{\text{number of beginning members who leave during the period}}{\text{number of members at beginning of period}}$$

Survival and Wastage Rates

$$\text{Survival Rate} = \frac{\text{number of new members who remain during a period}}{\text{number of new members}}$$

$$\text{Wastage Rate} = \frac{\text{number of new members who leave during a period}}{\text{number of new members}}$$

Drawing from seventeen codifications dealing with turnover, Price (1977, 24-43) identifies nineteen turnover correlates that regularly appear in the literature of the field. These correlates are considered to be important variables which denote relational links with turnover. They can also be referred to as demographic variables. It should be noted that these relations are not indicative of causation but rather are to be considered to be descriptive of observed data. These factors have generally been shown to correlate with turnover and are presented below with their degrees of correlation and also the correlation:

TABLE 3

TURNOVER CORRELATES

Correlate	Degree of Correlation	Turnover Correlation
Length of service	High	Low service: higher rate
Age	High	Young members: higher rate
Level of employment	High	High employment: higher rate
Level of skill (blue collar)	Medium	Unskilled: higher rate
Blue-collar vs. white-collar	Medium	Blue-collar: higher rate
Country	Medium	United States: higher rate
Education	Low	Better educated: higher rate
Manager vs. non-manager	Low	Non-managers: higher rate
Government vs. non-government	Low	Non-government: higher rate
Sex	Inconsistent	Females: higher rate
Time of work	Weak	Night work: higher rate
Place of birth	Weak	Urban areas: higher rate
Existence of pension plans	Weak	No plans: higher rate
Time of year	Weak	Warmer months: higher rate
Size of community	Unclear	Unclear
Marital status	Unclear	Unclear
Amount of work	Unclear	Unclear
Race	Unclear	Unclear
Existence of a union	Unclear	Unclear

Some of these factors are demographic (i.e., country and place of birth) and, as such, present much difficulty when one attempts to find a causal link for their correlation with turnover. Theoretical causal links can be postulated for others with more ease. Individuals with more service generally have more benefits and vested interest in their position (i.e., they have more to lose), so they are more apt to remain with an organization than quit.

Within the study of turnover, analytical variables believed to produce variations in turnover are referred to as determinants of turnover. Price (1977, 66-91) consolidated nineteen different turnover codifications into a table of twelve turnover determinants presented below with their strength of determination:

TABLE 4

TURNOVER DETERMINANTS

Determinant	Strength of Determination	Turnover Correlation
Pay	Strong	Lower pay: higher rate
Integration	Strong	Lower integration: higher rate
Communication (instrumental)	Strong	Lower level: higher rate
Communication (formal)	Strong	Lower level: higher rate
Centralization	Strong	Higher level: higher rate
Satisfaction	Unclear	Unclear
Opportunity	Unclear	Unclear
Routinization	Weak	Higher level: higher rate
Professionalism	Weak	Higher level: higher rate
Upward mobility	Weak	Lower mobility: higher rate
Distributed justice	Weak	Lower level: higher rate
Size	Mixed	Smaller size: higher rate

A number of determinants have their strength of determination listed as unclear or weak, this refers to the degree with which studies have supported the proposed correlation. It represents the confidence level for the correlation. It should be noted that satisfaction and opportunity can also be viewed as linking variables. Satisfaction represents a sociological state of the individual which has been brought about by the action of the other determinants. It is quite difficult to measure but is important as it is considered causal to turnover. Opportunity has a negative hygiene effect and together with satisfaction can be viewed as a direct causal precursor to turnover.

Turnover, as a phenomenon within an organization, can be viewed as causing changes in other descriptive variables. A consolidated table of ten propositions illustrating the impact that turnover has in an organization along with the type of impact and the degree of supporting data is presented in table 5 (Price 1977, 92-120; 1989, 461-73):

TABLE 5

TURNOVER PROPOSITIONS

Proposition	Type of Impact	Amount of Supporting Data
Administrative staff	Positive	Medium
Formalization	Positive - nonlinear	Medium
Integration	Negative	Medium
Satisfaction	Negative	Low
Innovation	Positive - nonlinear	Low
Centralization	Negative	Low
Effectiveness	Mixed	Varied

Proposition	Type of Impact	Amount of Supporting Data
Productivity	Negative	Varied
Communication (quantity)	Positive	Varied
Communication (accuracy)	Negative	Varied

To illustrate these propositions, the first example would be that an increase in turnover would likely cause an increase in the administrative staff of an organization. This would be due to the necessity to recruit more workers which increases the demands on the administrative staff.

These propositions serve as the functional link between turnover and measurable items within the organization. As the rate of turnover changes, it will cause changes in these variables which can, in turn, affect individuals within the organization. This can lead to further changes in the turnover rate. These effects can be viewed as feedback loops.

Sheehan (1991, 343-54) explores the effect of quitting on the coworkers who remain with the company. Job dissatisfaction is seen to increase as the reasons for quitting are more closely related to the stayer's job situation. This could be more important in those organizations where closeness of contact and employee similarity, rather than diversity, are fostered. In essence, the reasons why an individual quits are probably held by other individuals also.

Koch and Rhodes (1981, 145-61) investigated job satisfaction and found that both organization and personal factors together with the content of the job or task strongly influence turnover. The results are interesting because only one of the factors is related to job or task content. Factors determined to be important predictors of turnover are presented in table 6 below:

TABLE 6

PREDICTORS OF TURNOVER

Predictor	Type of Influence
Length of employment	Personal
Required task time	Job content
Peer leadership	Organizational
Communications flow	Organizational
Training duration	Organizational
Family income	Personal
Pay satisfaction	Organizational & Personal

Spector (1985, 693-713) found strong correlation between job satisfaction and a number of job related factors. His findings reinforce those of Koch and Rhodes in that most of the factors are not related to job content. It is of interest that the factors with strong correlations, are concerned with perception and commitment. These factors are presented in table 7 below together with the strength of correlation:

TABLE 7

JOB SATISFACTION CORRELATION FACTORS

Factor	Correlation
Perception of job	Strong
Perception of supervisor	Strong
Intention of quitting	Strong
Organizational commitment	Strong
Salary	Modest
Age	Modest
Job level	Modest
Absenteeism	Modest
Turnover	Modest

Lance (1991, 137-162), in modeling job satisfaction, organizational commitment, and precursors to voluntary turnover, found that job satisfaction and organization commitment act to diminish effects that perceptions of the work environment have on variables considered to be precursors to quitting. He found that job satisfaction and organizational commitment have an asymmetric reciprocal linkage between them. Each of these factors affected the other but to different degrees. This would indicate a feedback loop existing between these factors. The non-symmetry suggests that depending upon the relative degree of each linkage, the overall loop could be forced to either a positive or negative state.

Black and Gregersen (1990, 485-506) found that the strongest predictor of intention to quit was the factor of general satisfaction. They suggest that non-work expectations and satisfaction derived from activities outside the work environment need to be considered for any model of the turnover process.

Koslowsky (1987, 269-92) has used a dynamic systems approach to model turnover. He found a strong dependence on the role of stress which causes changes in employee attitudes over time. These attitudinal changes, acting within positive and negative feedback loops, are part of a process involving both the individual and the organization. His work presents a case for strong interdependence among the factors built into a turnover model. This concept takes on more relevance when incorporated into a many-individual model such as those using A-life techniques.

Mowday, Porter, and Stone (1978, 321-32) examined the relationships between employee characteristics and turnover in an organization. They found that leavers were characterized by a lower level of tenure, a higher need for autonomy, and a lower need for harm avoidance. A main conclusion of their work was that employee characteristics need to be considered as an important part of any comprehensive model of the turnover process.

An interesting study was performed by Maume (1991, 495-508) which explored the relation between child-care expenditures and women's turnover. Weekly child-care payments were found to be a significant predictor of employment turnover. The effect was also stronger for mothers of pre-schoolage children, did not vary with the wage level, and was not correlated with transitions between full-time and part-time work status. Again, this is a study which points out strongly the effect on turnover of non-work related factors.

Weisberg and Kirschenbaum (1991, 359-75) compared data from a model of turnover intent drawn from a subpopulation of a representative national sample to data at the national level. Their comparison was performed using multi-variate analysis. The findings were that older age, longer period of service, and lower occupational level were the best predictors of turnover intent. The factors of age and period of service seem to be at odds with the generally accepted result that older age and longer period of service are correlated with lower turnover rates. Their study was performed in Israel, so it might not be directly comparable to studies performed in the United States due to cultural effects. They also found that increasing levels of job satisfaction were correlated with decreased intention to quit. Their overall results were that turnover intent at the organizational level was, on the whole, similar to that at the national level. This finding has relevance in building organizational models to study turnover.

Weisberg and Kirschenbaum (1993, 987-1006) also examined the impact of sex on turnover and intent to quit. They found that gender was significantly correlated with turnover but not with intent to quit. Their findings are of interest when gender is included in a turnover model which incorporates both thinking of quitting and also the act of quitting.

Mee-Lim and Bain (1990, 401-14) studied the effects of quality of work-life (QWL) programs within a number of unionized firms. While their work was not directed toward turnover, they did report a mixed impact of QWL programs on turnover. QWL programs could be viewed as a component of the weak determinate of distributed justice or the intervening variable of satisfaction identified by Price (1977).

Igbaria and Siegel (1992, 101-26) surveyed a sample of engineers to develop and test an integrated model of quitting intention. Their model included role stressors, task characteristics, job involvement, job satisfaction, and organizational commitment as factors. Their result was that a direct and negative effect on turnover intention was found for organizational commitment. Indirect effects were found for the other factors. Job satisfaction was found to be a major factor influencing the variable of organizational commitment. Igbaria, together with Greenhaus (1992, 34-49) found the same results when studying the turnover intentions of management information systems employees. An interesting result from both studies is that it was found that task characteristics play an important role for predicting job involvement, career satisfaction, and intention to leave. This factor would seem to be related to the professionalism of the job.

To summarize, it appears that studies and models of turnover or intention to quit which have been done during the last ten years or so, have generally found that two main collections of factors have high correlations with turnover or intention to quit. Job satisfaction and organizational factors outweigh job content factors as predictors of turnover. This will be taken into account during the design of my model. Studies have also found many strong correlations of non-work related factors to turnover. Many of these factors can be explored using A-life models where many individuals are modeled.

Modeling

The purpose of a model should determine the type of model selected. Much modeling is performed and the descriptors of the models serve to identify or classify their uses. At the national level, employment forecasting is performed extensively in the aggregate by the Department of Labor using National Census data and Department of Labor statistics. These forecasts are generally for very broad employment categories and are often used as part of national econometric models. Individual state agencies also produce models of employment for their respective states. Finer divisions in specific fields or industries are also common with continual updates being published (National Research Council, Nuclear Engineering, 1990; Joint Engineering Management Council 1967).

Modeling of manpower needs is often performed using very different techniques and basic assumptions related to the nature of the variables involved. Algebraic models have been used to predict gross needs at the national level (National Research Council, Nuclear Engineering, 1990). More detailed models can be fabricated using the techniques of System Dynamics (Forrester 1961; 1969). In discussing the usefulness of System Dynamics within the context of modeling, Forrester (1975, 212-3) states:

> People would never attempt to send a space ship to the moon without first testing the equipment by constructing prototype models and by computer simulation of the anticipated space trajectories. No company would put a new kind of household appliance or electronic computer into production without first making laboratory tests. Such models and laboratory tests do not guarantee against failure, but they do identify many weaknesses that can be corrected before they cause full-scale disasters.

> Our social systems are far more complex and harder to understand than our technological systems. Why, then, do we not use the same approach of making models of social systems and conducting laboratory experiments on those models before we try new laws and government programs in real life? The stated answer is often that our knowledge of social systems is insufficient for constructing useful models. But what justification can there be for the apparent assumption that we do not know enough to construct models but believe we do know enough to design new social systems directly by passing laws and starting new social programs? I am suggesting that we do know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase. But I am confident, and substantial supporting evidence is beginning to accumulate, that the proper use of models of social systems can lead to far better systems, laws, and programs.
>
> It is now possible to construct realistic models of social systems in the laboratory. Such models are simplifications of the actual social system but can be far more comprehensive than the mental models that we otherwise use as the basis for debating governmental action.

The use and growth of models of social systems were closely tied to the availability of sufficient mathematical number crunching ability which we, today, equate with computer power. However, closely tied to the ability to obtain numeric answers, was the realization that as models became more complex and long term in scope, an answer was no longer the goal but rather an understanding of the dynamics of a complex system. Forrester (1975, 66) states:

> Simulation takes the emphasis off mathematics for the sake of analytical solutions. Instead, mathematics becomes important as a precise and orderly language for logical manipulation. Analytical solutions are no longer as important for the answers they give as for providing an additional perspective and insight into the nature of the elementary processes that underlie systems.

While these models have been very useful, it is important to remember the general shortcomings of these models, which are:

1. They are large scale models which often use statistical data for groups and treat cohorts rather than individuals.

2. They are human behavior models which use variability in individuals to generate a distribution of values for variables with the result that an individual is not modeled but rather a normalized individual is modeled.

Recently A-Life (Artificial Life) modeling techniques based upon individuals is becoming a useful tool. For example, VANT (*V*irtual *ANT*) models use a simple computer ant which is endowed with a genetic structure in which genes correspond to behavioral traits (Langton 1986; Levy 1992, 93-120). The behavioral traits when acted upon by the environmental factors result in the vants interacting with the environment in a specific fashion. The alleles (forms) of a gene are mapped to the values of a particular trait. For example, the trait of quitting a job when stress levels exceed a threshold value will have different values for different individuals. Coding these values to a vant gene would allow an entire organization of individuals to be modeled at a time. The model would resemble an organization comprised of individuals (treated as individuals) rather than being a model of a collective organization or a single individual. "The phenomenon of complex, perhaps unexpected, behavior developing from a simple set of rules occurs over and over in A-Life experiments and is termed emergent behavior" (Prata 1993, 20). The basic units of a situation are modeled together with their interactions, then the system is set in motion and left to evolve its own behavior.

Furthermore, in examining types of model formulation, Taylor and Jefferson (1994, 4-5) are of the opinion that:

> Models of population behavior for the study of ecosystem organization, population genetics, macroevolution, geographic dispersal, etc. have

> traditionally been expressed formally as systems of algebraic or differential equations. Unfortunately, equational models are subject to many limitations. For example, in many models it is common to refer to the derivative of a variable with respect to population size *N*. This in turn implies the assumption of very large populations in order for such a derivative to make sense, which has the effect of washing out small population effects, such as genetic drift, or extinction. Another difficulty is that it would take tens to hundreds of lines of equations to express even a simple model of an organism's behavior as a function of the many genetic, memory, and environmental variables that affect its behavior, and there are simply no mathematical tools for dealing with equational systems of that complexity. Furthermore, equational models are generally poor at dealing with highly nonlinear effects such as thresholding or if-then-else conditionals, which arise very frequently in the description of animal behavior.
>
> One of the most fundamental and successful insights of the field of Artificial Life has been the development of an alternative population modeling paradigm that dispenses with equations entirely, and represents a population procedurally, that is, as a set of coexecuting computer programs, one for each cell or one for each organism. We consider this feature, the representation of organisms by programs, to be the defining feature of "artificial life" models of population behavior, the property that distinguishes them from other mathematical or computational models of populations.
>
> Artificial Life models offer the advantage of coding an organism's behavior explicitly as a program, rather than implicitly as the solution to equations that must be integrated. This directness of encoding typically makes Artificial Life systems much easier to use and modify, as new information is obtained or new hypotheses are entertained, than is possible with equational models. Today most Artificial Life models represent each organism as a Lisp program, a finite automaton, or a neural net. The genes of the organism are represented variously as bit strings, character strings, or list structures, either contained within the organism or stored as a separate data object that serves to encode the structure or behavior of the organism. Software organisms can reproduce either asexually, with point mutations altering the genetic data passed from parent to child, or sexually, with the child's genome derived by combining information from two parent genomes.

An interesting experiment was conducted by Reynolds (Levy 1992, 76-80) in which the flocking behavior of birds was modeled using this technique. According to Reynolds' theory, a hypothesis based on observation and evaluation of the literature will be strengthened by being successfully implemented in a model. For his work, this did not mean that a real bird would actually use the rules of the model, but it showed, at least, that using those rules would produce a behavior that certainly appeared to be flocking.

The preceding has the implication that concepts of control whereby individuals within a system are either directed by the system or direct the system need to be reexamined. Resnick (1994, 4) believes that:

> This assumption of centralized control, a phenomenon I call the centralized mindset, is not just a misconception of the scientifically naive. It seems to affect the thinking of nearly everyone. Until recently, even scientists assumed that bird flocks must have leaders. It is only in recent years that scientists have revised their theories, asserting that bird flocks are leaderless and self-organized. A similar bias toward centralized theories can be seen throughout the history of science.

Viewing a system which has the rule structure of decision making by the individuals represents a new and different approach to system analysis. Ray (1994, 180) states:

> The new bottom-up approach creates a population of data structures, with each instance of the data structure corresponding to a single entity. These structures contain variables defining the state of an individual. Rules are defined as to how the individuals interact with one another and with the environment. As the simulation runs, populations of these data structures interact according to local rules, and the global behavior of the system emerges from these interactions. Several very good examples of bottom-up ecological models have appeared in the AL literature. However, ecologists have also developed this same approach independently of the AL movement and have called the approach "individual-based" models.

This serves to shift the emphasis to an approach of observation followed by synthesis. In this approach modeling is an integral and important part of seeking knowledge about a system. Resnick (1994, 231) states:

> One of the basic tenets of Artificial Life is that the best way to learn about living systems is to try to construct living systems (or, at least, models and simulations of living systems).

It also follows that a particular aspect of synthesis is that it is comprised of two main assumptions, one being deduction and prediction, the other being explanation. Bonabeau and Theraulaz (1994, 305-6) state:

> Being able to deduce the properties of a phenomenon, from a set of causes is not equivalent to explaining this phenomenon, because only a few among the many possible causes may be relevant. . . . Explaining the phenomenon amounts to determining what the relevant causes are. Note that the number of such causes might be very high in the case of complex living systems, making explanation intractable.

Representing a phenomenon using a simulation model has become a standard tool for a systems oriented approach. As an example within the field of ecology, Foin (1972, 481) states:

> The methods of systems ecology center upon the construction of a simulation model. Our approach is to construct a very general conceptual model, then to break it up into progressively smaller and more detailed modules. When the flowcharts are sufficiently detailed, data can be sought to quantify the static and dynamic variables, functions selected, and algorithms written for the functions. Particular care is exercised to include all the feedback loops possible within any developed submodel, and constant checks are made to insure all possible integration between modules.
>
> The central tool of model building is a sufficient computer to handle the simulation model. Any model that accurately simulates the natural complexity of human activity tends to become very large rapidly; even with fairly large machines . . . submodels can easily use all available internal storage and require programming tricks and high efficiency to run. The computer is also an appropriate tool for the systems analysis that goes into selection of mathematical functions.

A specific problem has come up when modeling complex systems and the severity of the problem seems to be proportional to the complexity of the system. The problem is what exactly is being modeled and, as such, exists as a problem of formulation rather than a theoretical restraint inherent with the modeling process. One becomes so lost in the multitude of trees that they cannot see the forest. Patten (1972, xii) offers the following discussion:

> First, a clear distinction between modeling behavior (dynamics) and modeling the mechanisms that produce behavior has not been arrived at. Mechanisms are nonlinear, but behavior, particularly the nominal or small perturbation behavior of adapted systems, tends to be linear. Models based on nonlinear representations of mechanisms have not been too successful in simulating behavior. The mathematical properties of nonlinear systems are just not consistent with the dynamics of real systems. The problems are compounded when complex patterns of interactions are involved.

Thus modeling has been seen to be an essential and intrinsic part of the study of dynamic complex systems. Modeling has been linked closely with computer development and is likely to continue to evolve. A-Life modeling is a recent development stemming from prior endeavors.

In the chronology from the first computer models to present day A-Life versions, the progenitors for A-Life models are the fields of cellular automata and genetic algorithms. Both fields have but a short history and the existence of each is largely dependent upon the recent advancement of computational power made available by developments in both computer hardware and software. Both also draw on the advent of computer graphics as a new tool to present and interpret large amounts of dynamic data. Both fields can also be traced back to seminal individuals.

Cellular Automata

The field of cellular automata was conceived in the works of John von Neumann, Stanislaw Ulam, and John Horton Conway. John von Neumann and Stanislaw

Ulam were both aware of the bottleneck in computation using serial processing (each cell is processed one at a time in a serial fashion) so they developed cellular automata as a tool to study and model complex systems. During 1948, von Neumann delivered a series of lectures called "Theory and Organization of Complicated Automata," at the University of Illinois. An intriguing question of concern was whether or not it was possible for a machine or automaton to reproduce itself. This concern or preoccupation with life and reproduction has remained in the field of cellular automata to this day. In 1952, von Neumann completed a description of a self-reproducing cellular automaton which used 29 states. During 1970, the game of "Life" by John Horton Conway was introduced to the public. During this time computer power was ever increasing which allowed more complex cellular automata to be studied. The advent of massively parallel computers such as the connection machine (256,000 processors) (Hillis 1987) was the hardware which gave promise to the field of cellular automata. Referring to an earlier version of the connection machine, Channell (1991, 124) states:

> Much of the early work was limited by a lack of hardware and only recently has W. Daniel Hillis, founder of Thinking Machine Corporation, built and marketed a parallel processing computer called the Connection Machine, with over sixty-five thousand processors.

In addition, special purpose computers (Systolic Processors) were built in limited quantities to attack the speed problem. Many new researchers were drawn to the field which eventually resulted in the first A-Life conference being organized by Langton in 1987.

A cellular automaton is a two-dimensional mathematical grid-like entity (sometimes three-dimensional) typically displayed on a computer screen divided into cells which are repeatedly updated using a universal rule structure applied in a parallel manner to all cells. Color, size, and position or some combination of these are typically used to convey the state or value of an individual cell. These cellular automata programs have three main properties (Rucker 1989, 2):

1. Parallelism: An individual cell is updated independent of all other cells. The action of updating all cells is referred to as a generation.
2. Locality: When a cell is updated, its new value depends upon its old value and the old value of its nearest neighbors.
3. Homogeneity: Each cell is updated according to the same rules.

Cellular automata can be used as good models for physical, biological, and sociological phenomena. Each cell (person, region of space, etc.) updates itself independent of other cells. It bases its new state on the value of its immediate surroundings or neighbors using some generally shared law of change or behavior. Wolfram (1984) holds the view that

> Cellular automata are examples of mathematical systems constructed from many identical components, each simple, but together capable of complex behavior. From their analysis, one may, on the one hand, develop specific models for particular systems, and, on the other hand, hope to abstract general principles applicable to a wide variety of complex systems.

As increasingly more complex systems were modeled and the ecology field took an early interest in this technique, a somewhat murky path for future cellular automata development slowly emerged. Channell (1991, 134) states:

> By explicitly using ideas and concepts drawn from biology as rules for cellular automata, researchers are beginning to explore the possibility of *artificial life*. Biologist Richard Dawkins has used Darwinian principles to create a computer program in which small stick figures evolve based on a simplified

> genetic code, random mutations, and a few rules governing natural selection. Christopher G. Langton at the University of Michigan used Edward O. Wilson's work on insect societies to create a colony of virtual ants, or "vants," which were programmed to cooperate in the task of building and following trails across the computer's screen.
>
> Although such forms of artificial life are clearly distinct from actual organic life, recent developments are moving the two forms closer to one another.

As a sidelight in the development of Artificial Intelligence, early work was performed using neural network techniques which share a methodological kinship with cellular automata in that it was also hardware limited. The specific aspect of the limitation was the very small degree of connectionism which could be achieved with the hardware of the time. This led to sufficient criticism to hinder work on neural networks for a decade. In discussing the objections raised by Minsky and Papert over the concepts of connectionism in computers, especially perceptrons; Channell (1991, 124-5) notes that:

> Although the artificial intelligence community still remains divided over connectionism, there have been some recent attempts to exploit a combination of rule-driven AI and emergent AI. Minsky has recently argued that the "advantages of distributed systems are not alternatives to the advantages of insulated systems; the two are complementary." In an expanded edition of their critical book on perceptrons, Minsky and Papert raise the possibility that artificial intelligence may arise from a combination or linkage of parallel processing and serial processing. They explain that they "have come to try to develop 'society of mind' theories that will recognize and exploit the idea that brains are based on many different kinds of interacting mechanisms." If a group of different types of neural nets were organized into a larger system so that some parts of the system were strongly connected to one another while other parts were relatively insulated, the advantages of both serial and parallel processing could be exploited. The idea of such a dualistic system seems to reflect a bionic world view in which intelligent behavior, traditionally seen as the exclusive province of the organic, emerges from a machine, transforming it into a vital machine.

Genetic Algorithms

The field of genetic algorithms, to a large degree, is a result of the work of John Holland. The research goals of Holland were to explain the adaptive processes of natural systems and to design software systems that retain the important mechanisms of natural systems. Adapting natural selection to the problem of machine learning resulted in genetic algorithms. Genetic based algorithms were conceived and developed as a technique for solving optimization problems. They have certain advantages over the three conventional search methods which consist of calculus-based, enumerative, and random methods. They differ from the conventional search techniques in four main ways (Goldberg 1989, 7):

1. Genetic algorithms work with a coding of the parameter set, not the parameters themselves.
2. Genetic algorithms search from a population of points, not a single point.
3. Genetic algorithms use payoff (objective function) information, not derivatives or other auxiliary knowledge.
4. Genetic algorithms use probabilistic transition rules, not deterministic rules.

In discussing the formulation of genetic algorithms, Mitchell and Forrest (1994, 281) state:

> The vast majority of current GA (genetic algorithm) implementations use a simple binary alphabet linearly ordered along a single haploid string. It should be noted that researchers interested in engineering applications have long advocated the use of simple "higher-cardinality alphabets," including, for example, real numbers as alleles. Given the fact that GA performance is heavily dependent on the representation chosen, this lack of diversity is surprising.

Genetic algorithms which represent a bottom up approach to machine intelligence were not widely publicized or studied as the top-down approach of the field of artificial intelligence became the dogma of the day. Only recently, due to the lack of real results from the field of artificial intelligence has there been a resurgence of interest in genetic algorithms. Collectively, concepts and techniques drawn from the fields of genetic algorithms and cellular automata are generally referred to as Artificial-Life which is emerging as a field in its own right.

A specific distinguishing characteristic of genetic algorithms is that they inherently deal with life including concepts such as birth, behavior, and death. Another characteristic is population which is a collection or group of individuals or agents. Dyer (1994, 112) states:

> One attractive feature of the AL approach is that the fundamental unit of manipulation is the *population*. Genetic operators are applied to populations and produce populations. This approach is in direct contrast to AI approaches. For example, in distributed artificial intelligence (DAI), researchers take the individual to be the fundamental unit and then attempt to engineer individual agents who will interact correctly to solve group-oriented tasks.

As stated earlier, modeling of behavior is an important aspect of Genetic algorithms. Mitchell and Forrest (1994, 279) state:

> Understanding and modeling social systems, be they insect colonies or human societies, has been a focus of many artificial-life researchers. GAs have played a role in some of these models, particularly those modeling the evolution of cooperation. Here we describe how the GA was used to evolve strategies for interaction in the context of the Prisoner's Dilemma.

Also Dyer (1994, 113) goes on to say:

> A very long-term goal of AL is to gain insight ultimately into the evolution and nature of human intelligence, through modeling the evolution of communication and cooperative behavior in lower life forms

While genetic algorithms have proved useful in modeling many phenomenon, they do have a drawback. The genetic congruence in their structure represents a severe environment for model formulation and programming. A gene sequence is difficult to relate to an observable characteristic. Mitchell and Forrest (1994, 281) touch upon this issue as follows:

> It is difficult to distinguish between "yet another cute simulation" and systems that teach us something important and general, either about how to construct artificial life or about the natural phenomena that they model. We suggest that artificial-life research should address at least one of these two criteria and that it is important to be explicit about what any specific system teaches us that was not known before. This is a much more difficult task than may be readily appreciated, so difficult in fact that we consider an open problem to develop adequate criteria and methods for evaluating artificial-life systems.
>
> On the modeling side it can be very difficult to relate the behavior of a simulation quantitatively to the behavior of the system it is intended to model. This is because the level at which Artificial-Life models are constructed is often so abstract that they are unlikely to make numeric predictions.

Artificial-Life Techniques

Artificial-Life, as a technique, draws upon the strengths of both genetic algorithms and cellular automata. It uses evolution as a powerful way to perform optimization using a computer and also provides a unique way of studying the evolution of natural phenomena. It allows the modeling of many individuals where the individual is truly individual. From the above, it can be seen that A-Life modeling techniques offer a new tool which can be adapted for use when modeling organizations comprised of many individuals. Channell (1991, 135) states:

> Some computer scientists are using artificial life to create new computer programs that emerge through a kind of Darwinian evolution rather than by

> being designed by a person. For example, Daniel Hillis at Thinking Machines has created a program to sort lists of numbers.

In this example, Hillis allowed a program which sorts lists to evolve toward a more efficient version in which the goal was to use fewer steps to achieve the sort. This optimization is performed via evolution.

Since Artificial-Life, as a technique, is inexorably linked to computing power and progress, some mention needs to be made concerning the future. Channell (1991, 135) further states:

> As vital machines become more and more sophisticated, the distinction between artificial life and actual life may become moot. In the opinion of J. Doyne Farmer, a leading specialist in artificial life at the Los Alamos National Laboratory, "Although computer viruses are not fully alive, they embody many of the characteristics of life, and it is not hard to imagine computer viruses of the future that will be just as alive as biological viruses."

As life becomes artificial and computerized, there is also a flip-side. In discussing Norbert Wiener and learning within high-order programs, Channell (1991, 142) states that "New developments in artificial life also raise questions about computers being predetermined." As simulation and modeling of complex systems is becoming the norm, artificial life, as a technique, is finding many new users drawn by its usefulness. Resnick (1994, 14) states:

> The new field of artificial life is a striking example of the growing interest in self-organization and decentralized scientific models. Artificial life researchers aim to gain a better understanding of living systems by creating computational versions of them - for example, creating artificial versions of ant colonies or bird flocks. In their efforts, artificial life researchers are guided by an abiding faith in decentralized approaches.

This decentralized strategy is predicated upon a number of guiding principles. To expand and discuss these "guiding heuristics" for thinking about decentralized worlds, Resnick (1994, 134) states:

> -*Positive Feedback Isn't Always Negative.* Positive feedback often plays an important role in creating and extending patterns and structures.
>
> -*Randomness Can Help Create Order.* Most people view randomness as destructive, but in some cases it actually helps make systems more orderly.
>
> -*A Flock Isn't a Big Bird.* It is important not to confuse levels. Often, people confuse the behaviors of individuals and the behaviors of groups.
>
> -*A Traffic Jam Isn't Just a Collection of Cars.* It is important to realize that some objects ("emergent objects") have an ever-changing composition.
>
> -*The Hills Are Alive.* People often focus on the behaviors of individual objects, overlooking the environment that surrounds the objects.

As A-Life is a new field, many concepts are not rigidly codified but exist rather as a collection of folk principles. These principles are often germane to the specific field for which a model is constructed. While working on models of politics which include alliances between competing members, control of territory, and warfare; Axelrod (1995, 33-4) discusses some discovered principles which give some insight into the dynamics of the system:

> The results of the model's performance can now be summarized in terms of six characteristics:
>
> 1. *Things usually don't settle down.* Instead, the history of the model shows considerable complexity. For example, as late as year 900. one of the populations suffered a series of fights that destroyed over three-quarters of the global wealth.
>
> 2. *Histories show considerable variability.* The combinations of wealthy actors, frequency of fights, and trends in population wealth differ considerably from one population to another. Even though each actor is

using the same decision rules, the results differ greatly because of random differences in initial wealth and in the order in which the actors become active.

3. *"Imperial overstretch" can bring down even the strongest actor.* As an actor becomes committed to others via tribute relationships and fighting together, it becomes exposed to the risks of whatever fights the others get into. Since actors decide on demands and responses based upon their own calculations, even a weak actor can choose to make or resist a demand for its own reasons, and thereby drag into the struggle a strong actor who is committed to it.

4. *Civil wars can occur among the smallest members of a cluster.* While the strongest members of a cluster typically can prevent a fight among members of the same cluster by taking sides, it would not do so if it had equal commitment to the two sides. Therefore, smaller members of a cluster may fight each other while the strongest member stands aside.

5. *A cluster can have more than one powerful member.* Clusters are often like empires, with one powerful actor and many weaker ones who pay tribute to it. But as we have seen in the case of [...], it is also possible for a second actor to grow strong in the shadow of the first.

6. *Initial endowment does not guarantee or even predict success.* Before clusters of commitments are established, wealth can be as much a handicap as an asset. The reason is that wealth makes an actor a lucrative target for other strong actors, and can make one over-confident in making demands.

Furthermore, in examining the processes of collaboration and competition within the framework of modeling alliances within the political arena, Findler and Malyankar (1995, 214-5) have found that:

1. Alliances may differ from one another in all possible characteristics and have no a priori motivation to collaborate.

2. If two or more alliances decide to collaborate, it is based on their momentarily shared goals, and on the accuracy and timings of their "network perception" (their perceptions of other alliances).

3. The goals of an alliance may be self-generated or induced by the environment.

4. The members of a single alliance or different alliances may assume a temporary, hierarchical or flat organizational structure if it serves their purpose and their internal power conditions.

5. The membership and the norms of an alliance may change dynamically in response to the changing environment and the individual agent's mentality.

6. The actions of an alliance may affect the others adversely if their goals are partially or totally exclusive.

7. The costs and benefits of an alliance depend on the actions of the other alliances as well. It may, however, be a non-zero-sum environment.

8. Conflicts arising between alliances may (but need not) be resolved through negotiation.

9. The malfeasance of an alliance (deliberate or accidental transgression of the norms) is to be discovered and reported by others.

10. When the goals and/or action of an alliance are found to violate the current norms, their expected value to the social entities in question is calculated. If this is greater than a certain threshold value, a suggested change to the norms (allowing the goal or action in question) is checked *vis-à-vis* the meta-norms, and, if found to be feasible, put to a vote. A negative vote by the majority (or plurality) can be followed by negotiations leading to an acceptable consensus.

It is acknowledged that while the preceding listed principles differ greatly in generality, they do represent insight concerning how system processes and structure dually influence and are also influenced by individual behavior and can guide one in the design of more accurate or precise models.

While the preceding examples illustrate guiding principles, the operative word for emphasis is "guiding" rather than "principles." These are not formula to build a system but aid in the understanding of complex behavior resulting often from quite simple rules. To elucidate this point, Resnick (1994, 134-5) states:

> These guiding heuristics are not very "strong." They are neither prescriptive nor predictive, nor are they unique to decentralized systems. They don't tell you precisely how to think about decentralized systems, nor do they tell you how to make accurate predictions about such systems. Rather, they are ideas to keep in mind as you try to make sense of an unfamiliar system, or to design a new one. They highlight some pitfalls to avoid, and some possibilities not to overlook. These heuristics will not (and should not) replace the centralized mindset. Rather, they can supplement the centralized mindset, leading to a richer set of mental models for making sense of systems in the world.

Of essential importance in the formulation of A-Life models is the role of the individual or agent. A system is more than just a collection of individuals. From a special or particular viewpoint, it is many individuals which form a system rather than a system consisting of many individuals. The emphasis of distinction is on the individual. The agent, congruent to a person or other life form, is a rule driven entity or system, in its own right, operating and interacting with other agents within an environment. Some general characteristics of an agent are that it is goal seeking, autonomous or independent, and adaptive. Maes (1994, 136) discusses these points as follows:

> An *agent* is a system that tries to fulfill a set of goals in a complex, dynamic environment. An agent is situated in the environment: It can sense the environment through its sensors and act upon the environment using its actuators. An agent's goals can take many different forms: they can be "end goals" or particular states the agent tries to achieve, they can be a selective reinforcement or reward that the agent attempts to maximize, they can be internal needs or motivations that the agent has to keep within certain viability zones, and so on. An agent is called *autonomous* if it operates completely autonomously, that is, if it decides itself how to relate its sensor data to motor commands in such a way that its goals are attended to successfully. An agent is said to be *adaptive* if it is able to improve over time, that is, if the agent becomes better at achieving its goals with experience. Notice that there is a continuum of ways in which an agent can be adaptive, from being able to adapt flexibly to short-term, smaller changes in the environment, to dealing with more significant and long-term (lasting) changes in the environment, that is, being able to change and improve behavior over time.

As an agent makes goal directed choices continually within a model, some discussion of this behavior is necessary to make a distinction which serves to set A-Life models apart from other models. Agent choices generally are not optimized in a classical sense. They attempt to meet or achieve the goal, but there is no incentive or premium for over achievement. To illustrate this point, an agent who finds more food than it can eat or store or transport is no better that an agent who finds sufficient food to satisfy hunger. Maes (1994, 147) provides a further discussion of this point:

> Given that it is theoretically impossible to prove what the optimal action selection policy for an agent is, how does the field evaluate a particular proposed solution? Researchers in adaptive autonomous agents are not interested in provable optimality of action selection, that is, in whether the agent takes the optimal path toward the goals, as they are in whether the action selection is robust adaptive, and whether the agent achieves its goals within the requirements and constraints imposed by the particular environment and task at hand. Among other issues, this means that the action selection mechanism should:
>
> -favor actions contributing to the goals; in particular, it should favor those actions that result in the most progress toward the goals.
>
> -be able to deal flexibly with opportunities and contingencies.
>
> -be real time (fast enough for the particular environment at hand and its pace of changes).
>
> -Minimize unnecessary switching back and forth between actions contributing to distinct goals.
>
> -improve on the basis of experience.
>
> -demonstrate graceful degradation when components break down or unexpected changes happen.
>
> -never get completely stuck in a loop or deadlock situation or make the agent mindlessly pursue an unachievable goal.

> -and, most importantly, be "good enough" for the environment and task at hand: As long as the agent manages to achieve its goals within the constraints (time, quality, etc.) required by the problem situation, the solution is considered an acceptable one. For example, as long as the robot manages to find the recharging station before its battery dies, as well as make progress toward its more task-specific goal of surveying the offices, it is considered an acceptable solution, even if it does not always follow optimal paths.

With the preceding as a foundation, it thus is apparent that the individual or agent is an independent system of its own, following rules, more often than not, of its own which, nevertheless, are structurally similar to the rules of other individuals. The richness of this structure allows and fosters a complexity which is similar to what we see exhibited in human behavior. Simulating this behavior via A-Life models allows experimentation, which could not otherwise be performed, aimed at understanding the human and human society.

The thrust of this research is to explore A-Life models and simulations to provide an improved methodology for their use along with a desire to bring together many aspects of Artificial-Life into a pseudo codification of principles which will allow a researcher to use A-Life techniques as an effective tool in the study of human phenomenon.

Theoretical Framework or Perspective for the Research

The theoretical framework for an understanding of the A-Life modeling of turnover lies not within the field of turnover but rather within the field of A-Life. Within the A-Life community, there is a growing movement toward a rejection of what is termed folk psychology. Smithers (1992, 31-40) refers to folk psychology as "the common sense psychological terms such as 'believe', 'desire', 'fear', 'feel', 'imagine', 'prefer', 'think', etc. whose everyday use is governed by a loose knit network of largely tacit principles, platitudes, and paradigms, and not by some system of well founded, coherent, and consistent natural laws, as is required of any scientific theory." This movement is called "eliminative materialism" and has been championed by Churchland (1988, 507-8).

Within this framework, I am viewing turnover as a psychological phenomenon which can be described and modeled by a collection of correlating variables. The purpose of the A-Life model is to achieve a dynamic complex simulation of the phenomenon being studied. As psychological phenomena are not well defined as to the relevant variables or equations linking variables, a degree of complexity can be achieved by using as many variables as possible. At the same time, though, the computer model must not be too complex so as to become intractable in use. Within the confines of the computer platform available, a few thousand individuals (different combinations of variables) can be modeled in a single simulation. The model progresses time-step by time-step where future values are determined both by the network and any learning that the network has achieved. The model provides a history of the values of the variables so that the observed characteristic (i.e., thinking of quitting) can be examined for each individual of the model as the values of each variable wax and wane over time. This will provide an understanding of how the variables of the model interact to affect changes in the studied behavior.

Price (1989) postulates that increased turnover will likely produce less productivity. He states "When turnover disrupts performance, productivity decreases; on the other hand, when turnover is accompanied by the displacement of poor performers and a decrease in withdrawal behaviors, productivity increases." He goes on to discuss the question of net impacts and whether or not turnover decreases productivity more than it increases it. This is a crucial point, for it is the summation of the performance of individuals which determine the calculated productivity of the organization. Some individuals will increase their performance and other will decrease their performance. Simulating the behavior of the individual allows one to understand the statistics applied to the organization as a whole. System statistics of correlations, by their nature, cannot be applied to the individual. Simulating the individual allows the cause and effect nature of the interaction to become known. To understand why organizational productivity should decrease when turnover increases, one must study each individual of the organization for each individual interacts with others. Only when one understands the behavior of the individual, can one then understand the statistical description of the organization.

An important element of the theoretical framework for simulating behavior in the field of A-Life is that there is no single or unique collection of variables which will produce or determine a specific behavior pattern. An individual who is thinking of quitting can have different observed values for the variables used to construct the model than another individual might have. To illustrate this point (using the variables of the sample model described in appendix 7), table 8 shows the variable values for three hypothetical individuals who have the same level of the characteristic "thinking of quitting":

TABLE 8

EXAMPLES OF VALUES FROM SAMPLE MODEL

Variable	Person A	Person B	Person C
Pay	Medium	Low	High
Centralization	Low	Medium	Medium
Length of service	High	High	Low
Age	Low	Medium	Low
Education	Medium	High	High
Management perception	Medium	Medium	Low
Thinking of quitting	Medium	Medium	Medium

This matches observed behavior in as much as individuals are treated as individuals and not just as clones having all the same variable values. A shortcoming in using statistical reductionist models is that there is a tendency to neglect or discard observations which do not fit the model. It becomes hard to explain the individual who is thinking of quitting, by all measures should not be. A-Life models allow a greater latitude in examining the interaction of all variables in producing the observed characteristic.

As an observed phenomenon, turnover has been studied in depth and many important variables have been identified which are correlated with or thought to be important in causing turnover. An A-Life framework accepts that all variables can be considered causal to turnover. Each individual can respond in a different manner to the same set of values of the variables due to the probabilistic nature of the connection construction causing the output. Thus, the individual and the model can be considered non-deterministic. The researcher, in accepting this principle, will no longer be shackled in attempting to search for a single magic management policy which will reduce turnover. An understanding of the behavior of a multitude of individuals can be useful to devise a set of policies for an organization to treat an individual as the individual and not as a statistical quantity. In this regard, organizational policies might be able to decrease the rate of turnover.

Significance of the Research

The significance of the research can be addressed by comparing it to other approaches within the fields of turnover and artificial life and addressing why this approach has advantages.

Significance to the Field of Turnover

This research would add an important new tool with which the behavior of turnover within the context of an organization can be studied. When an individual quits, the act will be noticed by others in the organization. This represents an information input to others which may play a part in their future behavior. This is significant as they are still within the organization and could also quit in the future. As every human interaction represents a perturbation to an autonomous system (an individual) and each individual receives a different set of perturbations over time, then it is desirable to study a large number of individuals. Each individual must remain as an individual within the model otherwise one soon ends up with a model of human behavior (consisting of a single idealized individual or a collective group of individuals) formed by condensing statistical data in which individual identity has been lost. An A-Life model can be used to model many thousands of individuals simultaneously.

Within the field of turnover, the set of variables correlated to turnover or thought by researchers to be causal to turnover is fairly consistent. Most models differ only in the specific subset of variables chosen and the relations used to link them. Most recent models use System Dynamics, multiple regression analysis, or analysis of variance techniques. For System Dynamics models, a relevant set of variables is selected and connected into a model. The model is not of individuals but of condensed data for a sample of individuals. The variables are given starting rates and values and the model is run. Adjustments are made to the rates and values of the variables but the basic model and connections are the same. For regression analysis models, variables are best-fit to observed data. However, the data is a statistical condensation of observations of individuals. For analysis of variance models, variations are explained in terms of the best set of variables which minimizes the variances. Employing A-Life techniques allows the use of a model in which the selection of variables and their connections can evolve over time through the use of communication between individuals and also meta-level functions controlling individual behavior. It also permits the modeling of a multitude of individuals for which each individual remains as an individual throughout the simulation by being modeled truly as an individual.

This research also provides a useful tool by which behavioral models can deal with interactions existing between the multitude of individuals and the organization.

Significance to the Field of Artificial-Life

Thus far Artificial-Life models have dealt with simple behavior such as environmental sensing (e.g., food and predator recognition) and simple motor control (e.g., food gathering and predator avoidance). Genetic algorithms for learning have been explored to understand the behavioral aspects of these actions. However, genetic algorithms are used when models are constructed for time scales allowing many generations of agents to evolve and, in a de facto sense, include birth and death of individuals within the model. The turnover model of this study is designed to use a time span within a single generation of individuals, therefore, genetic algorithms will not be used since there are no births or deaths occurring. Many of the computational techniques of genetic algorithms such as using a coding of the parameter set and using probabilistic transition rules will be used to construct the model. As all aspects of behavior can be considered as a type of learning, extending Artificial-Life models to higher level human actions (i.e., quitting and thinking of quitting) represent an advance in the usefulness of these techniques.

As the use of an A-Life type model to study an organizational setting with many individuals represents a new approach, unconventional insights are possible for the specific social problem addressed by this research. Of greater value perhaps, assuming the success of this research, is the validation of this research method which can lead to the application of this methodology to a wider range of social research issues and problems involving human behavior.

CHAPTER 3

SPECIFIC RESEARCH ISSUES / PROBLEMS / QUESTIONS

Articulation of Researchable Question

The research explores the use of an artificial-life type model to simulate an aspect of human behavior, using turnover as a test case for the simulation. A multi-stage process was followed to progress from the general area of interest to the final selection and statement of the research question which would serve as the test case for assessing the performance and suitability of an Artificial-Life engine to simulate a facet of human behavior. Thus, as turnover involves quitting, the first version for the statement of the research question is:

Why do individuals quit?

As an action which an individual makes only after considerable thought, the interest, from a research viewpoint, is to study, model, and simulate aspects of the thought and behavior process which precedes the action (quitting). Quitting, viewed as an action or process, has a gestation period. If one experiences a single stressor at work, he or she probably would not spurt out "I QUIT!" five seconds later. Moreover, since quitting ideally entails having another job already lined up, again, the act of quitting is not a spur of the moment action. Thinking about quitting does precede the act of quitting. The thought process of those who have just recently quit is inclusive of thoughts ranging in time from the initial thinking of quitting through the act of quitting. Inquiries, directed to individuals who have quit, concerning the thinking of quitting could be colored by the actual act of quitting. Recollection and interpretations of the thought process leading to the act of quitting could be different after the individual has quit. This phenomenon is an example of selective memory. For these reasons, the second version for the specific research question deals with the "why" of thinking about quitting or to reword it:

Why do individuals think of quitting?

As the research was to be performed within a federal organization using a sample population of engineers, the choice of setting further modified the research question so that the third and final version became:

Why do federally employed civilian engineers think of quitting?

Potential Surprises

During the research, it was not anticipated that there would be any surprises encountered during the field work. However, during the collation of the interview and questionnaire, it was recognized that there might be the discovery of new factors influencing the research question, regarded as important by the research subjects, to merit inclusion as additional variables in the model. These factors could result from the localized nature of the field work and would not be considered as major factors due to not being identified as major factors by other researchers during the literature review. The local importance could be in terms of a micro-geographic or micro-organizational nature.

The second order nature of the proposed model (i.e., research concerning thinking about quitting vs. research concerning quitting) could generate new and unexpected results as the simulation is run. The model was designed to have a sufficient level of complexity to lie between the following boundaries:

1. One boundary: A highly detailed model of a single individual with many factors that may have limited application when scaled up to cover many individuals.
2. Other boundary: A statistical model of a large number of individuals which, while useful for aggregate projections, does not accurately portray the individual as an individual.

This complexity level draws upon work by Wolfram and Langton (Langton 1992, 41-91) categorizing complex systems by the degree of complexity. Their work has roots in the cybernetics of Weiner, Ulam, and Von Neumann, among others. What has been demonstrated in fifty some years of study, is that complex systems are complex. What this means is that causality which exists at a local level is often masked by system parameters which are not intuitively obvious when using a static viewpoint. The richness of interaction is manifested when a dynamic viewpoint is used. Regarding the model used to simulate the population of research subjects, this means that there may very well be surprising behavior discovered when the simulation is run.

CHAPTER 4

THE RESEARCH APPROACH / METHODOLOGY

General Approach

The general approach followed for the research was to generate a list of relevant behavioral characteristics and environmental factors pertinent to the research question. This was based upon a survey of the appropriate turnover literature as a starting point. As this led to a plethora of possible variables for the model, a pruning was necessary to obtain a selection of about fifty potential variables. An informal information gathering interview was conducted with a few participants to explore the usefulness of the list and perhaps discover addition variables of interest. The initial list of variables was combined with the results of the participant interviews to sharpen the focus and roughly select the final variables to be used for the computer A-Life model. It was anticipated that the model would ultimately consist of no more than twenty variables. The choice of variables was made to underscore proposed functional relationships between them. At this point a questionnaire was developed to obtain pseudo-ranked values for each of the potential variables of the model. Using the results of the survey, the statistical tabulation of values was determined for the variables of interest (high, low, and mean). At that time, the selection of the variables and their value ranges was finalized for the initial model formulation.

The exploration consisted of setting the initial values of the behavioral characteristics for the individuals and also the initial values of the environmental factors.

The simulation was run until a small number of individuals were detected as having quit the organization to which they belong or until the predetermined time scope of the model. The behavioral values for these individuals were recorded and analyzed for the dynamic behavior just simulated. In addition, the simulation was scrutinized for any patterns of behavior or signs of emergent behavior during the computer trials. This was possible since, at each time step of the model, values for all the variables for each individual were written to a file. This created a "fossil record" which could be examined after the model was run. Seasonality analysis and regression techniques were used to search for behavior patterns. Visual observation of clustering as the simulation was run and a backward examination of the variable values for an individual who quit were techniques used to detect emergent behavior. This process was repeated until sufficient data was collected to draw conclusions pertaining to the dynamic behavior of the simulation.

Methodology

The theme of this research is that of a holistic perspective of a dynamic system (Patton 1990, 49-53). The research question is at the heart of a complex system of interactions among individuals. The system is also influenced by the interactions between individuals and the environment. The process is the important consideration. The attitudes of the research subjects about "quitting" are constantly changing as each new interaction is lived. Memories of some events fade and others are reinforced as each day passes. To research a single individual requires the study of the cadre of individuals with whom the interactions take place. It also requires knowledge of the environmental factors which influence the individual.

The orientation is primarily that of a systems perspective (Patton 1990, 78-82). None of the individuals who comprise the system can be studied separately from the system. The individual is part of the system and the interactions are the processes of the system. For an individual who quits an organization, the act is multifaceted:

1. The effect on the individual who quit
2. The effect on the organization that the individual quit
3. The effect on other individuals
4. The effect on other organizations

In addition, there is also a time dimension involved as these effects can occur over a finite time span. Moreover, the intensity of an effect can vary with time. To effectively analyze the system, you must be able to synthesize the system for manipulation (at least in the form of a model) and scrutiny. Specifically, the study of quitting an organization is one that just does not lend itself to actual physical experimental manipulation.

There is also present a hermeneutic perspective (Patton 1990, 84-5). An important part of the interpretation of the research is that it occurs within a tradition. To understand the tradition places one within the situational context of the research. To study the question of "thinking of quitting" implies that one has thought of "thinking of quitting." This spiral process leads to the perspective to report the perspective of the research subjects.

Using the format and content of Patton (1990, 160-1), the qualification of the research is presented in table 9. This table is useful as it establishes the position of the research within the realm of research types. While general in nature, it does distinguish the research from all other available qualifications.

TABLE 9

RESEARCH QUALIFICATION

Qualifier	Description
Type	Applied research
Purpose	Questions deemed important by one's discipline or personal intellectual interest
Focus	Questions deemed important to society
Desired results	Contributions to theories that can be used to formulate problem solving programs and interventions
Level of generalization	Within as general a time and space as possible, but clearly limited application context
Key assumptions	Human and societal problems can be understood and solved with knowledge
Standards for judging	Rigor and theoretical insight into the problem

The strategy for sampling used a stratified approach to achieve in-depth coverage of the potential factors used to build the model. The sampling was homogeneous in nature. It consisted of engineers with university engineering degrees employed by the federal government as civilians and classified and working as engineers. This excluded the following individuals:

1. Engineers in the military

2. Engineers working for state or local government
3. Engineers working for private companies
4. Non-degreed individuals classified as engineers
5. Engineers classified as managers
6. Engineers classified as other than an engineer
7. Engineers performing significant work other than in engineering

A sufficient sample was drawn to obtain acceptable data concerning the range of variable values which would be used to initialize the simulation. This was significant, because the numeric values assigned for the initial run of the model would be verified or derived using the data provided by the research subjects. Insufficient variability in the values could result in the model not exhibiting adequate dynamic behavior. The model would thus become static in nature. The dynamic behavior of a complex model is highly dependent upon the initial conditions for a given model formulation. This sensitivity to initial conditions is of critical concern when constructing a dynamic model. Traditionally though, it does not present a major impediment, for the useful output of the models is contained in the output variable relations rather than specific numeric values. Predicting increases or decreases overtime relative to starting values is generally the end result for dynamic system models of complex systems.

The sampling also relied upon the snowball effect to obtain research subjects who were thought to be thinking of quitting. Participants in the study were asked if they knew another engineer who was thinking of quitting. It was intended to contact the named individual and ask them to participate in the study also. Inclusion of these individuals would have provided an information rich sample. This would have allowed the extraction of additional useful data from a limited number of research subjects. However, no names were volunteered.

A summary of the design issues considered for the study is presented in table 10. This table follows the format used by Patton (1990, 197).

TABLE 10

DESIGN ISSUES AND OPTIONS

Issues	Sample Options and Considerations
Primary purpose of study	Applied research
Focus of study	Broad scope
Units of analysis	Individuals within an organization
Sampling strategy	Homogeneous and typical case
Types of data collected	Qualitative and quantitative
Analytical approach	Statistical analysis and A-Life modeling
Validity and confidence	Stratification of sampling and multiple perspectives
Time issues	Exploratory phase followed by short-term data collection
Confidentiality	Informed consent signature

The interview and questionnaire instrumentation developed for the research was selected and formalized prior to the field work. All instrumentation developed was field tested for validity prior to being used.

The appeal of this type of model is that it is bottom up in nature. Field observation and literature review are used to generate a short select number of variables considered germane to the problem at hand. These are coded to individual entities within the environmental space of the model and the model is run. Of great advantage, is the fact that due to the large number of individual entities that can be simulated within the model, a genre of social interaction can be modeled. Complex behavior often results from simple rules. This presents a useful tool for exploring human behavior, as human behavior is social interaction and it essentially presents difficulties when attempting to perform experiments.

Research Team

The research was performed by the submitter of this document including interviewing the participants and also distributing, collecting, and collating the results of the questionnaire. In addition, the researcher also constructed the simulation model, designed and programmed the computer simulation, and performed all of the analysis of the resultant data.

Research Sample

A number of engineers at a Federal government establishment (Naval Shipyard) were contacted and asked to participate in the research project. They were informed that the study was a privately conducted study with the results to be used for academic purposes only. Furthermore, they were told that any and all discussions, interview data, questionnaire responses and recorded conversations would be kept confidential. Those who agreed to participate were asked to orally give acknowledgment as to the above. This process continued until a satisfactory sample population of engineers was recruited for the study. The definition of satisfactory was based upon not gaining significantly any more variables of interest during the interview phase. As there exists considerable literature concerning turnover, it was not unreasonable to expect that most potential variables already have been identified in the literature.

Another point was that the model programming was initially conceived to use binary code to hold the values for the variables. Programming constraints would thus limit each variable to at most three bits of data. This would allow eight values per variable as a maximum. Twice this number or about sixteen subjects were considered sufficient to obtain an adequate distribution of values for an eight value variable. A level or flat distribution of sixteen observations for eight categories (values) would result in two observations per category (value). For this reasons, the initial number of research participants was roughly chosen to be sixteen. The recruitment proceeded in parallel with the interview and questionnaire phase.

The main criterion applied when recruiting subjects was that of a "typical case" sampling strategy. A "typical" working engineer, that is to say, an engineer who is below the grade level of an engineering supervisor or manager, was the desired subject for the study. The recruiting interview also attempted to identify any engineer who was thought to be starting or actually in the process of quitting. This would allow the use of a "snowball" sampling strategy whereby these individuals would most likely have strong or extreme views toward quitting as they are going through the process. This would have resulted in a stratified sampling scheme for those selected for the study of the research question, at least to some degree.

The participants in the research were given an interview and questionnaire. The survey questionnaire was developed beforehand and used to verify the quantification of the value range for the individual variables preselected during the literature review. It also attempted to identify and quantify any additional potential variables. The questionnaire was given to the individual subjects during the interview. This questionnaire was distributed, collected and analyzed. The data from all of the interviews was collated and potential variables of interest were extracted. Next, these variables were tabulated with those variables preselected during the literature review. The list of variables from the literature review and the questionnaire were pruned down by eliminating those variables which had a low total rank ordering score on the following properties:

1. Ability to be linked to other variables
2. Possess a time variability
3. Ability to be linked to environmental factors
4. Considered relevant by the research subject
5. Considered relevant by the literature review

The model, for which the simulation would run, was then constructed using the results of this survey.

CHAPTER 5

DESCRIPTION OF THE RESEARCH

This research embodied a two-fold structure: (1) exploring the use of an artificial-life type model and simulation engine and (2) using this engine to simulate turnover and thinking of quitting as an aspect of human behavior. In recognition of this duality, there are two sections in this chapter which describe the research. The first describes the survey design and the second describes the Artificial-Life model and simulation engine.

Survey Design

The survey was designed around a three-part division as to the variables about which information was desired. The information desired was general demographic data concerning the subjects, data concerning the attitudes, thoughts or beliefs of the subjects pertaining to the subject of turnover and the organization, and also additional volunteered information pertaining to the work environment.

Variable Selection & Inclusion

First, a group of eight demographic variables was selected which allows statistical cross tabulations of the survey results to be performed. These variables cover personal data (age, sex and marital status), general professional work status (graduation year, job position and union membership) and specific government work status (length of service and grade level). As some, if not all, of these variables would be included in the simulation, the tabulation of survey data was used to provide initial values for the simulation.

Next, the variables of turnover delineated in Price (1977) were taken as a starting point for the second part of the survey design. The list was roughly subdivided into two segments, those variables which are mainly demographic in nature or descriptive of the individual and those variables which mainly are descriptive of the organization or under the control of management. The main reason for this is that the algorithms of the model would probably implement each type slightly differently. Thus, it was thought prudent to make a split at this time for consistency. Each potential variable was examined for a number of characteristics to make a "Go or No-Go" decision for inclusion into the survey (see table 11).

TABLE 11

CRITERIA FOR INCLUSION OF VARIABLES INTO SURVEY

Criteria	Description
Universal applicability	Will, in general, be applicable to most of the sample population
Linkability	Can be causally linked to other variables
Programmability	Can be programmed into the model without much difficulty
Quantifiability	Can be quantified for use in a numeric model

As the final model (proposed version) was formulated to contain approximately ten variables of these types, it was decided to have a pool of three times that number of variables in the survey to have an adequate number to select from for the final model. This process resulted in thirty-two variables being selected for inclusion into the survey (21 demographic and 11 organizational) (see table 12 & 13).

TABLE 12

VARIABLES DEMOGRAPHIC OR DESCRIPTIVE OF THE INDIVIDUAL

Survey Question Number	Topic
A1	Age
A2	Length of service
A3	Education (formal)
A4	Membership in a union
A5	Level of employment (job level, grade, rank, or title)
A6	Manager vs. non-manager
A7	Pay
A8	Amount of work
A9	Government vs. non-government
A10	Fringe benefits (sick leave, vacation, travel, training, etc.)
A11	Satisfaction in job
A12	Degree to which work is routine or varied
A13	Professionalism (of your position, are you treated like a professional)
A14	Upward mobility (in your job)
A15	Integration within the organization (close knit, everyone pulls together)
A16	Communication (informal which helps get the job done)

Survey Question Number	Topic
A17	Communication (formal) (both written and oral)
A18	Centralization within the organization
A19	Fairness, equal treatment (within the organization)
A20	Size of organization
A21	Quality of supervision

TABLE 13

VARIABLES DESCRIPTIVE OF THE ORGANIZATION

Survey Question Number	Topic
B1	Administrative staff (size or importance)
B2	Formalization within the organization (as opposed to conducting business in an informal manor)
B3	Centralization (of command, control and communications)
B4	Communication within the organization (general quantity)
B5	Communication within the organization (general accuracy)
B6	Integration (working for a close knit group)
B7	Satisfaction (general morale level within the organization)
B8	Innovation (within the organization as a whole)
B9	Effectiveness (in achieving organizational goals)
B10	Productivity (of the organization as a whole)
B11	Intention of quitting (within the organization as a whole)

Finally, an open-ended section was developed which allowed the subject to enter any specific items or events which had an impact on their thinking of quitting.

This third section was broken down into thirteen topic areas where the subject could enter their response. This section was designed to obtain information concerning any specific variable which had not been previously identified in the literature of turnover. The general topic areas are listed in table 14 below.

TABLE 14

VARIABLES NOT IDENTIFIED BY LITERATURE

Survey Question Number	Topic
C1	Your specific work assignments (type of work)
C2	Your specific work assignments (quantity of work)
C3	Your specific work environment (building or work area)
C4	Your general work environment (shipyard)
C5	Your general living environment (Tidewater area)
C6	Your specific work organization (code or work group)
C7	Your general work organization (shipyard)
C8	Your general work organization (Federal government)
C9	Your specific supervisor or manager
C10	Your general management
C11	Other
C12	Other
C13	Other

Variable Quantification

As the purpose of the survey was to obtain baseline quantified values to initialize the variables used in the model, the survey questions had to reflect this design intent. As the A-Life scheme of representing variable values would use a limited number of values, it was decided to keep the allowed number of initial values lower than what was used in the model. This would allow the fanout of variety as the model is run. The survey focused upon obtaining a plus/minus type of ranking of the variables. As each variable represents a relation of that variable to turnover or thinking of quitting, the numeric format of the survey questions was put in the form of a three part check box type question. The first part asks if the subject believes that an impact (relation or correlation or causal effect) exists between the variable and turnover or thinking of quitting. The allowed responses were yes, no, or not sure. The response of yes would indicate that the subject believes that an impact does exists. The second part asks the subject to indicate the strength of the impact if the first part had been answered yes. The allowed responses were strong or weak. A response of strong would indicate that the subject believes that the impact, in quantifiable terms, is substantial. A response of weak would indicate that the subject believes that the impact is less than substantial. The third part asks for the subject to indicate the type of the impact if the first part had been answered yes. The allowed responses were positive or negative. A response of positive would indicate that the subject believes that a direct relation exists, while a response of negative would indicate that an inverse relation exists. For analysis and tabulation purposes, the textual responses were initially assigned values which roughly correspond to the r-value of a correlation (i.e., a range from -1.0 to +1.0). A strong impact was assigned a value of 0.8 and a weak impact was assigned a value of 0.3. A positive or negative impact was assigned the corresponding sign. However, it was later determined that it was advantageous to use an assigned rank order for the responses. As there were five responses, the rank ordering was from one through five (see table 15 for a tabulation of the coding used).

TABLE 15

RANK ORDER OF RELATIONS

Relation Exists	Degree	Sign	Rank Order
Yes	Strong	Negative	1
Yes	Weak	Negative	2
No	N/A	N/A	3
Yes	Weak	Positive	4
Yes	Strong	Positive	5
Not Sure *	N/A	N/A	3

* for analysis purposes (to not have missing values), "Not Sure" was rank ordered as 3

Pilot Test

A pilot test of the survey was performed using two subjects. Analysis of the responses and discussions with the individuals after the pilot survey indicated that some minor changes to the survey presentation were needed. Specifically, some of the variables were not comprehensible, that is, there was confusion as to the specifics of what the precise definition of a particular variable entailed. This was rectified by adding extra text to further define the variables where there was confusion. Another problem was that it was not always easy to understand the direction (algebraic sign) of the relation. Many were presented in a counter intuitive manner to standardize the relational direction so as the magnitude of the dependent variable increased as the independent variable increased, this was defined as the positive direction. This problem was rectified by adding a section after the description of each variable which defined what was to be taken as the positive direction.

Conducting the Survey

After the survey had been modified using the results of the pilot, it was duplicated for use. As the survey was designed to be conducted in a confidential manner, each survey was identified only by a penciled-in number. A coded table of the names of the actual participants was kept separately by the researcher to be able to contact the subjects after the initial validation checking of each survey to correct any errors on the survey form prior to data entry or to ask any post survey questions which might arise. Other than this, there is no identification of the participants by name in this research.

Data Entry

The numeric data from the survey was entered into a spreadsheet of a statistical program in preparation for analysis. The subjects were given a sequential number for case identification purposes to differentiate between cases. The raw data is presented in appendix 2.

The verbal responses were entered into multiple tables where each table held the responses for a single question. This allowed textual and content comparisons of response to be drawn from the data. The raw data is presented in appendix 3.

Tabulation of Numeric Survey Data

The raw numeric data for each survey question was analyzed for the following:

-Range (High & Low value) for each variable

-Mean value for each variable

-Cross correlations between variables and the demographic data

These results are given in appendix 2.

Tabulation of Textual Survey Data

The textual responses from the subjects were tabulated by question. For each question, a categorization of response was performed. These results are given in appendix 3.

Selection of Variables for Simulation

While the survey data provides a benchmark to which simulation results could be compared, the problem would be the creation of a specific model using specific variables. As the survey data was collected for a broad range of variables and it did not address the equational linking of these variables into a model of turnover, it was decided that to be consistent with the scope of this investigation of Artificial-Life models, to formulate a model of turnover similar to the model developed earlier in the proposal. Using this approach allowed the survey data to be used to initialize the values of variables which appear in the model. A detailed discussion of the model development process is given in appendix 4.

Artificial-Life Model

The actual construction of the Artificial-Life computer model involved many interlocking and related steps. The specific steps are discussed in detail in the following areas.

Construction of Model

The model program was constructed using QuickBasic© version 4.5 as the programming language. This was selected due to the author's familiarity with this language and the adequacy of the file and graphic handling capability. Moreover, sufficient mathematical functionality and array processing capability were available within the QuickBasic environment. To aid in the development process, some shareware graphic routines were utilized. Another factor, the ability to compile the source code into a stand-alone executable file influenced the choice, however, as the program development took place it was decided to forego developing the program into a stand-alone version but to run it solely within the QuickBasic environment for the reason of shortening the development time.

As the program used for this investigation could be expanded greatly to achieve increased graphic capability and ease of use of the keyboard interface, it would be desirable to rewrite it using a higher level language such as VisualBasic For Windows© or some variant of C++. This would also allow the simulation to run faster thus allowing the construction of models with more variables and/or more persons and a longer simulation time period. It would also allow addition of mouse routines and more flexible print and file handling routines.

Selection of Main Parameters

The main parameters of the model are those of the number of persons, the number of variables, and the number of time steps. These parameters determine the basic constraints for programming the model. A detailed discussion for each of these parameters is contained in the following sections.

Number of Persons

While simulations (ranging from System Dynamics to A-Life) have modeled from a single individual up to hundreds of thousands of individuals, consideration had to be given to specifying limits for this parameter.

In the proposal for this research, a model of one thousand individuals was described. During the initial programming, it was decided to limit the number of individuals modeled to preselected choices or values. Fewer than one hundred individuals were used for testing purposes during model construction or detailed display using multiple variables and more than one hundred individuals were intended for the general research model. With a program allowing the selection of up to two thousand individuals, it was felt that the program would be adequate for the intended research (see also the section on Screen Display Considerations).

Parisi, Cecconi and Cerini (1995, 251) investigated some aspects of group size in early societies which serves to bracket a useful range for the number of individuals in a simulation. They found that:

> Ethnographic evidence on hunter gatherer and other early types of society indicates a layered group structure with three levels: bands or overnight groups (30-50 individuals); clans and lineage groups (100-200 individuals); and tribes (500-2500 individuals).
>
> Of course, the next step in the evolution of human social groups is the emergence of groups of individuals living together when the individuals which constitute the group are not relatives.

A point to be made is that in constructing any computer simulation, a tradeoff exists between parameters. In this case, a larger number of individuals could result in an unacceptable runtime or data file size. Thus, an upper limit was applied to the program.

Number of Variables

The number of variables is another of the factors which effect the run time and file size of the program. During the initial construction of the program, it was determined that going over about fifty variables made the model difficult to program. In addition, the research on turnover models and A-Life models indicated that a satisfactory model could be constructed for this research without using more than fifty variables. This fifty variable choice was thus taken to be a design limit for the program.

Number of Time Steps

The selection of the number of time steps used within the program is dependent upon the factors of program step size and duration of physical time being modeled. This is important because a model with a larger number of time steps will run slower and require more memory and file space than a model with fewer time steps. A table which gives a relation between the time step size and duration of the model is presented below. To simulate a duration of five years with each time step being equivalent to one hour will require ten thousand time steps in the model. General equivalences are as follows based on a pseudo work life approximation whereby:

50 minutes≈ 1 hour

8 hours≈ 1 day

250 days≈ 1 year

TABLE 16

MATRIX OF TIME STEPS

Number of Steps	Size of Step		
	1 min	1 hour	1 day
1k	2 days	½ year	4 years
10k	20 days	5 years	40 years
100k	1 year	50 years	400 years
1m	10 years	500 years	4000 years

As this simulation of worker turnover is in the context of an initial cohort of workers in an organizational setting with no replacement, a bracket of an appropriate time duration should be greater than one year and also not exceed ten to twenty years. This is predicated upon a number of factors:

1. A majority of workers do not stay with a single organization longer than twenty years in the economic climate of today.
2. At least one or two years is needed to allow for long time-frame economic conditions to be included in the simulation. A cycle of recession and/or growth could not be simulated in less than this time duration.
3. If substantial turnover is occurring within time-frames of less than one year, then a model constructed to simulate this situation probably would not be useful for more sedate periods.
4. Generational effects and retirement start becoming larger factors as the time duration goes beyond ten to twenty years. This simulation does not attempt to model generational change.

Thus, initially to satisfy these criteria and keep the model reasonable in size, the time frame was selected to be about five years.

The size of each time step is likewise subjectively determined. With step sizes of one minute or hour, the likelihood will be for the simulation to result in most variables changing little, if any, for most of the duration of the simulation interspersed with small pockets of activity. A time step size of one day seems to allow a more even distribution of activity. Humans operate on a daily basis. We get up in the morning, do things (work, play, etc.), go to sleep and then start over again. A model of human behavior is that the once-daily sleep time is when the events of the day are processed by the brain. Thus, the human cycle of a day is biologically appropriate to use for the simulation.

The number of time steps used in the model, preferentially to ease the programming burden, should be simple quantities. Thus one thousand time steps with each time step representing a day give a simulation of about four years.

Screen Display Considerations

In designing the screen display to depict the output of the model, there were two considerations; first, a screen display where all of the individuals are displayed with the value of a single monitored variable selected from the total number of variables used in the model and second, a screen display where all of the individuals are displayed with the values of all of the variables used in the model. As the graphics programming was performed in EGA (640-by-350 pixels) resolution and the general design of portraying an individual is via a color coded circle, there is a limit to the amount of information which can be portrayed on the screen at one time. Initial testing with different sized circles and blocks indicated that a circle of about six to eight pixels in diameter with a center-to-center spacing of about ten pixels was optimal for viewing and detecting changes in variable values. This led to a rough upper limit of about fifty circles horizontally and forty circles vertically.

To standardize the programming of the display, certain preselected choices were made for the horizontal and vertical aspects. The choices made were from ten to fifty in steps of ten for the width and from ten to forty in steps of ten for the height. From this selection of width and height parameters, another selection was made for the product of the two. For example, two hundred individuals could be portrayed using either ten across and twenty high or twenty across and ten high. This dual method of presentation was resolved by having the horizontal resolution equal to or greater than the vertical resolution. From this, a matrix was made which codifies these selections as shown in table 17:

TABLE 17

RESOLUTION FOR MONITORING A SINGLE VARIABLE PER PERSON

Width	Height			
	10	20	30	40
10	100	-	-	-
20	200	-	-	-
30	300	600	-	-
40	400	800	-	-
50	500	1000	1500	2000

For monitoring multiple variables per individual, it was decided to present the individual horizontally and the variable value vertically. Using the same consideration as discussed previously, the number of individuals was given certain preselected values. Again, the display consideration limited the presentation to no more than fifty individuals with forty variables portrayed per individual.

TABLE 18

RESOLUTION FOR MONITORING MULTIPLE VARIABLES PER PERSON

Width [persons]	Height [number of variables]					
	5	10	20	25	30	40
5	25	50	100	125	150	200
10	50	100	200	250	300	400
20	100	200	400	500	600	800
25	125	250	500	625	750	1000
30	150	300	600	750	900	1200
40	200	400	800	1000	1200	1600
50	250	500	1000	1250	1500	2000

Validation

Often, for any model and in particular for a new type or class of model, the question of validation arises. Validation can have two aspects, the first being a benchmark check against the physical data used in the model and the second being a comparison against other types of formulations of models. Simulation models have often been criticized, in as much as they generally do not compare well against other older types of models. To a large degree, this is true but, it must be remembered that the results of a model are very dependent upon the techniques used and the reason or purpose for which it is constructed. A model built for predictive purposes will have more of an intrinsic need of validation than a model designed to explore the properties of a system. Patten (1972, xiii) discusses this point:

> Equally fundamental and equally problematic is model validation - the process of gaining confidence that a model aptly represents its real counterpart system for the purposes at hand. The current concept of validation is to control trajectories in the model's state space to conform to empirical trajectories of the real system. At best, this amounts to curve fitting through parameter adjustments, and is a very weak criterion. Needed is some form of validation theory that will guarantee output for certain classes and ranges of input and also guarantee correspondence of a model's internal structure to that of the real system. Otherwise, properties of a model revealed by systems analysis may not conform to properties of the prototype. The validation problem will also cause systems ecology to look to theory.

Early in the development of the techniques and methodology of System Dynamics, Forrester encountered much the same criticism. His response is just as apt today when considering the new techniques of Artificial-Life. Forrester (1975, 162) states:

> Two points must be recognized as a basis for discussing validity.
>
> First, a model cannot be expected to have absolute validity. A model is constructed for a purpose. It should be valid for that purpose but may be irrelevant or wrong for some other purpose. The importance of model purpose as the cornerstone for a discussion of validity has already been stated.
>
> A second essential point in clarifying a discussion of validity is to realize the impossibility of positive proof. The difficulty starts in selecting criteria of validity. There is no absolute proof but only a degree of hope, and confidence that a particular measure is pertinent in linking together the model, the real system, and the purpose. But assuming one has a measure of validity, one probably even so cannot prove the degree to which the model need meet the measure for a specific purpose. Also, if two very different kinds of models are so measured, there is no assurance that the model that better meets the measure is the more useful model. Furthermore there is always the possibility that a model meets the measure but for the wrong reasons which will invalidate the model when parameters or decisions are changed and the model is used to predict future modes of behavior rather than correspond to past modes.

A further point to consider is that human behavior, in the context of a model, is a complex system about which very little theoretical data is known but rather a preponderance of observed data. As a major use of human behavior models is to gain insight into the theoretical basis of behavior rather than being used in a predictive mode, seeking or attempting to provide absolute validation is not in the best interests of the research. Forrester (1975, 163) again provides a response for this point:

> On the subject of validation there is much criticism from the sidelines. But these critics give few positive suggestions stating what tests are both possible and acceptable to them. They appear not to realize that no positive proof is conceptually possible for any theory or model which rests on experimental observation rather than on an assumed set of postulates. Very often a critic asks that a model predict future events in a system or match an ensemble of past data. But, for broad-band systems, to which class belong social systems, this has been shown to be impossible in any useful way, where it is demonstrated that even with two identical models one is not an effective predictor of the other.

Other Considerations

Low-Order Integer Programming

Most, but not all, Artificial-Life models have used binary strings to represent variable values. This typically results in a low variety for the variables as the binary length has, more often than not, been low. A comparison between the variety available for fixed length strings when using binary or decimal representation is given in table 19.

TABLE 19

VARIETY FOR BINARY & DECIMAL REPRESENTATION

Binary		Decimal	
Length	Variety	Length	Variety
1	2	1	10
2	4	2	100
3	8	3	1k
4	16	4	10k
5	32	5	100k
6	64	6	1m
7	128	7	10m
8	256	8	100m

A main rationale for using binary representation is that it is biologically based on gene structure. A second reason is that this approach has become a methodology in the field of genetic algorithms and the methodology has carried over to artificial-life simulations.

Decimal representation allows more variety for a given representational length, but the main reason for consideration of decimal strings is that functional programming is greatly simplified. Many model have been built using Systems Dynamics and a decimal notation. For their intended purpose, these models were quite adequate. However, they and the methodology they are based upon cannot be expanded for use in models encompassing large numbers of individuals such as is prevalent in A-Life type models. On the other hand, the general relationships among the variables are often of value when extrapolated to an A-Life type model. This allows many model formulations to be revisited and reused.

Ultimately, as a binary or decimal viewpoint is primarily an observer phenomenon, this distinction is mainly of interest to the researcher or programmer.

Run Time & File Size Considerations

Of concern during the parameter selection and definition process were the run time and file size of the model. As it would become a problem to have the model run for more than a few hours, it was tested during the early stages of development with an arbitrary goal of producing a model within this guideline. Likewise, as the model is designed to write the values of each variable for each individual during each time step to a data file for later analysis, again an arbitrary limit of about two to three megabytes was imposed. This would still allow the data file to fit, via a compression routine, on a single diskette. The result of this testing is given in table 20.

TABLE 20

FILE TEST RUNS

Persons	Time Steps	Variables	File Size	Time to Run	Print Size	Actual or Estimate
10	50	5	15k	-	-	actual
20	50	5	30k	1 min	-	actual
10	50	10	25k	1 min	5 pages	actual
20	100	10	100k	3 min	-	actual
100	500	10	2500k	66 min	-	estimate
250	1000	20	25m	660 min	-	estimate

Conceptualization of the Artificial-Life Simulation Engine

During the development of the simulation engine, a conceptualization was performed which set the basic specifications for the configuration of the engine. This process was tedious due to the interlocking nature of the components and involved many reflexive moments of thought as how to best implement a desired component as almost every decision required adjustment in some other parameter. The final result of this process is detailed below in terms of the selected components built into the simulation engine.

1. Initialization - This component holds coded information which is used to assign values to each individual for the variables of the model for the initial time step. This was implemented using a set of distribution functions.
2. Length - This component specifies the variety or number of values allowed for each variable of the model. Each variable has the same length for all individuals while different variables can have different lengths.
3. Neighborhood - This component holds coded information concerning communication between individuals for each variable of the model. Individuals can transmit information about the values of selected variables to none, a subset, or all of the other individuals.
4. Dependence - This component is used for two purposes in close conjunction with the relationship component (see below). This is to specify whether a variable is dependent (the value is dependent upon the values of one or more other variables) or autonomous (the value is not dependent upon other variables

but can change using time based functions). If the variable is dependent, this component also specifies one of two different calculational algorithms to use. The specific autonomous function or dependent equation is given in the relationship component.

5. Relationship - This component holds either the time based function if the variable is autonomous or the variable equation if it is dependent.
6. Damping - This component is used to hold coded information used to damp the system response over time to more closely simulate the real-world behavior of some variable over time.

Main Program Logic

The program is divided into specific modules which deal with specific areas such as file handling, calculation and screen display. This section will discuss the main calculations used within the model. A more detailed documentation of the calculational logic and the precise order of calculations is given in appendix 5.

The simulation program starts by reading a configuration file which contains the specifics of the model to be simulated. It contains the selected choice for the number of persons, the number of variables, and the number of time steps. In addition, it contains an identifier number, name and six data items for each variable of the model. These items are initialization, length, neighborhood, dependence, relationship, and damping. These items are used to initialize or calculate the values of each variable for each person from one time step to the next. A more detailed description of the configuration file and its structure is given in appendix 6. After being read into memory, the program uses the configuration file data to generate the values for each variable for each person for the first time step. This step is referred to as the initialization of the model. This data is written to an initialization file which contains the data for the first time step only. This allows the same initial configuration to be simulated using various methods for the variable calculations. The program now performs the calculations for each variable and person, progressing from one time step to the next. The program writes to a model data file the values of each variable for each person from one time step to the next as it performs the calculations.

The generalities of the main calculational logic of the program are given as follows for the computation of the variables using the six data items of initialization, length, neighborhood, dependence, relationship, and damping:

Initialization Calculation of Variables

1. Minimum - The value of a variable is set to the lowest value allowed. For programming purposes, the lowest value was selected to be zero instead of the more usual value of one. This choice allows the range of acceptable values to be an even number.
2. Maximum - The value of a variable is set to the highest value allowed given the choice of the length of the variable. For ease of programming purposes, the length is expressed as a decimal value of one, two or three digits rather than the selection as a binary value which is often used for genetic algorithms.

A value of one means that the value of a variable is represented by one decimal digit and can thus range from zero through nine. A value of two means that the value of a variable is represented by two decimal digits and can thus range from zero through ninety-nine. A value of three means that the value of a variable is represented by three decimal digits and can thus range from zero through nine hundred ninety-nine.

3. Midpoint - The value of a variable is set to the median or midpoint value of the range allowed given the choice of the length or magnitude of the variable. As the range of acceptable values is an even number, a true integer midpoint does not exist. For the program model, it is calculated to be the next highest integer value above the mathematical midpoint. A length of one means that the range of values is from zero through nine and thus the midpoint of this range is five. A length of two would have a midpoint of fifty and a length of three would have a midpoint of five hundred.
4. Random - The value of a variable is set to a random value within the range allowed given the choice of the length of the variable. This results in an even or straight line distribution of values within the allowed range.
5. Random Range - The value of a variable is set to a random number between a user selected lower and upper bound. This results in an even or straight line distribution of values between the lower and upper bounds.
6. Constant - The value of a variable is set to a user selected constant value.

7. Bi-Modal - The value of a variable is set to one or the other of a pair of user selected constant values.
8. Normal - The value of a variable is set to a value calculated by applying a Gaussian probability density generator function to a randomly generated input value. This results in a normal or Gaussian distribution of values for that variable for the persons in the simulation.

Length of Variables

1. 1 - The value of the variable is expressed by one decimal digit. With a lowest allowed value of zero, this sets the range of the allowed values of the variable to be from zero through nine. This allows ten unique values.
2. 2 - The value of the variable is expressed by two decimal digits. With a lowest allowed value of zero, this sets the range of the allowed values of the variable to be from zero through ninety-nine. This allows one hundred unique values.
3. 3 - The value of the variable is expressed by three decimal digits. With a lowest allowed value of zero, this sets the range of the allowed values of the variable to be from zero through nine hundred ninety-nine. This allows one thousand unique values.

Neighborhood Calculation of Variables

1. None - The value of a variable is not dependent on the values of the same variable for any neighbor.
2. Block 5 - The value of a variable is dependent upon the average value of the same variable of a close and small set of neighbors. It is set to the average value of a block of five persons. The neighborhood is taken to be the block of four neighbors, construed to be the block in which the individual resides, together with the individual. The blocks do not overlap each other. Thus, the neighborhood of Person 23 would be persons 21 through 25. The previous block would be persons 16 through 20 and the subsequent block would be person 26 through 30. The choice of a neighborhood of four is based on that a block of five individuals is divisible into all the allowed values used for the number of individuals used within the simulation. A block of five individuals simplified the programming of the model. Other block sizes could also be used along with overlap among blocks being allowed. These possibilities could be implemented in a future version.
3. All - The value of a variable is dependent upon the averaged value of the same variable for all of the individuals in the simulation. It is set to the average value of all the individuals.

Dependence Calculation of Variables

1. Dependent - The value of a variable is dependent upon the values of one or more other variables. The dependence is written in the form of an equation using a specified syntax. The formulas for calculating the value is given in the Relation section.

2. Autonomous - The value of a variable is independent of the value of any other variable. It may, however, depend upon the values of the same variable of a group or set of different persons (see Neighborhood). A time rate of change of this type of variable is given in the Relation section.

Relationship Calculation of Variables

For Dependence = Dependent

1. Summation Method - The value of a variable is calculated by applying the two arithmetic operators of addition or subtraction to the indicated variables using a simple summation of the indicated values. The calculation may, however, depend upon the value of the same variable of a different person (see Neighborhood). An example follows:

$$V6=+V1-V2-V3+V4+V5$$

OR

$$V7=-V1-V2+V3+V4-V5$$

The calculated value, however, must conform to the length allowed for the variable. If, for example, the length of V6 is two or more then a calculated value for V6 of sixteen would be allowed. If the length of V6 is one then a calculated value for V6 of sixteen is greater than allowed by the length restriction and thus V6 would be set to nine as that is the highest allowed value for a length of one.

This method was designed for those relations where there is an equivalence of effect from specified values of the variables used in the equation. Depending upon the length of the variables in the equation, four specific calculational problems might arise. Caveats concerning these problems are given which refer to the following example:

$$V1=+V2+V3$$
$$\textbf{OR}$$
$$V4=+V5-V6$$

a. If the right-side variables have different lengths, the resulting sum can be unduly influenced or swamped by the variable with the greater length. In the example of table 21, V2 is at the low end of its range and V3 is at the high end. The resultant sum is at the high end due to the swamping effect of V3.

TABLE 21

SUMMATION SWAMPING EFFECT

Variable	Length	Value
+V2	1	1
+V3	2	80
V1 [sum]	2	81 [81]

b. If the resulting variable is of lesser length than any of the right-side variables and the sign of the variable with the greatest length is positive, the resulting sum might not be indicative of the relative magnitude of the right-side variable values. The sum could be forced to its maximum value. In the example of table 22, the resultant sum exceeds the allowed range and is thus set to the maximum allowed.

TABLE 22

SUMMATION FORCING TO MAXIMUM

Variable	Length	Value
+V2	1	5
+V3	2	50
V1 [sum]	1	9 [55]

c. If the resulting variable is of lesser length than any of the right-side variables and the sign of the variable with the greatest length is negative, the resulting sum might not be indicative of the relative magnitude of the right-side variable values. The sum could be forced to its minimum value. In the example of table 23, the resultant sum is lower than the allowed range and is thus set to the minimum allowed.

TABLE 23

SUMMATION FORCING TO MINIMUM

Variable	Length	Value
+V2	1	5
-V3	2	50
V1 [sum]	1	0 [-45]

d. If the resulting variable is of greater length than any of the right-side variables, the resulting sum might not be indicative of the relative magnitude of the right-side variable values. The sum could be forced to the lower portion of its allowed range. In the example of table 24, V2 is at the high end of its range and V3 is at the high end. The resultant sum is at the low end due to the allowed range of V1.

TABLE 24

SUMMATION FORCING TO LOWER RANGE

Variable	Length	Value
+V2	1	8
+V3	1	9
V1 [sum]	2	17 [17]

As the specific value a variable might obtain during any time step in not known a prior, one does not know if these situations will arise before the model is run. Moreover, if they do arise, one would have to specifically search the output data and examine each variable value for each time step to detect their occurrence. It must also be pointed out that the significance of any of these situations is not whether they occur or not but rather a matter of degree. The net effect for a model with many time steps could be an unwanted bias or drift of the variable values. To correct these computational deficiencies, another method of summing variables was developed. This method is referred to as the averaged method.

2. Averaged Method - The value of a variable is calculated by applying the two arithmetic operators of addition or subtraction to the indicated variables using a weighting technique which adjusts for the length of the variables being summed. The effect of this method is to normalize the summation result to a value corresponding to a variable of length one. As there are ten, one hundred or one thousand values for a variable of length one, two or three respectively, the averaging method applied a weighting factor of one, ten or one hundred respectively to variables of length one, two or three. The specifics of this calculation depend on the congruence of values for variables of different length which resulted in the calculational factor being one, eleven or one hundred eleven respectively to variables of length one, two or three (see congruence table of program values following). The calculation may, however, depend upon the value of the same variable of a different person (see Neighborhood). For example:

$$V6=(+V1-V2-V3+V4+V5)\div 5$$

OR

$$V7=(-V1-V2+V3+V4)\div 4$$

OR

$$V8=(-V1-V2+V3)\div 13$$

For the first two equations, variables V1 through V5 have a length of one and thus the indicated summations would be averaged by dividing by five or four respectively. For the third equation, variables V1 and V2 have a length of one and V3 has a length of two and thus the indicated summation would be averaged by dividing by thirteen (one plus one plus eleven).

The calculated value, however, must conform to the length allowed for the variable. If, for example, the length of V6 is two or more then a calculated value for V6 of sixteen would be allowed. If the length of V6 is one then a calculated value for V6 of sixteen is greater than allowed by the length restriction and thus V6 would be set to nine as that is the highest allowed value for a length of one.

TABLE 25

CONGRUENCE TABLE OF PROGRAM VALUES (BY LENGTH)

Length	Program Values									
1	0	1	2	3	4	5	6	7	8	9
2	00	11	22	33	44	55	66	77	88	99
3	000	111	222	333	444	555	666	777	888	999

For Dependence = Autonomous

1. Constant - The value of the variable is constant from one time step to the next.
2. Ramp Up 1 - The value of the variable is incremented at the rate of one per time step. The calculated value is adjusted so as not to exceed the allowed maximum value according to the length of the variable.
3. Ramp Up 10 - The value of the variable is incremented at the rate of one per ten time steps. The calculated value is adjusted so as not to exceed the allowed maximum value according to the length of the variable.
4. Ramp Up 100 - The value of the variable is incremented at the rate of one per one hundred time steps. The calculated value is adjusted so as not to exceed the allowed maximum value according to the length of the variable.
5. Ramp Up 250 - The value of the variable is incremented at the rate of one per two hundred fifty time steps. The calculated value is adjusted so as not to exceed the allowed maximum value according to the length of the variable.
6. Ramp Down 1 - The value of the variable is decremented at the rate of one per time step. The calculated value is adjusted so as not to exceed the allowed minimum value according to the length of the variable.
7. Ramp Down 10 - The value of the variable is decremented at the rate of one per ten time steps. The calculated value is adjusted so as not to exceed the allowed minimum value according to the length of the variable.

8. Ramp Down 100 - The value of the variable is decremented at the rate of one per one hundred time steps. The calculated value is adjusted so as not to exceed the allowed minimum value according to the length of the variable.

9. Ramp Down 250 - The value of the variable is decremented at the rate of one per two hundred fifty time steps. The calculated value is adjusted so as not to exceed the allowed minimum value according to the length of the variable.

10. Cycle 1 - The value of the variable is varied cyclically at the rate of one per time step. This results in a pseudo sine wave with a period of four time steps. The calculated value is adjusted so as not to exceed the allowed maximum or minimum value according to the length of the variable (e.g., 5→ 6→ 5→ 4→ 5→ 6→ 5→ 4→ 5→...).

11. Cycle 10 - The value of the variable is varied cyclically at the rate of one every ten time steps. This results in a pseudo sine wave with a period of forty time steps. The calculated value is adjusted so as not to exceed the allowed maximum or minimum value according to the length of the variable (e.g., 5→... 6→... 5→... 4→... 5→... 6→... 5→... 4→... 5→...).

12. Cycle 100 - The value of the variable is varied cyclically at the rate of one every one hundred time steps. This results in a pseudo sine wave with a period of four hundred time steps. The calculated value is adjusted so as not to exceed the allowed maximum or minimum value according to the length of the variable (e.g., 5→... 6→... 5→... 4→... 6→... 6→... 5→... 4→... 5→...).

Damping Calculation of Variables

There are two main functional methods used to damp the system response in order to more closely mirror the actual behavior of some variables with respect to time. Either, neither, or both of these methods can be used simultaneously.

The first method is rate damping which restricts or limits the change per time step value of a variable. The specific subtypes are mutually exclusive. This method includes the following:

1. None - The value of a variable is not adjusted using this technique.
2. Average - The new value of a variable is set to the arithmetic mean of the calculated value and the previous value of the variable. This modifier slows down the rate of change of a variable to dampen the response of the system.
3. Fixed - The new value of a variable is only allowed to change by a maximum of "x" units. Thus the new value would be set to the calculated value if the absolute difference between the calculated and previous value is less than "x" or if the absolute value is greater than "x," it would be set to the previous value plus or minus "x." This modifier fixes a maximum rate of change of a variable to dampen the response of the system.

The second method is value clamping which fixes or sets the value of a variable to a certain value if some specified condition is met. The specific subtypes are mutually exclusive. This method includes the following:

1. None - The value of a variable is not adjusted using this technique.

2. Floor - The new value of a variable is not allowed to go below a certain value. If the calculated value is less than the floor value, the new value would be set to the value of the floor. This places a floor of a minimum value for a variable.
3. Ceiling - The new value of a variable is not allowed to go above a certain value. If the calculated value is greater than the ceiling value, the new value would be set to the value of the ceiling. This places a ceiling of a maximum value for a variable.
4. Sticky Downward - The new value of a variable is only allowed to change in the upward direction. It is not allowed to go any lower than the previous value.
5. Sticky Upward - The new value of a variable is only allowed to change in the downward direction. It is not allowed to go any higher than the previous value.

Main Program Logic Summary

The preceding describes the workings for the model calculations within the program. A discussion of analysis and presentation of data is provided in chapter 6.

With the model constructed, various runs were performed using small test sets of persons, variables, and time steps to debug the program and check that the calculations were performed as conceptually intended. This check was necessary due to the serial nature of the calculating and the branching structure of a dependent or independent variable. Adjustments were made to the program code as required until the program performed properly and was considered satisfactory for the research runs.

The research runs were conducted using the model as described in appendix 7. The results of the model runs were saved in a data file for analysis, both within the program using a display and analysis module and also externally using appropriate standard statistical analysis techniques.

CHAPTER 6

ANALYSIS OF THE RESEARCH

The analysis of this research consists of two sections. The first consists of the analyses performed on the data from the survey and the second consists of the analyses performed on data from the model simulation. Each analysis is discussed in detail.

Analysis of Survey Data

The data from the survey was analyzed using statistical tools such as general statistical description of means, standard deviations, ranges and correlation analysis. Each specific statistical analysis is discussed in depth in the following sections.

Statistical Data Analysis of Demographic Variables

A general statistical description of an average participant in the survey would be:

- thirty-five years old ranging from twenty-seven to forty-nine years old
- ten years of government service ranging from a low of four to a high of twenty-one years
- graduated from college in 1982

For the participants as a group, the following breakdowns were observed:

- six of the twelve were married
- five of the twelve were union members

- four of the twelve were GS-11s and the rest GS-12s
- ten of the twelve were males
- none of the twelve was a manager

Due to the small sample size (twelve), the data might not be reflective of a larger population. This is not considered to be an inherent flaw, as the data was used to initialize variables in the simulation for the input sample population. The raw demographic data and calculated statistics are presented in table 34 and 40 of appendix 2.

Statistical Data Analysis of Survey Variables

In analyzing the survey data, leading zeros have been inserted into the variable number to aid in the sorting process (i.e., VA1 is equivalent to VA01).

When the data for the survey variables was sorted by mean:

- the lowest mean was observed for QB10 (productivity)
- the highest mean was observed for QB11 (intention of quitting)

This result indicates that these two variables had the strongest negative and positive relation with turnover respectively (see table 15 for interpretation of variable value).

When the data for the survey variables was sorted by standard deviation:

- the lowest standard deviation was observed for QA20 (organization size)
- the highest standard deviation was observed for QA11 (job satisfaction)

This result indicates that these two variables had the strongest agreement and disagreement among the survey participants as to the relation with thinking of quitting respectively (see table 15 for interpretation of variable value).

When the data for the survey variables was sorted by minimum to maximum value:

- for none of the variables, were all the values less than three
- for one variable, all the values were less than or equal to three

    QB09 (effectiveness)

- for four variables, all the values were greater than or equal to three

    QA20 (organization size)

    QA03 (education)

    QB03 (centralization)

    QB11 (intention of quitting)

- for one variable, all the values were greater than three

    QA20 (organization size)

In addition, for nineteen variables, the range of values was from one through five. These results indicate, that even with a small sample size, there is great disagreement among the survey participants. This observation bolsters the need to build models of autonomous individuals. These analyses are presented in tables 41 though 44 of appendix 2.

Cross Correlation Analysis of Demographic Variables

For the demographic variables, significant cross correlations were observed among age, length of service, and graduation date. This was to be expected since these variables are based on time duration. A summary is provided in table 26 below:

TABLE 26

DEMOGRAPHIC VARIABLE CROSS CORRELATIONS (part a)

	Age	Service	Grad Date
Age	-	.87	-0.96
Service	-	-	-0.93
Grad Date	-	-	-

In addition, a significant correlation was observed between union membership and marital status. In particular, all union members in the survey were not married. This could be a point for future investigation, but, relying on literature review, the correlation could be spurious. In addition, a discussion with a union steward for this union revealed that more of the union members were married than not. This anomaly is probably due to the small sample size. A summary is provided in table 27 below:

TABLE 27

DEMOGRAPHIC VARIABLE CROSS CORRELATIONS (part b)

	Married	Union
Married	-	-0.71
Union	-	-

No cross correlations were calculated for the variable of manager since all responses were negative. The full cross correlation analysis is presented in table 37 of appendix 2.

Correlation between Demographic and Survey Variables

Significant correlations between the demographic and survey variables were observed for the following cases:

TABLE 28

CORRELATIONS AMONG DEMOGRAPHIC AND SURVEY VARIABLES

Variable	Age	Service	Grad Date	Grade	Union
QA3	0.75	0.74	-0.79	-	-
QA8	-	-	-	0.59	-
QA9	-	0.62	-	-	-
QA15	-	-	-	-	0.59
QA21	-	-	-	-	0.70
QB10	-	0.75	-0.58	-	-

The mean of 4.16 for QA3 indicates a belief in a strong positive correlation between formal education and thinking of quitting. Thus the correlation between QA3 and age indicates that older individuals believe more strongly in the correlation between thinking of quitting and the amount of formal education. Similarly, individuals with longer service or an earlier graduation date believe more strongly in the correlation between thinking of quitting and the amount of formal education.

The mean of 3.66 for QA8 indicates a belief in a moderate positive correlation between the amount of work and thinking of quitting. Thus the correlation between QA8 and grade level indicates that higher grade individuals believe more strongly in the correlation between thinking of quitting and the amount of work.

The mean of 3.16 for QA9 indicates a belief in a slight positive correlation between working for the government and thinking of quitting. Thus the correlation between QA9 and length of service indicates that individuals with a greater length of service believe more strongly in the correlation between thinking of quitting and working for the government.

The mean of 2.33 for QA15 indicates a belief in a moderate negative correlation between the degree of organizational integration and thinking of quitting. Thus the correlation between QA15 and union membership indicates that union members believe more strongly in the correlation between thinking of quitting and the amount of organizational integration.

The mean of 2.41 for QA21 indicates a belief in a moderate negative correlation between the level of supervisory quality and thinking of quitting. Thus the correlation between QA21 and union membership indicates that union members believe more strongly in the correlation between thinking of quitting and the level of supervisory quality.

The mean of 1.50 for QB10 indicates a belief in a strong negative correlation between turnover and the level of productivity. Thus the correlation between QB10 and length of service indicates that individuals with a greater length of service believe more strongly in the correlation between turnover and the level of productivity. Similarly, individuals with an earlier graduation date believe more strongly in the correlation between turnover and the level of productivity.

No correlations were calculated for the variable of manager since all responses were negative. The full correlation analysis is presented in tables 38 and 39 of appendix 2.

Content Analysis of Survey Text Questions

The text of the additional survey questions was analyzed by classifying each response according to preselected categories. This category analysis is congruent to that performed by Maija Liisa Herweg (1996, Chapter 5).

Herweg used eight categories to analyze why Finnish and American sample populations work in addition to financial reasons. As quitting is the other side of the coin of working, it was a valid starting point in developing appropriate categories. Herweg's categories are presented in table 29 below:

TABLE 29

TEXT ANALYSIS CLASSIFICATION SCHEME

Category	Discussion
Ego	Personal satisfaction
Mental/boredom	Avoiding boredom
Mental/growth	Personal growth
Mental/sanity	Mental health reasons
Money	Solely for money
Social/self	Social interaction

Category	Discussion
Social/society	Contribution to society
Value	Reasons related to the cultural value system

This categorization was too fine to apply directly for a context analysis of the text survey questions considering the small sample size of the survey. Therefore, the three mental subcategories were combined into a single category and the two social subcategories were combined into one. It was also noted that an additional category which deals with technical issues would enhance the categorization. Thus, this resulted in six categories to be used for the content analysis. The final categorization is given in table 30 below:

TABLE 30

RESPONSE ANALYSIS CLASSIFICATION SCHEME WITH CODES

Category	Discussion	Code
Ego	Personal satisfaction	E
Mental	Related to one's mental state	M
Money	Solely for money	D
Social	Related to social interaction	S
Value	Reasons related to the cultural value system	V
Technological	Related to technological issues	T
N/A	Insufficient response for analysis	~

The thirteen open-ended textual questions of the survey were coded using the above scheme and the coded questionnaires are presented in appendix 3. The number of responses received for these questions is give in table 31 below:

TABLE 31

TEXTUAL QUESTIONS RESPONSE ANALYSIS

Quantity	Item	Comment
156	Total possible responses	(13 questions) X (12 people)
62	Total responses	Response other than blank or N/A
50	Analyzable responses	Sufficient response for analysis

Of the fifty analyzable responses, a matrix listing the tabulation of the categorized responses for each question is given in table 32 below:

TABLE 32

CATEGORIZED CODED TEXTUAL RESPONSE

Question	Ego	Mental	Money	Social	Value	Technical
1	1	5				1
2	1	5				
3		1		2		
4	1	1		1		1
5	1	1	1	3	2	
6	1	1		1		
7		3	1			
8		1	2		2	
9		3				
10		1				
11		3	1			

Question	Ego	Mental	Money	Social	Value	Technical
12				1		
13		1				
total	5	26	5	8	4	2
percentage	10	52	10	16	8	4

Analysis of Model Data

The data resulting from the model simulation was analyzed using both conventional statistical tools and also some new tools developed by the author specifically for this research.

Statistical Data for Model Variables

The model simulation has two kinds of variables, independent and dependent. As the independent variables are equationally fixed within the program and thus determined, no analysis is necessary for these variables.

Dependent variables were analyzed as to their range of values. Typical analysis are presented in tables 75 through 78 in appendix 8. When this is compared with the range of initial values, a view of the behavior of the individuals can be obtained.

Time Series Analysis for Model Variables

The data file containing the results of a trial simulation run was read into a statistical software package for time series analysis. The data was graphed as a line plot for each dependent variable of interest against time categorized by person. This technique was useful in observing the dynamic behavior for a specific variable on an individual by individual basis. This was not performed for any independent variables as their values are determined by the initial formulation. Also histograms for each dependent variable of interest categorized by person were made. This technique was useful in examining the total behavior or response map of an individual. A typical histogram is presented as figure 14 in appendix 8.

These types of analysis were not pursued for the full scale model run as it would have been necessary to generate the series of graphs separately for each variable. Moreover, with a model of five hundred individuals, allowing fifty graphs to be printed on a page, would result in ten pages of graphs for a single variable. While this specific technique does present useful information, one becomes bogged down in the detail that can be generated. Thus this technique was not pursued further for any major part of the analysis.

Trend Analysis for Model Variables

The technique of nonlinear regression analysis was explored to determine if it could be used to analyze the simulation data. It was not anticipated that this technique would prove useful since any regression analysis depends upon a determinism existing with the structure of the data and the simulation was designed to have sufficient complexity to be non-deterministic. The model variable of satisfaction used in the trial simulation was analyzed for its time dependent behavior as it is the state variable of the system. No useable results were obtained using this method as the formulation of the simulation program contains sufficient variety to be greatly complex so as to render normal nonlinear analysis not very useful. Moreover, this technique would not be performed for any independent variables as their values are determined by the initial formulation.

Planned revisions to the simulation program engine will include a limited degree of random behavior to more closely model human behavior which is considered to be more non-deterministic than predictable at the level of the individual. This serves to illustrate a major point of this research, in as much as a large collection of individuals has some statistical predictability while the individual does not. Moreover, it is the individual that performs actions and not the large collection or group or society.

Curve Fitting

The technique of curve fitting was explored to determine if it could be used to analyze the simulation data. It was not anticipated that this technique would prove useful since any curve fitting technique depends upon a determinism existing within the structure of the data and the simulation was designed to have sufficient complexity to be non-deterministic. The model variable of satisfaction used in the trial simulation was analyzed for its time dependent behavior as it is the state variable of the system. The curve fitting program attempted to fit a curve to the data. The curve library consisted of more than thirty-three hundred equational forms which included both linear and nonlinear equations of simple, polynomial, rational, peak, transition, and wave types. In addition, as the program had the ability to perform data smoothing, this was employed also in conjunction with the curve fitting process. The specific types of data smoothing available were polynomial interpolation, Fourier Domain editing, Lowess smoothing, and Savitzky Golay smoothing. Some fits were obtained but the goodness of fit was too low to be of any significance or the curve had been smoothed to the point where there was significant distortion of the underlying data features. The specific goodness of fit criteria used was the r^2 coefficient of determination. Overall, no useable results were obtained using these methods as the formulation of the simulation program contains sufficient variety to be greatly complex so as to render curve fitting and smoothing techniques not very useful. Moreover, this technique would not be performed for any independent variables as their values are determined by the initial formulation.

Visual Program Analysis for Model Variables

The simulation program included a routine which was designed to aid in the analysis of the model data. This routine reads the data from the data file which has been generated during a run of the simulation and presents the numeric values of the variables as a color coded graphic display. Various types of graphical display were programmed and tested with the final version being a rectangular display of filled circles. There are two display methods which were developed. The first presents the value of a single selectable variable for all individuals of the simulation and the second presents the value of all variables for all individuals of the simulation. The first method was designed for use with a large model of more than two hundred fifty individuals and observation of a single variable. The second method was designed mainly for testing purposes and for use with small simulations of fifty individuals or less with twenty-five variables or less. Screen resolution limits do not allow more than this to be presented with clarity. An example of this second method is given as figure 11 in appendix 8.

The color coding was performed using three color schemes of red, green or blue. Within each color scheme, the value of a variable was mapped to a lighter or darker shade of the primary color. The intent is to visually perceive the simulation via the sensory perception of changing colors and thus gain a holistic understanding of the dynamics of the system.

This technique was the main tool used to analyze the response of the model. It is acknowledged that this technique is dependent upon the ability of the observer to detect subtle changes in the graphic display. It was found that this skill was improved as more observations took place. As a backup method, manual scrutiny of the output data file was utilized to a limited degree particularly for examining the data from an area of interest detected during the graphical display. More effort to optimize the display speed and to explore other configurations of color and variable value representation would be needed to truly gain a holistic overview of the dynamics of the system. However this is beyond the scope of this research.

CHAPTER 7

CONCLUSIONS

The conclusions drawn from this research can be divided into two segments; the first deals with the field of turnover within the larger sphere of behavioral science and the second deals with artificial life within the larger sphere of model building. As this research involved work in numerous areas, a global assessment of the strengths and weaknesses was also performed. Moreover certain aspects of this research which contribute substantially to improving the world are also discussed.

Turnover and Behavioral Science

Within the field of turnover and the broader field of behavioral science, conclusions can be drawn from this research dealing with model formulation, variable representation, communication, depiction of hierarchy, and recycling of System Dynamics models.

Model Formulation

There are two basic purposes that a simulation can be used for: the first is to provide forecasts or predictions for events and the second is to explore some of the dynamics of the real system being simulated. The second purpose implicitly includes multiple formulations, as the model structure assumes importance rather than specific numeric values calculated for variables. The knowledge thus provided by a model formulation which closely simulates a real system can provide insight into previously unknown relations or linkages existing in the system itself.

Many previous models (e.g., System Dynamics) have not had an adequate repertoire of functions which could be used to describe human behavior over time. Some behavioral factors and variables such as pay do not exhibit regular patterns. Many are only now being explained in terms of catastrophe theory or chaos theory. Forgetting is one example, and "fight or flee" is another. Variables such as pay are "sticky," which did not show up in earlier models but, interestingly, today many professionals and middle managers are finding that salary levels are not as sticky downward as they once were due to the extensive downsizing that has been taking place. While it is difficult to describe these factors using traditional functions or equations, nevertheless, they can be empirically determined from observation and functionally applied to a model or used in a simulation.

During the initialization process for a many-person model, it becomes increasingly more difficult to perform a one-to-one match from the sample data to the initial values of the model variables as the size of the model increases. As there exists the ability to fabricate models of many thousands of individuals, the process by which statistical or derived data is used becomes important. Complex functions can be used to advantage during the initialization process. Distribution functions such as Binomial, Poisson, Uniform, Sinusoidal, Normal, Rayleigh, Gamma, Beta, Hypergeometric, and various others can be used. Also, the ability to manually derive a distribution from statistical data is a helpful addition.

The conclusion to be drawn from this section is that survey or statistical data is important to A-Life models as it is used to provide initial values for the various individuals in the model. Also, since a complete survey is a time intensive process, the use of distribution functions to represent the initial data is important as it allows models to be constructed with less effort.

Variable Representation

It is common during surveys to attempt to break down the value of a variable into ranks or specific numeric values. This does not reflect observed reality when dealing with internal variables such as "How satisfied are you"? or "How much do you like your supervisor"? An answer or response given will prove only to be a vague indicator of the thoughts of the subject. Also the words, themselves, do not convey a true picture; a response of "a lot" to the question "How satisfied are you"? can be tempered by the body language of the subject (e.g., eyes down, eyes up, legs crossed, legs uncrossed, etc.). The tonal qualities of the response are important also (fast, slow, rising pitch, declining pitch, hesitation, etc.). The preceding is difficult enough to apply to a single subject; trying to benchmark responses from multiple subjects is next to impossible. The conclusion is that it is very difficult to obtain a true picture of the internal state of a person.

When dealing with variables which manifest themselves in external observable and measurable actions, one can have some confidence in their values at least in a threshold sense. If a subject responded that he was dissatisfied with his job and then turned in his notice, then you would know that the dissatisfaction level exceeded an internal threshold value which led to the observed action of turning in his notice. This points out a conclusion that, at best, surveys can only obtain variable values relative to action thresholds.

Communication

Models of behavioral systems which attempt to closely mirror the physical information flow or communication seem to better serve the research in a sort of Occam's phenomenon (in which the simpler the explanation, the more it is preferred). If a behavioral model is attempting to model a situation in which there exists communications between individuals, in any sort of a network connection, such as person A talks to three others of the total population and person B talks to four others and so on for all individuals of the model, it depicts the communications more accurately if it models the actual communication connections also. As a corollary to this, it must be remembered that human communications are not static but they change over time with no apparent determinism. A conclusion is that an effective model needs to account for this also.

When incorporating communication within a many-person simulation, a conclusion is that some specific guidelines for questions to ask which can aid the formulation of the model are as follows:

1. How much information is transferred?
2. When is it transferred?

3. To whom is it transferred?
4. Accuracy of data transmission (information theory) between transmitter and receiver
5. How is information acted on?
6. Model of information as a behavioral variable. Retention, resolution of conflicting information, memory degradation, etc..

Depiction of Hierarchy

If a behavioral model is attempting to model a situation in which there exists a layered hierarchy, such as a company consisting of workers, supervisors, and managers, it depicts the relations more accurately if it models the hierarchy also. This is the same situation as discussed previously concerning Occam's phenomenon.

Current models need to be expanded to include multi-person and hierarchy interactions. When conducting a survey, you don't question a family, an office, a company, a city, a state, or a country. You can only ask questions at the level of an individual person. The higher level groupings are just that; they are mental constructions which are useful for purposes of describing many individuals existing within observer fabricated groupings. It is common to say that the company made a decision, but this is wrong. Even though there is ample evidence that decision-making within a company is very much a dynamic and complex process, it is still the individuals who say yes or no.

It is more common than not to read or hear statements such as "thirty-six percent of the city is poor" or "twenty-two percent of the voters prefer this candidate." These are not precise descriptors of the physical reality. A more accurate description of the reality would be that thirty-six percent of the residents of the city are poor or twenty-two percent of the individuals who are voters prefer a certain candidate. The city is not now, never was, or never will be poor in this context. Some of the residents are poor. Likewise, voters are not a physical entity that votes or splits its vote in a certain way. Individuals are the entities who vote and each one only votes in a specific and non-divisible way. Attributing descriptors of the individual to the level of the group or providing a breakdown of a collective group as if it were a single entity reflect a tendency to use imprecise linguistics. Models which remain at the level of the individual maintain an accurate depiction of the attributes of the individual. It is a conclusion that when formulating a many person model, one is forced to accept the reality that individuals perform action; a collection of individuals does not.

Recycling of System Dynamics Models

An important conclusion of this research is that there can be reuse of existing System Dynamics models with slight modifications. Making certain changes to the model formulation and program construction would allow the addition of communication and interaction among individuals in a many person environment. System Dynamics models are based on data derived from individuals and thus provide a valid starting point in the formulation of a many person model. Moreover, System

Dynamics by using feedback loops, possessing a diagrammatic language, and using operational thinking, have a methodology that is appropriate to Artificial-Life type models. From the above, the following conclusion can be drawn that reusing existing models can provide an important resource for A-Life models to build upon.

Artificial-Life

Within the field of A-Life and also the broader encompassing endeavor of model building, conclusions can be drawn from this research dealing with model formulation, program construction and constraints, variable representation, length of variables, graphic display consideration, and other considerations.

Model Formulation

As one formulates an A-Life model which simulates a many person environment, one becomes more aware of the physical reality of individuals rather than statistics concerning individuals. Individuals perform actions and this needs to be included in the formulation as the basic software engine of a simulation is coded for individuals performing actions. It is a conclusion that when building A-Life models, the researcher must think of individuals rather than collections of individuals.

Program Construction and Constraints

Constructing a software program requires consideration of many parameters. As part of any model building effort, choices have to be made to optimize a desired aspect. Ultimately, any computer program runs into constraints of run time duration, memory requirements, file size, display limitations, and other. At the same time, a researcher desires real time response, unlimited memory for an unlimited number of variables, complete data logging, instant data analysis and presentation, and other items. As the strength of an A-Life model is the representation of a large number of individuals, it is a conclusion that this aspect needs to be emphasized. If given a choice, with no other conflicting factors, a model which optimizes the number of individuals is seen to be a more appropriate model.

Variable Representation

As models of human behavior are usually based on survey data, the form of this data is important in the representation of it within the simulation. As just about all survey data exists in decimal form and the mathematical system is decimal, the overall preference for use in model building is to use decimal formulation and presentation. This avoids any forward or backward binary to decimal conversion or congruence problems. A conclusion from this research is that decimal representation is preferred to binary representation when constructing a many person A-Life type model.

Length of Variables

During the construction, testing and debugging of the simulation, it became apparent that a great deal of effort was being spent on the computational algorithms for use with variables of different length. In retrospect, the programming burden could have been eased by constructing the simulation and formulating the model to use variables of the same length. The true physical measure of each variable could then be mapped to the number of value choices available given the length selected for the variables. While this approach would have been useful, it was not pursued for the following reasons:

1. This simulation program was constructed using decimal calculational algorithms; however, the principles behind the calculations are predicated in the body of prior work performed using Artificial-Life techniques. The majority of these formulations use or allow different lengths for the variables. This prior work influenced this research.

2. This simulation program was initially designed to have further utility as a general Artificial-Life simulation engine. As many, if not most, Artificial-Life models allow multi-generations, an initial design parameter was to build this ability into the simulation engine. In multi-generational models, the length devoted to a variable becomes an important aspect of the simulation. In essence, when an individual belonging to a new generation is born, the values of the variables for the individual are determined in a genetic fashion based upon the variable values of the parents of the individual. When a crossover of genes takes place, the probability that a crossover will occur in a specific gene is higher for a gene with a greater length. Also, if mutations are allowed, again the probability that a mutation will occur in a specific gene is higher for a gene with a greater length. Thus the length of a variable will determine the

probability of a crossover or mutation. While the model for this research did not include the features of more than one generation or mutation, the variability allowed in the lengths of the variables was included in the formulation of the simulation engine.

An algorithm was developed during the final stages of the testing and debugging phase which alleviated the problems encountered from variables of different length. This method, which effectively normalized the values of the variables according to their length, allowed the relational calculations to be performed without the difficulties discussed in chapter five concerning the use of the summation method for relationship calculations. This method, referred to as the averaging method, was used for the model runs of this research. As the length problem was corrected, it was decided that to rebuild the simulation for a single choice of length would not be of benefit for this research, and multiple choices for lengths was kept in the formulation of the simulation engine and the model.

For a simulation engine which would be used exclusively for single-generation models, the choice of a single length for the variables would be preferable.

Graphic Display Considerations

A-Life mainly started after the beginning of the PC era so heavy reliance on graphical interface and a visual display orientation is part of the paradigm. As is often the case during the technological development of a concept or product, desires have grown faster than the supporting technology. An ever increasing use of graphics has led to a computational bottle neck. A specific aspect of this research was to explore graphical data display. The use of and heavy reliance on graphical data presentation prompts a discussion of the conclusions drawn concerning screen display size and the use of color.

Screen Display (size and resolution)

As high-end screen displays currently range from 1024-by-768 to 1600-by-1200 pixels, one has access to one to two million pixels of programmable discrete pieces of real estate to display data. As this research found, human perception seems to limit a typical screen display (seventeen to twenty-one inch monitor) to displaying about fifty-by-forty dynamically color coded entities with sufficient size to allow effective cognition to take place. This places an approximate upper limit of about two thousand individuals that can be displayed with current technology. The conclusion is that A-Life models have a capability to generate more data than can be graphically displayed and this will hinder the development somewhat.

Color Nomenclature and High Level Classification of Human Characteristics

Research described in the literature on human behavior and sociology and psychology has often used matrix classifications for broad characteristics, for example, classifying a person according to the attributes of power, nurturing, and wealth. There are many other examples, but all are attempts to distill many observable human phenomena into an analytically manageable set of characteristics. In the given example, a politician would generally have a high-power aspect while a nurse would have a high nurturing aspect. While these assigned attributes are not perfect, nevertheless, they do provide an insight into a high-level view of causes of human behavior.

As computer display of data has become more prevalent, the use of color is becoming an important tool that can be used to represent data for human characteristics. Colors have been classified according to many systems. A few of the more widely used models are described below.

1. RGB (Red Green Blue) - Based upon the additive primaries of red, green, and blue.
2. CMYK (Cyan Magenta Yellow Black) - Based upon the subtraction of cyan, magenta, and yellow, plus black.
3. HSL (Hue Saturation Lightness) - Based on Hue [position of a color along the color spectrum], Saturation [purity of a color from white to pure color], and Lightness [brightness of a color on a scale from black to white].
4. HSV (Hue Saturation Value) - Based on Hue [position of a color along the color spectrum], Saturation [purity of a color from white to pure color], and Value [vividness of a color].

To assist the understanding of the preceding color models, a number of terms are defined below:

1. Color model - Any of a variety of systems that represent or assist in the addition, subtraction, amount, or mix of color components and lightness.

2. Hue - Covers the color spectrum from red to orange, to yellow, to green, to blue, to indigo, and to violet.
3. Saturation - Refers to the purity of a color. The lower the saturation, the more the color is diluted with white.
4. Lightness - The brightness of a color. Pure color is fifty percent; white is one hundred percent, and black is zero percent.
5. Intensity - The vividness of a color.

These color models (when viewed as a model in which a single entity [a color] is used to depict three or four different level variables describing a holistic property of a system) can be used as a basis for the design of a model which would also use three or four variables, such as power, nurturing, and wealth, to describe a wide range of human behavior. This improves the analysis and presentation of data. From this, it can be concluded that color can be a very effective tool to use when presenting or analyzing data but needs further work for presenting A-Life model output.

Other Considerations

Throughout the last few hundred years, as mathematical ability has increased, there has been great growth in the ability to generate ever increasing amounts of data during the processes of analysis or synthesis. A common problem in science today is that there is often too much data to analyze effectively. This research concludes and points out that advances are needed in analysis techniques. As there is no current standard for the methodology of A-Life model formulation, a toolbox of acceptable techniques or a standard software package is still another advance that is needed.

Analysis Techniques

Since A-Life techniques generate reams of data during a simulation, more research and work is needed in the analysis end. Filtering, large data volume analysis techniques, and presentation techniques are all areas which could benefit from advances. The information overload inherent in large scale simulations has yet to be dealt with so as to have a toolbox of standard accepted techniques for data analysis and presentation. From this it can be concluded that the current set of analytical tools is insufficient for the purpose.

Extension of Artificial-Life Model Formulations to Human Social Systems.

Many A-Life models have been made dealing with simple animal behavior. Models have been built which deal with the social systems of ants and other insects. Colonies of many thousands of ants have been simulated in regards to behavior traits such as food foraging, fighting behavior, and others. Expanding these to the realm of human social systems is a natural continuation. The knowledge and expertise derived from these early models is instrumental in aiding the current state-of-the-art. Many of the findings of this research are in this vein, i.e., they serve as a guidepost for future development of A-Life type models.

Methodology of Formulation

During this research, a specific question arose as to why this research could not be performed using an off-the-shelf software package. The answer is that an A-Life modeling package does not currently exist. The software for this research was conceived, developed, written, tested, and used by the author. During this phase of the research it was determined from the review of A-Life model literature that there are no standards existing for such items as data file configuration, data initialization, analysis routines, among others. As with the development of any new technique, codification of steps, processes, and format soon take place as a methodology is formed. As a tool which is inseparable from the computer, it is a conclusion that A-Life models will benefit by having standard software packages available for researchers in many fields to use without being an expert in artificial life. While the program used in this research was only developed for this research, many of the problems encountered have been documented here and can serve future development.

Data Analysis and Representation

During the analysis of the simulation output of this research, it became apparent that better techniques are needed. This conclusion is also applicable to much of the scientific and engineering work today. The explosive growth of computing power and sensor capability that has taken place over the last few decades has led to an imbalance between the generation and analysis of data. Traditional techniques such as statistical and graphical analysis no longer seem up to the task. Innovation becomes a necessary prerequisite when designing or selecting appropriate tools to analyze experimental data. Speculation as to the nature of the tools of tomorrow can be divided into segments dealing with specialized tools appropriate for this research and general tools useful for any type of research. However. as specialized tools which could be further developed for this research can be considered as progenitors of more generalized tools and the focus is directed towards the tools appropriate to this research, the following discussion focuses on aspects and properties of pattern recognition tools based upon this research.

In addition, as an integral part of analysis is the form of data representation, a discussion of the use of the senses of taste, touch, smelling, sight, and hearing to portray data is useful.

Pattern Recognition

Pattern recognition is a circular process for which the start is the suspicion that some patterns exist. From this premise, one represents the data in some specific format to facilitate the detection of the suspected patterns. As pattern recognition and data representation are cognitive acts, they are based upon some prior knowledge of the data being examined. Without some degree of prior knowledge concerning the data, pattern detection is difficult. This is the basis behind the counter-conundrum of "I'll see it when I believe it!" The detection of a new and never-detected-before pattern is indeed a rare event. Thus, as the first step in the process of data analysis, pattern recognition is of paramount importance. Until patterns in the raw data are recognized, data is just data or rather numbers without meaning. As a cognitive act, pattern recognition supplies a form of meaning to subsets of or sequences in the data. Once detected, many varied tools can be applied to develop understanding and to gain knowledge. The progression from data to information to knowledge is applicable to all scientific inquiry. The usual implementation of pattern recognition is that of searching through the data for the existence of previously known patterns. With this as a background, possible specialized analysis tools appropriate for this research which could be developed are as follows: (see figure 1)

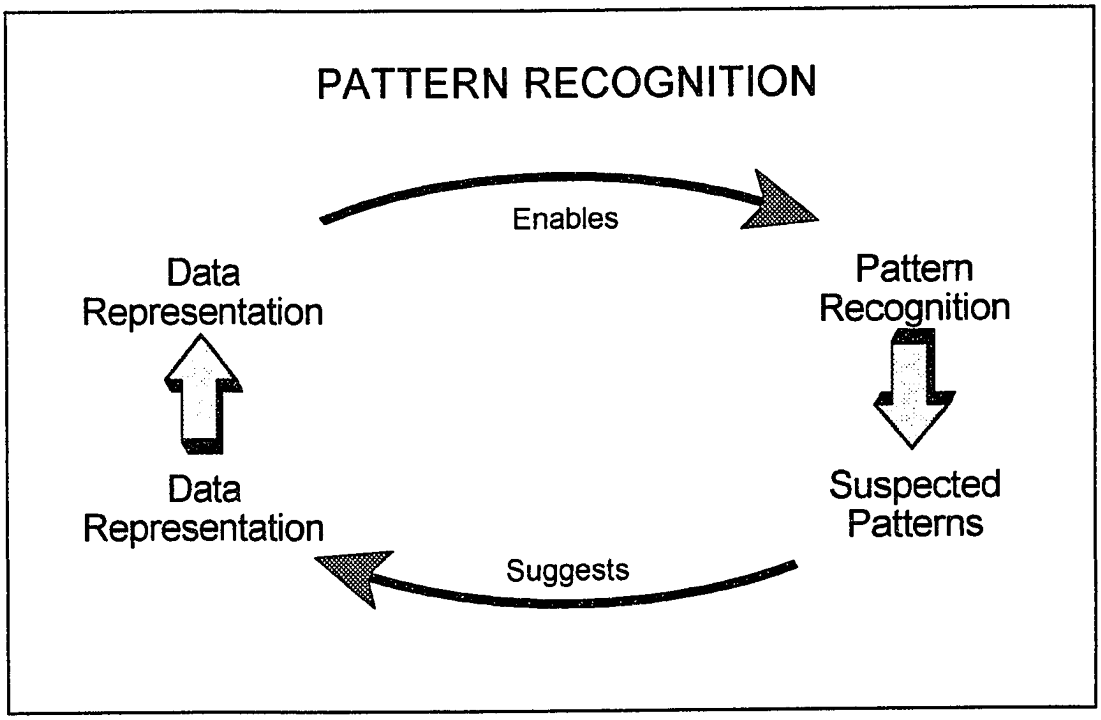

Figure 1 Pattern Recognition

1. Traditional statistical analysis of the number of people thinking of quitting. This could entail the calculation of ranges, frequency tables, percentiles or histograms of the values for thinking of quitting for either all or selected subsets [neighborhoods] of the individuals in the simulation.
2. Statistics of people stuck at extreme ends. This could be counting the number of people whose value for thinking of quitting goes to and remains at either of the extreme ends of the value scale.
3. Behavior of neighborhoods of individuals. This could entail the enumeration of the values of thinking of quitting for a subset of individuals tabulated over time which could be presented in a graph over time. This would give a dynamic view of the behavior.
4. Exceeding a threshold for an individual or neighborhood. This could include counting the gross number of people who exceed a selected value for thinking of quitting. This could be presented in a graph over time.
5. Global averages. This could entail the calculation and tabulation of the average value of thinking of quitting at each time period. This could be presented in a graph over time.
6. Expect system type conditions. This could entail the use of rule-based conditions such as mark this event as interesting:

   -If the value for management perception is in the highest quartile and

   -If the value for job performance is below the average and

   -If the value for economic condition has increased over the last year and

-If the value for thinking of quitting is above average.

7. Difference analysis (current to past or current to initial). This could entail calculating and plotting the difference in the current value for thinking of quitting to the initial or past values.
8. Moving averages (various time periods). This could entail the calculation of various moving averages for the values of thinking of quitting for individuals, neighborhoods or the total population.
9. Calculus based conditions such as first or second derivative. This could entail the calculation and plotting of the rate of change or inflection points for thinking of quitting.
10. Time based initiators. This could entail examining the values of thinking of quitting in time periods after the occurrence of some event. An example could be to observe what happens to thinking of quitting at least one hundred time periods after economic conditions have reached a local maximum inflection point and is turning down.
11. Time phased observations. This could involve observing and comparing the behavior of selected variables with varying degrees of lead or lag between them. An example could be to compare the values for thinking of quitting after a change in marital state.
12. Examples of interesting patterns. This could be observing how the values of thinking of quitting change over a period of a few years for a person who graduated less than five years ago compared to a person who graduated more

than ten years ago. This would be looking for a differential effect of one variable on another. This would be interesting for it would imply that there is not constancy of relations over time. This could also indicate that learning is taking place.

13. Examples of other key patterns. This could be observing a major feedback loop such as the one which links management perception to pay to job performance back to management perception. Within this loop, specific behavior of the variable values such as oscillation, rise time, overshoot, degree of damping, ring time, phase locking, etc. could be searched for and examined. These specific behaviors are mainly derived from the Electrical Engineering field where much work has been performed in circuit analysis. For this example, the electrical circuit suggests patterns which might occur in the model.

Sensual Form of Output

Traditionally, data has mainly been portrayed in a manner which depends upon the sense of sight. Comparatively little research has been performed to investigate the use of the other senses of taste, touch, smelling, and hearing to portray data. Even within the realm of visual presentation, it really has taken the advent of the computer and graphic display to progress beyond printed data and graphs. New forms of visual representation for both static and dynamic data display are being formulated and implemented. In chapter seven, the use of various color schemata to represent multiple human characteristics was discussed. Using color is but a single visual characteristic that can aid the depiction of data. Some other possibilities for the use of different senses to portray data are discussed below. This is not meant to be an exhaustive list, but it does enumerate some promising areas for further research.

Aural Representation [musical]

The sense of hearing has lagged far behind that of sight for portraying scientific data and assisting the analytical process. As an example of some esoteric conjecture of the use of audio representation, Paul McEnery (1995, 22-3) quotes Peter Stone (author of Symbolic Composer and EWorks software):

> When you look, your eye can take in two or three dimensions of data. When you listen, your ear can take in hundreds of simultaneous parameters of information. If we use sounds and music as a carrier, complex mathematical and symbolic data can be imported into a listener's neural system.

Further, in a review of the Symbolic Composer software, Spiros Antonopoulos (1995, 14-6) states:

> Bizarre and complex programming languages and scientific soundscape modeling environments [sic].
>
> Symbolic Composer creates music that represents what you see using computer graphics, such as autocatalytic reactions, chaos and fractal equations, solar systems, Brownian noise, number theory sequences, neurons, Fibonacci series, morphs, and transformations. You can even listen to an audio model of the AIDS virus. All this wraps together with ordinary composition operations from the past 400 years of music history into one helluvan [sic] aural sandwich.

While these techniques are currently on the technological fringe, they represent a fertile field for research. The potential for a data representation revolution is great.

Visual Representation [3-D or holographic]

In much the same vein as aural representation, visual representation using 3-Dimensional or holographic techniques is technically feasible. Much work has been performed in this area, but further advances in computational power and algorithmic simplification are needed to have these techniques come into the main-stream of scientific data representation. They offer the ability to peer into the data from differing views from which one can gain more insight than from 2-Dimensional representation. The addition of a third dimension increases greatly the amount of data which can be portrayed. It also increases the choices that can be made to select a particular dimension to act as a principal axis of representation. Holographic representation offers the possibility to change the axis of viewing or representation in real-time. Combining these techniques with the technology of virtual reality, could allow the user to manipulate the data directly in the sense that one becomes surrounded by or immersed in the data.

Tactile Representation [synthesizers and the like]

This means of data representation is the least well developed of the three discussed here. Other than providing force feedback for man-machine interfaces, little has been done to explore the sense of touch as a gateway for data representation and transmission. The field of music has perhaps made the most extensive use of this sense which can be demonstrated by statements such as, "a person plays an instrument with a fine sense of touch" or "his fingering was superb." To become a virtuoso, the development of a highly skilled sense of touch is required. Over the last few decades, as electronics have invaded the world of musical instruments, items such as the Moog synthesizer have been developed to further explore the use of touch. In this instrument, musical sounds, notes, and patterns are created depending upon the tactile position of the musicians hands. Feedback to the player consists of the sounds created and is instantaneous. Also, other similar instruments have been made to explore variations of this technique. To play rather than perform an analysis of data should be possible. While these techniques are mainly for transmission of tactile data, techniques such as power gloves, finger-force sensors, and remote manipulators deal with the receiver side. In exploring tactile representation, both are important.

Global Assessment of Research

To evaluate the wide range of work performed in support of this research (survey design and execution, model design, program design and construction, and analysis) a global assessment was made in terms of the strengths and weaknesses of the specific parts of the research. This assessment is a critical reflection of the various interlocking parts, each of which contributes to an overall assessment of the research.

Strengths of the Research

As part of the program design, a library of initialization functions was developed which allowed variables for individuals within the model to be given initial values in a simple manner by specifying the particular function. The functions developed for the program offer a wide degree of latitude for the choice of distribution functions. This allows the model to start with a high degree of similarity to real values without having to custom-create each variable value. Further development of the program would focus on creating an even larger set of distribution functions for the initialization process.

As part of the program design, a library of time-varying functions for independent variables was developed which allowed the values of the independent variables to be specified for the duration of the model run. The developed functions offer a wide degree of latitude for the choice of time-varying values. This allows the model to run with a high degree of similarity to real values without having to custom-create each independent variable value for each time step. Further development of the program would focus on creating an even larger set of time-varying functions for use in the model.

As part of the program design, computational algorithms were developed which allow for partial or full communication between individuals for any variable in the model. This mirrors the real world where people talk to other people about what they are thinking. Further development of the program would focus on allowing various patterns of communication to be modeled.

As part of the overall model and program design, many individuals can be modeled, whereby each individual remains as an individual for the calculational aspect of determining the values for each individual's variables. This mirrors the real world where people think and do things differently from each other.

As part of the program design, the ability to define variables using a simple computational summation of other variables was developed. In refining this computational process, a further step was conceptually developed and which could be implemented in a relational calculus which would be further descriptive of events in real life using a simple description scheme. As an example of this, table 33 adapted from Karakotsios and Bremer (1993, 205-8) describing these simple relations is presented:

TABLE 33

TWO PERSON RELATIONS

Relation Name	Person A	Person B	Effect
Mutualism	+	+	Both persons benefit
Predation/parasitism	+	-	One person benefits, the other suffers
Commensalism	+	0	One person benefits, the other ignores
Neutralism	0	0	Neither person affects the other
Amensalism	0	-	One person suffers, the other ignores
Competition	-	-	Each person inhibits the other

Weaknesses of the Research

On proceeding into the survey design, there should be considerable effort made to have an in-depth understanding of the generalities of the model and simulation that will be based upon the survey results. This will aid in selecting the type of data to be collected and help optimize the survey effort. It often happens that specific concerns during the model or simulation construction dictate certain specifications as to the data that can be used after it has already been collected. Thus, one should pay attention to the data needs of the model. As a large portion of this research dealt with exploring a new type of model, deficiencies in the survey design and collection of data should not be considered as major defects.

During the transition from developing the specifications of the model to creating the program which implements the simulation, there were many choices which were made for the particular calculational algorithms used. Robust engineering algorithms do not exist for behavioral relations. All the algorithms for the program were created during this research and while extensive testing was performed to ensure that they performed in a logical manner; they were not tested under all conditions which might occur in the simulation. Calculational degradation might occur particularly in cases where the number of time steps becomes large. This reinforces a finding that a well-tested methodology and toolbox of calculational functions are needed for a many-person model such as this.

During the simulation, computational instability due to feedback loops which result in either divergent behavior or wild oscillations may occur. Extensive testing and examination of the output were performed to detect and correct any of these problems. Still, it must be noted, this testing was not performed in an exhaustive manner for all conditions which might occur in the simulation. This point is similar to the previous weakness, and the need for a comprehensive methodology and toolbox is much the same.

During the conceptualization of the model and fitting survey data to variables within the model, there is a weakness, seemingly inherent in all behavior models, in the process of mapping the observed behavioral traits to numeric values. Human behavior was not designed by mathematicians, so a strict reliance of mathematical functions to describe relations is not justified by the biology of the phenomenon. For modeling and simulation purposes, it is generally sufficient to say that as effector A changes a bit, response B changes a bit also. Other than indicating the direction of change as being positive or negative, anything more is uncalled for. Ultimately, one is forced to move from a regimen of strict numeric hierarchy of values to a soft fuzzy world of rank ordered values where direction of change with time becomes the analytical tool. Many System Dynamics models avoid the use of numeric scales altogether for this reason.

Contribution of the Research

The contribution of this research can be discussed by dividing it into three areas and examining each in more detail. The areas cover the contribution to behavioral science, model building, and improving the world.

Contribution to Behavioral Science

Turnover models have been constructed using System Dynamics techniques, but these models mainly deal with a large number of variables which affect a single individual or a single organization. They serve to help understand the theoretical mechanisms of social interaction, but only at the single individual level or the overall organizational level. They do not deal with the social interactions among multiple individuals. They serve as a snapshot of an individual whereas A-Life models are the cinema. The success of this model adds to the tools available to better simulate and thus understand human behavior at the organizational level.

Contribution to Model Building

As the field of A-Life is quite young, new applications which use these techniques are still being developed. The field had its beginning at a conference held in September 1987 at Los Alamos, New Mexico. The issued promotional description of the conference follows:

> Artificial life is the study of artificial systems that exhibit behavior characteristic of natural living systems. It is the quest to explain life in any of its possible manifestations, without restriction to the particular examples that have evolved on earth. This includes biological and chemical experiments, computer simulations, and purely theoretical endeavors. Processes occurring on molecular, social, and evolutionary scales are subject to investigation. The ultimate goal is to extract the logical form of living systems.
>
> Microelectronic technology and genetic engineering will soon give us the capability to create new life forms *in-silico* as well as *in-vitro*. This capacity will present humanity with the most far-reaching technical, theoretical, and ethical challenges it has ever confronted. The time seems appropriate for a gathering of those involved in attempts to simulate or synthesize aspects of living systems (Levy 1992, 113-4).

Pertinent to this research, the themes of importance are behavioral characteristics, computer simulations, and social processes. Thus far, A-Life models have been used to simulate behavior in an exploratory fashion. Each new model pushes the frontier further ahead. The specific grouping of descriptors for this model are as follows:

1. Medium size model of greater than one hundred individuals
2. Model of a specific human behavior (thinking of quitting)

3. Model of a specific human characteristic (quitting)
4. Variability and change allowed in the environment

The success of this model serves to advance the boundaries of usefulness for A-Life models.

Improving the World

The act of quitting a job represents an economic loss to society. As each worker represents an investment in training and experience to perform his or her job, the investment made to achieve the required performance level will be lost. Depending upon the closeness of the skill content of the new job compared to the old, there is a greater or lessor loss involved. While the cost is borne by the organization and the individual, ultimately all of society pays as the cost is amortized over all members of the society. It is recognized that there is continual turnover in the job market for many reasons. There is a generally accepted level of turnover, which is structural in nature and beyond control. What is controllable is turnover over and above this structural level. All of society could benefit by having more goods and services available which could be provided by the lost labor.

This research has allowed the study of human systems using a simulation which more closely model the person as an individual rather than as a statistical condensation of individual data. Most data are gathered at the individual level but because of the lack of simulation program capabilities, these data have generally been condensed into sets and percentages which allowed it to be run using existing programs. This research breaks a barrier such that the simulation is not removed from the data by the insertion of a degrading step.

Future Use of the Research

Some possible future uses of this type of simulation are as follows:

1. Spread of AIDS and other infectious diseases - Human contact interactions within a population can be modeled (i.e., person A has contact with person B at time X, etc.). This then builds up a detailed overview of the interactions which are taking place and allows simulations to be run which allow the testing of a hypothesis. For this example, a simulation of sexual contact among bisexual individuals could be studied to learn more about the spread of AIDS from being initially observed mainly in the gay community to now being observed in the heterosexual population. Human contacts, disease detection, incubation period, active transmission period are some factors which could be examined with a simulation.
2. Purchase of a consumer item - Human decision making regarding the purchase of perhaps a car involves many interactions. Interactions that might be modeled include word-of-mouth comments from friends, family, and acquaintances, advertising from the manufacturer via television, radio, print media, and indirect means, such as sponsorship of sports activities and having the car used as a prop in a motion picture, and other information such as reviews and tests

which appear in car or consumer magazines. The response of individuals within a population can be modeled using this technique.

3. Voting in an election, such as for a President of a country - This human activity involves a large amount of interaction. Interactions that might be modeled include discussions and word-of-mouth comments from friends, family, and acquaintances, advertising from the candidates (both positive and negative) via television, radio, print media, speeches, indirect means such as published voting records, syndicated columns by political journalists, and other information such as endorsements by individuals and groups. This activity also involves a more detailed model formulation as many of the thought activities of the individual entail moral, educational, economic and other intricate issues. Nevertheless, a simulation could be performed as a means of understanding the myriad number of interactions which take place for this particular human endeavor.
4. Econometric modeling of a small city with capital inflows and outflows, wages, expenditures, etc. - The simulation of a city of perhaps fifty thousand individuals could be performed to gain insight into such areas as creation and transfer of wealth, taxing policies, competition in prices and wages, marketing concerns, links to state or national economic activity level and many other important topics.
5. Combat simulation at the division level for an army group which models each individual in virtual state space - Aspects such as level of training, equipment available for use, technology ranking of equipment, combat readiness, morale

level, command and control capability are just a few of the variables which could be modeled and simulated. The goal of this type of simulation would be to increase the combat effectiveness of the unit and assist in the shaping of strategic and tactical doctrine.

6. A submarine crew of one hundred persons to study their responses to a given stimulus, such as being out at sea for ten weeks and receiving a message which extends the time for another six weeks. A model of motivation would assist naval planners to study ways to reduce loss of morale and motivation.

7. A group of five hundred people work for a company in a community where the majority of job skills are not duplicated by other employers. A new company moves to the area and starts an operation which needs people with similar job skills. This situation causes competition for workers. What possible reverberations could take place in the labor pool. This could include upward wage pressure, job shifting and increased turnover as the previous balance between supply and demand for labor is upset.

Virtually any human activity for which there is an interest in understanding the dynamics of a population in which individuals perform activities and communication between individuals takes place is a candidate for the application of this type of model.

EPILOGUE

During the year and a half since performing the survey, the following changes have occurred in the status of the twelve survey participants:

1. One left government service for a job in private industry.
2. Two were reassigned by management to a different division within the same department.
3. One requested transfer and was reassigned by management to a different division within the same department.
4. One requested transfer and was reassigned by management to a different department.
5. Seven remain in the same position. (One is actively seeking another job as evidenced by sending out numerous resumes)

Even though some of these transfers were at the initiation of management, they still represent a loss of extensive training assets that have been incumbent with the individuals, both for direct training and on-the-job learning. With turnover of this magnitude, this is an indicator of the need to focus attention to this problem.

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APPENDIX 1

DESCRIPTION OF SURVEY FORM

This appendix contains a reproduction of the survey form which was used for the interviews.

SURVEY ON "THINKING OF QUITTING"

The following survey is to research the general question of turnover of engineers in the federal government. Thinking of quitting is an action which precedes voluntary turnover and has not been extensively studied. This survey will gather information concerning thinking of quitting which will be used to construct a behavioral model to explore various relationships among variables.

The information requested by this survey will be used for academic purposes. Any information gathered will not be reported or released in a specific form but only reported or published in the form of a statistical abstract. All data gathered will be held in confidence by the researcher and not released.

If you are seriously thinking of quitting in the near future and would be willing to participate in a more in-depth survey to aid this research, please contact me.

AGE ______

SEX male or female

LENGTH OF GOVERNMENT SERVICE ________

CIVIL SERVICE GRADE ______

YEAR OF GRADUATION ______

MANAGER yes or no

MARITAL STATUS married or not married

MEMBER OF A UNION yes or no

DETERMINATES OF TURNOVER

Please indicate if you feel that the factors below influence your "thinking of quitting." A positive impact is that you would think more of quitting as the value of the related variable increases and a negative impact is that you would think less of quitting as the value of the related variable increases. Some factors may not apply to you directly but answer the question as to how you believe that it would affect you.

1. Age (positive would be thinking of quitting is more related to greater age)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

2. Length of service (positive would be thinking of quitting is more related to longer length of service)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

3. Education (formal) (positive would be thinking of quitting is more related to more education)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

4. Membership in a union (positive would be thinking of quitting is more related to membership in a union)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

5. Level of Employment (job level, grade, rank, or title) (positive would be thinking of quitting is more related to a higher job level)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

6. Manager vs. non-manager (positive would be thinking of quitting is more related to managers)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

7. Pay (positive would be thinking of quitting is more related to higher pay)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

8. Amount of work (positive would be thinking of quitting is more related to more work)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

9. Government vs. non-government (positive would be thinking of quitting is more related to government workers)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

10. Fringe benefits (sick leave, vacation, travel, training, etc.) (positive would be thinking of quitting is more related to a larger amount of fringe benefits)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

11. Satisfaction in job (positive would be thinking of quitting is more related to a higher degree of satisfaction in your job)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

12. Degree to which work is routine or varied (positive would be thinking of quitting is more related to a routine job)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

13. Professionalism (of your position, are you treated like a professional) (positive would be thinking of quitting is more related to a higher degree of treatment as a professional)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

14. Upward mobility (in your job) (positive would be thinking of quitting is more related to a higher degree of upward mobility of your job)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

15. Integration within the organization (close knit, everyone pulls together) (positive would be thinking of quitting is more related to more integration within your organization)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

16. Communication (informal which helps get the job done) (positive would be thinking of quitting is more related to a larger amount of informal communication)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

17. Communication (formal) (both written and oral) (positive would be thinking of quitting is more related to a larger amount of formal communication)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

18. Centralization within the organization (positive would be thinking of quitting is more related to a higher degree of centralization)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

19. Fairness, equal treatment (within the organization) (positive would be thinking of quitting is more related to a higher degree of fairness)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

20. Size of organization (positive would be thinking of quitting is more related to a larger organization)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

21. Quality of supervision (positive would be thinking of quitting is more related to better quality supervision)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

IMPACT OF TURNOVER ON THE ORGANIZATION

Please indicate if you feel that the factors below are affected by turnover. A positive impact is that if turnover within the organization increases then the value of the factor increases and a negative impact is that if turnover within the organization increases then the value of the factor decreases. Some questions may not apply to your situation directly but answer the question as to how you believe that it would affect your situation.

1. Administrative staff (size or importance) (positive would be that if turnover increases then the size or importance of the staff increases)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

2. Formalization within the organization (as opposed to conducting business in an informal manor) (positive would be that if turnover increases then the formalization increases)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

3. Centralization (of command, control and communications) (positive would be that if turnover increases then the centralization increases)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

4. Communication within the organization (general quantity) (positive would be that if turnover increases then the quantity of communications increases)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

5. Communication within the organization (general accuracy) (positive would be that if turnover increases then the accuracy of communications increases)

Impact exists	☐ Yes	☐ No	☐ Not sure
Strength of impact	☐ Strong	☐ Weak	
Type of impact	☐ Positive	☐ Negative	

6. Integration (working for a close knit group) (positive would be that if turnover increases then the degree of integration increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

7. Satisfaction (general morale level within the organization) (positive would be that if turnover increases then the level of morale increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

8. Innovation (within the organization as a whole) (positive would be that if turnover increases then the degree of innovation increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

9. Effectiveness (in achieving organizational goals) (positive would be that if turnover increases then the degree of effectiveness increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

10. Productivity (of the organization as a whole) (positive would be that if turnover increases then the level of productivity increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

11. Intention of quitting (within the organization as a whole) (positive would be that if turnover increases then the general intention of quitting also increases)

Impact exists ☐ Yes ☐ No ☐ Not sure
Strength of impact ☐ Strong ☐ Weak
Type of impact ☐ Positive ☐ Negative

UNIQUE FACTORS RELATED TO THINKING OF QUITTING

For each of the categories listed below, please indicate if you feel there are other specific factors which influence your thinking of quitting and their impact. Answer only those which apply.

1. Your specific work assignments (type of work)
   factor: ______________________
   impact: ______________________
   ____

2. Your specific work assignments (quantity of work)
   factor: ______________________
   impact: ______________________
   ____

3. Your specific work environment (building or work area)
   factor: ______________________
   impact: ______________________
   ____

4. Your general work environment (shipyard)
   factor: ______________________
   impact: ______________________
   ____

5. Your general living environment (Tidewater area)
   factor: ______________________
   impact: ______________________
   ____

6. Your specific work organization (code or work group)
   factor: ______________________
   impact: ______________________
   ____

7. Your general work organization (shipyard)
   factor: ______________________
   impact: ______________________
   ____

8. Your general work organization (Federal government)

factor: ______________________________

impact: ______________________________

____

9. Your specific supervisor or manager

factor: ______________________________

impact: ______________________________

____

10. Your general management

factor: ______________________________

impact: ______________________________

____

11. Other

factor: ______________________________

impact: ______________________________

____

12. Other

factor: ______________________________

impact: ______________________________

____

13. Other

factor: ______________________________

impact: ______________________________

____

APPENDIX 2

STATISTICAL ANALYSIS OF SURVEY QUESTIONS

The following tables give the compilation of the statistical results from the analysis of the survey questions.

For tables 35, 36, 38, 39, 41, 42, 43, and 44, the following list gives the name describing each variable as the statistical tables use only the variable number. Some tables used a slightly different notation to facilitate sorting for which the notation of having or not having a extra zero is equivalent. Thus QA01 is the same as QA1.

Variable	Name	Variable	Name
QA01	Age	QA17	Formal Communication
QA02	Length of Service	QA18	Centralization
QA03	Education	QA19	Fairness
QA04	Union	QA20	Organization Size
QA05	Grade Level	QA21	Supervision Quality
QA06	Manager	QB01	Admin Staff Size
QA07	Pay	QB02	Formalism
QA08	Amount of Work	QB03	Centralization
QA09	Government	QB04	Quantity Communication
QA10	Fringe Benefits	QB05	Quality Communication
QA11	Job Satisfaction	QB06	Integration
QA12	Routine or Varied Work	QB07	Satisfaction
QA13	Professionalism	QB08	Innovation
QA14	Upward Mobility	QB09	Effectiveness
QA15	Organization Integration	QB10	Productivity
QA16	Informal Communication	QB11	Intention of Quitting

For tables 35, 36, 41, 42, 43, and 44, the following list gives the meaning of the value for a variable.

1. One indicates a response that a strong negative relation exists
2. Two indicates a response that a weak negative relation exists
3. Three indicates a response that no relation exists or not sure
4. Four indicates a response that a weak positive relation exists
5. Five indicates a response that a strong positive relation exists

TABLE 34

RAW SURVEY DATA (DEMOGRAPHIC VARIABLES)

	Age	Sex	Service	Grade	Grad	Manager	Married	Union
1	28	Male	4	GS-11	1990	No	No	Yes
2	39	Male	15	GS-11	1977	No	No	Yes
3	44	Male	21	GS-12	1970	No	Yes	No
4	28	Male	4	GS-11	1991	No	Yes	No
5	27	Female	5	GS-11	1990	No	No	No
6	49	Male	16	GS-12	1968	No	Yes	No
7	35	Male	12	GS-12	1983	No	Yes	No
8	35	Male	11	GS-12	1983	No	No	Yes
9	31	Male	8	GS-12	1986	No	Yes	No
10	33	Male	7	GS-12	1990	No	No	No
11	33	Male	11	GS-12	1984	No	Yes	No
12	38	Female	8	GS-12	1983	No	No	Yes

TABLE 35

RAW DATA (VARIABLES A1 THROUGH A21)

	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	QA9	QA10	QA11	QA12
1	4.0	3.0	3.0	3.0	1.0	1.0	1.0	2.0	3.0	1.0	1.0	4.0
2	3.0	3.0	5.0	3.0	3.0	5.0	5.0	3.0	5.0	3.0	5.0	5.0
3	5.0	5.0	5.0	5.0	4.0	2.0	1.0	5.0	5.0	1.0	1.0	2.0
4	1.0	2.0	3.0	3.0	2.0	3.0	1.0	4.0	3.0	5.0	1.0	1.0
5	4.0	4.0	4.0	3.0	2.0	4.0	1.0	2.0	3.0	1.0	1.0	5.0
6	1.0	1.0	5.0	3.0	2.0	2.0	2.0	5.0	3.0	2.0	1.0	4.0
7	2.0	2.0	4.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	1.0	4.0
8	1.0	1.0	5.0	1.0	1.0	5.0	1.0	5.0	3.0	2.0	1.0	1.0
9	1.0	1.0	4.0	3.0	1.0	3.0	2.0	5.0	3.0	1.0	1.0	4.0
10	5.0	4.0	3.0	3.0	1.0	4.0	1.0	4.0	2.0	1.0	1.0	5.0
11	4.0	4.0	4.0	3.0	5.0	3.0	4.0	3.0	4.0	3.0	5.0	4.0
12	2.0	2.0	5.0	3.0	5.0	3.0	5.0	3.0	1.0	5.0	5.0	3.0

	QA13	QA14	QA15	QA16	QA17	QA18	QA19	QA20	QA21
1	2.0	1.0	2.0	3.0	3.0	3.0	1.0	4.0	1.0
2	5.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	5.0
3	2.0	2.0	1.0	2.0	4.0	4.0	1.0	3.0	1.0
4	1.0	1.0	1.0	2.0	2.0	3.0	1.0	3.0	1.0
5	1.0	1.0	2.0	1.0	2.0	3.0	3.0	3.0	2.0
6	1.0	1.0	1.0	1.0	2.0	1.0	1.0	4.0	1.0
7	2.0	2.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0
8	1.0	1.0	5.0	5.0	1.0	3.0	1.0	3.0	5.0
9	2.0	1.0	2.0	3.0	3.0	3.0	2.0	4.0	2.0
10	2.0	1.0	2.0	3.0	3.0	3.0	1.0	3.0	2.0
11	5.0	5.0	3.0	3.0	3.0	3.0	5.0	4.0	1.0
12	4.0	5.0	3.0	3.0	3.0	3.0	4.0	3.0	5.0

TABLE 36

RAW DATA (VARIABLES B1 THROUGH B11)

	QB1	QB2	QB3	QB4	QB5	QB6	QB7	QB8	QB9	QB10	QB11
1	4.0	4.0	4.0	1.0	1.0	1.0	4.0	2.0	1.0	1.0	4.0
2	5.0	5.0	5.0	5.0	3.0	3.0	3.0	3.0	3.0	3.0	5.0
3	4.0	4.0	5.0	4.0	4.0	1.0	1.0	2.0	1.0	4.0	4.0
4	2.0	4.0	4.0	1.0	1.0	2.0	1.0	3.0	1.0	1.0	4.0
5	5.0	2.0	5.0	2.0	1.0	2.0	1.0	3.0	1.0	1.0	5.0
6	4.0	4.0	4.0	1.0	1.0	2.0	5.0	1.0	1.0	1.0	5.0
7	3.0	3.0	4.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	4.0
8	4.0	2.0	3.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	5.0
9	5.0	1.0	4.0	4.0	2.0	2.0	1.0	4.0	2.0	1.0	5.0
10	3.0	4.0	5.0	4.0	2.0	2.0	2.0	2.0	2.0	1.0	5.0
11	3.0	3.0	4.0	2.0	2.0	4.0	2.0	3.0	3.0	2.0	4.0
12	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	1.0	1.0	5.0

TABLE 37

CROSS CORRELATION OF DEMOGRAPHIC VARIABLES

Variable	Age	Sex	Service	Grade	Grad	Manager	Married	Union
Age	1.00	-.18	**.87**	.50	**-.96**	-	.26	.00
Sex	-.18	1.00	-.33	-.16	.22	-	-.45	.16
Service	**.87**	-.33	1.00	.45	**-.93**	-	.37	-.09
Grade	.50	-.16	.45	1.00	-.39	-	.35	-.25
Grad	**-.96**	.22	**-.93**	-.39	1.00	-	-.35	.03
Manager	-	-	-	-	-	-	-	-
Married	.26	-.45	.37	.35	-.35	-	1.00	**-.71**
Union	-.00	.16	-.09	-.25	.03	-	**-.71**	1.00

Correlations (survey-a.sta)
Marked correlations are significant at $p < .05000$
N=12 (Casewise deletion of missing data)

TABLE 38

CORRELATION OF DEMOGRAPHIC VARIABLES TO VARIABLES A1 THROUGH A21

Variable	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	QA9	QA10	QA11
Age	-.10	-.10	**.75**	.29	.34	-.13	.28	.52	.24	.02	.15
Sex	.07	.11	.19	-.00	.31	.13	.25	-.47	-.49	.24	.26
Service	.09	.15	**.74**	.41	.40	-.02	.20	.49	**.62**	-.16	.13
Grade	-.12	-.18	.37	.00	.24	-.05	.08	**.59**	-.22	-.12	-.00
Grad	.08	.04	**-.79**	-.36	-.36	.16	-.24	-.49	-.46	.07	-.12
Manager	-	-	-	-	-	-	-	-	-	-	-
Married	-.27	-.13	.00	.41	.23	-.44	-.11	.45	.31	.06	-.19
Union	-.12	-.22	.29	-.43	.00	.21	.39	-.27	-.11	.25	.41

Variable	QA12	QA13	QA14	QA15	QA16	QA17	QA18	QA19	QA20	QA21
Age	-.06	.12	.19	-.13	-.18	.18	-.39	-.11	.03	.11
Sex	.16	.05	.30	.07	-.29	-.10	.06	.48	-.32	.30
Service	-.08	.20	.19	-.04	-.07	.33	-.02	-.05	-.06	.07
Grade	-.13	.04	.24	.21	.29	.16	-.09	.04	.12	.07
Grad	.08	-.12	-.15	.16	.23	-.20	.30	.09	-.09	-.04
Manager	-	-	-	-	-	-	-	-	-	-
Married	-.24	-.12	.00	-.45	-.32	.22	-.13	-.06	.35	-.57
Union	-.13	.33	.24	**.59**	.57	-.16	.09	.09	-.13	**.70**

Correlations (survey-a.sta)
Marked correlations are significant at $p < .05000$
N=12 (Casewise deletion of missing data)

TABLE 39

CORRELATION OF DEMOGRAPHIC VARIABLES TO VARIABLES B1 THROUGH B11

Variable	QB1	QB2	QB3	QB4	QB5	QB6	QB7	QB8	QB9	QB10	QB11
Age	.10	.37	-.00	.20	.44	.01	.43	-.49	-.03	.45	.19
Sex	.12	-.31	-.11	.00	.08	.24	-.17	.30	-.34	-.23	.38
Service	.22	.30	.21	.35	.56	-.05	.13	-.38	.15	**.75**	-.04
Grade	-.19	-.32	-.34	.13	.24	-.00	-.14	-.27	.08	.00	.12
Grad	-.25	-.32	-.08	-.19	-.45	.02	-.37	.41	.01	**-.58**	-.08
Manager	-	-	-	-	-	-	-	-	-	-	-
Married	-.27	-.08	-.00	-.12	.00	.00	-.13	-.10	-.11	.17	-.51
Union	.19	.16	-.43	.00	.12	-.00	.27	.07	.16	.00	.24

Correlations (survey-a.sta)
Marked correlations are significant at $p < .05000$
N=12 (Casewise deletion of missing data)

TABLE 40

DESCRIPTIVE STATISTICS OF DEMOGRAPHIC DATA

Variable	Mean	Std.Dev	Minimum	Maximum
Age	35.00	6.66	27	49
Sex	1.16	.38	1	2
Service	10.16	5.23	4	21
Grade	11.66	.49	11	12
Grad	1982.91	7.69	1968	1991
Manager	1.00	0.00	1	1
Married	1.50	.52	1	2
Union	1.33	.49	1	2

Descriptive Statistics (survey-a.sta)
N=12 (Casewise deletion of missing data)

TABLE 41

DESCRIPTIVE STATISTICS OF VARIABLES A1 THROUGH B11

sorted by variable number

Variable	Name	Mean	Std.Dev	Minimum	Maximum
QA01	Age	2.75	1.60	1	5
QA02	Length of Service	2.66	1.37	1	5
QA03	Education	4.16	.83	3	5
QA04	Union	3.00	.85	1	5
QA05	Grade Level	2.50	1.50	1	5
QA06	Manager	3.16	1.19	1	5
QA07	Pay	2.16	1.58	1	5
QA08	Amount of Work	3.66	1.15	2	5
QA09	Government	3.16	1.11	1	5
QA10	Fringe Benefits	2.25	1.48	1	5
QA11	Job Satisfaction	2.00	1.80	1	5
QA12	Routine or Varied Work	3.50	1.44	1	5
QA13	Professionalism	2.33	1.49	1	5
QA14	Upward Mobility	2.00	1.53	1	5
QA15	Organization Integration	2.33	1.15	1	5
QA16	Informal Communication	2.66	1.07	1	5
QA17	Formal Communication	2.66	.77	1	4
QA18	Centralization	2.91	.66	1	4
QA19	Fairness	2.08	1.37	1	5
QA20	Organization Size	3.33	.49	3	4
QA21	Supervision Quality	2.41	1.67	1	5
QB01	Admin Staff Size	3.75	.96	2	5
QB02	Formalism	3.25	1.13	1	5
QB03	Centralization	4.16	.71	3	5
QB04	Quantity Communication	2.50	1.44	1	5
QB05	Quality Communication	1.83	1.02	1	4
QB06	Integration	2.00	.95	1	4
QB07	Satisfaction	2.00	1.34	1	5
QB08	Innovation	2.41	.90	1	4
QB09	Effectiveness	1.58	.79	1	3
QB10	Productivity	1.50	1.00	1	4
QB11	Intention of Quitting	4.58	.51	4	5

Descriptive Statistics (survey-a.sta)

TABLE 42

DESCRIPTIVE STATISTICS OF VARIABLES A1 THROUGH B11
sorted by mean and standard deviation

Variable	Name	Mean	Std.Dev	Minimum	Maximum
QB10	Productivity	1.50	1.00	1	4
QB09	Effectiveness	1.58	.79	1	3
QB05	Quality Communication	1.83	1.02	1	4
QB06	Integration	2.00	.95	1	4
QB07	Satisfaction	2.00	1.34	1	5
QA14	Upward Mobility	2.00	1.53	1	5
QA11	Job Satisfaction	2.00	1.80	1	5
QA19	Fairness	2.08	1.37	1	5
QA07	Pay	2.16	1.58	1	5
QA10	Fringe Benefits	2.25	1.48	1	5
QA15	Organization Integration	2.33	1.15	1	5
QA13	Professionalism	2.33	1.49	1	5
QB08	Innovation	2.41	.90	1	4
QA21	Supervision Quality	2.41	1.67	1	5
QB04	Quantity Communication	2.50	1.44	1	5
QA05	Grade Level	2.50	1.50	1	5
QA17	Formal Communication	2.66	.77	1	4
QA16	Informal Communication	2.66	1.07	1	5
QA02	Length of Service	2.66	1.37	1	5
QA01	Age	2.75	1.60	1	5
QA18	Centralization	2.91	.66	1	4
QA04	Union	3.00	.85	1	5
QA09	Government	3.16	1.11	1	5
QA06	Manager	3.16	1.19	1	5
QB02	Formalism	3.25	1.13	1	5
QA20	Organization Size	3.33	.49	3	4
QA12	Routine or Varied Work	3.50	1.44	1	5
QA08	Amount of Work	3.66	1.15	2	5
QB01	Admin Staff Size	3.75	.96	2	5
QB03	Centralization	4.16	.71	3	5
QA03	Education	4.16	.83	3	5
QB11	Intention of Quitting	4.58	.51	4	5

Descriptive Statistics (survey-a.sta)

TABLE 43

DESCRIPTIVE STATISTICS OF VARIABLES A1 THROUGH B11

sorted by standard deviation and mean

Variable	Name	Mean	Std.Dev	Minimum	Maximum
QA20	Organization Size	3.33	.49	3	4
QB11	Intention of Quitting	4.58	.51	4	5
QA18	Centralization	2.91	.66	1	4
QB03	Centralization	4.16	.71	3	5
QA17	Formal Communication	2.66	.77	1	4
QB09	Effectiveness	1.58	.79	1	3
QA03	Education	4.16	.83	3	5
QA04	Union	3.00	.85	1	5
QB08	Innovation	2.41	.90	1	4
QB06	Integration	2.00	.95	1	4
QB01	Admin Staff Size	3.75	.96	2	5
QB10	Productivity	1.50	1.00	1	4
QB05	Quality Communication	1.83	1.02	1	4
QA16	Informal Communication	2.66	1.07	1	5
QA09	Government	3.16	1.11	1	5
QB02	Formalism	3.25	1.13	1	5
QA15	Organization Integration	2.33	1.15	1	5
QA08	Amount of Work	3.66	1.15	2	5
QA06	Manager	3.16	1.19	1	5
QB07	Satisfaction	2.00	1.34	1	5
QA19	Fairness	2.08	1.37	1	5
QA02	Length of Service	2.66	1.37	1	5
QB04	Quantity Communication	2.50	1.44	1	5
QA12	Routine or Varied Work	3.50	1.44	1	5
QA10	Fringe Benefits	2.25	1.48	1	5
QA13	Professionalism	2.33	1.49	1	5
QA05	Grade Level	2.50	1.50	1	5
QA14	Upward Mobility	2.00	1.53	1	5
QA07	Pay	2.16	1.58	1	5
QA01	Age	2.75	1.60	1	5
QA21	Supervision Quality	2.41	1.67	1	5
QA11	Job Satisfaction	2.00	1.80	1	5

Descriptive Statistics (survey-a.sta)

TABLE 44

DESCRIPTIVE STATISTICS OF VARIABLES A1 THROUGH B11
sorted by minimum and maximum and variable number

Variable	Name	Mean	Std.Dev	Minimum	Maximum
QB09	Effectiveness	1.58	.79	1	3
QA17	Formal Communication	2.66	.77	1	4
QA18	Centralization	2.91	.66	1	4
QB05	Quality Communication	1.83	1.02	1	4
QB06	Integration	2.00	.95	1	4
QB08	Innovation	2.41	.90	1	4
QB10	Productivity	1.50	1.00	1	4
QA01	Age	2.75	1.60	1	5
QA02	Length of Service	2.66	1.37	1	5
QA04	Union	3.00	.85	1	5
QA05	Grade Level	2.50	1.50	1	5
QA06	Manager	3.16	1.19	1	5
QA07	Pay	2.16	1.58	1	5
QA09	Government	3.16	1.11	1	5
QA10	Fringe Benefits	2.25	1.48	1	5
QA11	Job Satisfaction	2.00	1.80	1	5
QA12	Routine or Varied Work	3.50	1.44	1	5
QA13	Professionalism	2.33	1.49	1	5
QA14	Upward Mobility	2.00	1.53	1	5
QA15	Organization Integration	2.33	1.15	1	5
QA16	Informal Communication	2.66	1.07	1	5
QA19	Fairness	2.08	1.37	1	5
QA21	Supervision Quality	2.41	1.67	1	5
QB02	Formalism	3.25	1.13	1	5
QB04	Quantity Communication	2.50	1.44	1	5
QB07	Satisfaction	2.00	1.34	1	5
QA08	Amount of Work	3.66	1.15	2	5
QB01	Admin Staff Size	3.75	.96	2	5
QA20	Organization Size	3.33	.49	3	4
QA03	Education	4.16	.83	3	5
QB03	Centralization	4.16	.71	3	5
QB11	Intention of Quitting	4.58	.51	4	5

Descriptive Statistics (survey-a.sta)

APPENDIX 3

CONTENT ANALYSIS OF SURVEY QUESTIONS

The tables presented in this appendix contain the transcribed responses to the survey question which asked if there are other specific factors which would influence their thinking of quitting and to indicate any impact for the factor. The code assigned for each response is shown also.

TABLE 45

FACTOR ANALYSIS OF SURVEY QUESTION ONE

Specific work assignments (type of work)

Subject	Factor	Impact	code
1	No control, no input	Makes me want to quit, strong	M
2	N/A	N/A	
3	Lack of complexity	Makes me stay here	M
4	The work does not interest me and is not what I expected when I got into it.	Strong	M
5	Administrative vs. technical - prefer more technically orientated work vs. administrative.	Influence me to quit	T
6	Yes	Medium	~
7	N/A	N/A	
8	N/A	N/A	
9	Yes - If you run out of challenges, you will be more likely to want to move on.		E
10	Applicability to career outside [shipyard]	The more applicable, the more likely to quit	M
11	N/A	N/A	
12	Lack of supervisory input.	Increases thinking about quitting	M

Code Key

E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 46

FACTOR ANALYSIS OF SURVEY QUESTION TWO

Specific work assignments (quantity of work)

Subject	Factor	Impact	code
1	Cyclic work	No impact	M
2	N/A	N/A	
3	N/A	N/A	
4	More work might be good but more uninteresting work is not necessarily good	Weak	M
5	Too few assignments - prefer many projects working at same time as opposed to just one or two.	Influence me to quit	M
6	Yes	High	~
7	N/A	N/A	
8	Yes - with such a large quantity of work it's difficult to accomplish it all. Men must feel or have a sense of accomplishment.	A major impact exists.	E
9	Yes - Too much work over extended periods can cause people to burnout and quit		M
10	N/A	N/A	
11	N/A	N/A	
12	If assigned too much work for available time.	Increases thinking about quitting	M

Code Key

E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 47

FACTOR ANALYSIS OF SURVEY QUESTION THREE

Specific work environment (building or work area)

Subject	Factor	Impact	code
1	People	Strong, makes you want to stay	S
2	N/A	N/A	
3	N/A	N/A	
4	Open areas increase work environmental satisfaction.	Strong	M
5	Not on work site as prefer to be - prefer to be on work site & converse with blue collar workers	Influence me to quit	S
6	Yes	Medium	~
7	N/A	N/A	
8	N/A	N/A	
9	No factor		
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 48

FACTOR ANALYSIS OF SURVEY QUESTION FOUR

General work environment (shipyard)

Subject	Factor	Impact	code
1	Negative people who don't care about their work	Strong, makes you want to leave	S
2	N/A	N/A	
3	N/A	N/A	
4	Working at the shipyard is a slight negative relative to working in another government agency or the private sector	Weak	M
5	Industrial atmosphere - like industrial setting/manufacturing environment.	Influence me not to quit	T
6	Yes	Medium	~
7	N/A	N/A	
8	N/A	N/A	
9	No factor		
10	N/A	N/A	
11	Lack of professionalism/too "blue" collar/too large	Employees develop no loyalty	E
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 49

FACTOR ANALYSIS OF SURVEY QUESTION FIVE

General living environment (Tidewater area)

Subject	Factor	Impact	code
1	Blue collar, red necks	Strong, makes me want to quit	E
2	N/A	N/A	
3	Family	Strong, positive - have turned down 3 jobs to stay here.	M
4	I like the Tidewater area but it would not stop me from quitting.	Weak	S
5	Busy, good location to city, beach, mountains - like area, lots of things to do outside work.	Influence me not to quit.	S
6	N/A	N/A	
7	N/A	N/A	
8	N/A	N/A	
9	Yes - Can work either way - depending on how it affects the individual		S
10	Cost of living is reasonably low.	Lower cost of living, less likely to quit.	D
11	Do not have "roots" here.	Easier to justify moving from area.	V
12	Crime.	Increases thinking about quitting.	V

<u>Code Key</u>

E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 50

FACTOR ANALYSIS OF SURVEY QUESTION SIX

Specific work organization (code or work group)

Subject	Factor	Impact	code
1	N/A	N/A	
2	N/A	N/A	
3	N/A	N/A	
4	The work would make it likely that I would find another job however I do like the people I work with.		S
5	No comments	N/A	~
6	Yes	Medium	~
7	N/A	N/A	
8	N/A	N/A	
9	Yes - Directly impacts job satisfaction which affects retention rates		E
10	Overtime is not fairly distributed.	The less overtime, more likely to quit.	M
11	N/A	N/A	
12	N/A	N/A	

<u>Code Key</u>
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 51

FACTOR ANALYSIS OF SURVEY QUESTION SEVEN
General work organization (shipyard)

Subject	Factor	Impact	code
1	N/A	N/A	
2	N/A	N/A	
3	Tenuous continued existence of the shipyard.	Weak, positive - makes me think of quitting.	M
4	The shipyard is too large and cumbersome which is frustrating	Weak, negative	M
5	Good work experience.	Influence me to gain as much experience as possible then move on.	M
6	Yes	Medium	~
7	N/A	N/A	
8	N/A	N/A	
9	No factor		
10	Downsizing.	Less opportunity for advancement therefore more likely to quit.	D
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 52

FACTOR ANALYSIS OF SURVEY QUESTION EIGHT

General work organization (Federal government)

Subject	Factor	Impact	code
1	Benefits	Strong, want to stay	D
2	N/A	N/A	
3	NRRO [Naval Reactors Representative Office]- Their personality type drive me bonkers	Makes me long to quit	M
4	N/A	N/A	
5	Good benefits, job security.	Influence me not to quit due to current job market (private sector)	D
6	Yes	Medium	~
7	N/A	N/A	
8	Yes	Major	~
9	Yes - I think federal workers are less likely to quit than our private sector counterparts		V
10	Federal workers generate little sympathy from general public there may become victim of Congress.	More likely to quit.	V
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 53

FACTOR ANALYSIS OF SURVEY QUESTION NINE

Specific supervisor or manager

Subject	Factor	Impact	code
1	Little guidance	Weak, want to leave	M
2	N/A	N/A	
3	N/A	N/A	
4	The management need more backbone and focus.	Weak	M
5	No comments	N/A	
6	Yes	High	~
7	N/A	N/A	
8	Yes	Major	~
9	Yes/No - Depends on your ability within the organization to move around		M
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 54

FACTOR ANALYSIS OF SURVEY QUESTION TEN

General management

Subject	Factor	Impact	code
1	N/A	N/A	
2	N/A	N/A	
3	N/A	N/A	
4	N/A	N/A	
5	No comments	N/A	
6	Yes	High	~
7	N/A	N/A	
8	Yes	Major	~
9	Yes - If you feel you are mistreated or being mismanaged, you will be more likely to leave		M
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 55

FACTOR ANALYSIS OF SURVEY QUESTION ELEVEN
Other

Subject	Factor	Impact	code
1	N/A	N/A	
2	The way different parts (codes) interact to achieve a goal.	The less cooperation between codes, the higher the frustration level is and the more likely I feel like quitting.	M
3	VA state lottery	Increases thinking of quitting	D
4	Direction and focus of group - our group has no long term focus where there seems like there should be some.	Strong	M
5	N/A	N/A	
6	N/A	N/A	
7	N/A	N/A	
8	N/A	N/A	
9	Potential for closure for BRAC [Base Realignment And Closure]or layoffs	If you think you may close, you will certainly start looking for a job.	M
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

<u>Code Key</u>
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 56

FACTOR ANALYSIS OF SURVEY QUESTION TWELVE
Other

Subject	Factor	Impact	code
1	N/A	N/A	
2	N/A	N/A	
3	N/A	N/A	
4	N/A	N/A	
5	N/A	N/A	
6	N/A	N/A	
7	N/A	N/A	
8	N/A	N/A	
9	Personal friendships	May increase your likelihood of staying on.	S
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

TABLE 57

FACTOR ANALYSIS OF SURVEY QUESTION THIRTEEN
Other

Subject	Factor	Impact	code
1	N/A	N/A	
2	N/A	N/A	
3	N/A	N/A	
4	N/A	N/A	
5	N/A	N/A	
6	N/A	N/A	
7	N/A	N/A	
8	N/A	N/A	
9	Lack of advancement potential	Causes people to leave when they might otherwise stay on.	M
10	N/A	N/A	
11	N/A	N/A	
12	N/A	N/A	

Code Key
E = Ego
M = Mental
D = Money
S = Social
V = Value System
T = Technology
~ = Insufficient Response

APPENDIX 4

PROTOTYPE OF MODEL CONSTRUCTION

As the building of the A-life type model to simulate turnover and thinking of quitting is a multi-stage process, a description of the steps will be discussed in detail. This appendix describes a prototype which, while smaller than the eventual model, will demonstrate all of the aspects of conceptualization and building the model. The selection of variables for the prototype model should not be construed as being the final selection of variables selected from the field research. As this research is involved with exploring the building of an A-Life model, there were different configurations of variables used for testing the model behavior. This was to gain an appreciation of the degree of robust behavior exhibited by the model. The variables of the prototype should be viewed as representative of the actual variables used.

The variables of pay and centralization were chosen for the prototype. Both of these are considered to be strong determinates of turnover. Three correlation variables were also used, those of length of service, age and education. The variable of satisfaction (which intervenes between turnover and both pay and centralization) was used also. These variables were chosen because they have appeared in many previous models, and data was available from the survey performed for this research.

Specific details of the relations of these variables to turnover are given below:

1. Pay - Successively higher amounts of pay will probably produce successively lower amounts of turnover.

2. Centralization - Successively higher amounts of centralization will probably produce successively higher amounts of turnover.
3. Length of service - Members with low lengths of service usually have higher rates of turnover than members with high lengths of service.
4. Age - Younger members usually have higher rates of turnover than older members.
5. Education - Better educated members usually have higher rates of turnover than less educated members.
6. Satisfaction - A higher degree of satisfaction will usually be associated with a lower turnover rate.

Combining these variables will result in a model as depicted in figure 2. This figure shows the variables of length of service, age and education in a functional relation with turnover. Likewise, the variables of pay and centralization are shown in a functional relation with turnover acting through the intervening variable of satisfaction. Finally, the intervening variable of satisfaction is shown in a circular relation with turnover. The sign of each relation is also indicated.

While this model depicts relations among the variables, some of the relations are tenuous and not conducive for modeling. For example, it is difficult to relate turnover to pay. However if a translational variable of management perception is inserted between turnover and the determinates, the relations are more clearly illustrated. If an increase in turnover will result in a decrease in management perception of the workers and if a decrease in the management perception of the workers will result

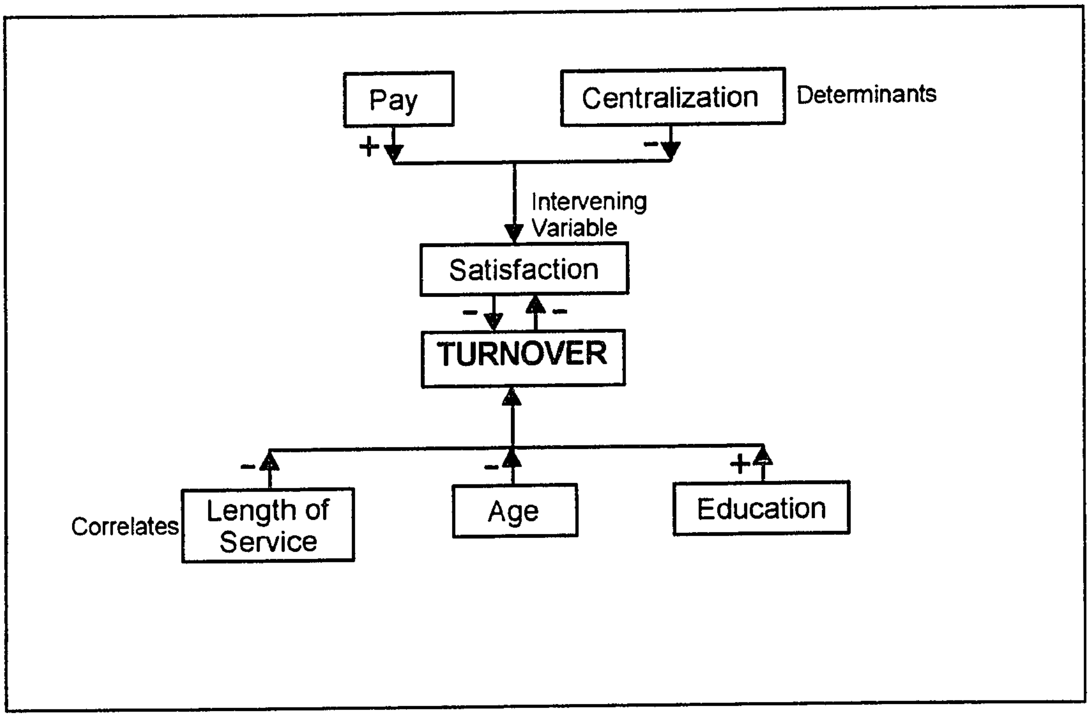


Figure 2 Model of Turnover

in a tendency toward lower pay, then turnover has been linked to pay by modelable variables. In a similar fashion, another translational variable of work performance serves to link satisfaction to management perception. When these changes have been added to the model, the model of figure 3 is the result.

This model, however, still does not depict interactions between other variables which can have an effect on turnover such as the general economic conditions, the actions of other individuals, and the precursor mental activity to quitting (thinking of quitting). The general economic conditions have an influence on the degree to which a person will search for another job. The actions of other individuals can often serve as a catalyst to galvanize some action. If you know someone who is quitting, has quit, or is thinking of quitting, your thinking of quitting can be stimulated so the actions of

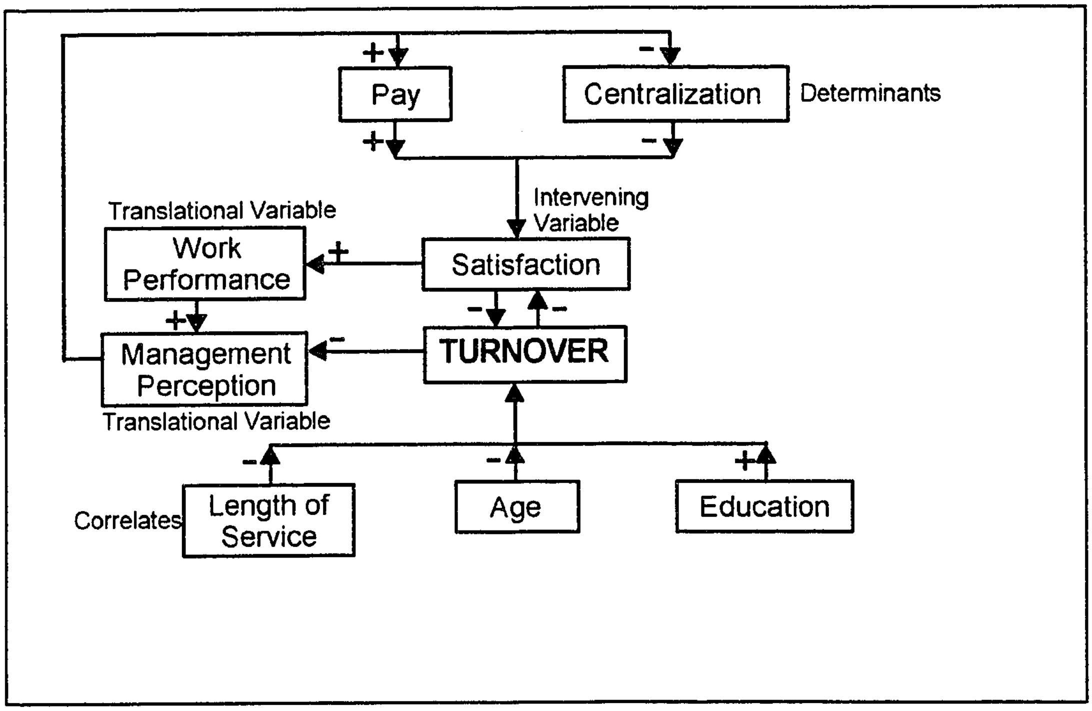


Figure 3 Model of Turnover (version 2)

others can play a large role in the modeling of turnover. Thinking of quitting is important since quitting does not occur without some degree of mental reflection upon the action, so thinking of quitting will be added to the model also. With these inclusions, this version of the model is depicted in figure 4.

Within each of these illustration, the functional relation has been given as being positive or negative. This has been determined from the literature review. During the actual construction of the final model, the sign and magnitude of the functional relation was determined using both the literature review and the field research. This provides a starting point to initialize the model.

These preceding models do not adequately characterize the essence of an a-life model which is the depiction of a large group of individuals (agents) which act

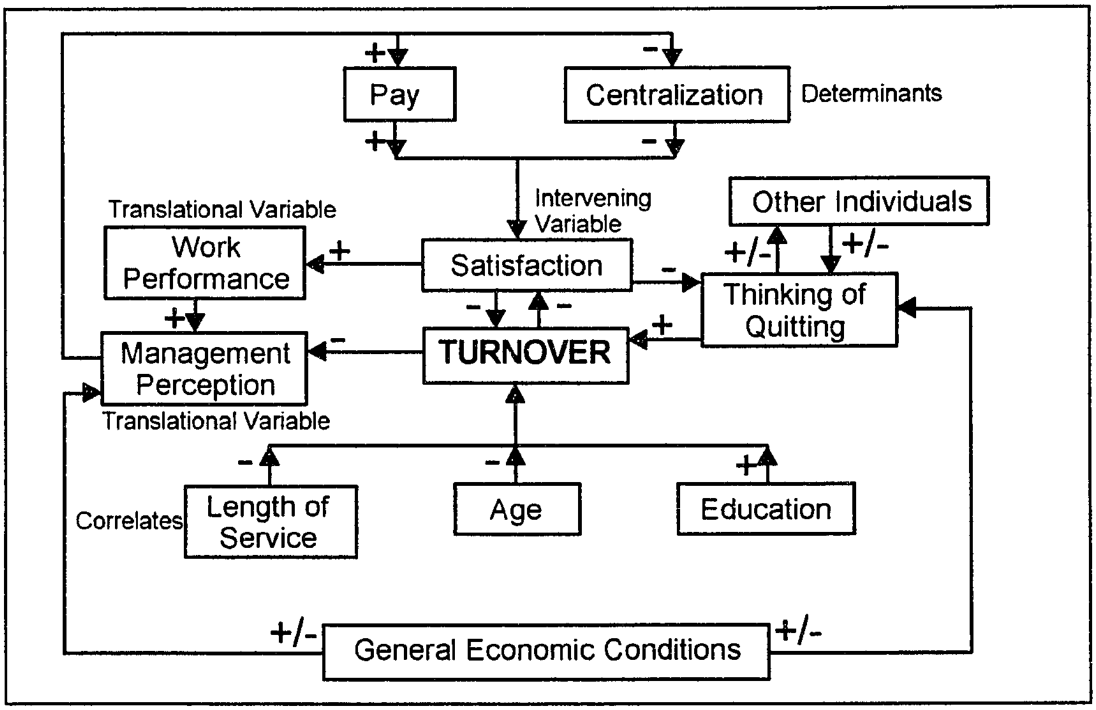


Figure 4 Model of Turnover (version 3)

according to their own values of internal variables and are effected by values of variables external to themselves. The external variables could be further divided into subgroups according to the degree of closeness, influence, or other distinctions which could be made. For the purposes of modeling turnover within an organizational setting, a class of variables, referred to as organizational variables, will be used. This class will include the variables of pay and centralization as they exist within the context of the organization, are determined by the organization, and act directly on the individual. Another class, called external variables, will refer to those of general economic conditions, other individuals, and management perception. These variables are more distant from the individual and generally are not influenced by the individual. Management perception, however, is influenced by the work performance of the

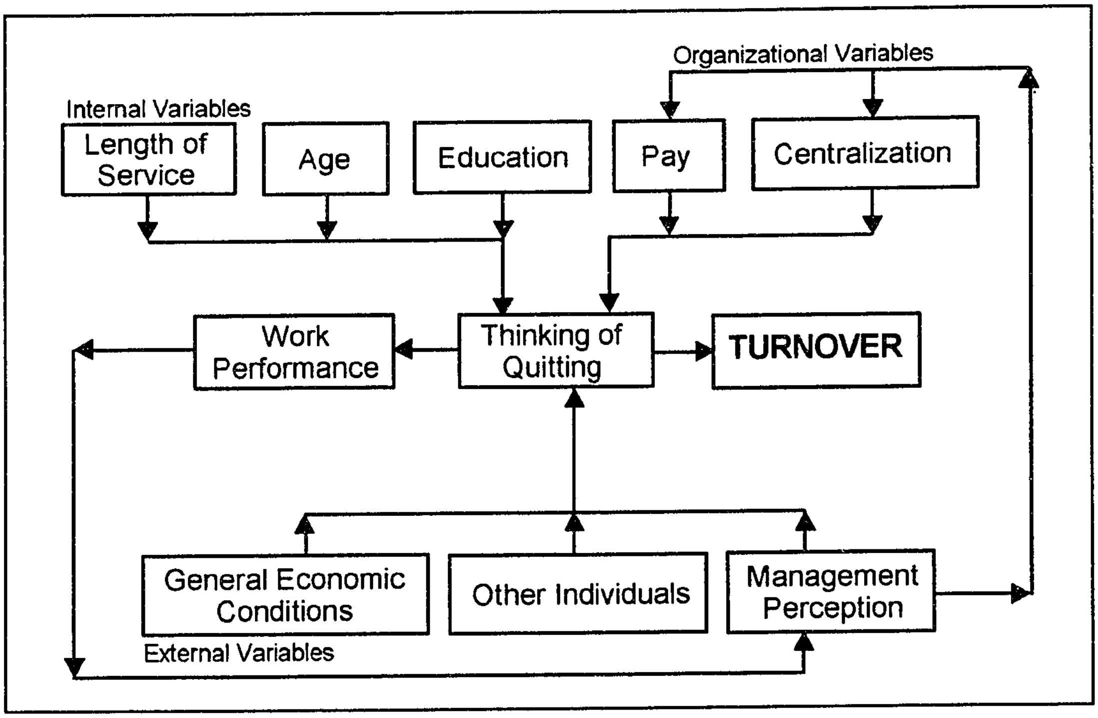


Figure 5 Model of Turnover (version 4)

individual and thus represents a feedback loop. The intervening variable of satisfaction will be dropped from this configuration as it could be viewed as a summation of the effects of the other variables. This depiction of the model is given in figure 5.

During the construction of the model, it was decided to add the variable representing union membership to the model. Data for this variable was collected during the survey. This resulted in the model having the final configuration as depicted in figure 6.

While these depictions are adequate for a conceptual view, they still do not represent the model in a programmable form. Figure 7 is presented which provides an annotation for each variable as a label. As an aid to understand this depiction, see the sections on "Dependence Calculation of Variables" and "Relationship Calculation of

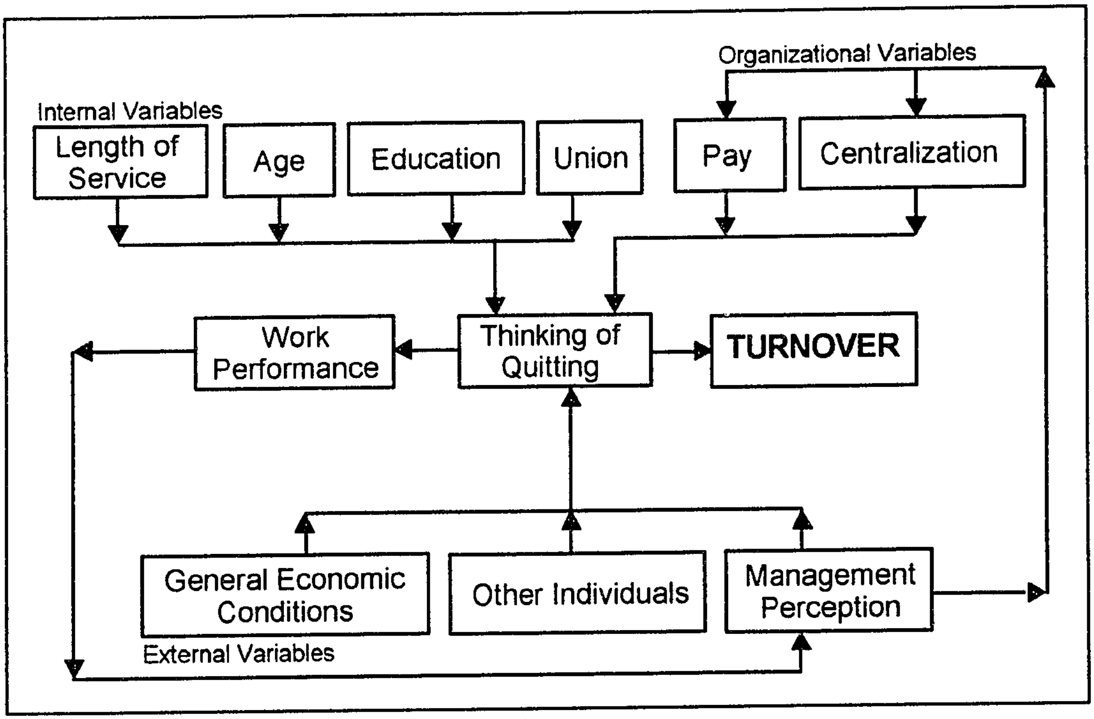


Figure 6 Model of Turnover (final version)

Variables" in chapter 5 and also the section on "Interpretation of Values for Variables" in appendix 5 for details). The model also adds two additional variables which are used within the program to hold the summations of other variables which act on thinking of quitting. These two additional variables were added such that the first would sum the variables generally having a positive correlation to thinking of quitting and the second would sum the variables generally having a negative correlation to thinking of quitting. Thus V10 (variable ten) holds the summed value of V2 plus V6 plus V7. Likewise V11 (variable eleven) holds the summed value of V1 plus V3 plus V4 plus V5 plus V9. Another change is that the depiction of an input from other individuals was removed as this is accomplished with the neighborhood calculation for each variable and thus it is not actually a variable itself. This communication can take

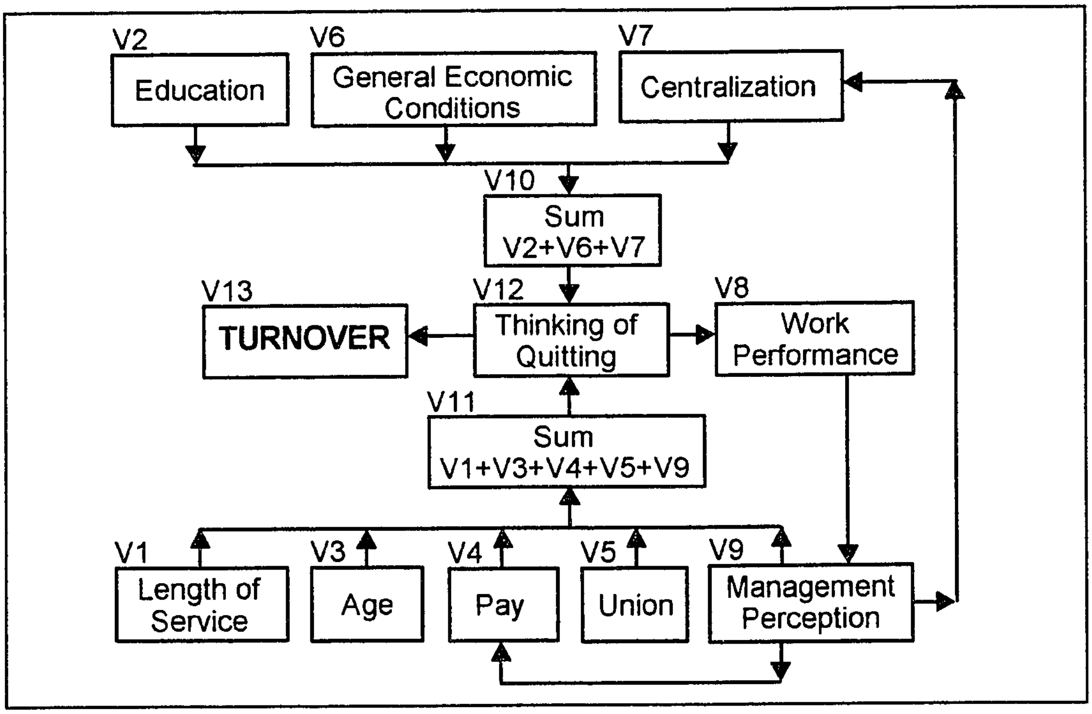


Figure 7 Model of Turnover (annotated version)

place for any variable in the model.

As an aid to visualize the model, figure 8 is presented. An individual "A" is depicted who is acted upon by both the external and organizational variables and also by it's own internal variables which are not shown. Individual "A" has outputs such as work performance which are variable over time and a binary irrevocable output of turnover which, if it occurs, removes the individual from the model. The individual also has an internal state variable of thinking of turnover that can be communicated to others. The model will track thinking of quitting over time. More individuals can be added to the model. Each is effected by the same external variables. The organizational variables can be different for groups of individuals thus representing a kind of departmental hierarchy in the organization. Each individual also has it's own separate

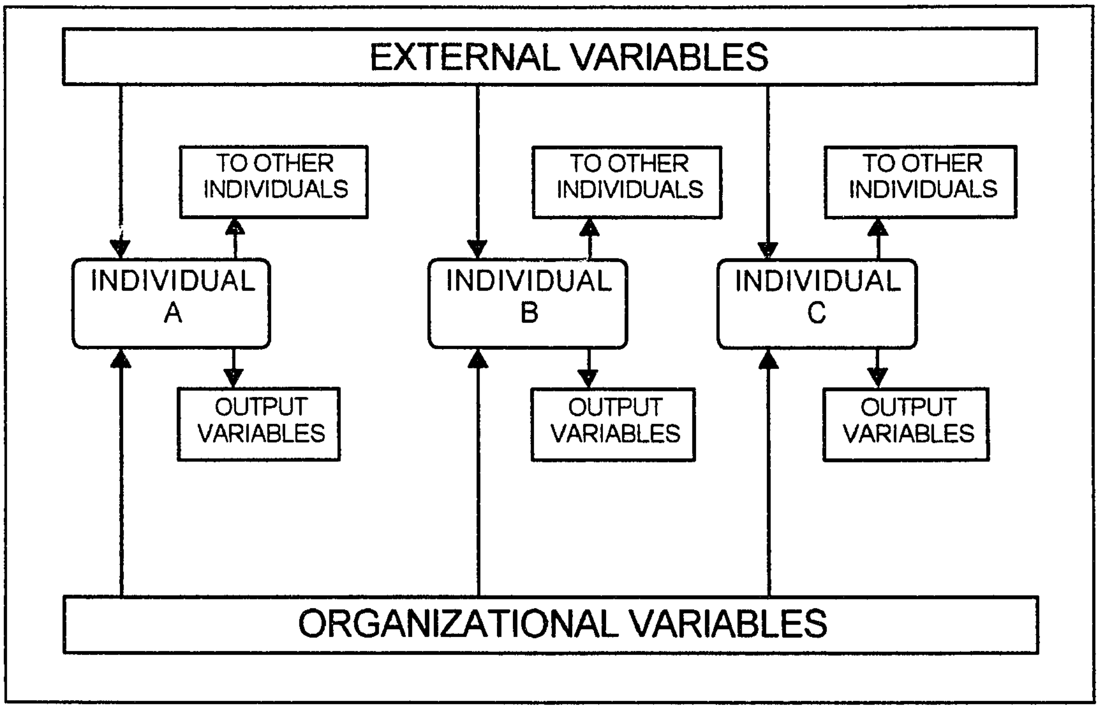


Figure 8 Model Representation

and unique set of values for the internal variables.

The next step was to quantize the variables. As part of this step, a basic decision had to be made. Should the model be binary or decimal in design. The majority of genetic algorithm based models have been binary, while, almost exclusively, the social data available is decimal. Both type of designs were considered and thus both types are discussed in this appendix. The model used for this research was chosen to be decimal because of the lack of binary subroutines and calculational functions available in the Quick Basic programming language and it also simplified the computations used within the program and model.

Notes on Model Formulation

As discussed in various section, this program could have been constructed using either binary or decimal techniques. The decimal version was chosen and is described in chapter five. The discussion here is to present some of the formulation process if the program had been binary. While these techniques were not used, they were considered and some of the concepts were implemented using decimal form.

Once the basic model configuration of variables was determined, the desired number of values for each variable determined the number of binary bits to allocate for each variable. This can be illustrated in the following table:

TABLE 58

DECIMAL VALUES PER BINARY BITS

Binary Bits	Number of Values
1	2
2	4
3	8
4	16
5	32
6	64
7	128

Thus if the variable pay is adequately described with the four values of high, above average, below average, and low which were determined during the field survey, then two binary bits would be needed to encode the values. This can be illustrated in table 59 following:

TABLE 59

EXAMPLE TWO BIT ENCODING

Value	Binary Code	Decimal Value
Low	00	0
Below average	01	1
Above average	10	2
High	11	3

To illustrate the diversity in the bit size of an individual used in A-life models, a program called Genesys/Tracker models 64,000 ants with 450 bits used per individual and will process about one hundred generations consisting of two hundred time steps per generation in an hour on a 16K-processor Connection Machine. Another program called AntFarm models 2,097,152 ants using 25,590 bits per individual and will process five hundred generations with fifty time steps per generation requiring sixteen hours on an 8K-processor Connection Machine. The Connection Machine has been used for many such experiments and a general range of parameter values during these experiments is given in table 60:

TABLE 60

CONNECTION MACHINE PARAMETERS

Item	Low Value	High Value
Individuals	512	10,000,000
Chromosomes	1	256
Bits per chromosome	10	128
Time steps per minute	100	1000

This serves to illustrate the diversity of parameter values used in A-Life models. A model built to run on a 486 based-PC will probably have about ten to twenty variables with a total gene length of 256 bits. The number of time steps would be on the order of one thousand with perhaps one thousand individuals. As more powerful machines become available, these parameters can be scaled upwards allowing more complex models to be simulated.

For the sake of this illustration, the gene functions of a program called MicroAnts are presented in figure 9. The coding structure (chromosome) of an individual ant is shown. One version of the program uses five functions while another uses nine. The greatest number of bits allocated to a function is for gene #1 (vision distance). Four bits allow sixteen values to be programmed for this function. Other functions use either one or two bits which allow two or four values for each function respectively. While this is a simple program, the behavior exhibited by the 'ants' is surprisingly complex and seemingly life-like.

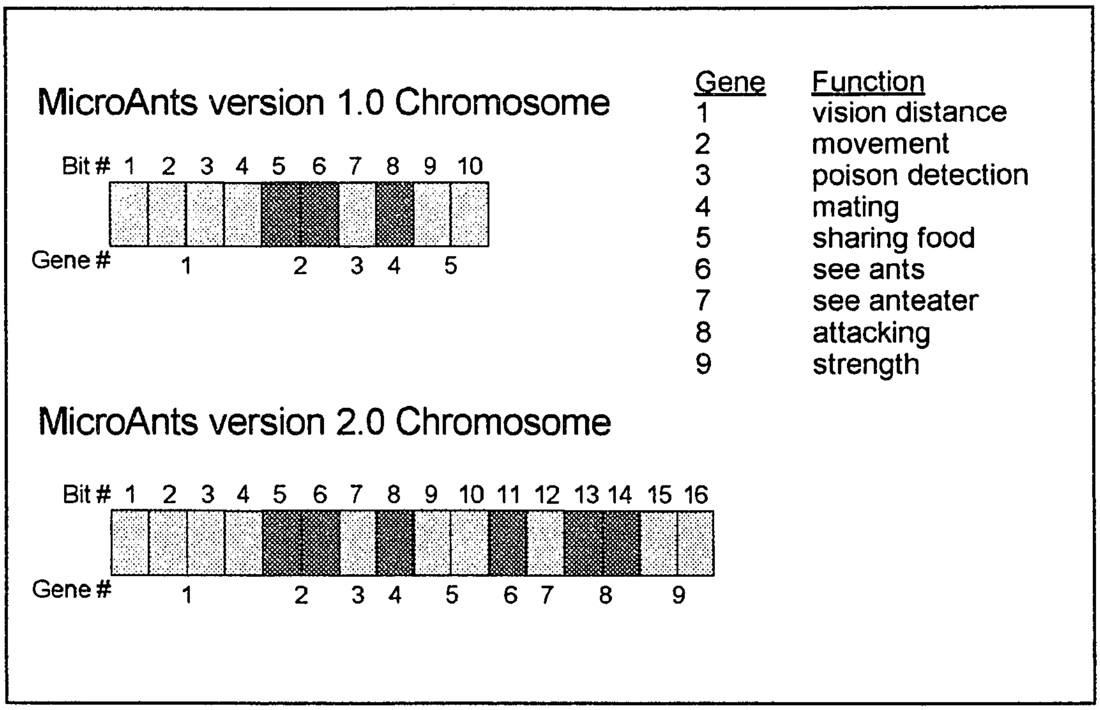


Figure 9 MicroAnt Program Structure

In the prototype for this research, five variables (the three correlates and the two determinates) are internal functions of the individual. Allowing eight values (three bits) for each variable means that fifteen bits will describe the five functions. The assignment of bits to each variable is given in table 61.

TABLE 61

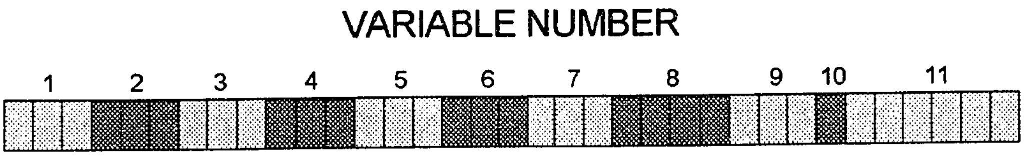
BINARY BIT ASSIGNMENT FOR MODEL

Variable	Number of Decimal Values	Binary Bits
Length of service	8	3
Age	8	3
Education	8	3

Variable	Number of Decimal Values	Binary Bits
Pay	8	3
Centralization	8	3
Economic conditions	8	3
Management perception	8	3
Other individuals	16	4
Work performance	8	3
Quitting	2	1
Thinking of quitting	64	6
Internal variables	-	9
Organizational variables	-	6
External variables	-	10
Action variables	-	4
State variable	-	6
Total	-	35

To thus represent each individual will require thirty-five bits of information contained in eleven variables or chromosomes. A graphical representation of this structure is given in figure 10. This figure also lists each variable and its associated bit length. This particular structure is only slightly more complex than that of the MicroAnts structure.

As each step in the model represents time, a determination of the size of the time step needed to be made. Table 62 represents various combinations of times steps and number of steps to obtain a desired total time duration for the model. A convenient time step size is that of one day. This is commensurate with the time scale that



Variable	# of Bits
1 Length of service	3
2 Age	3
3 Education	3
4 Pay	3
5 Centralization	3
6 Economic conditions	3
7 Management perception	3
8 Other individuals	4
9 Work performance	3
10 Quitting	1
11 Thinking of quitting	6

Binary model consists of
11 Variables with
35 Bits per Individual

Figure 10 Bit Assignment for Binary Model

we experience in daily life. It serves as a measure of the periodicity of work period. It is one day from the start of a work period to the next. This choice allows a model of about 1000 time steps to cover a period of about 4 years. During this time,the behavior of the individuals can be observed.

TABLE 62

TIME STEP COMBINATIONS AND MODEL TIME LENGTH

Time Step	Quantity of Steps	Approximate Time
Hour	10	1 day
"	100	10 days
"	1000	0.5 years
"	10000	5 years

Time Step	Quantity of Steps	Approximate Time
"	100000	50 years
Day	10	0.5 months
"	100	5 months
"	1000	4 years
"	10000	40 years

To illustrate the calculational aspects of the model, consider the variables of length of service, age, and education together with thinking of quitting and quitting. Studies have shown that length of service and age have a negative correlation to turnover and education has a positive correlation. Using thinking of quitting as an antecedent to quitting and relating length of service, age, and education to thinking of quitting, one develops the following relational form. Here, quitting is described to be a function of thinking of quitting which is, in turn, a function of service, age, and education.

$$\textit{Quitting} = F(\textit{thinking of quitting}) = F(\textit{service, age, education}) \tag{4}$$

With a relation specified, the next step is to quantize the values of the variables. Table 63 lists a division of the range of parameter values for each variable into eight categories, representing three binary bits of information. The binary coding is listed next to each category. The coding in the table is a binary coded decimal but other codings such as a gray code or non-binary code can be used. In this example, the binary coding for age and length of service is decreasing to reflect the negative correlation to turnover.

TABLE 63

CODING OF PARAMETER VALUES

Service (years)		Age (years)		Education (years)	
Value	BCD	Value	BCD	Value	BCD
1	111	< 25	111	< 10	000
2	110	25-30	110	10	001
3	101	30-35	101	12 (HS)	010
4	100	35-40	100	>12	011
5	011	40-45	011	14 (AS)	100
6	010	45-50	010	16 (BS)	101
7	001	50-55	001	18 (MS)	110
> 8	000	> 55	000	20 (PhD)	111

For this example, thinking of quitting can be depicted as a simple summation of the values for the three variables (service, age, and education). For this illustration, the new value of thinking of quitting does not depend upon what the previous value had been. Thus, the maximum value for thinking of quitting would be (111 + 111 + 111 = 10101) and the minimum value would be (000 + 000 + 000 = 00000). The maximum value would correspond to an individual with one year of service, under twenty five years old, and having twenty years of education. The minimum value would correspond to an individual with more than eight years of service, over fifty five years old, and having less than ten years of education. This binary implementation would be performed by arithmetic or logic statements within the program. This objective function value can be converted back to a description of thinking of quitting by dividing the range of the summation into an appropriate number of categories and providing the description for each category. This particular method works best where there is a linear gradation of values for each variable and the functional relation can be described as simple. This is illustrated using another table presented below:

TABLE 64

VALUES FOR THINKING OF QUITTING

BCD	Thinking of Quitting
00000 to 00010	none
00011 to 00101	very little
00110 to 01000	little
01001 to 01011	some
01100 to 01110	more than some
10000 to 10010	much
10011 to 10101	very much

Another method would be to use a look-up table. This method is more extensive and it allows the easy implementation of changes in the state value of the variable being dependent upon both the previous value of the state variable and other variables functionally related to it. Look-up tables depend upon the enumeration of all possible combination of variable values and for each combination provide the desired value for state variable. A particular strength of look-up tables is that they can depict non-linear relations and also relations which have steep peaks. Look-up tables are also used when the value of a variable depends upon the previous value. A partial example of a look-up table is presented in table 65. For this illustration, the first four lines show combinations with the old value of thinking of quitting to be a minimum. For line one, the values of service, age, and education are at a minimum which results in the new value of thinking of quitting not changing. For line two, the values of service, age, and education are at a maximum which results in the new value of thinking of quitting increasing. For line three and four, the values of age and education are at a maximum respectively which results in the new value of thinking of quitting increasing but not as much as in line two. To continue the illustration, the last four lines show combinations with the old value of thinking of quitting to be a maximum. For line five, the values of service, age, and education are at a minimum which results in the new value of thinking of quitting decreasing. For line six, the values of service, age, and education are at a maximum which results in the new value of thinking of quitting not changing. For line seven and eight, the values of age and education are at a maximum respectively which results in the new value of thinking of quitting decreasing but not as much as in line five.

TABLE 65

LOOK-UP TABLE

Thinking of Quitting [Old Value]	Service	Age	Education	Thinking of Quitting [New Value]
00000	000	000	000	00000
00000	111	111	111	00011
00000	000	000	111	00001
00000	000	111	000	00001
10101	000	000	000	10010
10101	111	111	111	10101
10101	000	000	111	10011
10101	000	111	000	10011

A particular advantage of look-up tables is that they can be used to efficiently represent non-linear relationships. They also permit efficient programming as machine code statements can often be used instead of higher level languages. They can also be implemented using text tables. A specific disadvantage is that they can often become quite large as all combinations of the variables should be represented. This can increase the run time of a program. For some combination of values, the actual enumeration might not be required as either it could represent a combination which might not occur or the specific use of the value is not needed for the particular application. They are most efficient when the number of permitted values for each variable is kept small. Overall, look-up tables represent the simplest implementation of a binary calculational engine for an A-life model.

The use of neural networks to represent and calculate the functions is another technique that can be employed. A Kohonen or sensory mapping is another alternative. Each of these techniques has certain advantages and disadvantages. Within a given model, more than one technique can be used at the same time. This often results in a model which is less computationally bound and will thus run faster or process more variables in a given amount of time. As A-life models can be quite complex, computational optimization becomes an important factor to consider during their design and construction.

Once the model is constructed and run for a specific starting set of variable values, the program will write, for each generation, the values of the variables to a file which can be examined and analyzed. A typical tool for analysis is to examine individuals who had high or low values for the state variable of thinking of quitting during the program run. Another technique is to perform statistical analysis and cross-tabulations of the individuals to examine similar and dissimilar groupings of variable values. Factor analysis is another tool which can be used to determine the effect of various factors within the model.

Using these tools, the model can be analyzed.

APPENDIX 5

DESCRIPTION OF ARTIFICIAL-LIFE MODEL PROGRAM

This appendix contains a detailed description of the calculations used within the program. These are presented in an annotated pseudo-programming wording to more closely correspond with the actual program language. Also there is a listing of the main calculational variables used with the program and a slight description of each. Also included are several tables which present the code structure used in the program. These tables include some of the configurations of the model which have been run as part of this research. This appendix also contains a listing of the interpretations used to convert variable values to the program values.

Order of Variable Calculations within Program for PVVAL

1. The first determination is to read the value for the initialization of the variable from the configuration file. This is performed once and results in the values for time step zero.

IF VInit = Minimum
THEN the value of a variable is set to the lowest value allowed given the choice of VLen (length of the variable).

IF VInit = Maximum
THEN the value of a variable is set to the highest value allowed given the choice of VLen (length of the variable).

IF VInit = Midpoint
THEN the value of a variable is set to the median or midpoint value of the range allowed given the choice of VLen (length of the variable).

IF VInit = Random
THEN the value of a variable is set to a random value within the range allowed given the choice of VLen (length of the variable).

IF VInit = Random Range (Lxxx-Uxxx)
THEN the value of a variable is set to a random value within the range of an lower and upper bound and also within the range allowed given the choice of VLen (length of the variable).

IF VInit = Constant (Cxxx)
THEN the value of a variable is set to a constant value within the range allowed given the choice of VLen (length of the variable).

IF VInit = Bi-Modal (BLxxx-Uxxx)
THEN the value of a variable is set to one or the other of a pair of user selected values within the range allowed given the choice of VLen (length of the variable).

IF VInit = Normal (NLxxx-Uxxx)
THEN the value of a variable is set a value calculated by applying a Gaussian probability density generator function to a randomly generated value which results in a normal or Gaussian distribution of values for this variable. The plus and minus three standard deviations points and the mean are selected as follows:

a. If supplied by the user, the distribution is calculated with the user supplied values the minus and plus three standard deviation points which describe the distribution. The mean is centered between these points.

b. If not user supplied, the distribution is centered over the allowed range. The mean is calculated as the midpoint of the allowed range and the standard deviation is calculated as one sixth of the allowed range.

2. The next determination is whether the value of VDep (Dependence) is 'Dependent' or 'Autonomous'.

If VDep = Autonomous AND

VRel = Constant
THEN the value of the variable is constant from one time step to the next.

VRel = Ramp Up 1
THEN the value of the variable is incremented at the rate of a value of "one" per time step.

VRel = Ramp Up 10
THEN the value of the variable is incremented at the rate of a value of "one" per ten time steps.

VRel = Ramp Up 100
THEN the value of the variable is incremented at the rate of a value of "one" per one hundred time steps.

VRel = Ramp Up 250
THEN the value of the variable is incremented at the rate of a value of "one" per two hundred fifty time steps.

VRel = Ramp Down 1
THEN the value of the variable is decremented at the rate of a value of "one" per time step.

VRel = Ramp Down 10
THEN the value of the variable is decremented at the rate of a value of "one" per ten time steps.

VRel = Ramp Down 100
THEN the value of the variable is decremented at the rate of a value of "one" per one hundred time steps.

VRel = Ramp Down 250

THEN the value of the variable is decremented at the rate of a value of "one" per two hundred fifty time steps.

VRel = Cycle 1

THEN the value of the variable is varied cyclically at the rate of "one" per time step. This results in a pseudo sine wave having an amplitude of one and a period of four time steps.

VRel = Cycle 10

THEN the value of the variable is varied cyclically at the rate of "one" per ten time steps. This results in a pseudo sine wave having an amplitude of one and a period of forty time steps.

VRel = Cycle 100

THEN the value of the variable is varied cyclically at the rate of "one" per one hundred time steps. This results in a pseudo sine wave having an amplitude of one and a period of four hundred time steps.

OR

If VDep = Dependent

THEN the relation is read by the parser and the following determinations are made:

Sign - the sign (+ or -) value for the subsequent variable which indicated the arithmetic operation to be performed on the variable

V - indicates that the subsequent digit or digits indicate the tag number of the variable

or ## - indicates the tag number of a variable

The indicated operation is then performed on the specified variables and the result is stored as the value for the specified dependent variable. If the summation method is used, then the arithmetic result is used. If the averaged method is used, then the value is weighted by the length of each variable where a length of one, two or three has a weighting factor of one, ten or one hundred respectively. The calculational weighting factor used was one, eleven, or one hundred eleven. This adjusts the values to take into account the different lengths of the variables. The result is rounded to an integer value and the value is adjusted proportionally with the allowed length range.

3. The next step is the check for overflow conditions:

If VLen = 1
THEN the value is adjusted to be within the range of 0 to 9
If VLen = 2
THEN the value is adjusted to be within the range of 0 to 99
If VLen = 3
THEN the value is adjusted to be within the range of 0 to 999

4. The next determination is to read the value for neighborhood and perform the following calculation:

IF VNeighbor = None
THEN the value of the variables is not adjusted.

IF VNeighbor = Block 5
THEN the value of the variables is set to the average integer value of the block of five persons containing the person for which the neighborhood variable is being calculated.

IF VNeighbor = All
THEN the value of the variables is set to the average integer value of all of the persons in the model.

5. The next step is to recheck for overflow conditions:

If VLen = 1
THEN the value is adjusted to be within the range of 0 to 9
If VLen = 2
THEN the value is adjusted to be within the range of 0 to 99
If VLen = 3
THEN the value is adjusted to be within the range of 0 to 999

6. The next determination is to read the value for damping and perform the following calculation:

If VDamp = None (rate)
THEN the value of the variable is not adjusted.

If VDamp = Average
THEN the value of the variable is set to the average of the newly calculated value and the value during the last time step.

If VDamp = Fixed (Fxxx-)

THEN the value of a variable is only allowed to change from the value during the last time step by a maximum of "x" units in either a positive or negative direction according to the direction of the newly calculated value from the old value. If the calculated change is less than "x" units then the newly calculated value is used.

If VDamp = None (value)

THEN the value of the variable is not adjusted.

If VDamp = Floor (-Fxxx)

THEN the value of the variable is not allowed to go below a fixed value. This sets a floor to the value.

If VDamp = Ceiling (-Cxxx)

THEN the value of a variable is not allowed to go above a fixed value. This sets a ceiling to the value.

If VDamp = Sticky Downward (-StDn)

THEN the value of the variable is not allowed to go below the previous value. The variable thus can only stay the same or increase with each time step.

If VDamp = Sticky Upward (-StUp)

THEN the value of the variable is not allowed to go above the previous value. The variable thus can only stay the same or decrease with each time step.

7. The next step is to recheck for overflow conditions:

If VLen = 1

THEN the value is adjusted to be within the range of 0 to 9

If VLen = 2

THEN the value is adjusted to be within the range of 0 to 99

If VLen = 3

THEN the value is adjusted to be within the range of 0 to 999

TABLE 66

DEFINITIONS OF VARIABLES USED WITHIN PROGRAM

Name	Description	Type
NumP	Number of Persons	I4
NumT	Number of Time Steps	I4
NumV	Number of Variables	I4
NumPText	Text "Number of Persons"	S15
NumTText	Text "Number of Time Steps"	S15
NumVText	Text "Number of Variables"	S15
PNum	Person Number	I4
TNum	Time Step Number	I4
VNum	Variable Number	I4
PVVal ( )	Value of (p,v) in current time step	I(1-3)
PVValOld ( )	Value of (p,v) in previous time step	I(1-3)
PVInit ( )	Value of (p,v) in initial time step	I(1-3)
V ( )	Variable Number	I4
VName$ ( )	Variable Name	S15
VLen ( )	Variable Length	I1
VRel$ ( )	Variable Relation	S20
VInit$ ( )	Variable Initialization	S10
VDep$ ( )	Variable Dependence	S10
VNeighbor$ ( )	Variable Neighborhood	S10
VDamp$ ( )	Variable Damping	S10
p	Loop Ct for person	I
t	Loop Ct for time	I
v	Loop Ct for variable	I
k	Loop Ct	I
holder ( )	parser - position of "+ or - or first blank space"	I
sholder ( )	parser - holder for "+ or -"	I
vholder ( )	parser - variable number	I

Name	Description	Type
dig ( )	parser - number of digits for variable number	I
s	parser - counter for variables in equation	I

S = String variable
I = Integer variable

TABLE 67

BLANK MODEL DESCRIPTION FORM

Var #	Var Name	Len	Depend	Init	Neighbor	Relation	Damping
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							

TABLE 68

VALUES [DESCRIPTIONS] USED IN PROGRAM

Var #	Var Name	Len	Depend	Init	Neighbor	Relation	Damping
1		1	Autonomous	Minimum	None	Constant	None
2		2	Depend Sum	Maximum	Block 5	Ramp Up1	Average
3		3	Depend Avg	Midpoint	All	Ramp Up10	Fixed
4				Random		Ramp Up100	Floor
5				Random Range		Ramp Up250	Ceiling
6				Constant		Ramp Dn1	Sticky Down
7				Normal		Ramp Dn10	Sticky Up
8				BiModal		Ramp Dn100	
9						Ramp Dn250	
10						Cycle 1	
11						Cycle 10	
12						Cycle 100	

TABLE 69

VALUES [PROGRAM COMMAND LANGUAGE SET] USED IN PROGRAM

Var #	Var Name	Len	Depend	Init	Neighbor	Relation	Damping
length	15	1	10	10	10	20	10
1		1	Autonomous	Minimum	None	Constant	None-rate
2		2	Depend-Sum	Maximum	Block 5	Ramp Up1	Average
3		3	Depend-Avg	Midpoint	All	Ramp Up10	Fixed [Fxxx]
4				Random		Ramp Up100	None-value
5				Random Range [Lxxx-Uxxx]		Ramp Up250	Floor [-Fxxx]
6				Constant [Cxxx]		Ramp Dn1	Ceiling [-Cxxx]
7				Normal [NLxxx-Uxxx]		Ramp Dn10	Sticky Dn [-StDn]
8				BiModal [BLxxx-Uxxx]		Ramp Dn100	Sticky Up [-StUp]
9						Ramp Dn250	
10						Cycle 1	
11						Cycle 10	
12						Cycle 100	
13						[±Vx{xx}]	

TABLE 70

MODEL USED FOR PROTOTYPE TESTING (CONFIGURATION FILE)

Var #	Var Name	Len	Depend	Init	Neighbor	Relation	Damping
1	Length Service	2	Autonomous	Random Range L005-U025	None	Ramp Up10	None
2	Education	1	Autonomous	Random Range L004-U009	None	Constant	None
3	Age	2	Autonomous	Random Range L025-U055	None	Ramp Up10	None
4	Pay Grade	1	Depend-Avg	Random Range L006-U007	None	+V9	Fixed [F001] & Sticky Dn
5	Union	1	Autonomous	BiModal BL000-U009	None	Constant	None
6	Economic Condition	1	Autonomous	Constant C005	None	Cycle 10	None
7	Centralization	1	Depend-Avg	Random	None	-V9	Fixed [F001]
8	Work Performance	2	Depend-Avg	Random	None	-V12	Fixed [F001]
9	Management Perception	2	Depend-Avg	Random	None	+V8	Fixed [F001]
10	Sum Plus	2	Depend-Avg	Midpoint	None	+V2+V6+V7	None
11	Sum Minus	2	Depend-Avg	Midpoint	None	-V1-V3-V4-V5-V9	None
12	Thinking of Quitting	2	Depend-Avg	Midpoint	Block 5	+V10+V11	Fixed [F001]
13	Turnover	2	Depend-Avg	Midpoint	None	+V12	None

TABLE 71

MODEL AS DESCRIBED IN PROPOSAL

Var #	Var Name	Len	Depend	Init	Neighbor	Relation	Damping
1	Length Service	2	Autonomous	Random	None	Ramp Up250	None
2	Education	1	Autonomous	Random	None	Constant	None
3	Age	2	Autonomous	Random	None	Ramp Up250	None
4	Pay Grade	2	Autonomous	Random	None	Constant	None
5	Union	1	Autonomous	Random	None	Constant	None
6	Economic Condition	2	Autonomous	Random	None	Cycle 100	None
7	Centralization	2	Autonomous	Random	None	Constant	None
8	Work Performance	2	Depend-Sum	Random	None	+V12	None
9	Management Perception	2	Depend-Avg	Random	None	+V8	None
10	Sum 1 to 4		Depend-Sum		None	+V1+V2+V3+V4	None
11	Sum 5 to 7		Depend-Sum		None	+V5+V6+V7	None
12	Thinking of Quitting	2	Depend-Avg	Random	None	+V10+V11	None
13	Turnover		Depend-Avg		None	+V12	None

Interpretation of Values for Variables

1. Length of Service [length 2] range = 00 - 99 = actual years of government service.

2. Education [length 1] range = 0 - 9 = year of university study.

University Achievement	Years at University	Variable Value
High school degree	0	0
Associate degree	2	2
Bachelor degree	4	4
Masters degree	6	6
Doctorate degree	9	9

3. Age [length 2] range = 00 - 99 = actual chronological age

4. Pay Grade [length 1] range = 0 - 9 = table of values

Pay Grade	Grades above GS-5	Variable Value
GS-5	0	0
GS-6	1	1
GS-7	2	2
GS-8	3	3
GS-9	4	4
GS-10	5	5
GS-11	6	6
GS-12	7	7
GS-13	8	8
GS-14	9	9

There also exists Civil Service pay grade levels GS-15 through GS-18. These are outside the scope of this model as the simulations uses working engineers who are not engineering managers. Generally pay grade levels of GS-13 and GS-14 are considered to be middle managerial positions and pay grade levels of GS-15 and above are considered to be senior managerial positions.

5. Union [length 1] range = 0 - 9 = table of values

Union Membership	Variable Value
No	0
Yes	9

6. Economic Conditions [length 1] range = 0 - 9 = table of values

Economic Conditions	Variable Value
Super Bad	0
Worse than Bad	1
Bad	2
Less than Average	3
Low Average	4
High Average	5
Better than Average	6
Good	7
Better than Good	8
Super Good	9

7. Centralization [length 1] range = 0 - 9 = table of values

Centralization	Variable Value
Extremely Decentralized	0
Very Decentralized	1
Decentralized	2
Slightly Decentralized	3
Very Slightly Decentralized	4
Very Slightly Centralized	5
Slightly Centralized	6
Centralized	7
Very Centralized	8
Extremely Centralized	9

8. Work Performance [length 2] range = 00 - 99 = table of values

Work Performance	Variable Value
Super Bad	00
Worse than Bad	11
Bad	22
Less than Average	33
Low Average	44
High Average	55
Better than Average	66
Good	77
Better than Good	88
Super Good	99

9. Management Perception [length 2] range = 00 - 99 = table of values

Management Perception	Variable Value
Super Bad	00
Worse than Bad	11
Bad	22
Less than Average	33
Low Average	44
High Average	55
Better than Average	66
Good	77
Better than Good	88
Super Good	99

10. Sum 1 to 4 [length 2] range = 00 - 99

This is the sum of variables 1 through 4

11. Sum 5 to 7 [length 2] range = 00 - 99

This is the sum of variables 5 through 7

12. Thinking of Quitting [length 2] range = 00 - 99 = table of values

Thinking of Quitting	Variable Value
None of the Time	00
Rarely	11
Infrequently	22
Occasionally	33
Moderately Often Low	44
Moderately Often High	55
Recurrently	66
Frequently	77
Almost Constantly	88
All the Time	99

13. Turnover [length 2] range = 00 - 99 = table of values

Turnover	Variable Value
No	< TBD value
Yes	>= TBD value

APPENDIX 6

FILE STRUCTURE

This appendix contains three tables which provides the detail for the structure used in the configuration, initialization, and data files respectively. Within each file, the general convention used was that a data record or line uses a hard-return as a delineator and within each record, fields are delineated by the use of a comma.

TABLE 72

CONFIGURATION FILE STRUCTURE

Rec #		Fld 1	Fld 2	Fld 3	Fld 4	Fld 5	Fld 6	Fld 7	Fld 8
Description		Numeric Descriptor	Text	Length	Dependence	Initialization	Neighborhood	Relation	Damping
Length in Program		4%	15$	1%	10$	10$	10$	20$	10$
Rec 1		# Persons NumP	"Persons" NumPText	-	-	-	-	-	-
Rec 2		# Time Steps NumT	"Time Steps" NumTText	-	-	-	-	-	-
Rec 3		# Variables NumV	"Variables" NumVText	-	-	-	-	-	-
Rec 4 - N	Program Name	V( )	VName$( )	VLen( )	VDep$( )	VInit$( )	VNeighbor$( )	VRel$( )	VDamp$( )
Rec 4		Var 1 Number	"Variable 1"	VLen(1)	VDep$(1)	VInit$(1)	VNeighbor$(1)	VRel$(1)	VDamp$(1)
Rec 5		Var 2 Number	"Variable 2"	VLen(2)	VDep$(2)	VInit$(2)	VNeighbor$(2)	VRel$(2)	VDamp$(2)
Rec N		Var N Number	"Variable N"	VLen(n)	VDep$(n)	VInit$(n)	VNeighbor$(n)	VRel$(n)	VDamp$(n)

TABLE 73

INITIALIZATION FILE STRUCTURE

Rec #	Fld 1	Fld 2	Fld 3	Fld 4	Fld 5	Fld 6	Fld 7	Fld K
Description	Time Step Number	Person Number	Variable 1 Value	Variable 2 Value	Variable 3 Value	Variable 4 Value	Variable 5 Value	Variable K Value
Length in Program	5%	4%	1-3% VLen(1)	1-3% VLen(2)	1-3% VLen(3)	1-3% VLen(4)	1-3% VLen(5)	1-3% VLen(K)
Program Name	TNum	PNum	PVInit(p,v)	PVInit(p,v)	PVInit(p,v)	PVInit(p,v)	PVInit(p,v)	PVInit(p,v)
Rec 1	Time Step 0	Person 1	PVInit(1,1)	PVInit(1,2)	PVInit(1,3)	PVInit(1,4)	PVInit(1,5)	PVInit(1,k)
Rec 2	Time Step 0	Person 2	PVInit(2,1)	PVInit(2,2)	PVInit(2,3)	PVInit(2,4)	PVInit(2,5)	PVInit(2,k)
Rec P	Time Step 0	Person P	PVInit(p,1)	PVInit(p,2)	PVInit(p,3)	PVInit(p,4)	PVInit(p,5)	PVInit(p,k)

PVInit is used to hold the value for the initial time step.

TABLE 74

DATA FILE STRUCTURE

Rec #	Fld 1	Fld 2	Fld 3	Fld 4	Fld 5	Fld 6	Fld 7	Fld K
Description	Time Step Number	Person Number	Variable 1 Value	Variable 2 Value	Variable 3 Value	Variable 4 Value	Variable 5 Value	Variable K Value
Length in Program	5%	4%	1-3% VLen(1)	1-3% VLen(2)	1-3% VLen(3)	1-3% VLen(4)	1-3% VLen(5)	1-3% VLen(K)
Program Name	TNum	PNum	PVVal(p,v)	PVVal(p,v)	PVVal(p,v)	PVVal(p,v)	PVVal(p,v)	PVVal(p,v)
Rec 1	Time Step 0	Person 1	PVVal(1,1)	PVVal(1,2)	PVVal(1,3)	PVVal(1,4)	PVVal(1,5)	PVVal(1,k)
Rec 2	Time Step 0	Person 2	PVVal(2,1)	PVVal(2,2)	PVVal(2,3)	PVVal(2,4)	PVVal(2,5)	PVVal(2,k)
Rec P	Time Step 0	Person P	PVVal(p,1)	PVVal(p,2)	PVVal(p,3)	PVVal(p,4)	PVVal(p,5)	PVVal(p,k)
Rec P+1	Time Step 1	Person 1	PVVal(1,1)	PVVal(1,2)	PVVal(1,3)	PVVal(1,4)	PVVal(1,5)	PVVal(1,k)
Rec P	Time Step 1	Person P	PVVal(p,1)	PVVal(p,2)	PVVal(p,3)	PVVal(p,4)	PVVal(p,5)	PVVal(p,k)
Rec TP	Time Step T	Person P	PVVal(p,1)	PVVal(p,2)	PVVal(p,3)	PVVal(p,4)	PVVal(p,5)	PVVal(p,k)

PVVal is used to hold the value for the current time step.
PVValOld is used to hold the value for the previous time step.
PVInit is used to hold the value for the initial time step.

APPENDIX 7

SAMPLE ARTIFICIAL-LIFE MODEL RESULTS

This appendix contains a sample printout of configuration data, an initialization file and the associated model run. The configuration data was used for the initialization and data run. This example model of thirteen variables used twenty persons for twenty five time steps.

Model Configuration

```
20,"Persons",0,"!","!","!","!","!"
25,"Time Steps",0,"!","!","!","!","!"
13,"Variables",0,"!","!","!","!","!"
 1,"Length Service ",2,"Autonomous","L005-U025","None","Ramp Up10","None"
 2,"Education      ",1,"Autonomous","L004-U009","None","Constant","None"
 3,"Age            ",2,"Autonomous","L025-U055","None","Ramp Up10","None"
 4,"Pay Grade      ",1,"Depend-Avg","L006-U007","None","+V9            ","F001-StDn"
 5,"Union          ",1,"Autonomous","Random","None","Constant","None"
 6,"Econ Condition ",1,"Autonomous","C005","None","Cycle 10","None"
 7,"Centralization ",1,"Depend-Avg","Random","None","-V9            ","F001"
 8,"Work Perform   ",2,"Depend-Avg","Random","None","-V12           ","F001"
 9,"Manage Precept ",2,"Depend-Avg","Random","None","+V8            ","F001"
10,"Sum 1 to 4     ",2,"Depend-Avg","Midpoint","None","+V2+V6+V7      ","None"
11,"Sum 5 to 7     ",2,"Depend-Avg","Midpoint","None","+V1+V3+V4+V5+V9","None"
12,"Think of Quit  ",2,"Depend-Avg","Midpoint","Block 5","+V10+V11       ","F001"
13,"Turnover       ",2,"Depend-Avg","Midpoint","None","+V12           ","None"
```

Model Initialization

```
Time Person V(1 2 3 4 5 6 7 8 9 10 11 12 13)

0, 1, 5, 4, 30, 6, 5, 5, 5, 3, 40, 50, 50, 50, 50
0, 2, 19, 4, 39, 6, 8, 5, 4, 90, 31, 50, 50, 50, 50
0, 3, 21, 7, 55, 6, 7, 5, 4, 5, 67, 50, 50, 50, 50
0, 4, 21, 9, 52, 6, 9, 5, 0, 54, 77, 50, 50, 50, 50
0, 5, 10, 7, 47, 7, 7, 5, 1, 8, 99, 50, 50, 50, 50
0, 6, 18, 4, 25, 6, 3, 5, 6, 53, 27, 50, 50, 50, 50
0, 7, 14, 4, 42, 6, 3, 5, 9, 36, 64, 50, 50, 50, 50
0, 8, 10, 7, 30, 7, 6, 5, 1, 22, 70, 50, 50, 50, 50
0, 9, 18, 4, 54, 6, 2, 5, 2, 37, 15, 50, 50, 50, 50
0, 10, 7, 8, 53, 6, 7, 5, 6, 23, 24, 50, 50, 50, 50
0, 11, 12, 4, 40, 6, 6, 5, 7, 85, 31, 50, 50, 50, 50
0, 12, 22, 9, 26, 6, 8, 5, 5, 42, 28, 50, 50, 50, 50
0, 13, 11, 8, 31, 6, 7, 5, 5, 78, 16, 50, 50, 50, 50
0, 14, 11, 7, 43, 6, 5, 5, 4, 91, 50, 50, 50, 50, 50
0, 15, 17, 5, 31, 6, 2, 5, 9, 42, 98, 50, 50, 50, 50
0, 16, 19, 9, 52, 7, 5, 5, 1, 6, 81, 50, 50, 50, 50
0, 17, 13, 7, 53, 6, 8, 5, 3, 24, 30, 50, 50, 50, 50
0, 18, 12, 9, 39, 7, 6, 5, 9, 49, 35, 50, 50, 50, 50
0, 19, 11, 5, 26, 6, 7, 5, 5, 98, 92, 50, 50, 50, 50
0, 20, 25, 8, 28, 7, 1, 5, 0, 5, 54, 50, 50, 50, 50
```

Model Data Run

```
Time Person V(1 2 3 4 5 6 7 8 9 10 11 12 13)

1, 1, 5, 4, 30, 6, 5, 5, 5, 4, 39, 51, 27, 50, 50
1, 2, 19, 4, 39, 6, 8, 5, 5, 89, 32, 48, 32, 50, 50
1, 3, 21, 7, 55, 6, 7, 5, 3, 6, 66, 59, 49, 50, 50
1, 4, 21, 9, 52, 7, 9, 5, 1, 53, 76, 51, 52, 50, 50
1, 5, 10, 7, 47, 8, 7, 5, 0, 9, 98, 48, 53, 50, 50
1, 6, 18, 4, 25, 6, 3, 5, 7, 52, 28, 55, 25, 50, 50
1, 7, 14, 4, 42, 6, 3, 5, 8, 37, 63, 66, 41, 50, 50
1, 8, 10, 7, 30, 7, 6, 5, 2, 23, 69, 48, 39, 50, 50
1, 9, 18, 4, 54, 6, 2, 5, 3, 38, 16, 40, 30, 50, 50
1, 10, 7, 8, 53, 6, 7, 5, 7, 24, 23, 70, 30, 50, 50
1, 11, 12, 4, 40, 6, 6, 5, 6, 84, 32, 59, 30, 50, 50
1, 12, 22, 9, 26, 6, 8, 5, 6, 43, 29, 70, 28, 50, 50
1, 13, 11, 8, 31, 6, 7, 5, 6, 77, 17, 66, 22, 50, 50
1, 14, 11, 7, 43, 6, 5, 5, 4, 90, 51, 59, 36, 50, 50
1, 15, 17, 5, 31, 7, 2, 5, 8, 43, 97, 70, 48, 50, 50
1, 16, 19, 9, 52, 7, 5, 5, 2, 7, 80, 55, 52, 50, 50
1, 17, 13, 7, 53, 6, 8, 5, 4, 25, 29, 55, 35, 50, 50
1, 18, 12, 9, 39, 7, 6, 5, 8, 49, 36, 84, 31, 50, 50
1, 19, 11, 5, 26, 7, 7, 5, 4, 97, 93, 55, 45, 50, 50
1, 20, 25, 8, 28, 7, 1, 5, 1, 6, 53, 48, 36, 50, 50

2, 1, 5, 4, 30, 6, 5, 5, 5, 5, 38, 51, 27, 49, 50
2, 2, 19, 4, 39, 6, 8, 5, 6, 88, 33, 51, 33, 49, 50
2, 3, 21, 7, 55, 6, 7, 5, 3, 7, 65, 55, 49, 49, 50
2, 4, 21, 9, 52, 7, 9, 5, 2, 52, 75, 55, 52, 49, 50
2, 5, 10, 7, 47, 9, 7, 5, 0, 10, 97, 44, 53, 49, 50
2, 6, 18, 4, 25, 6, 3, 5, 6, 51, 29, 59, 25, 49, 50
2, 7, 14, 4, 42, 6, 3, 5, 7, 38, 62, 62, 40, 49, 50
2, 8, 10, 7, 30, 7, 6, 5, 3, 24, 68, 51, 38, 49, 50
2, 9, 18, 4, 54, 6, 2, 5, 4, 39, 17, 44, 30, 49, 50
2, 10, 7, 8, 53, 6, 7, 5, 7, 25, 24, 73, 30, 49, 50
2, 11, 12, 4, 40, 6, 6, 5, 6, 83, 33, 55, 30, 49, 50
2, 12, 22, 9, 26, 6, 8, 5, 6, 44, 30, 73, 29, 49, 50
2, 13, 11, 8, 31, 6, 7, 5, 7, 76, 18, 70, 23, 49, 50
2, 14, 11, 7, 43, 6, 5, 5, 4, 89, 52, 59, 36, 49, 50
2, 15, 17, 5, 31, 8, 2, 5, 7, 44, 96, 66, 48, 49, 50
2, 16, 19, 9, 52, 7, 5, 5, 2, 8, 79, 59, 51, 50, 50
2, 17, 13, 7, 53, 6, 8, 5, 5, 26, 28, 59, 34, 50, 50
2, 18, 12, 9, 39, 7, 6, 5, 7, 49, 37, 81, 31, 50, 50
2, 19, 11, 5, 26, 8, 7, 5, 3, 96, 94, 51, 45, 50, 50
2, 20, 25, 8, 28, 7, 1, 5, 2, 7, 52, 51, 36, 50, 50

3, 1, 5, 4, 30, 6, 5, 5, 6, 6, 37, 51, 26, 48, 49
3, 2, 19, 4, 39, 6, 8, 5, 6, 87, 34, 55, 33, 48, 49
3, 3, 21, 7, 55, 6, 7, 5, 3, 8, 64, 55, 48, 48, 49
3, 4, 21, 9, 52, 7, 9, 5, 2, 51, 74, 59, 52, 48, 49
3, 5, 10, 7, 47, 9, 7, 5, 0, 11, 96, 44, 53, 48, 49
3, 6, 18, 4, 25, 6, 3, 5, 6, 50, 30, 55, 25, 48, 49
3, 7, 14, 4, 42, 6, 3, 5, 6, 39, 61, 59, 40, 48, 49
```

```
Time Person V(1 2 3 4 5 6 7 8 9 10 11 12 13)

3, 8, 10, 7, 30, 7, 6, 5, 3, 25, 67, 55, 38, 48, 49
3, 9, 18, 4, 54, 6, 2, 5, 5, 40, 18, 48, 30, 48, 49
3, 10, 7, 8, 53, 6, 7, 5, 7, 26, 25, 73, 30, 48, 49
3, 11, 12, 4, 40, 6, 6, 5, 6, 82, 34, 55, 30, 49, 49
3, 12, 22, 9, 26, 6, 8, 5, 6, 45, 31, 73, 29, 49, 49
3, 13, 11, 8, 31, 6, 7, 5, 7, 75, 19, 73, 23, 49, 49
3, 14, 11, 7, 43, 6, 5, 5, 4, 88, 53, 59, 37, 49, 49
3, 15, 17, 5, 31, 9, 2, 5, 6, 45, 95, 62, 48, 49, 49
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APPENDIX 8

ANALYSIS OF MODEL SIMULATION

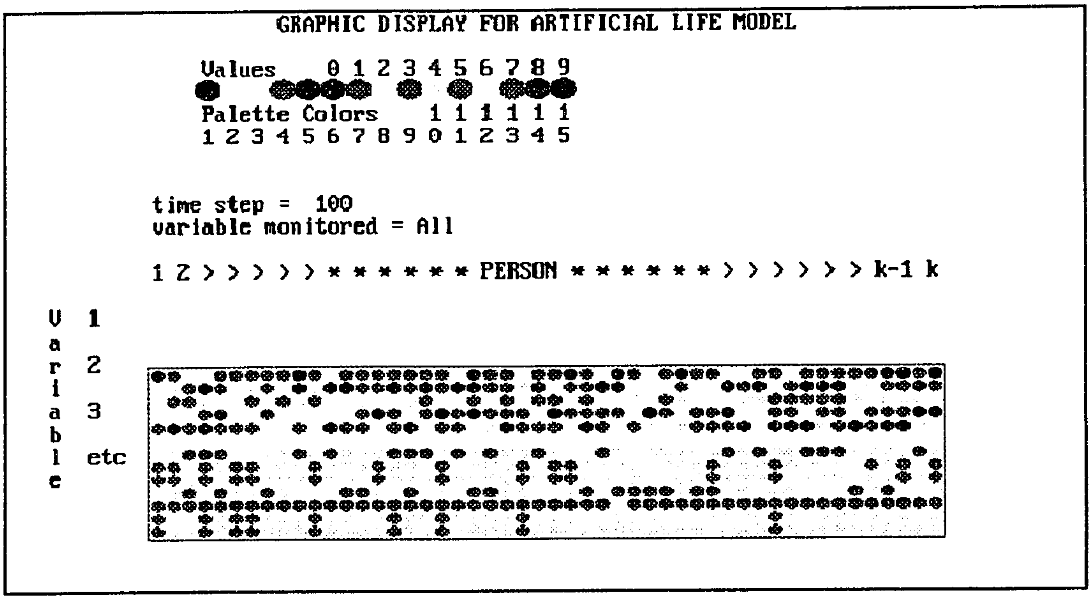
This appendix includes some examples of graphs and plots that were produced during the analysis of the model simulation data. The items included are:

Graphic output display for Artificial-Life model

Chernoff plots

Output analysis tables

Output histogram



```
                  GRAPHIC DISPLAY FOR ARTIFICIAL LIFE MODEL

                 Values    0 1 2 3 4 5 6 7 8 9

                 Palette Colors    1 1 1 1 1 1
                 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5

              time step =  100
              variable monitored = All

              1 2 > > > > > * * * * * * PERSON * * * * * * > > > > > > k-1 k

   V  1
   a
   r  2
   i
   a  3
   b
   l  etc
   e
```

Figure 11 Screen Dump of Program Display

This display presents a screen dump from the analysis segment of the program. It was created by screen capturing an output screen as the model was running and pasting the image into a paint program. The colors were converted to grey scale and the image saved as a PCX file.

This example uses the same data from a model of thirteen variables with fifty persons for one hundred steps. At each time step, the graphic display updates the image to reflect the current values for each variable for each person for that time step.

Chernoff Plots

Chernoff plots are depicted by schematic faces for which the relative values of variables selected for the plot are represented by variations of specific facial features. In general, one can control the shape of the face, nose, mouth, eyes, eyebrows, and ears. In specific terms, variables can be linked to the following facial features:

1. Face width
2. Ear level
3. Half-face height
4. Eccentricity of upper face
5. Eccentricity of lower face
6. Length of nose
7. Position of center of mouth
8. Curvature of mouth
9. Length of mouth
10. Height of center for eyes
11. Separation of eyes
12. Slant of eyes
13. Eccentricity of eyes
14. Half-length of eye
15. Position of pupils
16. Height of eyebrows
17. Angle of eyebrows
18. Length of eyebrows
19. Radius of ear
20. Nose width

While useful for presenting behavioral data in terms of likes or dislikes, this technique has some disadvantages. It becomes cumbersome for presenting data on many individuals, it requires a great deal of experimentation to obtain a good assignment of variables and their values to the facial features. For example, a neutral value for satisfaction when mapped to the mouth curvature must be adjusted to a neutral appearing mouth and a positive or negative value for satisfaction must then be scaled to obtain the desired degree of smile or frown respectively.

For these examples, the final time step data of a test model of twenty individuals was used. The first graph presents a plot of the values for management perception and the second presents that of thinking of quitting.

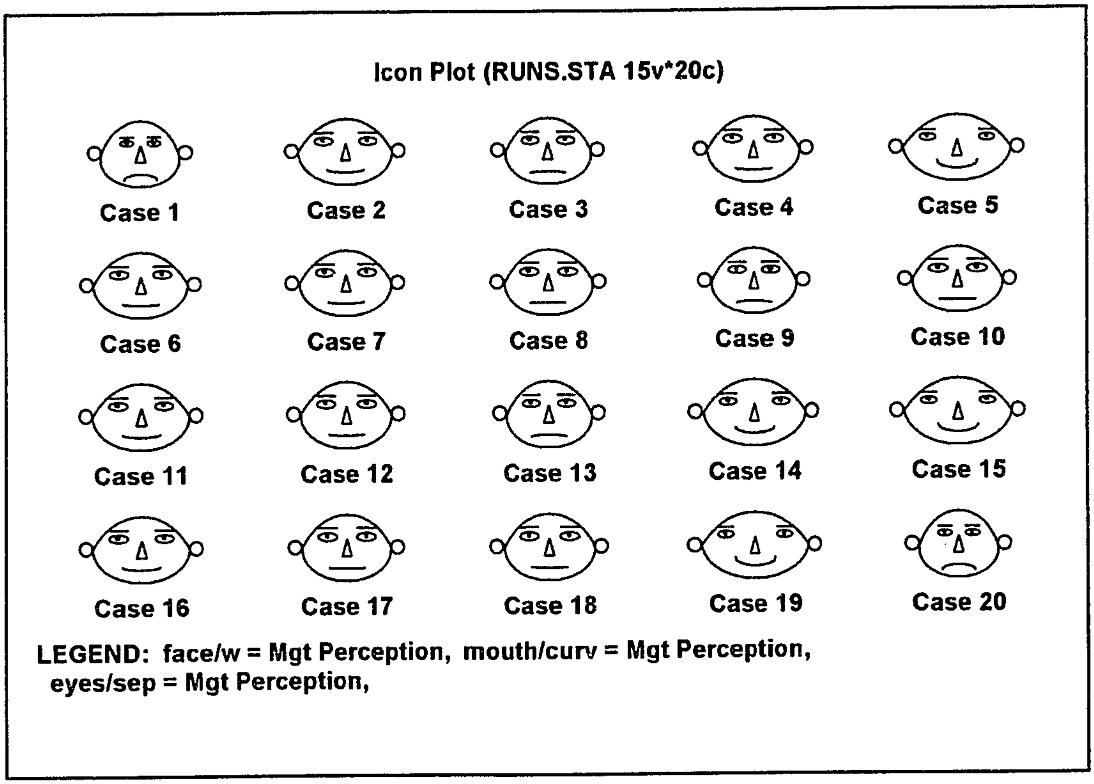


Figure 12 Chernoff Plot of Management Perception

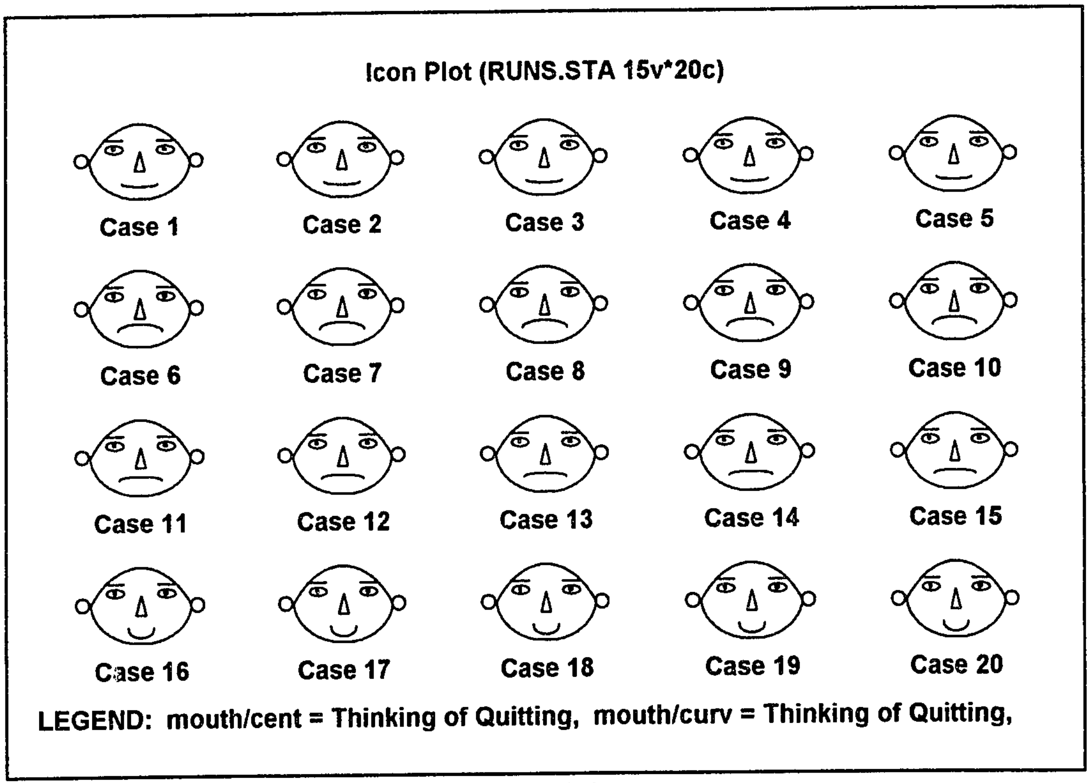


Figure 13 Chernoff Plot of Thinking of Quitting

TABLE 75

GROUPED RANGE OF MANAGEMENT PERCEPTION

Value	Count	Cumul. Count	Percent
0<=x<5	9	9	.018
5<=x<10	58	67	.116
10<=x<15	97	164	.194
15<=x<20	117	281	.234
20<=x<25	151	432	.302
25<=x<30	355	787	.710
30<=x<35	4023	4810	8.046
35<=x<40	9327	14137	18.654
40<=x<45	15049	29186	30.098
45<=x<50	12977	42163	25.954
50<=x<55	5396	47559	10.792
55<=x<60	1390	48949	2.780
60<=x<65	265	49214	.530
65<=x<70	206	49420	.412
70<=x<75	172	49592	.344
75<=x<80	156	49748	.312
80<=x<85	101	49849	.202
85<=x<90	72	49921	.144
90<=x<95	58	49979	.116
95<=x<100	21	50000	.042
Missing	0	50000	0.000

TABLE 76

GROUPED RANGE OF THINKING OF QUITTING

Value	Count	Cumul. Count	Percent
0<=x<5	0	0	0.000
5<=x<10	0	0	0.000
10<=x<15	0	0	0.000
15<=x<20	0	0	0.000
20<=x<25	0	0	0.000
25<=x<30	0	0	0.000
30<=x<35	0	0	0.000
35<=x<40	17	17	.034
40<=x<45	1528	1545	3.056
45<=x<50	6380	7925	12.760
50<=x<55	13941	21866	27.882
55<=x<60	14944	36810	29.888
60<=x<65	9123	45933	18.246
65<=x<70	3863	49796	7.726
70<=x<75	204	50000	.408
Missing	0	50000	0.000

TABLE 77

RANGE OF THINKING OF QUITTING

Value	Count	Cumul. Count	Percent	Cumul. Percent
38	2	2	.004	.004
39	15	17	.030	.034
40	58	75	.116	.150
41	63	138	.126	.276
42	305	443	.610	.886
43	246	689	.492	1.378
44	856	1545	1.712	3.090
45	688	2233	1.376	4.466
46	1785	4018	3.570	8.036
47	991	5009	1.982	10.018
48	1962	6971	3.924	13.942
49	954	7925	1.908	15.850
50	2265	10190	4.530	20.380
51	1521	11711	3.042	23.422
52	3455	15166	6.910	30.332
53	2097	17263	4.194	34.526
54	4603	21866	9.206	43.732
55	2248	24114	4.496	48.228
56	4812	28926	9.624	57.852
57	2222	31148	4.444	62.296
58	4070	35218	8.140	70.436
59	1592	36810	3.184	73.620
60	2361	39171	4.722	78.342
61	1144	40315	2.288	80.630
62	2206	42521	4.412	85.042
63	1108	43629	2.216	87.258
64	2304	45933	4.608	91.866
65	921	46854	1.842	93.708
66	1584	48438	3.168	96.876
67	485	48923	.970	97.846

Value	Count	Cumul. Count	Percent	Cumul. Percent
68	724	49647	1.448	99.294
69	149	49796	.298	99.592
70	162	49958	.324	99.916
71	16	49974	.032	99.948
72	18	49992	.036	99.984
73	4	49996	.008	99.992
74	4	50000	.008	100.000
Missing	0	50000	0.000	100.000

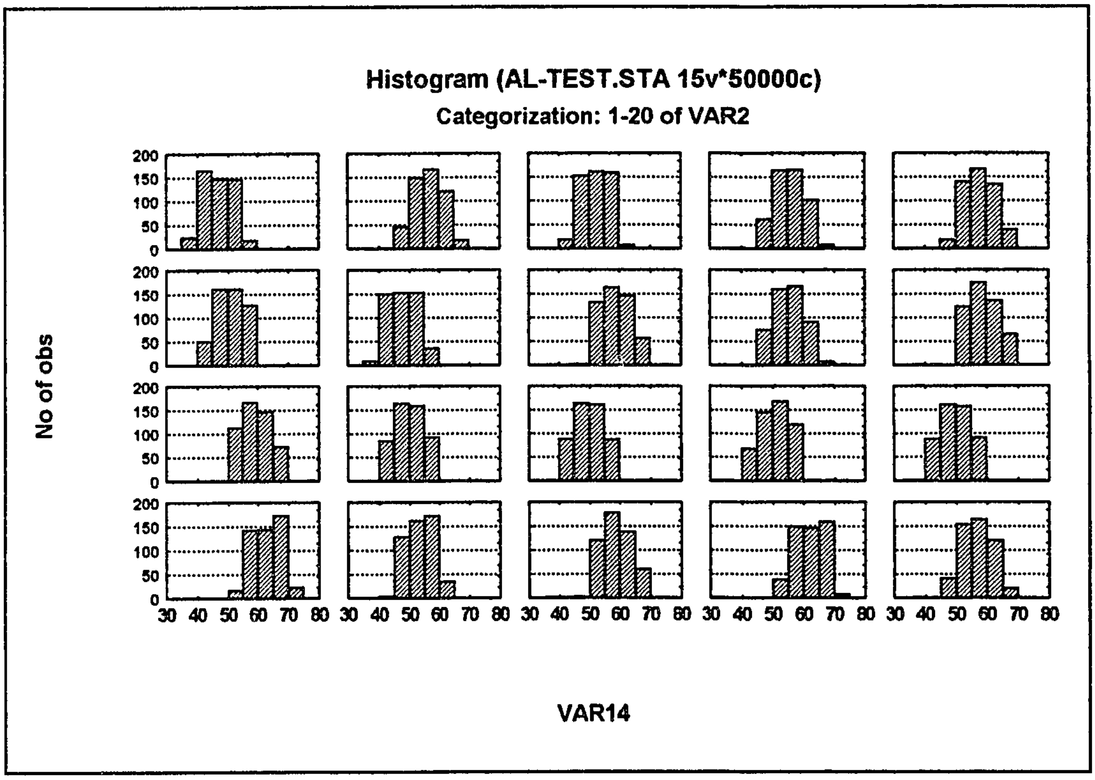


Figure 14 Histogram of Thinking of Quitting

APPENDIX 9

PROGRAM LISTING OF ARTIFICIAL-LIFE MODEL

This appendix contains the source code for the calculational and graphic presentation routines developed and used in the program. Code adapted from shareware routines and functions used for menu generation is not included as this code is not specific for this application.

Source Code of Artificial-Life Simulation Program

```
DECLARE SUB Agraph (VLen())
DECLARE SUB FConfigWrite ()
DECLARE SUB modelcalc (PVInit())
DECLARE SUB InitModel ()
DECLARE SUB PTest ()
DECLARE SUB PGreen ()
DECLARE SUB PRed ()
DECLARE SUB PBlue ()

' DECLARE statements for all the QBSCR routines
DECLARE FUNCTION BlockSize% (L%, r%, t%,
B%)
DECLARE FUNCTION ColorChk ()
DECLARE FUNCTION GetBackground% (row%,
col%)
DECLARE FUNCTION GetForeground% (row%,
col%)
DECLARE FUNCTION GetVideoSegment! ()
DECLARE FUNCTION MakeMenu% (choice$(),
numOfChoices%, justify$, leftColumn!, rightColumn!,
row%,
marker$, fg%, bg%, hfg%, hBG%, qfg%, qbg%)
DECLARE FUNCTION SubMenu% (choice$(),
currentMenu%, numOfChoices%, justify$,
leftColumn!, rightColumn!, row%, marker$, fg%,
bg%, hfg%, hBG%, qfg%, qbg%)
DECLARE FUNCTION SelectList$ (items$(),
numItems%, topRow%, botRow%, leftCol%,
maxWidth%, normFG%, normBG%, hiFG%, hBG%)
DECLARE SUB BlockRestore (L%, r%, t%, B%,
scrArray%(), segment!)
DECLARE SUB BlockSave (L%, r%, t%, B%,
scrArray%(), segment!)
DECLARE SUB ClrScr (mode%, fillChar$)
DECLARE SUB DisplayEntry (entry$, qfg%, qbg%,
hfg%, hBG%, fg%, bg%, marker$, actionCode%)
DECLARE SUB EditString (st$, leftCol%, row%,
foreColor%, backColor%)
DECLARE SUB GetScreen (file$)
DECLARE SUB MakeWindow (topRow!, leftCol!,
botRow!, rightCol!, foreColor%, backColor%,
windowType%, frameType%, shadowColor%,
explodeType%, label$)
DECLARE SUB MultiMenu (menusArray$(),
numEntries%(), menuTitles$(), justify$, marker$,
shadowCode%, fg%, bg%, hfg%, hBG%, qfg%,
qbg%, menuSelected%, menuEntrySelected%)
DECLARE SUB PutScreen (file$)
```

```
DECLARE SUB ScrnRestore (firstLine%, lastLine%,
scrArray%(), segment)
DECLARE SUB ScrnSave (firstLine%, lastLine%,
scrArray%(), segment)
DECLARE SUB ViewList (list$(), listLen%,
maxWidth%, topRow%, botRow%, leftCol%, fg%,
bg%)
DECLARE SUB wipe (top%, bottom%, lft%, rght%,
back%)

'CONSTants required by the Screen Routines
CONST FALSE = 0, TRUE = NOT FALSE
CONST LEFTARROWCODE = -99
CONST RIGHTARROWCODE = -98

CONST NumPtxt = "Persons"
CONST NumTtxt = "Time Steps"
CONST NumVtxt = "Variables"

COMMON SHARED NumV, NumP, NumT, Drive$,
Datapath$, D$, S$
COMMON SHARED PVInit(), VLen()
COLOR 1, 7
' $DYNAMIC
INPUT "enter A for A:\ or C for C:\QB45\PHD\ ",
input1$
IF input1$ = "A" THEN Datapath$ = "A:\"
IF input1$ = "a" THEN Datapath$ = "A:\"
IF input1$ = "C" THEN Datapath$ =
"C:\QB45\PHD\"
IF input1$ = "c" THEN Datapath$ = "C:\QB45\PHD\"

D$ = CHR$(186)
S$ = CHR$(179)

'DIM V(4)
'DIM VName$(4)
DIM VLen(4)
'DIM VInit$(4)
'DIM VRel$(4)
DIM VDamp$(4)

scr1:
CLS 0
LOCATE 8, 10
PRINT , "1 = Initialize a new model to a JIF file"
PRINT , "2 = not yet Read an old model from start
and rerun"
```

```
PRINT , "3 = not yet Read an old model from last record and continue"
PRINT , "4 = not yet"
PRINT , "5 = Run model in memory"
PRINT , "6 = Config File Management (JCF file)"
PRINT , "90 = TEST GRAPHICS"
PRINT , "98 = TEST SEGMENT"
PRINT , "99 = end program"
PRINT , "100 = Kill file AL-TEST.JDF"
LOCATE 20, 14
INPUT ; "enter your choice"; A$
CLS
SELECT CASE A$
CASE "1"
InitModel
CASE "2"
CASE "5"
CALL modelcalc(PVInit())
CASE "6"
FConfigWrite
CASE "90"
CALL Agraph(VLen())
CASE "98"
ATest
CASE "99"
GOTO 500
CASE "100"
KillALTEST.JDF
END SELECT
GOTO scr1
30 'lcalc
GOTO 500
500 PRINT "NumV", NumV, NumP, NumT
END

SUB Agraph (VLen())
GRAPHICSROUTINE:
CLS
SCREEN 9
'attribute number 0-5 for program colors (6 values)
PALETTE 0, 0
PALETTE 1, 1
PALETTE 2, 2
PALETTE 3, 3
PALETTE 4, 4
PALETTE 5, 63

LOCATE 10, 10
PRINT "B = Blue Palette "
LOCATE , 10
PRINT "R = Red Palette "
LOCATE , 10
PRINT "G = Green Palette "
LOCATE , 10
PRINT "T = Test Palette "
PRINT
LOCATE , 12
INPUT ; "Select Palette ", pal$
SELECT CASE pal$
CASE "B", "b"
PBlue
CASE "R", "r"
PRed
CASE "G", "g"
PGreen
CASE "T", "t"
PTest
END SELECT
'color attribute has been set for 6-15 (10 colors)
CLS

start:
OPEN Datapath$ + "AL-TEST.JCF" FOR INPUT AS #1
INPUT #1, NumP, F2$, F3, F4$, F5$, F6$, F7$, F8$ 'Read NumP
INPUT #1, NumT, F2$, F3, F4$, F5$, F6$, F7$, F8$ 'Read NumT
INPUT #1, NumV, F2$, F3, F4$, F5$, F6$, F7$, F8$ 'Read NumV
REDIM VName$(NumV)
FOR i = 1 TO NumV
INPUT #1, F1, VName$(i), F3, F4$, F5$, F6$, F7$, F8$
NEXT i
CLOSE #1

'w=width, h=height
IF NumP = 5 THEN w = 5: h = NumV
IF NumP = 10 THEN w = 10: h = NumV
IF NumP = 20 THEN w = 20: h = NumV
IF NumP = 25 THEN w = 25: h = NumV
IF NumP = 30 THEN w = 30: h = NumV
IF NumP = 40 THEN w = 40: h = NumV
IF NumP = 50 THEN w = 50: h = NumV
IF NumP = 100 THEN w = 10: h = 10
IF NumP = 200 THEN w = 20: h = 10
IF NumP = 300 THEN w = 30: h = 10
IF NumP = 400 THEN w = 40: h = 10
IF NumP = 500 THEN w = 50: h = 10
IF NumP = 600 THEN w = 30: h = 20
IF NumP = 800 THEN w = 40: h = 20
IF NumP = 1000 THEN w = 40: h = 25
IF NumP = 1500 THEN w = 50: h = 30
IF NumP = 2000 THEN w = 50: h = 40
IF NumP >= 100 THEN INPUT "Enter the variable to monitor  ", vv
```

```
OPEN Datapath$ + "AL-TEST.JDF" FOR INPUT AS
#1
REDIM PVVal(NumP, NumV)
'REDIM VLen(NumV)
INPUT "Enter min or max for highlighting   ", mm$
IF mm$ = "min" THEN PALETTE 6, 63
IF mm$ = "max" THEN PALETTE 15, 63

SCREEN , , 1, 0
LOCATE 1, 20
PRINT "GRAPHIC DISPLAY FOR ARTIFICIAL LIFE
MODEL"

LOCATE 3, 14
PRINT "Values    0 1 2 3 4 5 6 7 8 9 "
LOCATE 5, 14
PRINT "Palette Colors    1 1 1 1 1 1 "
LOCATE 6, 14
PRINT "1 2 3 4 5 6 7 8 9 0 1 2 3 4 5"
FOR ccc = 1 TO 15
CIRCLE (91 + 16 * ccc, 48), 8, ccc
A$ = "P" + STR$(ccc) + "," + STR$(ccc)
DRAW "X" + VARPTR$(A$)
NEXT ccc 'calculate the pixel (X and Y) startpoints
and endpoints for EGA screen
yend = 350 - 30
ystart = (yend - ((h - 1) * 8))
xstart = (640 - ((w - 1) * 10)) / 2
xend = 640 - xstart
LINE (xstart - 6, ystart - 5)-(xend + 6, yend + 5), 7,
B

LOCATE 14, 2
PRINT "V  1"
LOCATE 15, 2
PRINT "a  "
LOCATE 16, 2
PRINT "r  2"
LOCATE 17, 2
PRINT "i  "
LOCATE 18, 2
PRINT "a  3"
LOCATE 19, 2
PRINT "b  "
LOCATE 20, 2
PRINT "l  etc"
LOCATE 21, 2
PRINT "e  "

'MAIN DO LOOP
'read data values and assign to PVVal(p,v)
DO
FOR p = 1 TO NumP
 INPUT #1, TNum, PNum
 FOR V = 1 TO NumV
  INPUT #1, PVVal(PNum, V)
```

```
NEXT V
NEXT p
LOCATE 9, 10
PRINT "time step = "; TNum
LOCATE 10, 10
IF NumP <= 50 THEN PRINT "variable monitored =
All"
ELSE PRINT "variable monitored = V"; vv
LOCATE 11, 10
IF NumP >= 100 THEN PRINT VName$(vv)
LOCATE 12, 10
PRINT "1 2 > > > > > * * * * * * PERSON * * * * * *
> > >
> > > k-1 k"
yy = 0
xx = 0

'Calculation Loop
FOR y = ystart TO yend STEP 8
xx = 0
yy = yy + 1
FOR x = xstart TO xend STEP 10
xx = xx + 1
pp = xx + (yy - 1) * w
IF VLen(yy) = 1 THEN A = PVVal(xx, yy) + 6
IF VLen(yy) = 2 THEN A = INT(PVVal(xx, yy) / 11)
+ 6
A$ = "P" + STR$(A) + "," + STR$(A)
'CIRCLE (x!,y!),R,color,start,end,aspect
CIRCLE (x, y), 4, A
'DRAW   Pn1,n2  n1% is fill attribute, n2% is border
attribute).
DRAW A$
NEXT x
NEXT y

PCOPY 1, 0
LOOP UNTIL EOF(1)
CLOSE #1
SLEEP
endagraph:
SCREEN 0
PALETTE
COLOR 1, 7
CLS
END SUB

SUB FConfigWrite
scnfcw1:
CLS 0
COLOR 1
LOCATE 10
PRINT , "1 = write a new config file"
PRINT , "2 = NOT YET - modify an old config file"
PRINT , "3 = read and display an old config file"
COLOR 5
```

```
PRINT , "4 = NOT YET"
COLOR 1
PRINT , "99 = return to main menu"
LOCATE 20, 14
INPUT ; "enter your choice"; A$
CLS
SELECT CASE A$
CASE "1"
GOTO fcw10
CASE "2"
GOTO fcw20
CASE "3"
GOTO fcw30
CASE "4"
GOTO fcw40
CASE "99"
GOTO 100
CASE ELSE
GOTO scnfcw1
END SELECT
GOTO scnfcw1

fcw10:
PRINT "writing a new config file"
'INPUT "enter number of persons", NumP
INPUT "enter number of time steps  ", NumT
INPUT "enter number of variables   ", NumV
LOCATE 6, 5
PRINT TAB(25); "Number of Time-Steps"; TAB(50);
"Number
of Variables"
LOCATE 7, 5
PRINT TAB(25); NumT; TAB(50); NumV

REDIM V(NumV)
REDIM VName$(NumV)
REDIM VLen(NumV)
REDIM VDep$(NumV)
REDIM VInit$(NumV)
REDIM VNeighbor$(NumV)
REDIM VRel$(NumV)
REDIM VDamp$(NumV)
LOCATE 7
A$ = "1234567890"
PRINT A$ + A$ + A$ + A$ + A$ + A$ + A$ + A$
D$ = CHR$(186)
S$ = CHR$(179)
LOCATE 9
PRINT D$; TAB(3); "V#"; TAB(6); S$; "Name";
TAB(22); S$; "Len";
PRINT TAB(26); S$; "Dependence"; TAB(37); S$;
"Init";
PRINT TAB(48); S$; "Neighbor"; TAB(59); S$; "Re-
lation"; TAB(80); D$
PRINT
'segment to initialize values for calls to selectlist
```

```
MaxChoices% = 12
REDIM VCNumP$(17)
REDIM VCLen$(MaxChoices%)
REDIM VCDep$(MaxChoices%)
REDIM VCInit$(MaxChoices%)
REDIM VCNeighbor$(MaxChoices%)
REDIM VCRel$(MaxChoices%)
REDIM VCDamp$(MaxChoices%)
REDIM WinTitle$(MaxChoices%)
VCNumP$(1) = "5"
VCNumP$(2) = "10"
VCNumP$(3) = "20"
VCNumP$(4) = "25"
VCNumP$(5) = "30"
VCNumP$(6) = "40"
VCNumP$(7) = "50"
VCNumP$(8) = "100"
VCNumP$(9) = "200"
VCNumP$(10) = "300"
VCNumP$(11) = "400"
VCNumP$(12) = "500"
VCNumP$(13) = "600"
VCNumP$(14) = "800"
VCNumP$(15) = "1000"
VCNumP$(16) = "1500"
VCNumP$(17) = "2000"
VCLen$(1) = "1"
VCLen$(2) = "2"
VCLen$(3) = "3"
VCDep$(1) = "Depend-Sum"
VCDep$(2) = "Depend-Avg"
VCDep$(3) = "Autonomous"
VCInit$(1) = "Minimum"
VCInit$(2) = "Maximum"
VCInit$(3) = "Midpoint"
VCInit$(4) = "Random"
VCInit$(5) = "Range"
VCInit$(6) = "Constant"
VCInit$(7) = "Normal"
VCInit$(8) = "Other"
VCNeighbor$(1) = "None"
VCNeighbor$(2) = "Block 5"
VCNeighbor$(3) = "All"
VCNeighbor$(4) = "Other"
VCRel$(1) = "Constant"
VCRel$(2) = "Ramp Up1"
VCRel$(3) = "Ramp Up10"
VCRel$(4) = "Ramp Up100"
VCRel$(5) = "Ramp Up250"
VCRel$(6) = "Ramp Dn1"
VCRel$(7) = "Ramp Dn10"
VCRel$(8) = "Ramp Dn100"
VCRel$(9) = "Ramp Dn250"
VCRel$(10) = "Cycle 1"
VCRel$(11) = "Cycle 10"
VCRel$(12) = "Cycle 100"
```

```
VCDamp$(1) = "None"
VCDamp$(2) = "Average"
VCDamp$(3) = "Fixed"
WinTitle$(1) = "Length"
WinTitle$(2) = "Depend"
WinTitle$(3) = "Init"
WinTitle$(4) = "Neighbor"
WinTitle$(5) = "Relation"
WinTitle$(6) = "Persons"
WinTitle$(7) = "Damping"

'Enter Number of Persons
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0,
WinTitle$(6)
NumP = VAL(SelectList$(VCNumP$(), 17, 11, 16,
10, 14, 15, 4, 14, 0))

'Enter Variable Number
FOR k = 1 TO NumV
V(k) = k
NEXT

'Enter Variable Name
FOR k = 1 TO NumV
VName$(k) = LEFT$("Name ?" + SPACE$(10), 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "enter Name for variable " + STR$(k)
EditString VName$(k), 45, 10, foreGround%, back-
Ground%
NEXT
COLOR 1, 7
wipe 9, 11, 1, 80, 7

'Enter Variable Length
FOR k = 1 TO NumV
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) + WinTitle$(1)
VLen(k) = VAL(SelectList$(VCLen$(), 3, 11, 16, 10,
14, 15, 4, 14, 0))
NEXT

'Enter Variable Dependence
FOR k = 1 TO NumV
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) + WinTitle$(2)
VDep$(k) = SelectList$(VCDep$(), 3, 11, 16, 10, 14,
15, 4, 14, 0)
NEXT

'Enter Variable Initialization
FOR k = 1 TO NumV
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) + WinTitle$(3)
VInit$(k) = SelectList$(VCInit$(), 8, 11, 16, 10, 14,
15, 4, 14, 0)
'Enter Bounds for Random Range
IF VInit$(k) = "Range" THEN
VInit$(k) = LEFT$("Lxxx-Uxxx ", 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "Enter Lower & Upper Range for Variable " +
STR$(k)
EditString VInit$(k), 55, 10, foreGround%, back-
Ground%
COLOR 1, 7
wipe 9, 11, 1, 80, 7
END IF
'Enter Value for Constant
IF VInit$(k) = "Constant" THEN
VInit$(k) = LEFT$("Cxxx ", 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "Enter Constant Value for Variable " +
STR$(k)
EditString VInit$(k), 55, 10, foreGround%, back-
Ground%
COLOR 1, 7
wipe 9, 11, 1, 80, 7
END IF
'Enter Values for Normal Distribution
IF VInit$(k) = "Normal" THEN
VInit$(k) = LEFT$("NLxxx-Uxxx", 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "Enter -3 Std Dev & +3 Std Dev Points for
Variable " + STR$(k)
EditString VInit$(k), 55, 10, foreGround%, back-
Ground%
COLOR 1, 7
wipe 9, 11, 1, 80, 7
END IF
NEXT

'Enter Neighborhood
FOR k = 1 TO NumV
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) + WinTitle$(4)
VNeighbor$(k) = SelectList$(VCNeighbor$(),
MaxChoices%, 11, 16, 10, 14, 15, 4, 14, 0)
NEXT

'Enter Relation
FOR k = 1 TO NumV
```

```
IF VDep$(k) = "Autonomous" THEN GOTO AREL
ELSE
GOTO DREL

AREL:
'enter relation for autonomous variables
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) + WinTitle$(5)
VRel$(k) = SelectList$(VCRel$(), MaxChoices%, 11,
16, 10,
14, 15, 4, 14, 0)
GOTO ENDREL

DREL:
'enter relation for dependent variables
VRel$(k) = LEFT$("?" + SPACE$(10), 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "enter Relation for variable " + STR$(k)
EditString VRel$(k), 45, 10, foreGround%, back-
Ground%

ENDREL:
COLOR 1, 7
wipe 9, 25, 1, 80, 7
NEXT

'Enter Damping
FOR k = 1 TO NumV
MakeWindow 10, 9, 17, 26, 15, 4, 0, 0, -1, 0, "V" +
STR$(k) +
WinTitle$(7)
VDamp$(k) = SelectList$(VCDamp$(), 3, 11, 16, 10,
14, 15, 4, 14, 0)
'enter damping coefficient
IF VDamp$(k) = "Fixed" THEN
VDamp$(k) = LEFT$("Fxxx ", 15)
COLOR 15, 2
foreGround% = 15
backGround% = 2
LOCATE 10, 10, 0
PRINT "Enter Fixed Damping Modifier for Variable "
+ STR$(k)
EditString VDamp$(k), 55, 10, foreGround%, back-
Ground%
COLOR 1, 7
wipe 9, 25, 1, 80, 7
END IF
NEXT

LOCATE 11, 1
COLOR 5, 7
FOR k = 1 TO NumV
PRINT D$; TAB(3); V(k); TAB(6); S$; VName$(k);
TAB(22); S$; VLen(k); TAB(26); S$; VDep$(k);
PRINT TAB(37); S$; VInit$(k); TAB(48); S$;
VNeighbor$(k); TAB(59); S$; VRel$(k); TAB(80); D$
PRINT VDamp$(k)
NEXT
OPEN Datapath$ + "AL-TEST.JCF" FOR OUTPUT
AS #1
WRITE #1, NumP, NumPtxt, 0, "!", "!", "!", "!", "!"
WRITE #1, NumT, NumTtxt, 0, "!", "!", "!", "!", "!"
WRITE #1, NumV, NumVtxt, 0, "!", "!", "!", "!", "!"
FOR k = 1 TO NumV
WRITE #1, k, VName$(k), VLen(k), VDep$(k),
VInit$(k), VNeighbor$(k), VRel$(k), VDamp$(k)
NEXT
CLOSE #1
SLEEP
GOTO scnfcw1

fcw20:
GOTO scnfcw1

fcw30:
OPEN Datapath$ + "AL-TEST.JCF" FOR INPUT AS
#1
PRINT "Entries in file: A:\AL-TEST.JCF": PRINT
FOR k = 1 TO 3
INPUT #1, F1, F2$, F3, F4$, F5$, F6$, F7$,
F8$'Read entries
from file.
PRINT D$; TAB(3); F1; TAB(8); S$; F2$; TAB(19);
D$
NEXT
LOCATE 8, 1
PRINT D$; TAB(3); "V#"; TAB(6); S$; "Name";
TAB(22); S$; "Len";
PRINT TAB(26); S$; "Dependence"; TAB(37); S$;
"Init";
PRINT TAB(48); S$; "Neighbor"; TAB(59); S$; "Re-
lation";
TAB(80); D$
PRINT TAB(6); S$; "Damping"
PRINT
"______________________________________________
_____"
DO UNTIL (EOF(1))
INPUT #1, F1, F2$, F3, F4$, F5$, F6$, F7$,
F8$'Read entries from file.
'Read entries into memory.
PRINT D$; TAB(3); F1; TAB(6); S$; F2$; TAB(22);
S$; F3; TAB(26); S$; F4$;
PRINT TAB(37); S$; F5$; TAB(48); S$; F6$;
TAB(59); S$; F7$; TAB(80); D$
PRINT TAB(6); S$; F8$
LOOP
CLOSE #1
```

```
SLEEP
GOTO scnfcw1

fcw40:
GOTO scnfcw1

100
COLOR 1, 7
END SUB

SUB InitModel
'read configuration
CLS
OPEN Datapath$ + "AL-TEST.JCF" FOR INPUT AS
#1
PRINT "Entries in file: A:\AL-TEST.JCF": PRINT
LOCATE 10, 1
INPUT #1, NumP, F2$, F3, F4$, F5$, F6$, F7$,
F8$ 'Read
entries from file.
INPUT #1, NumT, F2$, F3, F4$, F5$, F6$, F7$, F8$
'Read
entries from file.
INPUT #1, NumV, F2$, F3, F4$, F5$, F6$, F7$,
F8$ 'Read
entries from file.
REDIM V(NumV)
REDIM VName$(NumV)
REDIM VLen(NumV)
REDIM VDep$(NumV)
REDIM VInit$(NumV)
REDIM VNeighbor$(NumV)
REDIM VRel$(NumV)
REDIM VDamp$(NumV)
PRINT NumP, NumT, NumV
PRINT
PRINT D$; TAB(3); "V#"; TAB(6); S$; "Name";
TAB(22); S$;
"Len";
PRINT TAB(26); S$; "Dependence"; TAB(37); S$;
"Init";
PRINT TAB(48); S$; "Neighbor"; TAB(59); S$; "Re-
lation";
TAB(80); D$
PRINT TAB(6); S$; "Damping"
k = 0
DO UNTIL (EOF(1))
k = k + 1
INPUT #1, V(k), VName$(k), VLen(k), VDep$(k),
VInit$(k),
VNeighbor$(k), VRel$(k), VDamp$(k)
PRINT D$; TAB(3); V(k); TAB(6); S$; VName$(k);
TAB(22); S$; VLen(k); TAB(26); S$; VDep$(k);
PRINT TAB(37); S$; VInit$(k); TAB(48); S$;
VNeighbor$(k); TAB(59); S$; VRel$(k); TAB(80); D$
PRINT TAB(6); S$; VDamp$(k)
LOOP
CLOSE #1
SLEEP
'print to screen
OPEN Datapath$ + "AL-TEST.JIF" FOR OUTPUT
AS #1
F1 = 0
F2 = 0
NumP$ = "Persons"
NumT$ = "Time Steps"
NumV$ = "Variables"
CLS
PRINT "file name: AL-TEST.JCF"
LOCATE 6, 5
PRINT "Number of Persons"; TAB(25); "Number of
Time-Steps"; TAB(50); "Number of Variables"
LOCATE 7, 5
PRINT NumP; TAB(25); NumT; TAB(50); NumV
LOCATE 9, 1
PRINT D$; TAB(3); "V#"; TAB(6); S$; "Name";
TAB(22); S$; "Len";
PRINT TAB(26); S$; "Dependence"; TAB(37); S$;
"Init";
PRINT TAB(48); S$; "Neighbor"; TAB(59); S$; "Re-
lation"; TAB(80); D$
PRINT TAB(6); S$; "Damping"
COLOR 5, 7
LOCATE 11, 1
FOR k = 1 TO NumV
PRINT D$; TAB(3); V(k); TAB(6); S$; VName$(k);
TAB(22); S$; VLen(k); TAB(26); S$; VDep$(k);
PRINT TAB(37); S$; VInit$(k); TAB(48); S$;
VNeighbor$(k); TAB(59); S$; VRel$(k); TAB(80); D$
PRINT TAB(6); S$; VDamp$(k)
NEXT

'Initialization
'DO for each person & variable
'read the code for the init type of calculation in
VInit$(K)
'read the code for the length of each variable in
VLen(K)
'calculate and write initialization
REDIM PVVal(NumP, NumV)
REDIM PVValOld(NumP, NumV)
REDIM PVInit(NumP, NumV)

RANDOMIZE 5
randinit = RND(-1)
PRINT "Time Per";
FOR V = 1 TO NumV
PRINT TAB(5 * V + 7); "V";
LTRIM$(RTRIM$(STR$(V)));
NEXT
PRINT
SLEEP
```

```
FOR j = 1 TO NumP
PRINT 0; TAB(5); j; TAB(11);
PRINT #1, 0; ","; j;
FOR k = 1 TO NumV
IF VInit$(k) = "Minimum" THEN PVVal(j, k) = 0
IF VInit$(k) = "Maximum" AND VLen(k) = 1 THEN
PVVal(j, k) = 9
IF VInit$(k) = "Maximum" AND VLen(k) = 2 THEN
PVVal(j, k) = 99
IF VInit$(k) = "Maximum" AND VLen(k) = 3 THEN
PVVal(j, k) = 999
IF VInit$(k) = "Midpoint" AND VLen(k) = 1 THEN
PVVal(j, k) = 5
IF VInit$(k) = "Midpoint" AND VLen(k) = 2 THEN
PVVal(j, k) = 50
IF VInit$(k) = "Midpoint" AND VLen(k) = 3 THEN
PVVal(j, k) = 500
IF VInit$(k) = "Random" AND VLen(k) = 1 THEN
PVVal(j, k) = INT((9 - 0 + 1) * RND + 0)
IF VInit$(k) = "Random" AND VLen(k) = 2 THEN
PVVal(j, k) = INT((99 - 0 + 1) * RND + 0)
IF VInit$(k) = "Random" AND VLen(k) = 3 THEN
PVVal(j, k) = INT((999 - 0 + 1) * RND + 0)

'Calculate Random Range
IF LEFT$(VInit$(k), 1) = "L" THEN
SELECT CASE VLen(k)
CASE 1
lb = VAL(MID$(VInit$(k), 4, 1))
ub = VAL(MID$(VInit$(k), 9, 1))
CASE 2
lb = VAL(MID$(VInit$(k), 3, 2))
ub = VAL(MID$(VInit$(k), 8, 2))
CASE 3
lb = VAL(MID$(VInit$(k), 2, 3))
ub = VAL(MID$(VInit$(k), 7, 3))
END SELECT
PVVal(j, k) = INT((ub - lb + 1) * RND + lb)
END IF

'Calculate Constant Value
IF LEFT$(VInit$(k), 1) = "C" THEN
SELECT CASE VLen(k)
CASE 1
PVVal(j, k) = VAL(MID$(VInit$(k), 4, 1))
CASE 2
PVVal(j, k) = VAL(MID$(VInit$(k), 3, 2))
CASE 3
PVVal(j, k) = VAL(MID$(VInit$(k), 2, 3))
END SELECT
END IF

'Calculate Normal Distribution
IF LEFT$(VInit$(k), 2) = "NL" THEN
SELECT CASE VLen(k)
CASE 1
lb = VAL(MID$(VInit$(k), 5, 1))
ub = VAL(MID$(VInit$(k), 10, 1))
CASE 2
lb = VAL(MID$(VInit$(k), 4, 2))
ub = VAL(MID$(VInit$(k), 9, 2))
CASE 3
lb = VAL(MID$(VInit$(k), 3, 3))
ub = VAL(MID$(VInit$(k), 8, 3))
END SELECT
x = RND
IF x <= .0016 THEN y = -3!
IF x > .0016 THEN y = -2.9
IF x > .00225 THEN y = -2.8
IF x > .00305 THEN y = -2.7
IF x > .0041 THEN y = -2.6
IF x > .00545 THEN y = -2.5
IF x > .0072 THEN y = -2.4
IF x > .00945 THEN y = -2.3
IF x > .0123 THEN y = -2.2
IF x > .0159 THEN y = -2.1
IF x > .02035 THEN y = -2!
IF x > .02575 THEN y = -1.9
IF x > .0323 THEN y = -1.8
IF x > .04025 THEN y = -1.7
IF x > .0497 THEN y = -1.6
IF x > .0608 THEN y = -1.5
IF x > .0738 THEN y = -1.4
IF x > .0888 THEN y = -1.3
IF x > .10595 THEN y = -1.2
IF x > .1254 THEN y = -1.1
IF x > .1472 THEN y = -1!
IF x > .1714 THEN y = -.9
IF x > .198 THEN y = -.8
IF x > .22695 THEN y = -.7
IF x > .25815 THEN y = -.6
IF x > .2914 THEN y = -.5
IF x > .32655 THEN y = -.4
IF x > .36335 THEN y = -.3
IF x > .4014 THEN y = -.2
IF x > .44045 THEN y = -.1
IF x > .4801 THEN y = 0
IF x > .5199 THEN y = .1
IF x > .55955 THEN y = .2
IF x > .5986 THEN y = .3
IF x > .63665 THEN y = .4
IF x > .67345 THEN y = .5
IF x > .7086 THEN y = .6
IF x > .74185 THEN y = .7
IF x > .77305 THEN y = .8
IF x > .802 THEN y = .9
IF x > .8286 THEN y = 1!
IF x > .8528 THEN y = 1.1
IF x > .8746 THEN y = 1.2
IF x > .89405 THEN y = 1.3
IF x > .9112 THEN y = 1.4
IF x > .9262 THEN y = 1.5
```

```
IF x > .9392 THEN y = 1.6
IF x > .9503 THEN y = 1.7
IF x > .95975 THEN y = 1.8
IF x > .9677 THEN y = 1.9
IF x > .97425 THEN y = 2!
IF x > .97965 THEN y = 2.1
IF x > .9841 THEN y = 2.2
IF x > .9877 THEN y = 2.3
IF x > .99055 THEN y = 2.4
IF x > .9928 THEN y = 2.5
IF x > .99455 THEN y = 2.6
IF x > .9959 THEN y = 2.7
IF x > .99695 THEN y = 2.8
IF x > .99775 THEN y = 2.9
IF x > .9984 THEN y = 3!
PVVal(j, k) = INT((ub - lb + 1) * (y / 6 + .5) + lb)
END IF
'Retain init value for use later
PVInit(j, k) = PVVal(j, k)
'print to screen & print to file
PRINT PVVal(j, k); TAB(5 * k + 11);
PRINT #1, ","; PVVal(j, k);
NEXT
PRINT
PRINT #1,
NEXT
1000 CLOSE #1
COLOR 1, 7
SLEEP
END SUB

SUB modelcalc (PVInit())
INPUT ; "Display to screen?   Y[es] or N[o]", sflag$
CLS
OPEN Datapath$ + "AL-TEST.JCF" FOR INPUT AS
#1
PRINT "Entries in file: A:\AL-TEST.JCF": PRINT
INPUT #1, NumP, F2$, F3, F4$, F5$, F6$, F7$,
F8$ 'Read entries from file.
INPUT #1, NumT, F2$, F3, F4$, F5$, F6$, F7$, F8$
'Read entries from file.
INPUT #1, NumV, F2$, F3, F4$, F5$, F6$, F7$,
F8$ 'Read entries from file.
PRINT "Number of Persons"; TAB(25); "Number of
Time-Steps"; TAB(50); "Number of Variables"
LOCATE 4, 5
PRINT NumP; TAB(25); NumT; TAB(50); NumV
REDIM V(NumV)
REDIM VName$(NumV)
REDIM VLen(NumV)
REDIM VDep$(NumV)
REDIM VInit$(NumV)
REDIM VNeighbor$(NumV)
REDIM VRel$(NumV)
REDIM VDamp$(NumV)
```

```
LOCATE 9, 1
PRINT D$; TAB(3); "V#"; TAB(6); S$; "Name";
TAB(22); S$; "Len";
PRINT TAB(26); S$; "Dependence"; TAB(37); S$;
"Init";
PRINT TAB(48); S$; "Neighbor"; TAB(59); S$; "Re-
lation"; TAB(80); D$
PRINT TAB(6); S$; "Damping"
k = 0
DO UNTIL (EOF(1))
k = k + 1
INPUT #1, V(k), VName$(k), VLen(k), VDep$(k),
VInit$(k), VNeighbor$(k), VRel$(k), VDamp$(k)
PRINT D$; TAB(3); V(k); TAB(6); S$; VName$(k);
TAB(22); S$; VLen(k); TAB(26); S$; VDep$(k);
PRINT TAB(37); S$; VInit$(k); TAB(48); S$;
VNeighbor$(k); TAB(59); S$; VRel$(k); TAB(80); D$
PRINT TAB(6); S$; VDamp$(k)
LOOP
CLOSE #1
SLEEP
'EXIT SUB
CLS

'open init file for input to read the init values & as-
sign to
PVValOld(p,v)
OPEN Datapath$ + "AL-TEST.JIF" FOR INPUT AS
#1
REDIM PVVal(NumP, NumV)
REDIM PVValOld(NumP, NumV)
REDIM PVInit(NumP, NumV)
PRINT "Time Per";
FOR V = 1 TO NumV
 PRINT TAB(5 * V + 7); "V";
LTRIM$(RTRIM$(STR$(V)));
NEXT V
PRINT
SLEEP
'read init values and assign to PVVal(p,v) &
PVInit(p,v)
FOR p = 1 TO NumP
 INPUT #1, TNum, PNum
 PRINT TNum; TAB(5); PNum; TAB(11);
 FOR V = 1 TO NumV
  INPUT #1, PVVal(PNum, V)
  PRINT PVVal(PNum, V); TAB(5 * V + 11);
  PVInit(PNum, V) = PVVal(PNum, V)
 NEXT V
 PRINT
NEXT p
CLOSE #1
SLEEP
CLS

'Write to the jdf file
```

```
OPEN Datapath$ + "AL-TEST.JDF" FOR OUTPUT
AS #1
'transfer PVVal(p,v) to PVValOld(p,v)
'ERASE VTotal
REDIM VTotal(NumV)
FOR V = 1 TO NumV
 FOR p = 1 TO NumP
  PVValOld(p, V) = PVVal(p, V)
  'calculate totalized values for each variable
  VTotal(V) = VTotal(V) + PVVal(p, V)
  PVVal(p, V) = 0
 NEXT p
 NEXT V

'Calculate new values of PVVal(p,v) using
PVValOld(p,v):rel,dep,neighbor,len,damp
REDIM holder(10)
REDIM sholder$(10)
REDIM vholder(10)
REDIM dig(10)
REDIM VLenMax(3)
REDIM VLenMin(3)
VLenMax(1) = 9
VLenMax(2) = 99
VLenMax(3) = 999
VLenMin(1) = 0
VLenMin(2) = 0
VLenMin(3) = 0

'MAIN T LOOP
FOR t = 1 TO NumT
' LOCATE 10, 40
' PRINT "Time = "; t
'PVLOOP 1
 FOR p = 1 TO NumP
  FOR V = 1 TO NumV
   'calculate the new value for PVVal(p,v) using
VDep & VRel
& VLen & VNeighbor
   'select case for dependence or autonomous
   SELECT CASE VDep$(V)
    CASE "Autonomous"
 SELECT CASE VRel$(V)
  CASE "Constant"
   PVVal(p, V) = PVValOld(p, V)
  CASE "Ramp Up1"
   PVVal(p, V) = PVValOld(p, V) + 1
  CASE "Ramp Up10"
   IF t MOD 10 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) + 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Ramp Up100"
   IF t MOD 100 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) + 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Ramp Up250"
   IF t MOD 250 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) + 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Ramp Dn1"
   PVVal(p, V) = PVValOld(p, V) - 1
  CASE "Ramp Dn10"
   IF t MOD 10 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) - 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Ramp Dn100"
   IF t MOD 100 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) - 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Ramp Dn250"
   IF t MOD 250 = 0 THEN
   PVVal(p, V) = PVValOld(p, V) - 1
   ELSE PVVal(p, V) = PVValOld(p, V)
   END IF
  CASE "Cycle 1"
   'ROUTINE FOR CYCLE 1; changes by a value of
1 each time step
    mm = 0
   'calculate the new value based on PVInit and t
mod 4
   IF t MOD 4 = 1 THEN
    mm = 1
   ELSEIF t MOD 4 = 3 THEN
    mm = -1
   ELSE
    mm = 0
   END IF
   PVVal(p, V) = PVInit(p, V) + mm
  CASE "Cycle 10"
   'ROUTINE FOR CYCLE 10; changes by a value
of 1every ten time steps
    mm = 0
   'calculate the new value based on PVInit and t
mod 40
   IF (10 <= t MOD 40 AND t MOD 40 < 20) THEN
    mm = 1
   ELSEIF (30 <= t MOD 40 AND t MOD 40 < 40)
THEN
    mm = -1
   ELSE
    mm = 0
   END IF
   PVVal(p, V) = PVInit(p, V) + mm
  CASE "Cycle 100"
   'ROUTINE FOR 100 CYCLE; changes by a value
of 1every hundred time steps
    mm = 0
```

```
   'calculate the new value based on PVInit and t
mod 400
   IF (100 <= t MOD 400 AND t MOD 400 < 200)
THEN
    mm = 1
   ELSEIF (300 <= t MOD 400 AND t MOD 400 <
400)
THEN
    mm = -1
   ELSE
    mm = 0
   END IF
   PVVal(p, V) = PVInit(p, V) + mm
  END SELECT

    CASE "Depend-Sum", "Depend-Avg"
VRelTrim$ = LTRIM$(RTRIM$(VRel$(V)))
k = 0
FOR S = 1 TO 18
SELECT CASE MID$(VRelTrim$, S, 1)
 CASE "-", "+" 'holder = position of +/- array &
sholder =
+/- array
  k = k + 1
  holder(k) = S
  sholder$(k) = MID$(VRelTrim$, S, 1)
END SELECT
NEXT S
'end of string plus one
holder(k + 1) = LEN(VRelTrim$) + 1
FOR S = 1 TO k
dig(S) = holder(S + 1) - holder(S) - 2
vholder(S) = VAL(MID$(VRelTrim$, holder(S) + 2,
dig(S)))
NEXT S
sumvholder = 0
FOR S = 1 TO k
'search for "+" or "-" & generate sums
IF sholder$(S) = "+" THEN PVVal(p, V) = PVVal(p,
V) +
PVValOld(p, VAL(MID$(VRel$(V), holder(S) + 2,
dig(S))))
IF sholder$(S) = "-" THEN PVVal(p, V) = PVVal(p,
V) + VLenMax(VLen(vholder(S))) - PVValOld(p,
VAL(MID$(VRel$(V), holder(S) + 2, dig(S))))
IF VLen(vholder(S)) = 1 THEN sumvholder =
sumvholder + 1
IF VLen(vholder(S)) = 2 THEN sumvholder =
sumvholder + 11
IF VLen(vholder(S)) = 3 THEN sumvholder =
sumvholder + 111
NEXT S
IF VDep$(V) = "Depend-Avg" THEN
'Adjustment to length of receiving field
IF VLen(V) = 1 THEN PVVal(p, V) = CINT(PVVal(p,
V) / sumvholder)
IF VLen(V) = 2 THEN PVVal(p, V) = CINT(11 *
PVVal(p, V) / sumvholder)
IF VLen(V) = 3 THEN PVVal(p, V) = CINT(111 *
PVVal(p, V) / sumvholder)
END IF
    'PRINT "V len sumv pvval   "; V, VLen(V),
sumvholder,
PVVal(p, V)
    'SLEEP

    END SELECT

   'Adjustment for maximum or minimum allowed
value
   IF VLen(V) = 1 AND PVVal(p, V) > 9 THEN
PVVal(p, V) = 9
   IF VLen(V) = 2 AND PVVal(p, V) > 99 THEN
PVVal(p, V) = 99
   IF VLen(V) = 3 AND PVVal(p, V) > 999 THEN
PVVal(p, V) = 999
   IF PVVal(p, V) < 0 THEN PVVal(p, V) = 0
NEXT V
NEXT p

'Neighbor Calculation
   FOR V = 1 TO NumV
   'select case for neighbor
   SELECT CASE VNeighbor$(V)
    CASE "None"
    CASE "Block 5"
 B5 = NumP / 5
 REDIM Psub(B5)
 FOR p = 1 TO NumP
  FOR B = 1 TO B5
  IF INT((p - 1) / 5) + 1 = B THEN Psub(B) =
Psub(B) +
PVVal(p, V)
  NEXT B
 NEXT p
 FOR p = 1 TO NumP
 PVVal(p, V) = CINT(Psub(1 + INT((p - 1) / 5)) / 5)
 NEXT p
    CASE "All"
 VTotal = 0
 FOR p = 1 TO NumP
 VTotal = VTotal + PVVal(p, V)
 NEXT p
 FOR p = 1 TO NumP
 PVVal(p, V) = CINT(VTotal / NumP)
 NEXT p
    CASE "Other"
    CASE ELSE
   END SELECT
   NEXT V

 'Adjustment for maximum or minimum allowed value
```

```
FOR p = 1 TO NumP
FOR V = 1 TO NumV
IF VLen(V) = 1 AND PVVal(p, V) > 9 THEN
PVVal(p, V) = 9
IF VLen(V) = 2 AND PVVal(p, V) > 99 THEN
PVVal(p, V) = 99
IF VLen(V) = 3 AND PVVal(p, V) > 999 THEN
PVVal(p, V) = 999
IF PVVal(p, V) < 0 THEN PVVal(p, V) = 0
NEXT V
NEXT p

'Damping calculation
FOR p = 1 TO NumP
FOR V = 1 TO NumV
'select case for damping-part 1
SELECT CASE MID$(VDamp$(V), 1, 4)
CASE "None"
CASE "Mean"
PVVal(p, V) = CINT((PVVal(p, V) + PVValOld(p, V))
/ 2)
CASE ELSE
END SELECT
IF LEFT$(VDamp$(V), 1) = "F" THEN
x = VAL(MID$(VDamp$(V), 2, 3))
dif = PVVal(p, V) - PVValOld(p, V)
IF dif > 0 AND dif > x THEN PVVal(p, V) =
PVValOld(p, V) + x
IF dif > 0 AND dif < x THEN PVVal(p, V) =
PVValOld(p, V) + dif
IF dif < 0 AND -dif > x THEN PVVal(p, V) =
PVValOld(p, V) - x
IF dif < 0 AND -dif < x THEN PVVal(p, V) =
PVValOld(p, V) + dif
END IF

'select case for damping-part 2
SELECT CASE MID$(VDamp$(V), 6, 4)
CASE "None"
CASE "StDn"
IF PVVal(p, V) < PVValOld(p, V) THEN PVVal(p, V)
= PVValOld(p, V)
CASE "StUp"
IF PVVal(p, V) > PVValOld(p, V) THEN PVVal(p, V)
= PVValOld(p, V)
CASE ELSE
END SELECT
IF MID$(VDamp$(V), 6, 1) = "F" THEN
x = VAL(MID$(VDamp$(V), 7, 3))
IF PVVal(p, V) < x THEN PVVal(p, V) = x
END IF
IF MID$(VDamp$(V), 6, 1) = "C" THEN
x = VAL(MID$(VDamp$(V), 7, 3))
IF PVVal(p, V) > x THEN PVVal(p, V) = x
END IF
NEXT V
```

```
NEXT p

'Adjustment for maximum or minimum allowed value
FOR p = 1 TO NumP
FOR V = 1 TO NumV
IF VLen(V) = 1 AND PVVal(p, V) > 9 THEN
PVVal(p, V) = 9
IF VLen(V) = 2 AND PVVal(p, V) > 99 THEN
PVVal(p, V) = 99
IF VLen(V) = 3 AND PVVal(p, V) > 999 THEN
PVVal(p, V) = 999
IF PVVal(p, V) < 0 THEN PVVal(p, V) = 0
NEXT V
NEXT p

'PRINT LOOP & PRINT TO FILE & RESET VAL-
UES
'PVLOOP 3
FOR p = 1 TO NumP
  IF sflag$ = "Y" OR sflag$ = "y" THEN PRINT t;
TAB(5); p; TAB(11);
  PRINT #1, t; ","; p;
FOR V = 1 TO NumV
  IF sflag$ = "Y" OR sflag$ = "y" THEN PRINT
PVVal(p, V);
TAB(5 * V + 11);
  PRINT #1, ","; PVVal(p, V);
'reset PVVal() to Zero @ end of time step
  PVValOld(p, V) = PVVal(p, V)
  PVVal(p, V) = 0
NEXT V
'PRINT v, VTotal(v)
  IF sflag$ = "Y" OR sflag$ = "y" THEN PRINT
  PRINT #1,
NEXT p
  IF sflag$ = "Y" OR sflag$ = "y" THEN PRINT
STRING$(35, "=")
  IF sflag$ = "N" OR sflag$ = "n" THEN LOCATE
10, 25:
PRINT "Time Step "; t
NEXT t
CLOSE #1
SLEEP
GOTO finish:

finish:
SCREEN 0
COLOR 1, 7

END SUB

SUB PBlue'set attribute 6-15 for blue colors (10
values)
PALETTE 6, 1
PALETTE 7, 33
PALETTE 8, 41
```

```
PALETTE 9, 57
PALETTE 10, 9
PALETTE 11, 25
PALETTE 12, 11
PALETTE 13, 27
PALETTE 14, 31
PALETTE 15, 31
END SUB

SUB PGreen'set attribute 6-15 for green colors (10
values)
PALETTE 6, 16
PALETTE 7, 10
PALETTE 8, 42
PALETTE 9, 34
PALETTE 10, 2
PALETTE 11, 18
PALETTE 12, 58
PALETTE 13, 50
PALETTE 14, 30
PALETTE 15, 22
END SUB

SUB PRed'set attribute 6-15 for red colors (10
values)
PALETTE 6, 32
PALETTE 7, 4
PALETTE 8, 12
PALETTE 9, 5
PALETTE 10, 13
PALETTE 11, 29
PALETTE 12, 45
PALETTE 13, 53
PALETTE 14, 52
PALETTE 15, 36
END SUB

SUB PTest'set attribute 6-15 for test colors (10
values)
PALETTE 6, 1
PALETTE 7, 9
PALETTE 8, 11
PALETTE 9, 27
PALETTE 10, 63
PALETTE 11, 23
PALETTE 12, 30
PALETTE 13, 54
PALETTE 14, 38
PALETTE 15, 60
END SUB
```

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EDUCATION

1977	Bachelor of Science in Business Administration. Northeastern University
1980	Master of Business Administration. Northeastern University
1987	Bachelor of Science in Mechanical Engineering. Old Dominion University
1996	Doctor of Philosophy in Engineering Management. Old Dominion University

ACADEMIC HONOR SOCIETIES

ΒΓΣ	[Beta Gamma Sigma]	Business Administration
ΠΤΣ	[Pi Tau Sigma]	Mechanical Engineering
ΦΚΦ	[Phi Kappa Phi]	General Academic

WORK BACKGROUND

The researcher is currently working at the Norfolk Naval Shipyard and has had experience in the Nuclear Engineering, Radiological Engineering, and Environmental Engineering Departments. Previous experience include serving in the Engineering Department on a U.S. naval nuclear submarine and a graduate internship at IBM-Finland in Helsinki.