Emergent Behavior of the US Government Workforce:
An Agent-based Model of Worker Departure

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Abstract

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Over the past few decades, the public sector has seen significant change in the political and economic environment due to greater interdependencies between agencies and the private sector, globalization, and rapid technological change. The resulting uncertainty introduces a number of challenges such as demands for greater efficiency and effectiveness, and a need to move towards more entrepreneurial practices.

Using the interdisciplinary approach of computational organization theory, organizational theories of worker satisfaction and turnover were evaluated through the use of agent-based modeling and validated with thirteen years of US government employment data. In contrast to a traditional system engineering approach of decomposition, the complex adaptive system approach focuses on the emergent behavior of individual agents self-organizing and adapting.

The model demonstrates an evolutionary process of origination, diffusion, and retention. Initially, the workforce population is unable to sustain small groups resulting in high attrition rates across all population segments. As the average group size increases the retirement eligible segment begins to balance with the onboarding of entry-level workers creating stability. The model phenomenon confirms that groups of a critical size improves employee satisfaction and lowers employee turnover.

Exhibiting the characteristics of a complex adaptive system, the emergent behavior of group formation and the balancing of minimally satisfied and highly satisfied workers reveals the impact of worker attributes and workforce composition. The incompatibility of small group sizes with the demographics of the US government workforce establishes the importance of understanding workforce composition and organizational design.

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List of Acronyms/Symbols

ABM	Agent-based Model
CAS	Complex Adaptive Systems
COT	Computational Organization Theory
NDS	Non-linear Dynamic System
ODD	Overview, Design, and Details
OPM	Office of Personnel Management
σ	Standard Deviation

Chapter 1 Introduction

After a decade of US Government growth, post 9/11, a new era of declining budgets is forcing agencies to evaluate core capabilities, efficiency of operations, and organizational constructs. Individual organizations may be optimized but macro-level or "emergent" trends are not readily understood. Despite a vast array of computational models, individual organizational theories remain fractured requiring integration and a focus on emergent behaviors (Ashworth and Carley 2007).

In contrast to a traditional systems engineering approach of analysis through decomposition of a system into subsystems assuming a stable environment, a complex adaptive system approach is based on self-organization and emergent behavior (Sage and Rouse 2009). Due to the complexity of large interconnected organizations and the changing operating environment, this approach is the most appropriate to understand the effects of worker departure. Building on existing research and frameworks for complex adaptive systems and computational organizational theory, an agent based modeling technique is well suited to evaluate the complex adaptive nature of an organization (Robertson and Caldart 2008).

1.1 Objective

The objective of modeling worker behavior with a complex adaptive system approach is illustrating holistic behavior based on localized rules and the significance of self-organization. Using over a decade's worth of publicly available personnel data from US government agencies as a guide, an agent-based model (ABM) has been constructed assessing emergent behavior based on the satisfaction of workers and the workforce

environment. The model aims to understand the emergent behaviors of employee turnover and employee satisfaction and the effects of turnover on the organizational composition.

1.2 Relevance

Over the past few decades, the public sector has seen significant change in the political and economic environment due to greater interdependencies between agencies and the private sector, and rapid technological change (White 2000). The resulting uncertainty introduces a number of challenges such as demands for greater efficiency and effectiveness, and a need to move towards more entrepreneurial practices (White 2000).

In addition to the challenges of external changes, the U.S. Federal Government is projected to lose a significant portion of its workforce through attrition, primarily due to retirement (OPM 2008), amounting to five hundred thousand senior managers over the course of several years (Trahant 2008). Understanding the complex dynamics of the workforce across career and life stages is critical to fostering sustainable operations that are effective and efficient.

1.3 Organization of the Dissertation

The dissertation is organized into six chapters including: introduction, literature review, methodology, model overview, analysis and discussion, and conclusion. Conceptually, the document provides the theoretical basis for studying the emergent behavior of a workforce, the associated research framework and simulation methods, the details of an agent-based model, and an analysis of the simulation results elaborating on the theory.

Chapter 2, literature review, provides an evaluation of the relevant theories and empirical data associated with modeling the behavior of a workforce. The theories are related to organizational computation, complex adaptive systems, and organizational principles with a focus on groups, worker turn over, and career stages.

Chapter 3, methodology, describes the use of simulation as a research method and details a framework for organizational simulation. The agent-based modeling approach associated with modeling emergent behavior draws from fields of study including systems theory, engineering, economics, and natural sciences. The research framework is rooted in computational organization theory and is specific to modeling a workforce population.

Chapter 4, model overview, design concepts, and details, follows a standard methodology for describing an agent-based model with the goal of providing complete transparency into the model's design and implementation. Additionally, the source code of the modeling is provided in the appendix.

Chapter 5, analysis and discussion, provides the results of simulation scenarios and a discussion of the emergent behavior. The chapter is separated into two section focused on a model of workers without replacement, and a model with replacement. The model without replacement predominantly focuses on the initial group formation. Building on the group formation concepts, the model with replacement focuses on the effects of new workers, worker retirement, and groups over time. Additionally, a validation of each model is provided.

Lastly, Chapter 6, conclusion, discusses the limitations of the research, provides recommendations for future research, and a concluding discussion.

Chapter 2 Literature Review

Studying the emergent behavior of worker departure draws on the existing research across a broad spectrum of fields, spanning from systems theory, natural sciences, game theory, artificial intelligence, and mathematics to organizational sociology and psychology. The specific areas of computational organization theory and complex adaptive systems (CAS) are inherently interdisciplinary and the most relevant to simulating worker departure through agent-based modeling. In addition, research concerned with organizations, groups or teams, and individual behavior provides the underpinning for the simulation parameters and assumptions. Using an agent-based modeling approach, the individual behavior literature on the study of turnover, and career or life stages is critical and directly supports the agent traits. Lastly, an overview of the U.S. government workforce has been incorporated to provide context to the empirical data set.

2.1 Computational Organization Theory (COT)

The field of computational organization theory (COT) is an interdisciplinary research approach integrating organization theories, empirical findings, and computational analysis coupled with computer simulation (Sage and Rouse 2009). In support of simulation, Ostrom (1988) identifies five dilemma's facing social behavior theory development due to complexity including: single dependent variables do not sufficiently address the dynamics of multifaceted phenomena; verbal theories cannot adequately describe the emergence of roles and structure within group processes; latent variables cannot be observed directly; interdependent variables cannot be analyzed concurrently;

and observing behavior over time is problematic due to feedback processes that expose the four previous dilemmas (Ostrom 1988).

2.1.1 History of COT

The application of computer simulation to social systems spans three periods of development over the past fifty years including: macro-level, micro-level, and agent-based models (Macy and Willer 2002). Beginning in the 1960s, macro simulations, typically based on sets of differential equations, were used to forecast phenomena such as population demographics or traffic (Macy and Willer 2002). Micro simulations began in the 1970s with the a 'bottoms up' approach focused on modeling individual processes in a socially isolated fashion (Macy and Willer 2002). Agent-based models emerged in the 1980s differentiated by the ability of agents to act autonomously, behave with interdependence, follow simple individual rules, and adapt (Macy and Willer 2002).

The field of computational organization theory was formalized with the founding of the Journal of Computational Organization Theory (CMOT) in 1995 and continues to be influential (Meyer, Zaggl et al. 2011). Organizational modeling within the last ten years has "come of age" due to the rapidly declining time and cost of creating models, the establishment of scalable development platforms, and the integration of organizational modeling into conventional educational programs (Levitt 2004).

2.1.2 Modeling and Computational Analysis

Computational modeling or computer simulation is a form of mathematical modeling usually employed when a closed form solution is not available (Carley 2009). The simulation models supporting the computational analysis of organizational theory can be

organized into three comprehensive categories including agent-based models, expert systems, and mathematical models (Ashworth and Carley 2007). Complex system models are among the most common forms of computational models consisting of agent-based models and system dynamics models (Carley 2009).

Agent based models use a specific technique of simulating autonomous agents allowing for modeling of complex phenomena and interactions (Safarzyska and van den Bergh 2010). Agent-based models originated from within the field of artificial intelligence (Gilbert and Terna 2000) and the modeling technique is well suited to evaluate the complex adaptive nature of an organization (Robertson and Caldart 2008).

System dynamics modeling is a technique consisting of causal loops simulating stocks and flows that can model complex relationships. System dynamics modeling originates from cybernetics and industrial dynamics developed by Forrester (1958) (Bérard 2010). In economics, models have been constructed to simulate innovation processes, pricing strategies, the timing of research and development, consumer behavior, and competition (Milling 2002). Relative to social behavior, the system dynamics of decision making have modeled based on the heuristics of behavioral decision theory (Sterman 2000) Recently, system dynamics has been combined with other systems approaches, such as soft systems methodology, to better model complexity (Rodriguez-Ulloa and Paucar-Caceres 2005).

2.2 Complex Adaptive Systems Theory (CAS)

The study of complex adaptive systems (CAS) is rooted in the field of complexity theory popularized by the American Interdisciplinary Santa Fe Institute founded in 1984

(Goldstein 1999), and the European group originating from work by Prigogine (1955) and others (Benbya and McKelvey 2006).

In terms of systems theory, complexity can be understood in the following three ways: characterized by autonomous entities or agents that self-organize and adapt to the environment of a continuously evolving larger system (Sage and Rouse 2009); characterized by a distributed system without central organization with many interconnected parts; and characterized by unpredictable behavior (Fuchs 2003). Complexity theory with respect to organizational theory has a broad spectrum of concepts. An analysis of organizational theory research related to complexity theory by Wallis (2009) differentiated forty-seven concepts (Wallis 2009).

2.2.1 'Micro', 'Macro', and 'Meso'

The emergent behavior of a complex adaptive system is the 'macro' level phenomena of a population resulting from the 'micro' level decisions of individuals. The 'meso' level of the system refers to groups smaller than the population; the 'critical masses' of self-organized individuals within institutions (Elsner 2010). The process of change or evolution at the 'meso' level is termed the 'meso trajectory' consisting of three phases: 'origination', 'diffusion', and 'retention' (Dopfer, Foster et al. 2004).

2.2.2 CAS Characteristics

A review of CAS literature by Alaa (2009) yields fifteen characteristics or principles including: a large number of components, variation and diversity, connectivity and interdependence, far-from equilibrium, unpredictability and non-linearity, adaptation to environment, interactions, feedback, learning, path-dependence, self-organization, and

coevolution . Extending Alaa's characteristics with research from organizational science, computational science of evolutionary models, and emergence, additional characteristics are considered including: emergence and complex patterns, creation of new order and diffusion, attractors, reflexivity, lock-in, and bounded rationality. A summary of the characteristics with the associated research is provided in Table 2-1.

Table 2-1 Extending Characteristics of Complex Adaptive Systems (Alaa 2009)

	Emergence		**Complex Adaptive Systems**			**Organizational Theory**	**Computational Theory**
	Alaa, G. (2009)	Goldstein, J. (1999)	Mitleton-Kelly, E. (2003)	Benbya, H. and B. McKelvey (2006)	Bergmann Lichtenstein, B. M. (2000)	Anderson, P. (1999)	Safarzyska, K. and J. C. van den Bergh (2010)
Emergence/Complex patterns	x	x	x		x	x	
Self-organisation/ Creation of New Order/ Selection/ Diffusion	x	x	x		x	x	x
Attractors		x				x	
Coevolution/ reflexivity	x		x	x			x
Autopoiesis/ self-production	x			x			
Non-linearity	x	x			x	x	
Complexity	x	x	x	x	x	x	x
Large number of components	x			x			
Diversity/Variety	x			x			x
Feedback	x		x	x		x	x
Connectivity/ Interdependence	x		x		x	x	
Far-from-equilibrium/ Dissipative	x	x	x	x		x	
Path Dependence/ Lock-in	x		x				x
Historicity/Time	x		x				
Adaptation/Learning	x		x	x			x
Bounded Rationality							x

A detailed delineation of additional research assimilated across facets of organizational theory, systems and scientific theory, and computational methods or theory is provided in Appendix A.

2.2.2.1 Organizational Emergence

The concept of emergence is defined across various fields of study including natural sciences, systems theory, and social sciences. The characteristics of emergent entities from natural sciences includes: the existence of hierarchy; 'higher order laws'; 'unpredictable novelty'; 'irreducibility'; and 'multiple realization' (Golds and Kay 2010). Irreducibility is defined as the inability to the reduce a system and reproduce the behavior using mathematics (Boschetti and Gray 2007). From systems theory, emergence refers to the principles of 'Holism' (viewing a system as whole and not a collection of components); the presence of positive and negative feedback; and 'boundary conditions' (Golds and Kay 2010). In an organizational context, emergence refers to the structures or patterns that form during the process of self-organization in complex systems (Goldstein 1999). A review of self-organization in recent management literature yields two major themes including: the creation of organizations without external control, and the cooperation of individuals to achieve a shared goal (Mahmud 2009).

As depicted by Goldstein (1999) in Figure 2-1 the mathematical and scientific roots of emergence, CAS, computational theory, and nonlinear dynamical system directly support emergence in self-organizing systems.

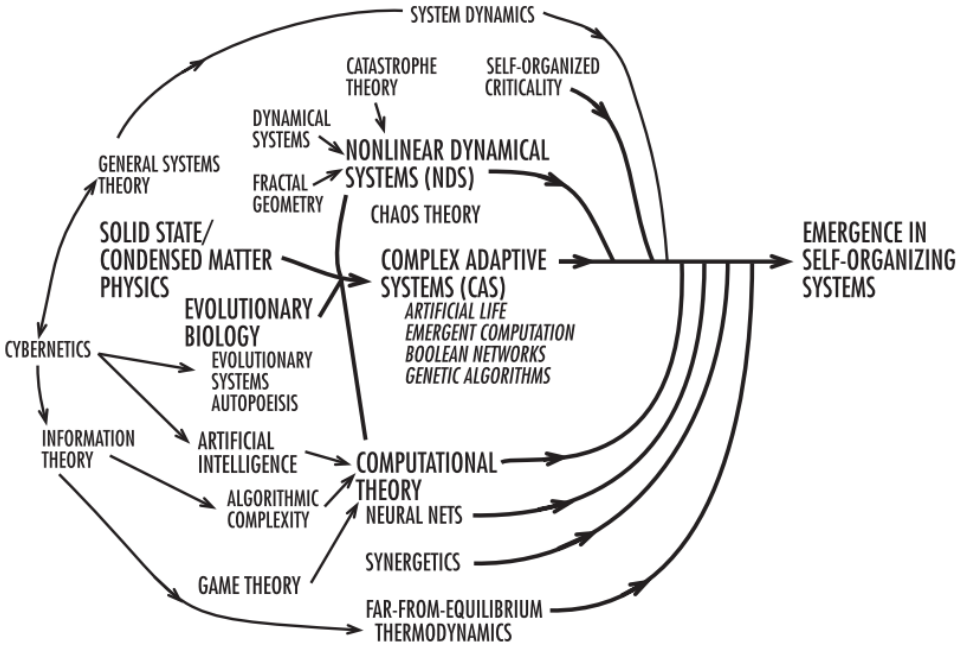


Figure 2-1 Mathematical and scientific roots of emergence (Goldstein 1999)

2.2.2.2 Self-organization, Multi-level Evolution, and Group Selection

Self-organization encompasses processes of variation, selection, feedback, multi-level evolution, and group selection (Safarzyska and van den Bergh 2010). The non-linear interactions of large numbers of agents or components involving positive feedback loops overcome weaker behaviors leading to grouping and emergent higher level structures (Anderson 1999).

As depicted in Figure 2-2 social self-organization is characterized by agents acting and resulting structures constraining and enabling the agents in an interdependent fashion (Fuchs and Hofkirchner 2005).

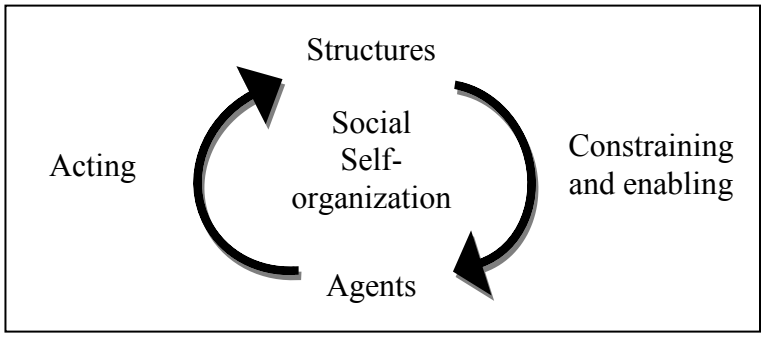


Figure 2-2 Self-Organization in Social Systems (Fuchs and Hofkirchner 2005)

2.2.2.3 Far-from equilibrium and Dissipative structure

The concept of far from equilibrium originates from the study of thermodynamics, where the second law of thermodynamics applies to closed systems reaching a fixed equilibrium, dissipative structures occur when an open system state is maintained far from equilibrium with the addition of new energy (Anderson 1999). The term "dissipative structures" refers to configurations where injected energy is lost (Lichtenstein 2009). Dissipative structures are associated with self-organization and the creation of new order and increasing complexity preventing the system from devolving into random behavior (Liu 1996). Applying far-from-equilibrium theory to organizations, organizational change referred to as "revolution to evolution" (Greiner 1972) demonstrates cycles of stability and chaos yielding new structures and stages of development (MacIntosh and MacLean 1999). In contrast to traditional in-equilibrium assumptions providing for tractable solutions, a system out of equilibrium shows perpetually 'novel behavior' without arriving to a steady-state (Arthur 2006).

2.2.2.4 Non-linearity and unpredictability

The assumptions underlying a non-linear dynamic system (NDS) directly supporting the behavior of complex adaptive systems include: change is a constant; the system is not reducible to its parts; mutual dependence; and behavior is non-proportional. (Bergmann Lichtenstein 2000). The concept of constant change is aligned with the far-from-equilibrium theories and depiction of a dynamic system not reaching a steady-state or cyclical equilibrium (Anderson 1999). Fundamental to the bottoms-up approach of CAS, micro or local agents interact with simple rules creating macro level phenomena that cannot be explained by any single agent. This approach is consistent with the NDS assumption of non-reducibility. The assumption of a non-linear dynamic system being non-proportional refers to the effect of small input changes having large effects on output, or large inputs having little effect on outcome (Bergmann Lichtenstein 2000).

2.2.2.5 Coevolution

The concept of coevolution refers to the two or more systems or organizations related to each other affecting the evolution of one another (Safarzyska and van den Bergh 2010). Coevolution occurs when individuals are required to continuously adapt due to the strategies of another individual (Kim and Kaplan 2006). This mutual dependency between entities and the effect on an overall organization is different from just adaption to an environment, implying each individual can influence the overall organization (Mitleton-Kelly 2003). As detailed by Lewin and Volberda (1999), the nature of coevolution includes: adaption over long periods of time, path dependencies, 'multilevelness', 'multidirectional causalities' , non-linearity, positive feedback, and path dependence (Lewin and Volberda 1999).

2.2.2.6 A large number of components

A common feature to all complex adaptive systems is a great number of components interacting simultaneously (Holland 1992). The complexity is dependent on the number of components and the connections between the components (Fuchs 2003). This magnitude of interactions across large number of elements underlies the emergent behavior and phenomena such as non-linearity and unpredictability.

2.2.2.7 Variation and diversity

Variation is fundamental condition required for adaptation in a complex adaptive system (Axelrod and Cohen 2008). Diversity can be formalized based on individuals changing strategies, 'individual behavior mixing', or varying individuals with different constant behaviors (Safarzyska and van den Bergh 2010). Within agent-based models, a combination of both varied individuals and changing behavior over time may be represented (Safarzyska and van den Bergh 2010).

2.2.2.8 Connectivity and Interdependence

In social systems, the concept of connectivity and interdependence refers to the impact of an individual's action on the entirety of an organization, group, or system (Mitleton-Kelly 2003). Drawing from natural sciences, the degree of connectivity determines the influence of an individual on related individuals and the strength of propagation (Mitleton-Kelly 2003). The greater the interdependence the wider the effects of an individual will have throughout the environment (Mitleton-Kelly 2003).

2.2.2.9 Feedback

The study of feedback originates from the field of cybernetics and a focus on modeling interactions (Anderson 1999). Feedback, from a systems dynamics perspective, is traditionally defined as positive or negative, with positive feedback reinforcing a behavior and negative feedback moderating a behavior generating stability (Mitleton-Kelly 2003). Feedback is a key characteristic of a complex adaptive system preventing the isolation of individual entities and reduction of the system to analyze system level behavior (Anderson 1999) .

2.2.2.10 Bounded Rationality

The concept of bounded rationality (Simon 1958) relates an individual's limitations in assessing the complexity of their environment and the uncertainty of future circumstances to a deterministic set of behavior (Safarzyska and van den Bergh 2010). In line with the notion of bounded rationality, the adaptive behavior of agents within a CAS seek to improve their own fitness without regard to the macro-level conditions of the overall organization (Anderson 1999).

2.2.2.11 Adaptation

The NK model (Kauffman 1993) formulated by Stuart Kauffman structures the adaptation and selection process through an analytic model of an organization with N attributes and K interaction between attributes establishing a fitness landscape. (Levinthal 1997). Within an organization, adaptation is the result of individual agent actions attempting to improve their fitness (Anderson 1999) consistent with the concept of bounded rationality.

2.2.2.12 Path-dependence and lock-in

Path dependence (Arthur 1994) refers to the positive and negative feedback loops that foster expansion and stability (Mitleton-Kelly 2003). Originating from economic theory, a positive feedback loop is associated with growth to the point of diminishing returns where negative feedback stabilizes the behavior (Kuosa 2007). Path dependence builds on the events of the past reinforcing the early adoption of a specific behavior or environment resulting in a 'lock-in' to that condition (Arthur 1989).

2.2.2.13 Attractors and Bifurcation

Drawing from chaos theory and non-linear dynamical systems, attractors refers to entities that dominate a system and create a new order when a system bifurcates. (Goldstein 1999) Within the field of mathematics, bifurcation theory concentrates on the effect of small parameter changes to overall system behavior (Hazy and Ashley 2011). In the context of complex adaptive systems, evolving processes that appear to be random may revolve around attractors in a deterministic fashion (Anderson 1999).

2.2.2.14 Historicity and Time

Within complex adaptive systems, the aspect of time is fundamental to the underlying behavior and emerging phenomena. A strong dependence on time is integral to the nature of a complex system (Bérard 2010). Time is particularly relevant to the interdependencies of agents as they interact over time, adapt, and coevolve (Mitleton-Kelly 2003).

2.3 Organizational Theory

Extensive research has been conducted on work groups or teams in the fields of psychology and sociology throughout the twentieth century. Drawing from sociology, the major theories related to organizations over the last 50 years are summarized into the concept of dualism (rational and natural systems). For purposes of evaluating the US government workforce, a subset of research related to the concept of a firm is most relevant. From the various domains of psychology, the dynamics of a group can be broken down into the areas of leadership, roles, processes, and decision making or problem solving. The processes aspect of groups is the most applicable research to the behaviors being evaluated. Lastly, the behavior and functioning of an individual is characterized by the research in personality and cognition. The subset of research on individual behavior concerned with career stages and the aspects or causes of turnover are the most significant to evaluation of worker departure. The following concept map, Figure 2-3, depicts the interdependencies of the organization, the group, and the individual and the corresponding areas of research considered:

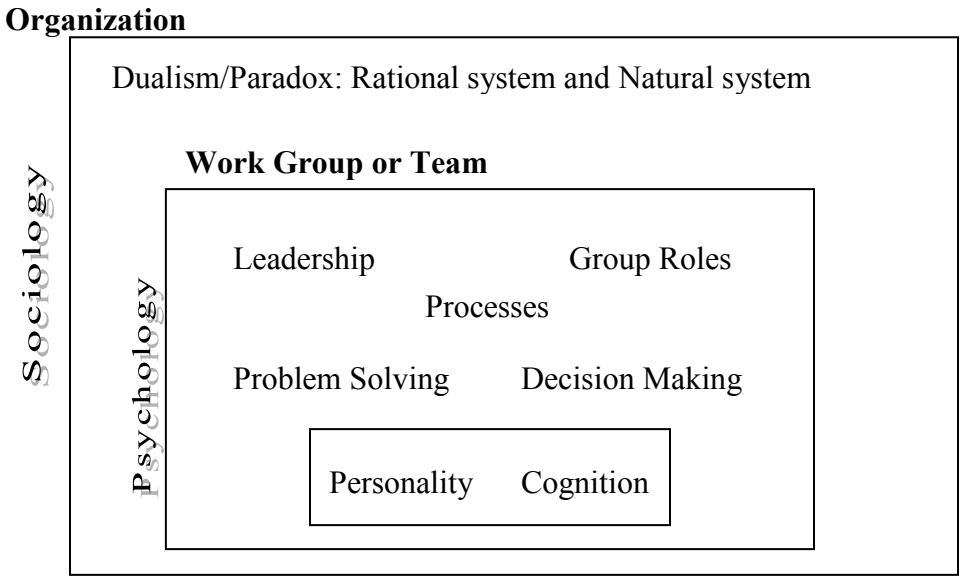


Figure 2-3 Concept Map of Organizational Theory

2.3.1 Organization

W. Richard Scott's "Reflections on a Half-Century of Organizational Sociology" provides an overview of the emergence of organizational sociology and current trends. Prior to the 1930s, the study of organizations was dominated by industrial engineering and operations research (Scott 2004). Barnard (Barnard 1938) and Selznick (Selznick 1948) were among the first scholars to focus on organizations as not only production systems but adaptive social systems (Scott 2004). This duality was firmly established throughout the 1950s with Gouldner (Gouldner 1959) concept of "rational system" and "natural system", and Blau (Blau 1955) focus on the "dilemmas" of bureaucracy (Scott 2004). As the field matured, sociology began to integrate concepts from other fields, such as economics with transaction costs, and complexity with network theory (White, Boorman et al. 1976), (Scott 2004). A Behavioral Theory of the Firm (Cyert and March 1963) greatly influenced organizational science fostering organizational learning theory and evolutionary economics utilizing the prescribed tenets of developing process oriented models and linking the models to empirical observations (Argote and Greve 2007).

2.3.1.1 Organizational Life Cycle

The organizational life cycle is depicted by four stages of development: 'entrepreneurial', 'collectivity', 'formalization', and 'elaboration' (Daft 1998). The entrepreneurial stage age is at the onset of an organization characterized by creativity and the need for leadership during rapid growth and change (Daft 1998). The collectivity stage centers around establishing hierarchy, leadership with direction and goals, and the need to delegate (Daft 1998). The formulization stage initiates more formal procedures and bureaucracy with systems for controlling activities denoted as 'red tape' (Daft 1998).

Lastly, the elaboration stage looks to reduce bureaucracy in order to more effective by collaborating across the hierarchy (Daft 1998). Consistent with the 'meso trajectory' of complex adaptive systems, underlying the organizational life cycle and the maturation process, the evolution of rules or norms follow the process of 'origination', 'diffusion', and 'retention' defining the behavior within the organization(Ostrom and Basurto 2011).

2.3.1.2 Organizational Structure

A review of organization theory literature over the past fifty or more years by Nissen (2007) yields over thirty distinct organizational forms (Nissen 2007). The grouping of organizational forms by Mintzberg (1979) provides a broad classification of forms including: 'Simple Structure', 'Machine Bureaucracy', 'Professional Bureaucracy', 'Divisionalized Form', and 'Adhocracy' (Nissen 2007). Each organizational form captures the degree of hierarchy and the nature of the work through organization elements (operating core, strategic apex, middle line, techno-structure, and support staff), forms of coordination (mutual adjustment, direct supervision, standardization of work processes, outputs, and skills), and design elements such as unit size and grouping (Nissen 2007).

2.3.2 Work Groups or Teams

Group behavior has been studied in the field of psychology with influential works as far back as the 1920s by Follet and Mayo (Senior and Swailes 2004). The systematic study of behavioral roles in groups came out the work of Benne and Sheats (1948) and Bales (1950) identifying categories of roles spanning from task-management to

interpersonal (Hobson, Strupeck et al. 2010). Table 2-2 (Blenkinsop and Maddison 2007) summarizes various role frame works developed over the past 50 years:

Table 2-2 History of Team Role Frameworks (Blenkinsop and Maddison 2007)

Author	Year	No of Team roles	Description
Benne and Sheats	1948	27	Group task roles and individual roles
Bales	1955	12	Positive and negative interpersonal and task roles
Belbin	1981	8	Company Worker, Chairman, Shaper, Plant, Resource Investigator, Monitor-Evaluator, team Worker and Completer Finisher
Woodcock	1989	12	Leader, Challenger, Expert, Ambassador, Innovator, Diplomat, Conformer, Output-Pusher, Quality-Controller, Supporter, Reviewer, Judge
Parker	1990	4	Challenger, Contributor, Communicator and Collaborator
Belbin	1993	9	Added the role Specialist
Senior	1998	6	Variation on Belbin Roles

The historic focus of research on the effectiveness of teams has been rooted in system models that process inputs and outputs (Ilgen, Hollenbeck et al. 2005). The input-process-output (I-P-O) model was established through the works of Steiner (1972) , McGrath (1984), and Hackman (1987) (Ilgen, Hollenbeck et al. 2005). The concept of a team as an adaptive dynamic system has generated new theoretical models (McGrath, Arrow et al. 2000) which account for input and outputs over time with varying environments (Ilgen, Hollenbeck et al. 2005). Studying adaptive teams has led to computational models to understand the complexities of team behavior (Ilgen, Hollenbeck et al. 2005).

The study of group dynamics arising from the field of social psychology has shown the formation of groups to be chaotic and disjointed (Katz 1993). Group size effects the

communication effectiveness between members, the tendency towards hierarchy, and relationship between groups (Morgan, Morgan et al. 2010). Importantly, the collective performance of a group is better in groups that are more cohesive, have worked together longer, and have shared values (Morgan, Morgan et al. 2010).

2.3.3 Individual

The research on individual behavior relevant to the workplace focuses on cognition and personality. The psychological research on the cognitive capabilities of managers and employees stems from the fields of human factors and organizational psychology (Hodgkinson and Healey 2008). Studies on individual career and life stages and turnover directly support the factors considered in modeling work departure.

Human Factors spans engineering psychology, human performance, and ergonomics. The notion of schema or long term memory (Bartlett 1932) and mental models (Craik 1943) led to the analysis of skilled performance in terms of human information processing (Hodgkinson and Healey 2008). This research focused on complex industrial processes and systems until Card et al.'s (1983) research initiated the "era of human computer interaction" (Hodgkinson and Healey 2008). This interaction has now evolved in a complex workplace with human factors researchers adopting the (Zhang and Norman 1994) cognitive engineering approach (Hodgkinson and Healey 2008).

The field of organizational psychology originated with Simon's (1947) notion of bounded rationality which led to the concepts of rational decision making (March and Simon 1958) based on available information (Hodgkinson and Healey 2008). The field evolved with the development of attribution theory (Kelley 1967), study of heuristics and biases and influence on judgment (Tversky and Kahneman 1974), social identity theory

(Tajfel and Turner 2001), and the influence of backgrounds and values and beliefs (Hambrick and Mason 1984), (Hodgkinson and Healey 2008).

The "Big Five" model of personality (Norman 1963), extraversion, emotional stability, agreeableness, conscientiousness, and culture can be traced back to research as early as the 1930s with McDougall (1932) (Barrick and Mount 1991). Five factor models continued evolving for over 40 years through work of Fiske (1949), Tupes and Christal (1992), and Hakel (1974) (Barrick and Mount 1991). Remarkably, research has widely adapted the 5 factor model and demonstrated validity across various theoretical frameworks and across different cultures (Barrick and Mount 1991).

2.3.3.1 Career and Life Stages

There have been numerous studies of investigating the effects of career stages and age on an individual's commitment to the workplace and overall career development (Ornstein, Cron et al. 1989). The Super model of career stages (Super 1957) defines a worker's career by the following four stages: 'exploration', 'establishment', maintenance', and disengagement'(Low and Bordia 2011). Levinson's model of life development (Levinson 1978) consists of four 'life eras' including: early childhood (up to twenty years ago), early adulthood (twenty to forty years old), middle adulthood (forty to sixty years old), and late adulthood (over sixty) (Ornstein, Cron et al. 1989). Bridging the transitions between stages, career adaptability is a central theme to career development and coping with the uncertainty of the workplace (Savickas 1997).

The 'exploration stage' is defined by a worker's first entry into the workforce and an assessment of whether the work is interesting (Low and Bordia 2011) and aligns to the beginning of the early adulthood. Notably, studies of new employees indicate unusually

high turnover of about fifty percent (Holton 2001). The 'establishment' stage is denoted by a worker's adaption to the organization and a greater focus on career progression (Low and Bordia 2011) and aligned to the end of early adulthood progressing to the greatest level of organizational commitment (Ornstein, Cron et al. 1989). The 'maintenance' stage begins the leveling off of performance and a worker's focus on stability and minimizing change (Low and Bordia 2011) and associated with middle adulthood (Ornstein, Cron et al. 1989). Lastly, the 'disengagement' stage is associated with a worker's transition into retirement with steady loss of commitment to the organization (Low and Bordia 2011) and late adulthood (Ornstein, Cron et al. 1989).

2.3.3.2 Turnover

The organization theory pertinent to worker departure is concerned with employee turn-over or attrition. The study of employee turnover has been of considerable focus since the early twentieth century yielding hundreds of quantitative studies (Cotton and Tuttle 1986). A recent meta-analysis of employee turnover confirmed the established the established precursors and associations of employee turnover such as job satisfaction, demographics, organization and work environment factors, and the nature of the job with the best predictor of employee-turnover being job satisfaction (Griffeth, Hom et al. 2000).

One facet of employee turnover critical to understanding the emergent behavior of self-organizing is the effects of groups on employee departure. Studies on group-oriented culture empirically support that group-oriented culture is associated with higher job satisfaction and lower employee turnover (Mohr, Young et al. 2012). In a study of job satisfaction by Moynihan and Pandey (2007), group culture is shown to positively and

significantly be associated with job satisfaction, organizational commitment, and job involvement (Moynihan and Pandey 2007). On the other hand, a decline in group functioning occurs with large turnover of workers as the group member acclimate to the new members (Carley 1992).

With respect to team size, research has found individuals within large teams to be less satisfied due to the psychological distance between members (Pearce and Herbik 2004). Although, a study by Pearce and Herbik (2004) on team commitment did not find team size significantly affected team behavior concluding that optimal team size varies based on the nature of the task (Pearce and Herbik 2004).

2.4 Empirical Data Set: U.S. Government Workforce

The US Office of Personnel Management provides the personnel records for ninety-six percent of the Federal government spanning the past fourteen years for five hundred agencies. The dataset is exclusively Federal workers and exclusively civilian workers covering the Executive Branch with the exclusion of the Postal Service and many intelligence agencies. Evaluating over twenty-six million records, ninety-three percent of the employee population is within twenty-one large agencies with an average of one point eight million employees per year. Within each of the agencies, a range of one to sixty-four sub-agencies are delineated. For each of the employees, a record includes: location, occupation, salary level, pay grade, gender, age, and tenure. An initial evaluation has identified forty-two occupations within five broad engineering or technical disciplines including engineering, information technology, logistics, math, and management. The employee population consists of three hundred and seven thousand to three hundred and

seventy thousand technical or management employees from 1998 to 2011. The details of US government workforce empirical dataset are provided in Tables 2-3 and 2-4.

Table 2-3 Empirical Data Set: U.S. Government Workforce by Year

Federal Government (96%)

Fiscal Year	Agencies	SubAgencies	Employees
1998	115	512	1,810,341
1999	111	509	1,772,333
2000	115	508	1,762,559
2001	116	512	1,772,533
2002	116	511	1,819,107
2003	115	520	1,848,378
2004	120	528	1,856,441
2005	120	536	1,860,949
2006	118	530	1,852,825
2007	119	531	1,862,404
2008	120	522	1,938,821
2009	122	527	2,038,183
2010	124	537	2,113,210
2011	124	541	2,130,253
Average	118	523	1,888,453

Total Personnel Records: 26,438,337

Agencies with over 10,000 Employees (93%)

Fiscal Yr.	Agencies	SubAgencies	Employees
1998	20	392	1,734,617
1999	20	391	1,696,259
2000	20	387	1,690,716
2001	20	389	1,700,435
2002	20	387	1,747,072
2003	21	397	1,786,047
2004	21	401	1,794,253
2005	21	407	1,798,340
2006	21	404	1,788,593
2007	21	404	1,799,821
2008	21	394	1,874,172
2009	21	397	1,971,431
2010	21	405	2,042,012
2011	21	408	2,057,298
Average	21	397	1,820,076

Total Personnel Records: 25,481,066

Table 2-4 Empirical Data Set: U.S. Government Workforce by Agency in 2011

Agencies	# of Employees	# of Sub-agencies
AF-DEPARTMENT OF THE AIR FORCE	178,279	64
AG-DEPARTMENT OF AGRICULTURE	105,126	31
AR-DEPARTMENT OF THE ARMY	283,837	53
CM-DEPARTMENT OF COMMERCE	47,626	14
DD-DEPARTMENT OF DEFENSE	112,534	30
DJ-DEPARTMENT OF JUSTICE	116,273	12
DL-DEPARTMENT OF LABOR	16,298	21
DN-DEPARTMENT OF ENERGY	16,381	2
EP-ENVIRONMENTAL PROTECTION AGENCY	18,777	1
GS-GENERAL SERVICES ADMINISTRATION	12,739	18
HE-DEPARTMENT OF HEALTH AND HUMAN SERVICES	85,642	14
HS-DEPARTMENT OF HOMELAND SECURITY	198,242	13
HU-DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT	9,758	31
IN-DEPARTMENT OF THE INTERIOR	77,225	11
NN-NATIONAL AERONAUTICS AND SPACE ADMINISTRATION	18,632	10
NV-DEPARTMENT OF THE NAVY	199,594	21
ST-DEPARTMENT OF STATE	12,595	1
SZ-SOCIAL SECURITY ADMINISTRATION	67,136	1
TD-DEPARTMENT OF TRANSPORTATION	57,721	13
TR-DEPARTMENT OF THE TREASURY	106,403	13
VA-DEPARTMENT OF VETERANS AFFAIRS	316,480	34
Grand Total	**2,057,298**	**408**

Chapter 3 Methodology

Modeling through simulation is the applied method for studying the effects of worker departure on organizational composition and groups. Due to the complexity of social phenomena, simulation has been recognized as a third approach to developing theory alongside verbal articulation and mathematics (Ostrom 1988).

3.1 Simulation

Simulation has been widely accepted as a methodology in the natural sciences and engineering. Complex system models such as Kauffman's model (NK), Arthur's model of lock-in, Von Neumann Neighborhood, may be tailored to incorporate new theories across various disciplines (Leydesdorff 2002). Simulation has more recently been adopted for organizational or social theory due to the development of agent-based models (Gilbert and Terna 2000).

Social science experiments traditionally focus on either macro level theories within sociology or micro level theories within psychology (Levitt 2004). Agent-based models bridge micro and macro theories by modeling individual behavior and validating the model against macro-level empirical data (Levitt 2004). Therefore, the empirical validation of agent-based models is performed at the individual level and at the aggregate level (Marks 2007).

The modeling process entails formulating the research question; assembling hypothesis for essential processes; choosing scales, processes, and parameters; implementing the model; and analyzing and testing (Railsback and Grimm 2011). An agent-based model introduces specific requirements for computation including:

individual entities seeking a goal in an autonomous fashion; flexible behavior able to deal with uncertainty, and the interaction between agents (Yilmaz 2006), and the absence of any centrally controlled of behavior (Richiardi 2012). Accordingly, agents are defined as individual, unique, and autonomous entities that can interact with each other and their local environment (Railsback and Grimm 2011).

Netlogo (Wilensky 1999) is the specific tool employed in the worker departure simulation. Netlogo is a simulation tool for modeling complex systems evolving over time. The tool utilizes a multi-agent programming and modeling environment to instruct large numbers of concurrently operating independent agents (Tisue and Wilensky 2004). In comparison to other agent-based modeling tools, Netlogo was selected due to being well supported in the academic community and due to enabling the expedient creation of models (Robertson 2005).

The overarching behavior of the simulation of worker departure is based on Schelling's segregation model (Schelling 1971) and introduces the concept of career stages and collective worker satisfaction. Each agent has assigned preferences of satisfaction and an attribute of satisfaction which fluctuates based on the agents in their surroundings. Using a basic seeking behavior, groups form and evolve based on the actions of the individuals creating 'neighborhoods' of agents.

3.2 Research Framework

A rigorous analysis of organizational simulation models by Ashworth and Carley (2007) assessed organizational simulations from the period of 1989 to 2003 and characterized the models based on 245 capability evaluation factors (Ashworth and Carley 2007). The framework consists of fifteen traits within the following constructs:

inputs (resources, history, culture and environment), transformation processes (composition, organization context, psychosocial traits, informal networks, interactive processes, and technology), outputs (performance, attitude, and behavior), and linkages (strategy and action) (Ashworth and Carley 2007). The relationships between the constructs within the organization simulation framework are illustrated by Ashworth and Carley (2007) in Figure 3-1.

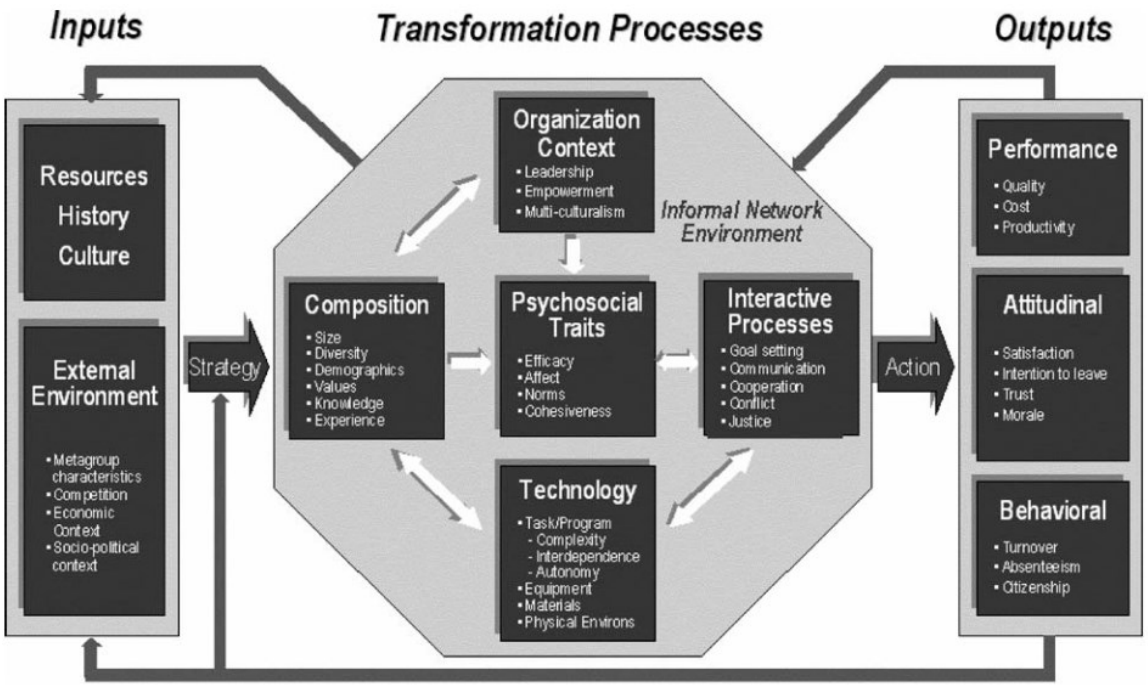


Figure 3-1 Organization Simulation Framework (Ashworth and Carley 2007)

Using the comprehensive framework of organizational simulation by Ashworth and Carley (2007) as a guide, the framework for assessing worker departure focuses on a specific subset of transformation processes and outputs. Within the transformational processes, the factors of group size and demographics are considered. Within the output construct, the attitudinal output of satisfaction and intention to leave and the behavior

output of turnover are examined. Due to the complex nature of the model, interdependencies exist between the worker dimensions of demographics and attributes of attitude as well as the composition and stability of the workforce. The following conceptual model, Figure 3-2, depicts the factors and sub-factors:

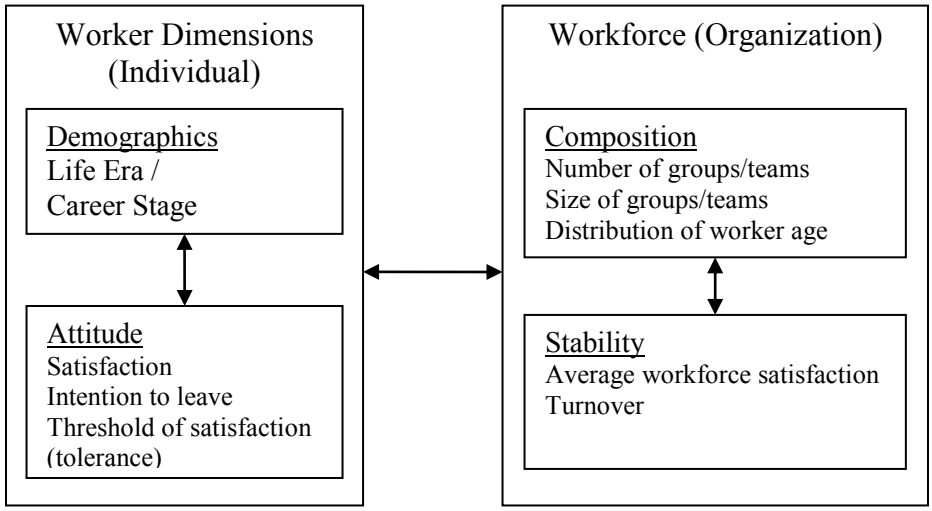


Figure 3-2 Conceptual Model of Work Departure

The effects of individual demographics, intention to leave, and turnover on the organization form and stability are evaluated based on the composition of groups and overall attrition rate. Specifically, group size is a critical factor to organizational emergence (Elsner 2010). By measuring the relationships between worker satisfaction and the workforce, this study aims to relate individual attributes and behavior to the composition and stability of an organization. A detailed formulation of the worker departure model is provided in Chapter 4 using the "Overview, Design concepts and Details" (ODD) protocol (Grimm, Berger et al. 2010).

Chapter 4 Model Overview, Design concepts, and Details

Following the ODD protocol (Grimm, Berger et al. 2010), overview, design concepts, and details have been provided to describe the agent-based model assessing worker departure and behavior. The overview section provides a broad description of the model including the purpose, the entities, state variables and scales, and process overview and scheduling. The design concepts section describes the model behavior detailing the basic principles and characteristics such as emergence, sensing, adaptive behavior, collectives, and observations. Lastly, the details section spans the model initialization and data input as well as the specific routines and sub routines employed.

4.1 Overview

The simulation of worker departure is constituted by two agent-based models (ABM) of seeking behavior within an organization. The foundational model (Model I) is not time bound and evaluates the workforce without worker replacement. The workforce without replacement model generalizes the workforce into three broad categories of highly satisfied, moderately satisfied, and minimally satisfied workers and demonstrates grouping behavior. Building on Model I, the workforce with replacement model (Model II) introduces a time scale and segments the workforce into age groups providing a greater level of insight into the worker behavior across career stages.

For the purposes of the models I and II, satisfaction is defined as a worker's lack of tendency to seek a new job (intention to leave) and the likelihood of staying in the workforce. This approach generalizes satisfaction to encompass the established precursors and associations of employee turnover such as job satisfaction, demographics,

organization and work environment factors, and the nature of the job (Griffeth, Hom et al. 2000).

4.1.1 Purpose

The models aim to understand the emergent behaviors of employee turnover and employee satisfaction and the effects of turnover on the organizational composition. The effects of individual demographics, intention to leave, and turnover on the organization form and stability are evaluated based on the composition of groups and overall attrition rate.

4.1.2 Entities, State Variables, and Scales

The ABM includes government employees represented as agents and the global environment affecting all agents. The agent's state is based on the variable Satisfaction assessed on a scale from zero to one hundred percent. A satisfaction of zero results in a worker exiting the workforce and a worker at the maximum satisfaction of one hundred percent is the least likely to seek new employment opportunities.

The model landscape and processes are governed by the tool NetLogo (Wilensky 1999). NetLogo terminology for time increments is "ticks" and distance is "patches". Figure 4-1 illustrates a 7x7 model space of forty-nine patches with a population of agents.

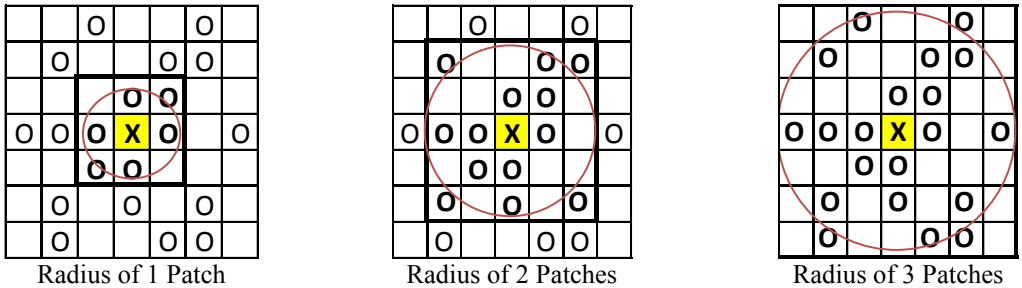


Figure 4-1 Illustration of Netlogo Model Space

In Figure 4-1, the highlighted agent at the center of model, denoted with the symbol X, observes the attributes of surrounding agents within a defined radius. The Netlogo command 'in-radius' reports the surrounding agents based on a distance measured from the center of the patch.

The Worker Departure models are configured with a population of one thousand agents in a model space of a 101 by 101 torus yielding a density of approximately one agent per ten patches. The agents move at a rate of 2 patches per tick. For Model I, without replacement, the temporal and spatial scales are not explicitly defined. For the Model II, with replacement, each tick is defined as one week of time. Therefore, a year is represented by fifty-two ticks.

4.1.3 Process overview and scheduling

The agents have a single basic process of seeking an environment of acceptable collective satisfaction. The model process starts with an initial population randomly distributed in the model space. For Model I, the process ends when all agents either stop seeking or exit the model. For Model II, the effects of workers retiring and entering the model allow the model to run in perpetuity and the process ends based on a predefined time. There are no additional model processes that affect the behavior of the agents.

The agent seeking behavior governs the agent's evaluation of the collective satisfaction, the agent movement, and the agent's level of satisfaction. The collective satisfaction for each agent is assessed by averaging the satisfaction of neighboring agents within a defined radius or range (satisfaction radius). Figure 4-2 illustrates a worker assessing the average satisfaction of neighboring workers based on a satisfaction radius or 1 patch, 2 patches, and 3 patches.

		75			80	
	85			60	75	
			50	80		
70	60	75	**X**	35		75
		90	75			
	90		60		50	
	75			80	90	

Radius of 1 patch: [(50 + 80 + 75 + 35 + 90 + 75)/6] = **67.5**

Radius of 2 patches: [(85+60+75+50+ 80+60+75+35+90+75+90+60+50)/13] = **68.1**

Radius of 3 patches: [(75+80+85+60+75+50+80+ 70+60+75+35+75+90+75+90+60+50+75+80+90)/20] = **71.5**

Figure 4-2 Agent Seeking Behavior Example 1

The agent decision to seek a new environment is based on the collective satisfaction being less than a defined threshold of an acceptable environment (satisfaction threshold). Based on the example illustrated in Figure 4-2, if the worker has a satisfaction threshold of 70 then a satisfaction radius of 1 patch or 2 patches yields an average satisfaction of 67.5 and 68.1 and would not be acceptable. Consequently, the agent would then seek a new environment. At a radius of three patches yielding an average satisfaction of 71.5, the worker's threshold is met and the worker would not seek a new environment.

Assuming a satisfaction radius of 2 patches in example 1, the worker would migrate a distance of 2 patches to a new location and reassess the new environment. Figure 4-3 illustrates the migration of the worker and the associated average satisfaction. In example 2, the worker satisfaction threshold of 70 is satisfied with a radius of 2 patches and the worker would stop seeking.

		75			80	
	85			60	75	
			50	80		
70	60	75		35		75
		90	75			
	90		60	**X**	50	
	75			80	90	

Radius of 1 patch: [(75 + 60 + 50 + 80 +90) / 5] = **71**

Radius of 2 patches: [(75+35+75+90+75+60+50+80+90+75+80)/11] = **71.4**

Radius of 3 patches: [(75+80+85+60+75+50+80+ 70+60+75+35+75+90+75+90+60+50+75+80+90)/20] = **71.5**

Figure 4-3 Agent Seeking Behavior Example 2

Lastly, the agent's level of satisfaction either grows or decays based the decision to seek a new environment. The agent will migrate across the model space until a collective satisfaction above the satisfaction threshold is found. The migration process and seeking decays the satisfaction of the agent at a pre-determined decay rate. The agent will stop if an acceptable satisfaction is found and when stopped the agent's satisfaction will grow at a pre-determined growth rate. If an agent's satisfaction reduces to zero before finding an acceptable environment, the agent exits the model.

4.2 Design Concepts

An agent-based model may exhibit various indeterminate behaviors that cannot be reproduced with structured equations. To fully capture and understand these behaviors, the model design must consider the concepts of emergence, adaptation, objective seeking, learning, prediction, sensing, interaction, scheduling, stochasticity, collectives, and observation (Railsback and Grimm 2011).The design concepts relevant to the worker departure model include emergence, sensing, adaptive behavior and objectives, collectives, and observations. The design concepts not explicitly considered include prediction, interaction, and stochasticity.

4.2.1 Basic Principles

The basic concept examined in the worker departure ABM is the formation of groups or self-organization among agents to achieve an acceptable shared environment.

4.2.2 Emergence

The macro-level results of the model of interest include the group formation in terms of size and number, the worker departure and associated worker attrition, and the composition of worker segmentation of satisfaction.

4.2.3 Sensing

The workers sense the satisfaction of their neighboring workers based on a common radius set by the model.

4.2.4 Adaptive Behavior and Objective

The workers adapt to their environment by assessing the satisfaction of their neighboring workers and migrating if a basic satisfaction condition is not satisfied. The model sets the objective of a satisfaction threshold for each agent as the basis for evaluating the environment. If the average satisfaction of neighboring workers is below the threshold the worker migrates to a new location. The distance of the migration per time step is common to all agents. If the average satisfaction is above the threshold the objective is met and the worker stops seeking.

4.2.5 Collectives

The organization of the agents into collectives or groups is fundamental to achieving the objective of acceptable satisfaction conditions. The model assumes a worker cannot function independently of the organization. If a worker does not have any neighboring workers, regardless of current satisfaction, the worker will seek another worker.

4.2.6 Observations

The outputs observed in the model via plots include the overall attrition, the attrition rate, the group count and average group size, the average migration distance, average population satisfaction, and composition of the worker satisfaction segments.

4.3 Details

4.3.1 Initialization and Input Data

The initialization data provides the basis for the models' agent population characteristics and behavior. The initialization and input data of the models I and II vary due to the differences in scope and complexity. Because Model I is not time bound, the model uses the average worker population and attrition statistics to guide the initialization and evaluation. Model II requires additional parameters to account for the various age groups and new workers being added.

4.3.2 Model I. Workforce Departure without Replacement

The starting population of the model consists of three segments of agents: highly satisfied, moderately satisfied, and minimally satisfied. Each segment is defined by a starting satisfaction and a minimum satisfaction. The starting satisfaction establishes the level of commitment of the agents when the model is initialized. The minimum satisfaction establishes the range of satisfaction for the segment as workers seek opportunities to increase satisfaction. The highly satisfied segment is initiated at sixty-nine percent of the overall population with a starting satisfaction of ninety-five percent and a minimum satisfaction of eighty-eight percent. The moderately satisfied segment is initiated at nineteen percent of the overall population with a starting satisfaction of

eighty-five percent and a minimum satisfaction of seventy-three percent. The minimally satisfied segment is initiated at twelve percent of the overall population with a starting satisfaction of thirty-five percent and a minimum satisfaction of zero.

The segment populations of satisfaction are based on the historical distribution of the US government workforce and associated attrition. The distribution of the workforce is illustrated in Figure 4-4, and Figure 4-5 illustrates the attrition.

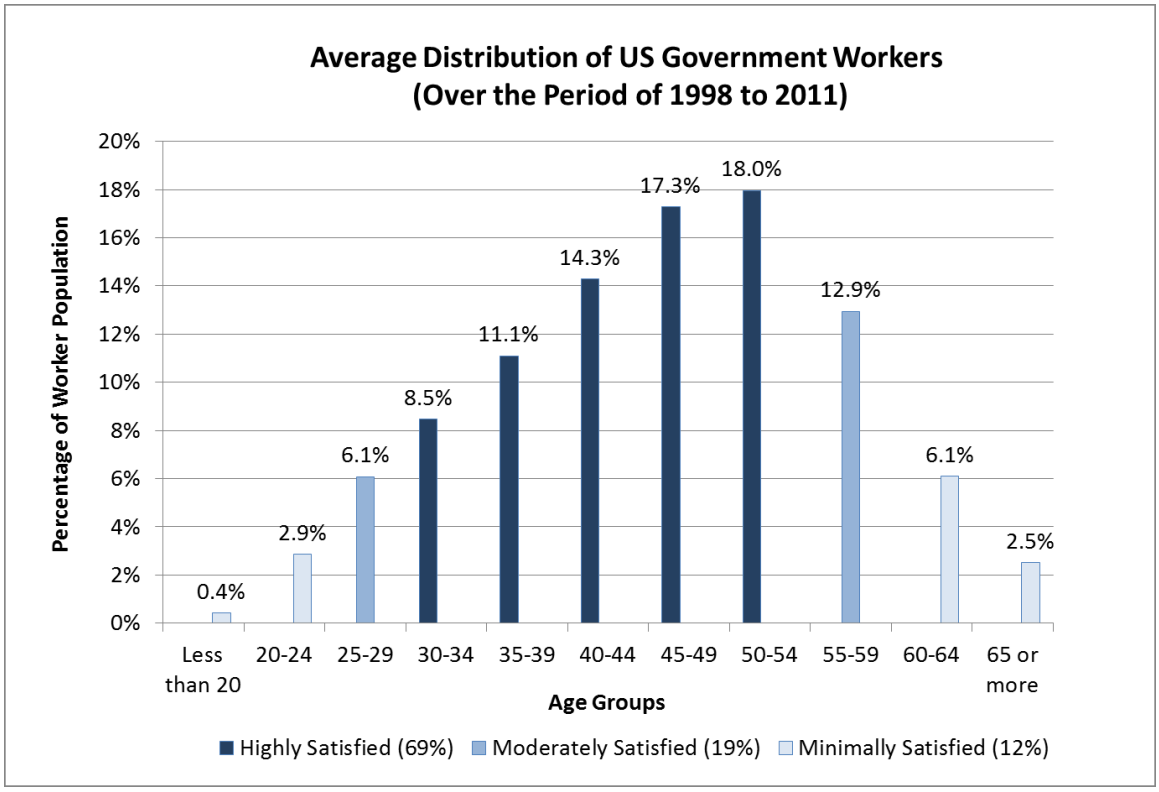


Figure 4-4 Average Age Distribution of US Government Workers

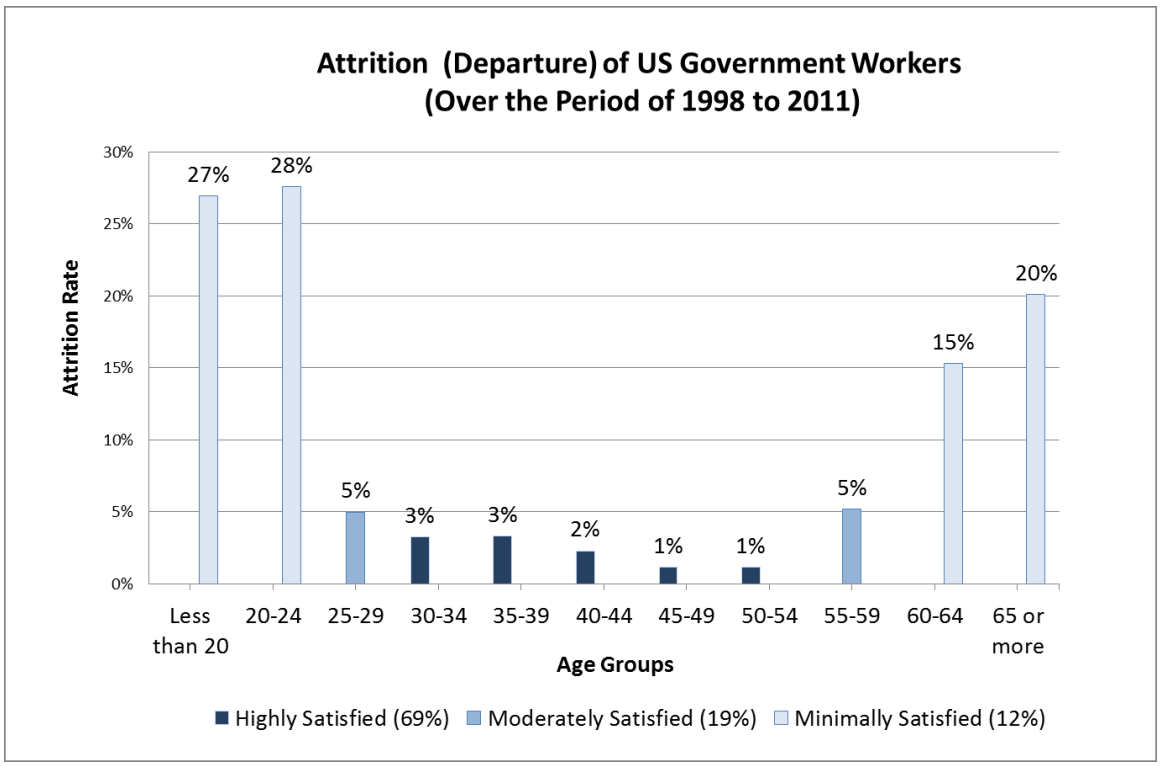


Figure 4-5 Average Attrition of the US Government Workforce

To facilitate the seeking process, the model is initiated with the global variables of satisfaction radius, satisfaction threshold, satisfaction growth rate, and satisfaction decay rate. The satisfaction radius is set to 2 patches and the satisfaction threshold is set to seventy-five percent satisfied. The satisfaction growth is set to seventy-five hundredths of a percent and satisfaction decay is set to one percent. There is no input data required for Model I without replacement.

4.3.3 Model II. Workforce Departure with Replacement

The starting population of the model consists of nine age groups representing the segments of agents: highly satisfied, moderately satisfied, and minimally satisfied. The highly satisfied segment consists of five age groups; thirty to thirty-four , thirty-five to thirty-nine, forty to forty-four, forty-five to forty-nine, and fifty to fifty-four. The

moderately satisfied segment consists of the two age groups; twenty-five to twenty-nine and fifty-five to fifty-nine. The minimally satisfied segment contains the remaining ages of eighteen to twenty-four and over sixty. The over sixty age group is defined as any worker with an age greater than sixty years and is not bound by a maximum age. Because the model incorporates time based attributes, the model is initialized with the starting population of the empirical data set. The following figure, Figure 4-6, provides the distribution of the US government workforce in year nineteen ninety-eight:

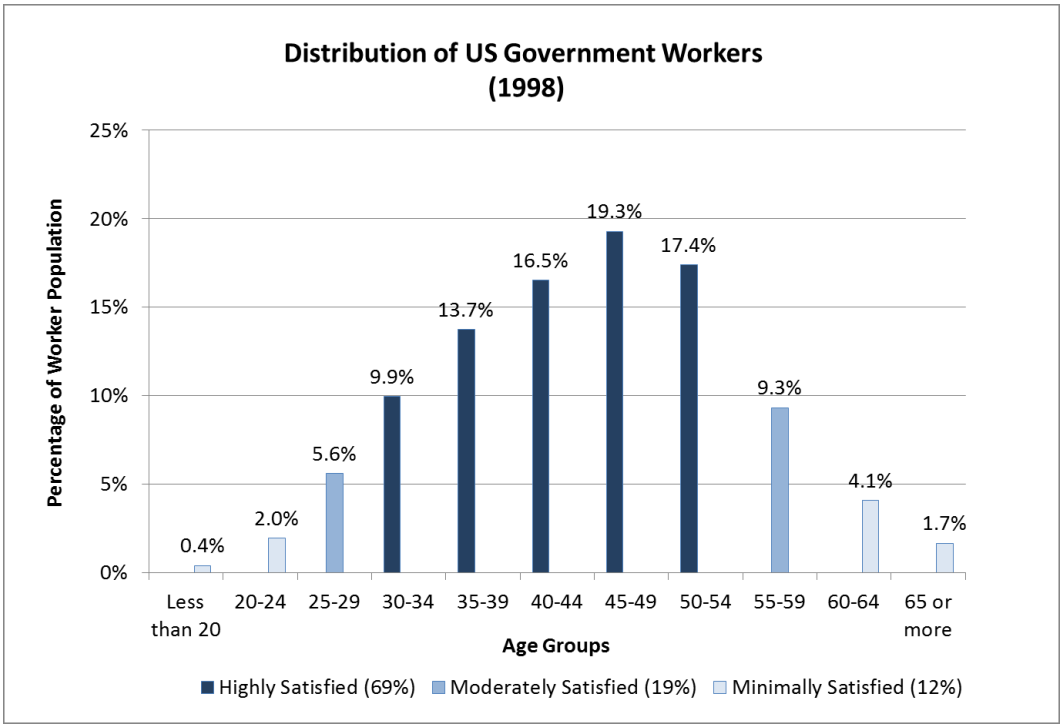


Figure 4-6 Age Distribution of US Government Workers in 1998

Each age group is defined by a starting satisfaction, satisfaction threshold, satisfaction growth, and satisfaction decay. The starting satisfaction establishes the level of commitment of the agents when the model is initialized. The satisfaction threshold determines whether average satisfaction of neighboring workers is acceptable. The satisfaction growth parameter determines content (non-seeking) workers growth in

satisfaction and the decay parameter decreases satisfaction when a worker is seeking a new group. To facilitate the seeking process, the model is initiated with the global variables of satisfaction radius, and satisfaction growth factor. The satisfaction radius is set to 2 and the satisfaction growth factor is set to seventy-five hundredths of a percent.

The starting satisfaction of the highly satisfied segment is set to ninety-five percent with a satisfaction threshold ranging from seventy-two point five to seventy-two percent. The growth of ninety-five percent is factored by the satisfaction growth factor of seventy-five hundredths yielding a weekly growth of seven point one percent. The decay of the highly satisfied segment ranges from ten percent to six point five percent per week aligned to the declining attrition rate of the empirical data for ages thirty to fifty-four.

The starting satisfaction of the moderately satisfied segment is set to eighty percent with a satisfaction threshold ranging from seventy-two point five to seventy-one percent. The growth of eighty-five percent for the twenty-five to twenty-nine age group is factored by the satisfaction growth factor of seventy-five hundredths yielding a weekly growth of six point four percent. The growth of the fifty-five to fifty-nine age group is a negative point five percent reflecting the beginning of the retirement career stage. The decay of the twenty-five to twenty-nine age group is set to thirteen percent and the decay parameter of the fifty-five to fifty-nine age group is set one hundred percent reflecting immediate departure from the workforce upon retirement.

Lastly, the starting satisfaction of the minimally satisfied segment is set to sixty-five percent with a satisfaction threshold ranging from seventy-five to eighty percent. The satisfaction growth for the less than twenty-four and greater than sixty age groups is negative two and two and a quarter percent reflecting the new employee and retirement

career stages. The decay of the less than twenty-four age group is set to ten percent and the decay parameter of the greater than sixty age group is set one hundred percent reflecting immediate departure from the workforce upon retirement. The following table, Table 4-1, summarizes all of the initialization parameters for each of the age groups:

Table 4-1 Initialization Parameters by Age Group

Satisfaction/Ages:	Minimal	Moderate	High					Moderate	Minimal
Parameters	Less than 24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60 or more
Population	19	55	95	135	165	190	170	90	55
Starting Satisfaction	65	80	95	95	95	95	95	80	65
Satisfaction Threshold	75	72.5	72.5	72.5	72.5	72	72	71	80
Satisfaction Growth	-2	85	95	95	95	95	95	-0.5	-2.25
Satisfaction Growth (factored) *	-0.2	6.4	7.1	7.1	7.1	7.1	7.1	-0.04	-0.17
Satisfaction Decay *	10	13	10	10	7.5	7	6.5	100	100
Growth to Decay Ratio	-2%	49%	71%	71%	95%	102%	110%	-0.04%	-0.17%

*** Growth and Decay rates are based on a time increment of 1 week.**

The input data required for the model II with worker replacement consists of adding workers to maintain a fixed population. The new workers are added based on the historical distribution of US government workers. The following figure, Figure 4-7, illustrates the distribution used in the model:

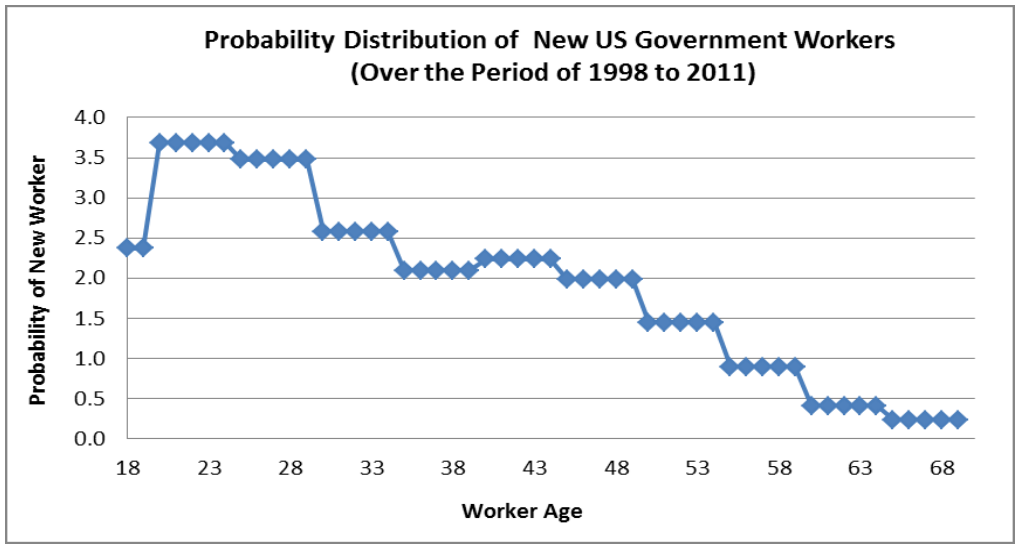


Figure 4-7 Average Age Distribution of new US Government Workers

Chapter 5 Analysis and Discussion

The effects of individual employee departure and job seeking behavior on organization composition is demonstrated by the results of an ABM and validated by the historical employment data of the US government. The results and associated analysis are provided in two sections corresponding with Models I and II, with and without worker replacement.

5.1 Model I: Behavior without Worker Replacement

5.1.1 Emergent Behavior

The outcomes from a single simulation run are provided to illustrate the emergent behavior of the workforce in terms of worker satisfaction and attrition rates, group formation, and the behavior of worker segments. It is important to note, due to the stochastic nature of the ABM, the specific results of a single run do not reflect the average results of the model.

5.1.2 Worker Satisfaction and Attrition

The average satisfaction of the overall population starts at eighty-five percent centered on the starting satisfaction of the moderately satisfied segment then lowers to eighty-three percent by the thirty-seventh time step (Figure 5-1). Two-thirds of the worker seeking occurs during this initial period as represented by the average migration of ten patches (Figure 5-2). As attrition begins, the average satisfaction climbs towards the highly satisfied of eighty-eight percent. The lag in workers exiting the workforce can be attributed to the starting satisfaction of the minimally satisfied at thirty-five percent and the satisfaction decay of one percent per time step (Figure 5-3). Even though the

attrition begins at the thirty-ninth time step due to the starting satisfaction of the minimally satisfied, the pattern of attrition fluctuates throughout the remainder of the seeking process (Figure 5-4).

Figure 5-1 Model I. Plot of Avg. Satisfaction

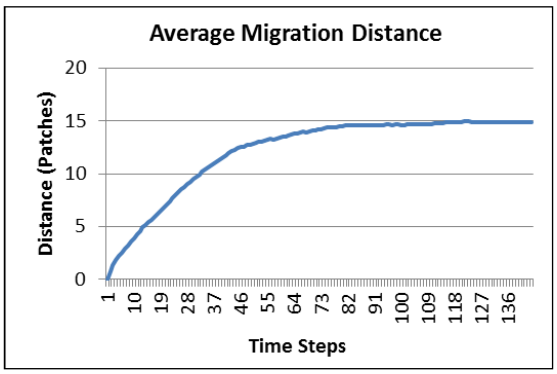


Figure 5-2 Model I. Plot of Average Migration

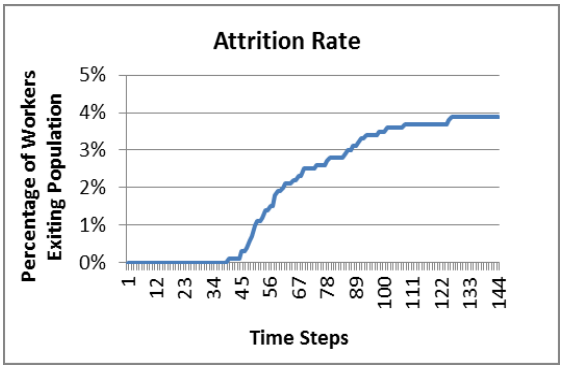


Figure 5-3 Model I. Plot of Attrition rate

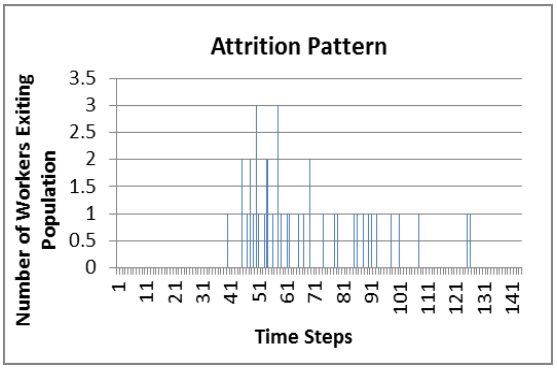


Figure 5-4 Model I. Plot of Attrition Pattern

5.1.3 Group Formation

The group formation of the workers can be accounted for by the average group size and the number of groups. The satisfaction radius provides the basis for the worker's evaluation of their environment following the notion of bounded rationality. If the satisfaction radius is decreased the average satisfaction of the workers would reduce until all workers exit the workforce. Due to the majority of the population residing in the highly satisfied segment, if the radius is increased the workers would easily achieve an

acceptable satisfaction assessment and minimal seeking and attrition occurs. Figure 5-5 illustrates the satisfaction radius concept from the span of 1 to 3 patches.

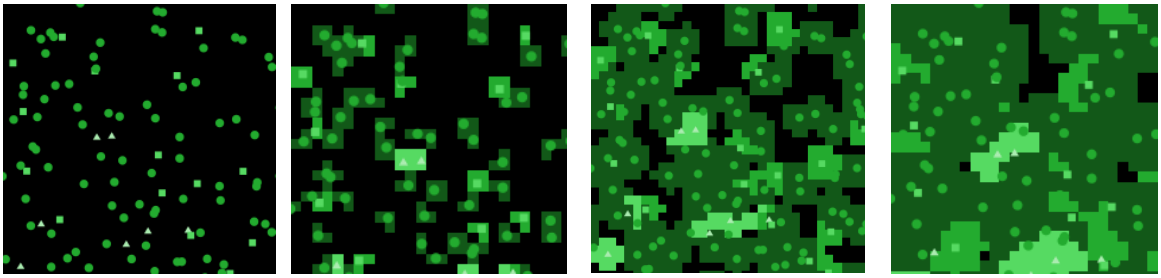


Figure 5-5 Illustration of Worker Satisfaction Radius

At the launch of the model, the agents are randomly distributed with a density of one agent per ten patches (Figure 5-6) and groups are formed based on the satisfaction radius of two patches (Figure 5-7). A radius of two patches demonstrates an attrition of 4.6% over five hundred simulation runs in line with historic attrition averages of the US government workforce. The departure of workers in model I is without replacement illustrating a single group formation process that remains in place until the model is manually stopped.

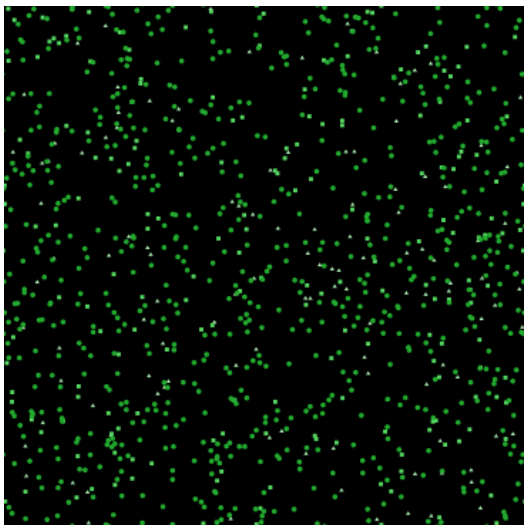


Figure 5-6 Model I. Illustration of Initial Distribution

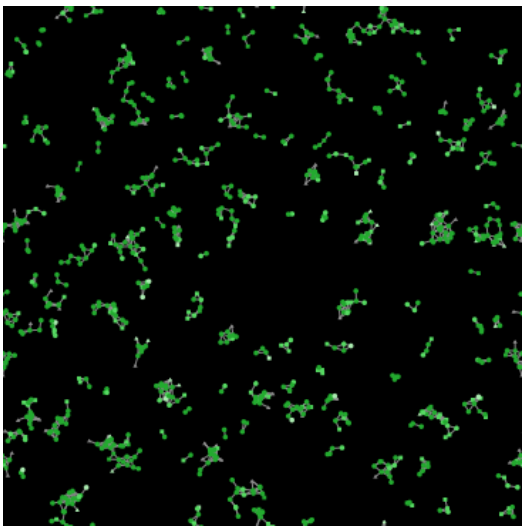


Figure 5-7 Model I. Illustration of Group Formation

The group size begins at an average of three workers per group and stabilizes at group sizes of eight (Figure 5-8). As the smaller groups combine to achieve acceptable satisfaction conditions the total number of groups reduces accordingly (Figure 5-9).

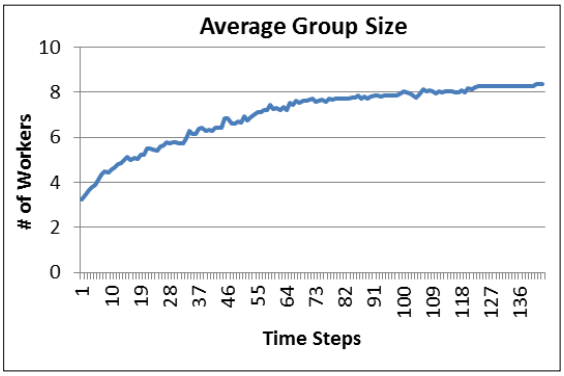


Figure 5-8 Model I. Plot of Average Group Size

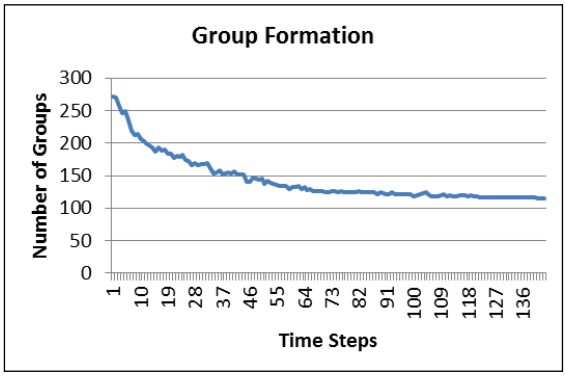


Figure 5-9 Model I. Plot of Groups Formed

5.1.4 Worker Behavior

The worker departure model without replacement is primarily focused on the behavior of the workers across three periods: initial period of workers seeking without attrition, period of attrition and worker rebalancing, and a steady state with minimal migration (Figure 5-10). With the workforce population initiated in the three worker segments of highly satisfied, moderately satisfied, and minimally satisfied, a phenomenon of workforce balancing occurs as the average satisfaction fluctuates. The global satisfaction threshold of seventy-five percent determines whether agents migrate throughout the model. As the average satisfaction approaches the threshold the population skews towards the moderately satisfied. In the initial period, the population of smaller groups is unable to sustain the average satisfaction and satisfaction reduces until workers exit the model. As attrition begins, average satisfaction increases and the workforce begin to return to the initial composition of segments. As illustrated in Figure

5-10, the workforce takes almost twice as long to return to the previous composition of satisfied workers. Beyond this rebalancing, the model continues to increase in satisfaction as a small number of workers continue to seek. Because new entrants of minimally satisfied workers are not introduced at the point of rebalancing, the steady state portion of behavior does not reflect empirical findings.

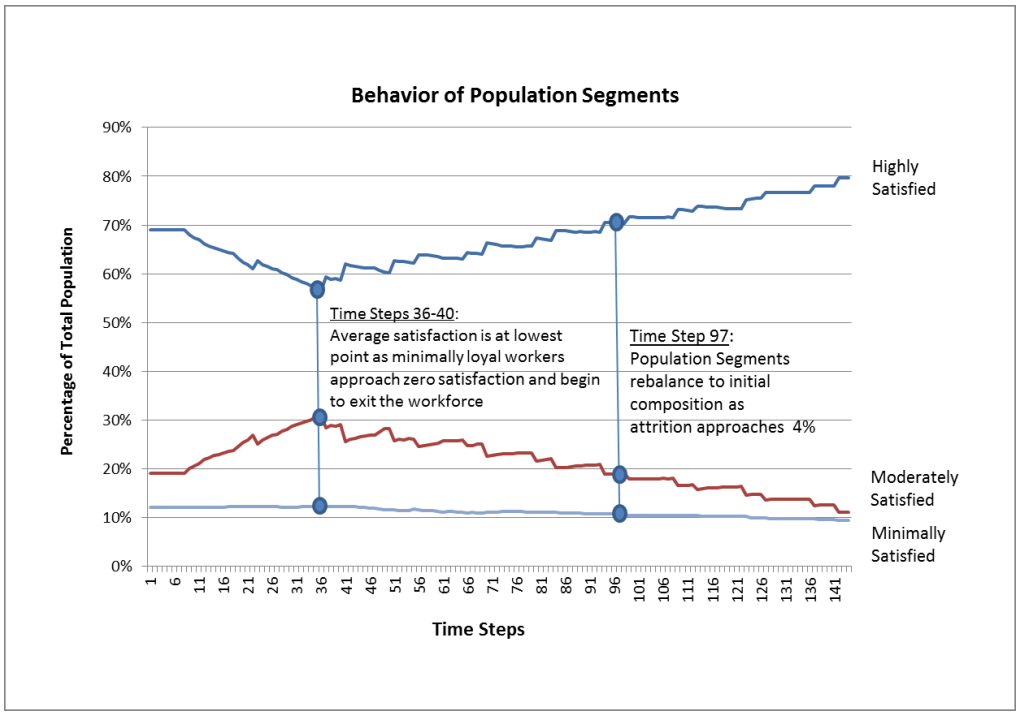


Figure 5-10 Model I. Agent Behavior by Population Segments of Satisfaction

5.1.5 Validation of Results

The primary mechanism for validating the results of the worker departure ABM is the comparison of attrition observations to the empirical US government employment data. The assessment is performed for the overall workforce population as well as the defined segments of worker satisfaction derived from the trends of particular age groups.

Using the historical trends of attrition, the government workforce satisfaction can be segmented into three broad categories. Approximately seventy percent of the workforce,

ages spanning thirty to fifty-four, falls below the overall attrition rate of five percent. Nineteen percent of the workforce, ages twenty-five to twenty-nine and fifty-five to fifty-nine, is at the overall attrition rate. The remaining eleven percent, ages below twenty-five and greater than fifty-nine, is substantially above the overall attrition rate.

The results of running the ABM five hundred times produced a mean attrition rate of 4.6% with a range of attrition rates from 2.2% to 7.5% (Table 5-1). The mean rate of attrition of the model is within ten percent of the US government attrition rates over the past thirteen years with an approximately equivalent range of rates.

Table 5-1 Comparison of Simulation Results and Empirical Data

Comparison of Attrition Statistics

	Agent-Based Model	*US Gov. Employment Data*
Mean	0.046	0.051
Standard Error	0.0004	0.004
Median	0.046	0.054
Standard Deviation	0.008	0.015
Range	0.053	0.054
Minimum	0.022	0.022
Maximum	0.075	0.076
Count*	500	13

*Count represents 500 simulation runs for the agent-based model and 13 years of empirical data (years 1999 to 2011).

To evaluate the validity of attrition for the three worker segments, the variation from the historic average as a proportion of the overall population was considered. Approximately seventy percent of the workforce, ages spanning thirty to fifty-four, constitutes thirty percent of the attrition. Nineteen percent of the workforce, ages twenty-five to twenty-nine and fifty-five to fifty-nine, account for twenty percent of the attrition. The remaining eleven percent, ages below twenty-five and greater than fifty-nine, represents fifty percent of the attrition. Because the variation of one segment directly

affects the variation of the other segments, the absolute value of the variation was averaged across all three segments to determine a single attrition variation rate throughout each run. Notably, the minimum attrition variation rate coincides with the workforce phenomenon of rebalancing the population segments. Therefore, the minimum attrition variable rate was used to validate the model.

The results of running the ABM five hundred times produced a mean attrition variation rate of the segments of 10.8% with a range of rates from .6% to 87.3% (Table 5-2). The model produced attrition variation rate of the segments twenty percent greater than of the US government rates over the past thirteen years. This difference can be attributed to five percent of the simulation runs producing anomalous results. When ninety-five percent, three standard deviations, of the simulation runs were considered the mean directly equated to the US government data.

Table 5-2 Comparison of Simulation Results and Empirical Data for Segments

Comparison of Segmented Population Attrition Variation Statistics

	Agent-Based Model	*Agent-Based Model (3σ)*	*US Gov. Employment Data*
Mean	0.108	0.090	0.090
Standard Error	0.004	0.002	0.015
Median	0.081	0.078	0.088
Standard Deviation	0.096	0.052	0.055
Range	0.867	0.264	0.212
Minimum	0.006	0.006	0.013
Maximum	0.873	0.270	0.226
Count*	500	473	13

*Count represents 500/473 simulation runs for the agent-based model and 13 years of empirical data (years 1999 to 2011).

5.2 Model II: Behavior with Worker Replacement

In contrast to Model I, Model II incorporates the addition of new workers and the concept of time. By introducing a timescale, the age of the workers and associated career

and life stages provides another mechanism to modify satisfaction. Model II exhibits similar group formation during the initialization of the model and illustrates the group dynamics with the effects of new workers and workers retiring.

5.2.1 Emergent Behavior

The outcomes from thirty simulation runs are provided to illustrate the emergent behavior of the workforce in terms of worker satisfaction and attrition rates, group formation, and the behavior of worker segments. It is important to note, due to the stochastic nature of the ABM, the specific results of a single run do not reflect the average results of the model.

5.2.2 Worker Satisfaction and Attrition

The average satisfaction of the overall population starts at eighty-eighty percent weighted towards the starting satisfaction of the moderately and highly satisfied segments (ages twenty-five to fifty-nine) then raises to over ninety-five percent as the groups form in the first few years and then declines towards the starting satisfaction by year fifteen (Figure 5-11). The worker seeking reaches its maximum during this fifteen year period as represented by the average migration of six and a half patches (Figure 5-12). Unlike Model I, there is no lag in attrition at the start of the model due to workers retiring and new workers entering, the attrition immediately increases until groups are formed and continues to fluctuate around six percent (Figure 5-13). The initial average age of forty-three, based on the empirical data of 1998, increases until year ten reaching to over forty-eight then declines back down to just over forty-six (Figure 5-14).

The four measures of worker behavior and the associated demographic of age (satisfaction, attrition, migration, and age) portray the complexity of the group formation process and the interdependences between the individual workers affecting the overall worker population. While the first fifteen years illustrate the most variability across all measures, the maximum or peak level appears soonest for attrition (year 2), then followed by satisfaction (year 3), average age in year ten, and lastly average migration in year fifteen.

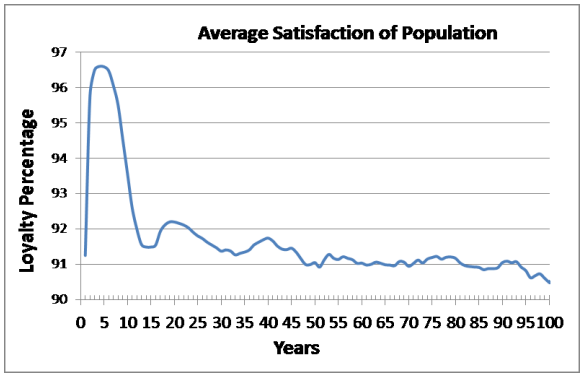


Figure 5-11 Model II. Plot of Avg. Satisfaction

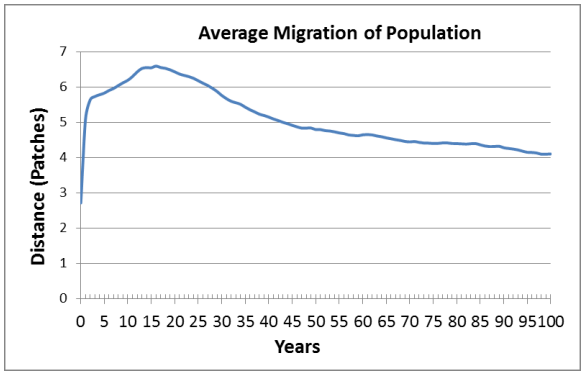


Figure 5-12 Model II. Plot of Average Migration

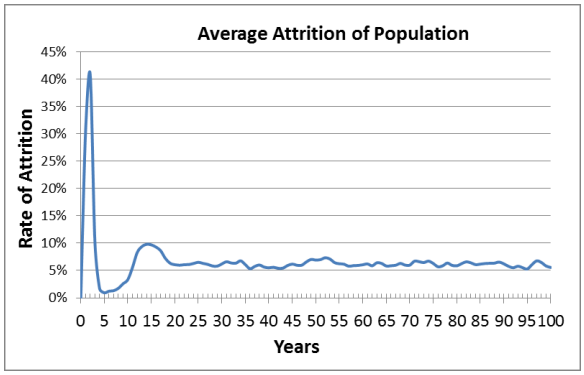


Figure 5-13 Model II. Plot of Attrition rate

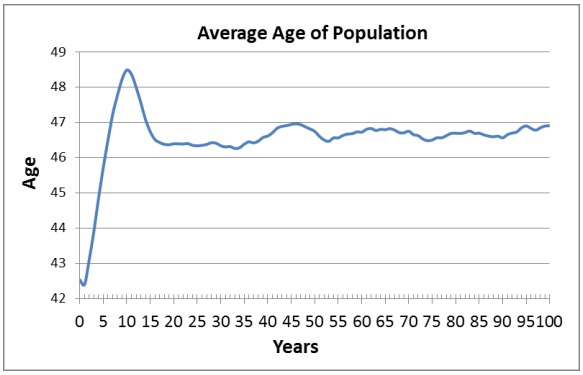


Figure 5-14 Model II. Plot of Average Age

5.2.3 Group Formation

Like in Model I, the group formation of the workers is accounted for by the average group size and the number of groups. As demonstrated in Model I, a satisfaction radius of two patches provides a representative amount of worker seeking behavior leading with a balance of attrition and stable groupings.

Using the results of thirty simulation runs, with worker replacement and retirement the group size begins at an average of three workers per group and continues to group sizes of eight by year five aligned with a drop in attrition culminating the group formation process (Figure 5-15) As the model continues beyond year five the average group size continues to grow. With a fixed population of workers, total number of groups reduces accordingly from a peak one hundred forty-six groups in year 2 (Figure 5-16).

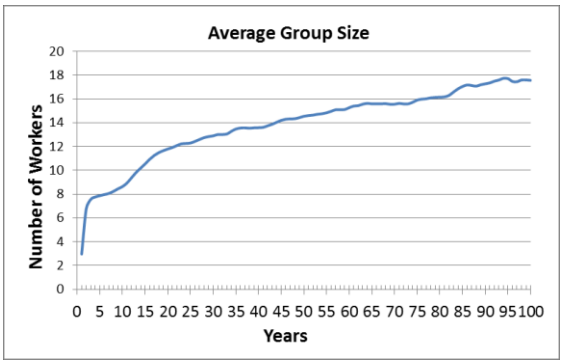


Figure 5-15 Model II. Plot of Average Group Size

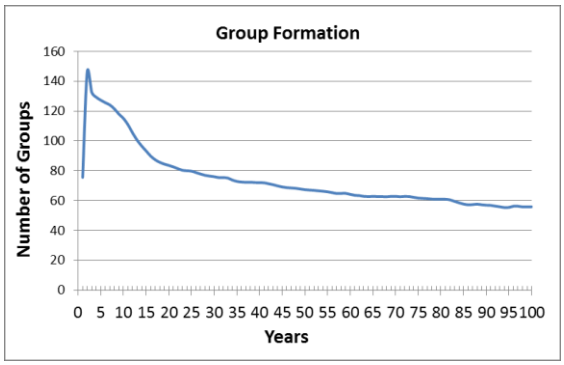


Figure 5-16 Model II. Plot of Groups Formed

To further illustrate the group formation process and the overall self-organization of the workers, the worker and group dynamics of two individual simulation runs are provided.

Figure 5-17 shows an example of a concentrated group of minimally satisfied workers leading to high turnover of all workers within a specific region of the population. The green symbols represent the workers and the red patches represent a region where a worker has quit. The four illustrations in Figure 5-17 depict the initialization period or

'origination', the immediate turnover of workers within year 1 as groups form, the culmination of workers actively seeking by year 5, and the retention of the group formations in year 10. Figures 5-18 and 5-19 illustrate the effects of the group formation process on the individual worker segments. The high turnover of the eighteen to twenty-four age group demonstrates the dramatic effect of a concentrated population and the inability to sustain the demographic. The steady decline of the highly satisfied group (Figure 5-19), thirty to fifty-five, illustrates the imbalance of the US government workforce moving toward retirement without the sufficient retention of entry level workers.

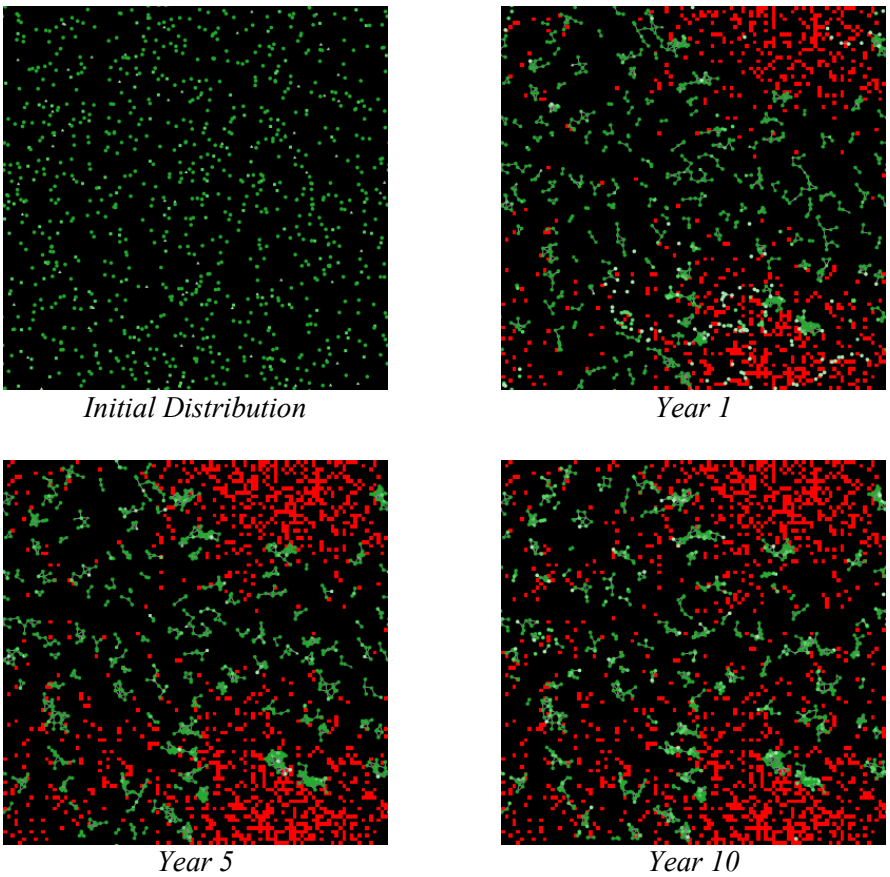


Figure 5-17 Model II. Illustration of Group Formation - Concentrated

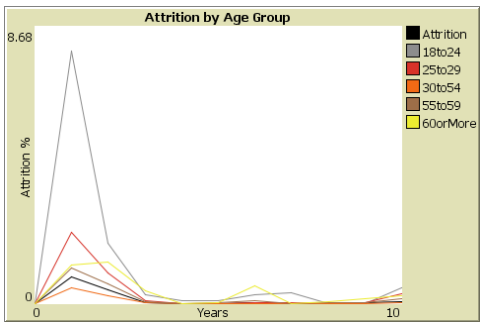


Figure 5-18 Model II. Attrition by Age Group - Concentrated

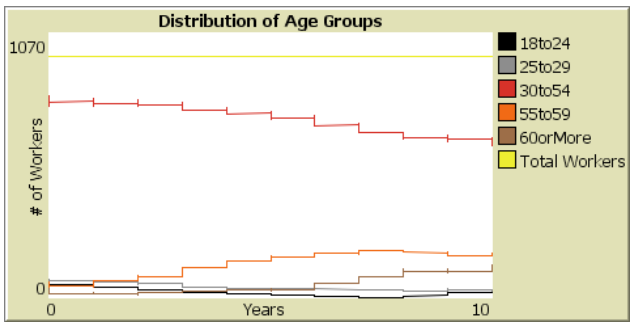
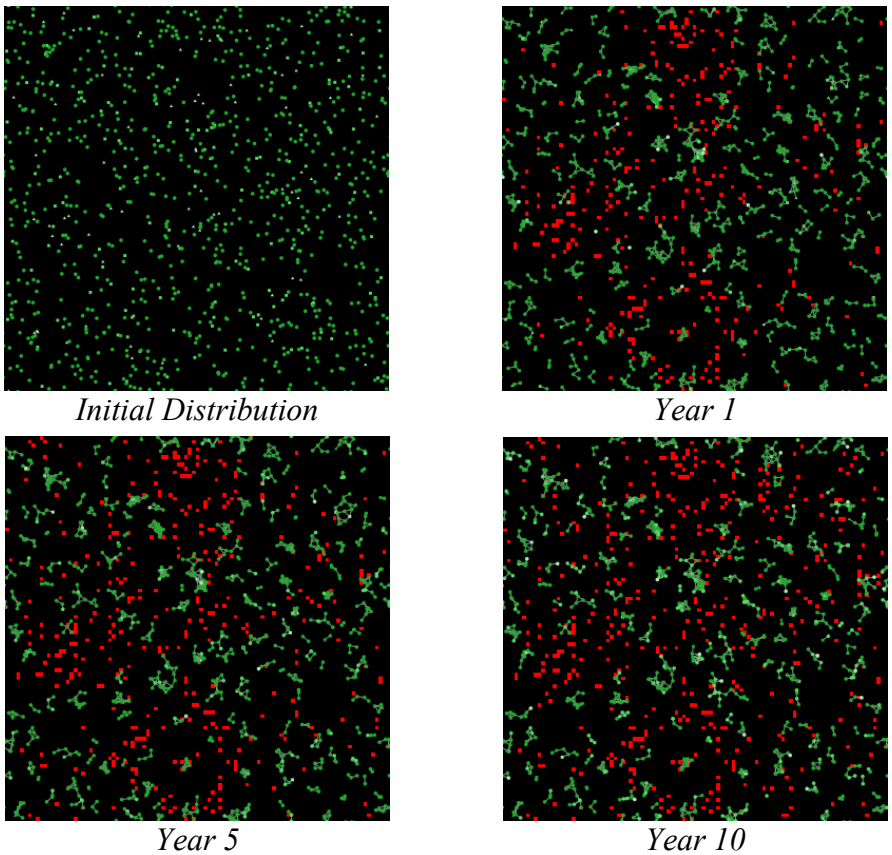


Figure 5-19 Model II. Distribution by Age Group - Concentrated

Figures 5-20 through 5-22 show an example of a dispersed group of minimally satisfied workers leading to moderate turnover of workers throughout the population. The same origination, diffusion, and retention process occurs with a dispersed minimally satisfied population but with a more uniform distribution of groups throughout the model.



Initial Distribution *Year 1*

Year 5 *Year 10*

Figure 5-20 Model II. Illustration of Group Formation – Dispersed

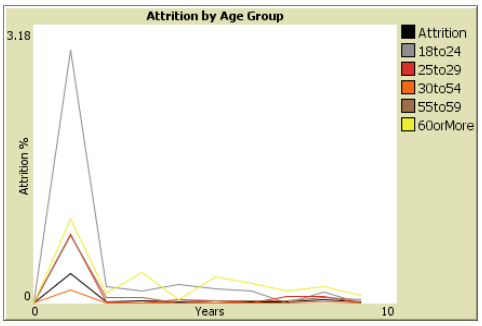


Figure 5-21 Attrition by Age Group – Dispersed

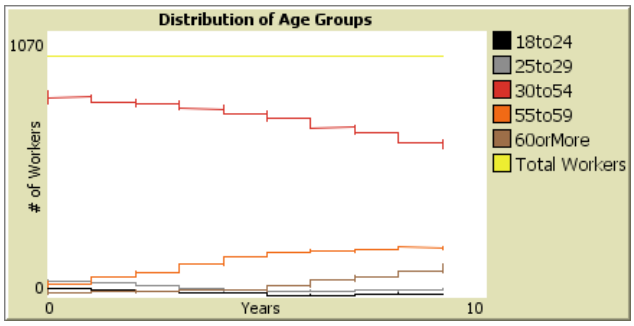


Figure 5-22 Distribution by Age Group– Dispersed

Even with the uncertainty of the initial population and the entrants of the new workers, the contrasting simulation runs exhibit similar attrition rates and distribution of age groups by the end of year ten. The adaptive behavior of the workers demonstrates the emergent behavior of group formation under a variation of initialization conditions.

5.2.4 Worker Behavior

The behavior of the workers can be divided into two periods: initial period of workers seeking acceptable groups with a high level of attrition and worker rebalancing between the entry of new employees and retirements, and a steady state with stable rates of migration and attrition (Figure 5-23).

With the workforce population initiated in the three worker segments of highly satisfied (ages thirty to fifty-four), moderately satisfied (ages twenty-five to twenty-nine and thirty to fifty-four), and minimally satisfied (eighteen to twenty-four and over sixty), a phenomenon of workforce balancing occurs as the average satisfaction fluctuates and groups form. The satisfaction threshold of each age group determines whether agents migrate throughout the model. Additionally, the satisfaction decay determines the rate of satisfaction lost during seeking. The satisfaction thresholds and decays are aligned with

the life and career stages of the workers. With the highest thresholds and decay assigned to the minimally satisfied segment, entry level workers and retirement eligible workers have the highest intention to quit.

During the initial period, the population of smaller groups with average group sizes of less than five is unable to sustain the required average satisfaction and workers continuously exit the model resulting in high attrition rates across all population segments. As the average group size surpasses five workers, the composition of the workforce begins to normalize and the retirement eligible segment grows balancing the population with the new entrants. The incompatibility of a small group size with the composition of the US government workforce demonstrates the importance of the organizational life cycle and the required alignment with the workforce.

After year twelve, as illustrated in Figure 5-23, the workforce composition is balanced with the largest segment of highly satisfied (ages thirty to fifty-four) at sixty-four percent. The result directly equates to the US government empirical data. With a starting population percentage of seventy-seven percent in 1998, the US government empirical data of the highly satisfied worker segment reduction to just over sixty-three percent in 2011.

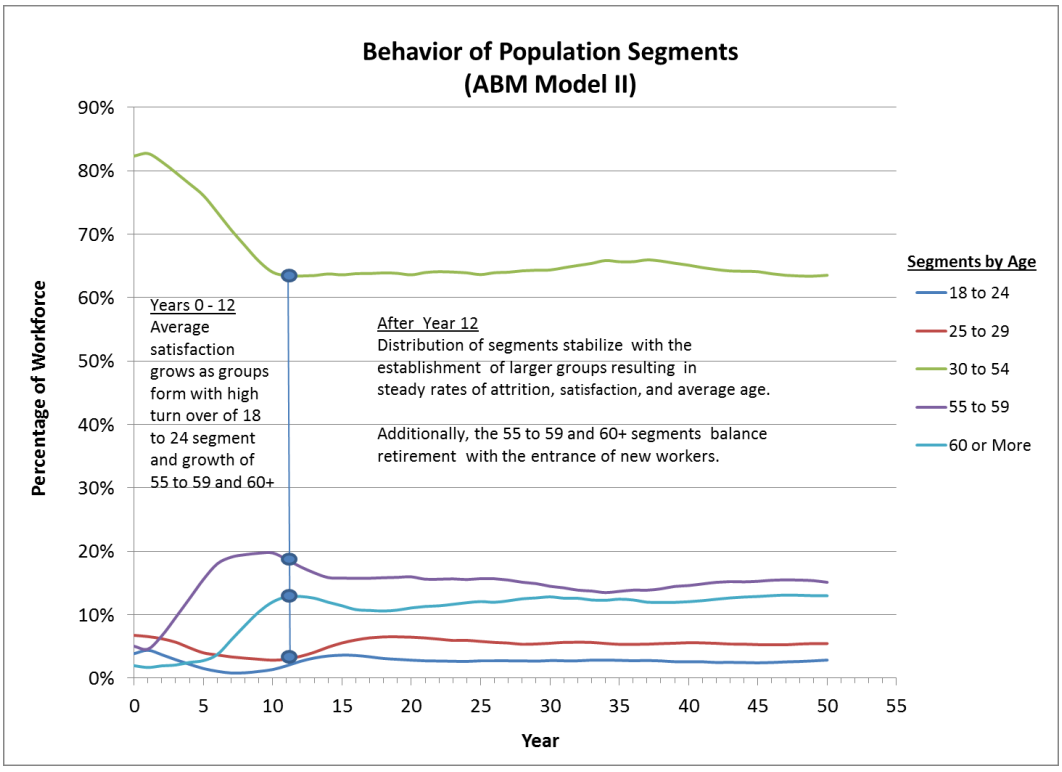


Figure 5-23 Model II. Agent Behavior by Population Segment

5.2.5 Validation of Results

The primary mechanism for validating the results of the worker departure ABM with worker replacement is the comparison of attrition observations to the empirical US government employment data. The assessment is performed for the overall workforce population as well as the defined segments of worker satisfaction derived from the trends of particular age groups.

In contrast to Model I where time is not considered, to validate the agent-based model of the workforce with worker replacement, a systems dynamics model (Figure 5-24) has been constructed using the historical attrition rates and historical new worker age distributions. Unlike the ABM where the attrition is not prescribed in the model and the behavior is stochastic, the systems dynamic model is mathematically modeled using the

average attrition rate for each age group to directly forecast the overall attrition rate of the population. The model is constructed using the tool "iThink", and the method of integration is Euler's Method. The associated equations for the model can be found Appendix D.

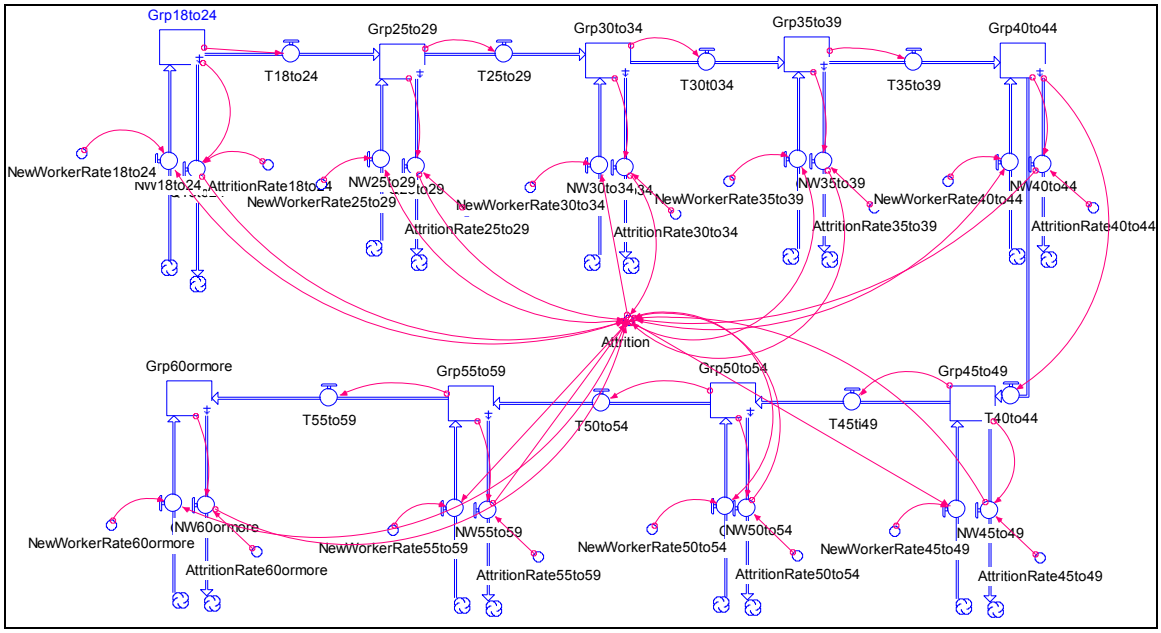


Figure 5-24 Systems Dynamics Model of US Federal Workforce

Starting with the empirical population in 1998, the forecasting model shows the decline in the highly satisfied segment with the corresponding rise in the retirement eligible population segments of fifty-five to over sixty. Additionally, the eighteen to twenty-four and twenty-five to twenty-nine segments achieve a comparable steady-state. A comparison of the agent-based on model and the empirically based systems dynamics model for the population segments is shown in Figure5-25.

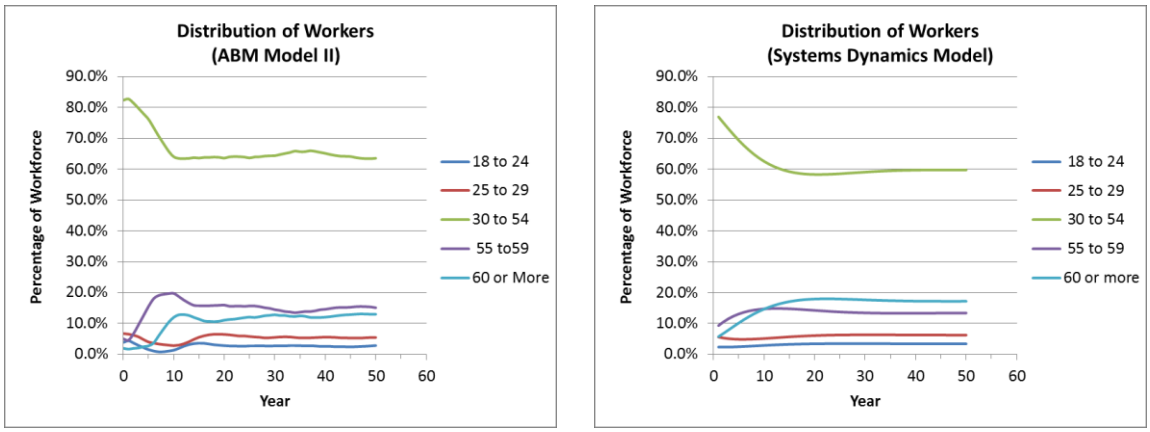


Figure 5-25 Worker Distribution Comparision of ABM Model II to Emperical Data

The results of running the ABM model II thirty times for fifty years produced a mean attrition rate of 7.1% with a range of attrition rates from 0.1% to 40.1% (Table 5-3) reflecting the first two years of high attrition due to group formation with worker replacement. Excluding the first two years, the results of the ABM with worker replacement produced a mean attrition rate of 6% with a range of attrition rates from 0.1% to 10.2%. Due to the skew of the employment data, the median is a better basis of comparison reflecting the progression of attrition from 1998 to 2011.

Table 5-3 Comparison of Simulation and Empirical Data Attrition Rates

	Agent-Based Model II (Years 1 to 50)	*Agent-Based Model II (Years 3 to 50)*	*Systems Dynamics Model (Years 1 to 50)*	*US Gov. Employment Data*
Mean	0.071	0.060	0.059	0.051
Standard Error	0.0089	0.0031	0.0008	0.004
Median	0.061	0.061	0.062	0.054
Standard Deviation	0.063	0.021	0.006	0.015
Range	0.399	0.092	0.022	0.054
Minimum	0.009	0.009	0.041	0.022
Maximum	0.409	0.102	0.063	0.076
Count*	50	48	50	13

*Count represents associated 50/48 years across 30 simulation runs for the ABM model and 50 years of 1 simulation run for the systems dynamics model and 13 years of empirical data (years 1999 to 2011).

Figure 5-26 illustrates the result of the agent-based model and the systems dynamics model along with the empirical average. The results of the validation illustrate the effects of the group formation process, the rebalancing of the workforce, and the resulting stabilization falling in line with the expected attrition.

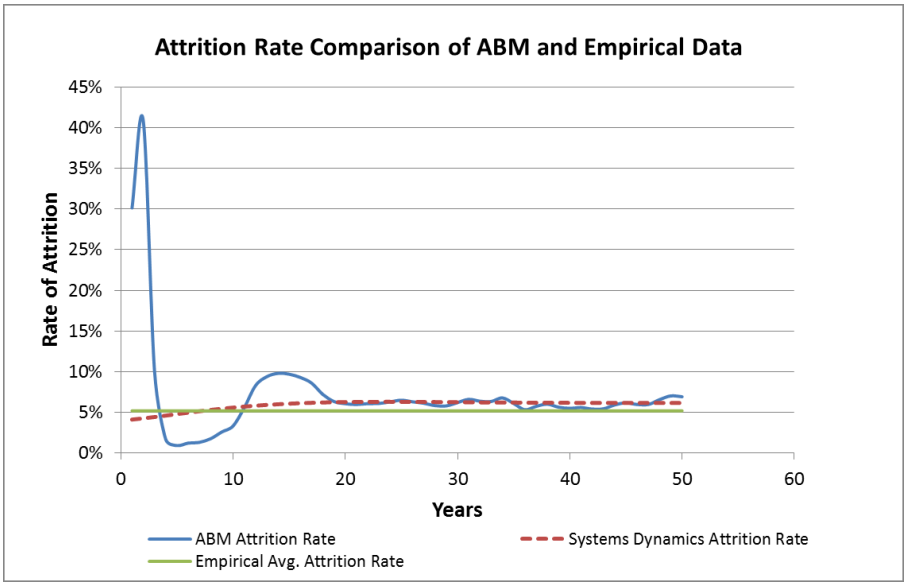


Figure 5-26 Attrition Rate Comparision of ABM Model II to Emperical Data

Chapter 6 Conclusion

6.1 Limitations and Recommendations

The limitation of assessing the emergent behavior of the US Government workforce is the applicability of the findings to the workforce of other employment sectors. Further research to develop the relationship of the empirical employment data and the model parameters across a variety of organizations could determine if the model is generalizable and broaden its utility. Additionally, the model design is limited to a general profile of a worker. Building on the existing model, additional worker attributes available in the empirical data such as agency, gender, profession, and grade could provide further insight into the behavior of the U.S. government workforce.

Lastly, the model with worker replacement demonstrates cycles of employment with a fixed number of workers allowing a rebalancing of the workforce independent of any external factors. Extending the model to vary the population size, external factors such as the economy or world events could be incorporated to evaluate the ability of the US government workforce to grow or shrink and the associated impacts.

6.2 Conclusion

Following the interdisciplinary approach of computational organization theory, organizational theories of worker satisfaction and turnover were evaluated through the use of computer simulation and validated with empirical data. Research concerned with organizations, groups or teams, and individual behavior provided the underpinning for the simulation parameters and assumptions. The study of employee turnover has been of considerable focus since the early twentieth century yielding hundreds of quantitative

studies (Cotton and Tuttle 1986). Satisfaction is utilized to measure a worker's lack of tendency to seek a new job (intention to leave) and the likelihood of staying in the workforce. The model of the US government workforce generalizes satisfaction to encompass the established precursors and associations of employee turnover such as job satisfaction, demographics, organization and work environment factors, and the nature of the job (Griffeth, Hom et al. 2000).

Guided by thirteen years of US government employment data, an agent-based model facilitated individual worker behaviors yielding the formation of teams and the changing composition of the overall workforce. Following the principles of the complex adaptive systems and emergence, the individual agents self-organized and adapted to achieve acceptable environmental conditions of worker satisfaction. The existence of minimally satisfied workers is shown to lower the average satisfaction of the overall workforce requiring a critical mass of satisfied worker groupings to stabilize the workforce. The resulting attrition rate and composition of the employees turned-over was compared against the US government employment data illustrating the validity of the model. The model phenomenon confirms that groups of a critical size improves employee satisfaction and lowers employee-turnover.

The four measures of worker behavior and the associated demographic of age (satisfaction, attrition, migration, and age) portray the complexity of the group formation process and the interdependences between the individual workers affecting the overall worker population. While the first fifteen years illustrate the most variability across all measures, the maximum or peak level appears soonest for attrition (year 2), then followed by satisfaction (year 3), average age in year ten, and lastly average migration in year

fifteen. Following the maturation process of an organization, the 'origination' or initialization demonstrated the immediate turnover of workers within year 1 with an average group size of three workers, 'diffusion' or adaption culminated by year 5 yielding average groups of eight workers, and the 'retention' of the group formations was achieved by year 10 with average group size growth leveling off to a steady rate.

With the highest thresholds and decay assigned to the minimally satisfied segment, entry level workers and retirement eligible workers have the highest intention to quit. During the initial period, the population of smaller groups with average group sizes of less than five is unable to sustain the required average satisfaction and workers continuously exit the workforce resulting in high attrition rates across all population segments. As the average group size surpasses five workers, the composition of the workforce begins to normalize and the retirement eligible segment grows balancing the population with the new entrants. The incompatibility of a small group size with the composition of the US government workforce demonstrates the importance of the organizational life cycle and the required configuration of the workforce.

The US government workforce and the modeled behavior clearly exhibited the characteristics of a complex adaptive system. A large number of components were represented in the model with a population of one thousand agents in a model space of a 101 by 101 torus yielding a density of approximately one agent per ten patches yielding group sizes from as small as two to three workers to groups of over one hundred workers. Variation and diversity was introduced by randomly distributing the workers over the model space, varying the satisfaction behavior by career stage, and distributing the age of new workers based on a probability distribution.

Self-organization and adaptation to the environment was demonstrated by the group formation through the agent's evaluation of the collective satisfaction, the agent's movement, and the agent's level of satisfaction. Accordingly, the workforce exhibited unpredictability and non-linearity due to the multitude of individual agent decisions to seek a new environment based on the collective satisfaction. Despite the complexity and adaptation, the observed emergent behavior of group formation and balancing of minimally satisfied and highly satisfied workers revealed the impact of the worker attributes and workforce composition.

The resulting insights found by the ABM modeling worker departure is due to the increased realism of using individual workers based on empirical data (Nilsson and Darley 2006). The model mitigates the dilemma's facing social behavior theory development due to complexity (Ostrom 1988) by evaluating multiple dependent variables, evaluating emergence of structure within groups, modeling latent variables that cannot be observed directly such as satisfaction, analyzing interdependent variables concurrently, and observing behavior over time.

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Appendix A – Literature Review Details by Topic and Era

Topic	Era	Author/Date	Organizational Theory Focus	Systems/Scientific Theory	Analytic Theory/Method
CAS	1980-2000	Levinthal, D. A. (1997)	Organization	adaptation, variety, emergence	simulation, Theory
	After 2000	Bergmann Lichtenstein, B. M. (2000)	Organization	connectivity/interdependence/ neighborhoods, non-linearity, emergence, Self-organisation, Creation of New Order, complexity	non-linear dynamic systems
		Mitleton-Kelly, E. (2003)	Organization	adaptation, Path Dependence, feedback, Dissipative, Far-from-equilibrium, co-evolution, connectivity/interdependence/ neighborhoods, emergence, Self-organisation, Creation of New Order, complexity, Time	case study/survey
		Benbya, H. and B. McKelvey (2006)	Organization	large number of components, adaptation, variety, feedback, Dissipative, Far-from-equilibrium, co-evolution, complexity	theory
		Kim, R. M. and S. M. Kaplan (2006)	Organization	adaptation, co-evolution	case study/survey
		Nilsson, F. and V. Darley (2006)		complexity, bounded rationality	Simulation
		Glor, E. D. (2007)	Organization	adaptation, variety, emergence, Self-organisation, Creation of New Order	
		Kuosa, T. (2007)		Path Dependence, Dissipative, Far-from-equilibrium	theory
		Lichtenstein, B. B. (2009)		Dissipative, Far-from-equilibrium	
		Wallis, S. E. (2009)		complexity	theory

Topic	Era	Author/Date	Organizational Theory Focus	Systems/Scientific Theory	Analytic Theory/Method
Emergence	1980-2000	Katz, J. A. (1993)	Organization, group size	emergence	
		Goldstein, J. (1999)	Organization, structure	Dissipative, Far-from-equilibrium, non-linearity, emergence, Self-organisation, Creation of New Order, complexity, attractors	
		MacIntosh, R. and D. MacLean (1999)		feedback, Dissipative, Far-from-equilibrium, emergence, complexity	case study/survey
	After 2000	Fuchs, C. and W. Hofkirchner (2005)	Organization, structure, Individual	emergence, Self-organisation, Creation of New Order	
		Hall, W. P. (2005)	Organization	autopoiesis/self-production, adaptation	
		Boschetti, F. and R. Gray (2007)		emergence	
		Alaa, G. (2009)	Organization, structure	autopoiesis/self-production, adaptation, feedback, Dissipative, Far-from-equilibrium, connectivity/interdependence/ neighborhoods, emergence, complexity, Time	case study/survey
		Mahmud, S. (2009)	Organization	emergence, Self-organisation, Creation of New Order	case study/survey
		Elsner, W. (2010)	Organization, group, size	co-evolution, connectivity/interdependence/ neighborhoods, emergence	
		Golds, C. and R. Kay (2010)	Organization	autopoiesis/self-production, adaptation, feedback, emergence	

Topic	Era	Author/Date	Organizational Theory Focus	Systems/Scientific Theory	Analytic Theory/Method
Modeling	1980-2000	Axtell, R., R. Axelrod, J. Epstein and M. Cohen (1996)			Simulation, ABM, Validation
		Tisue, S. and U. Wilensky (2004)			Simulation, ABM, Technique
	After 2000	Gilbert, N. and P. Terna (2000)			Simulation, ABM, Technique
		Macy, M. W. and R. Willer (2002)	group processes	interdependence/neighborhoods, emergence, Self-organisation, and, the, Creation, of, New, Order	Simulation, ABM, Technique, Validation
		Milling, P. M. (2002)			Simulation, Systems, Dynamics, Case Study
		Levitt, R. E. (2004)			Simulation, ABM, Case Study
		Yilmaz, L. (2006)			Simulation, ABM, Validation
		Ashworth, M. J. and K. M. Carley (2007)	Organization, Group Processes, Group Composition, Individual Traits/Processes		Simulation, ABM, Framework, Validation
		Marks, R. E. (2007)		interdependence/neighborhoods	Simulation, ABM, Validation
		Carley, K. M. (2009)			Simulation, ABM, Systems Dynamics, Case Study
		Grimm, V., U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske and S. F. Railsback (2010)			Simulation, ABM, Framework
		Railsback, S. F. and V. Grimm (2011)		adaptation, emergence, time	Simulation, ABM, Framework, Technique, Validation
Theory	1960-1980	Schelling, T. C. (1971)	Individual	Dissipative, Far-from-equilibrium, tipping point, connectivity/interdependence/neighborhoods	theory
	1980-2000	Ostrom, T. M. (1988)		feedback, connectivity/interdependence, Complexity, Time	theory
	After 2000	Leydesdorff, L. (2002)		adaptation, Path, Dependence/lock-in	Simulation, Cellular automata, Theory
		Robertson, D. A. and A. A. Caldart (2008)	Organization	adaptation, Far-from-equilibrium, emergence	simulation, Theory
		Sage, A. P. and W. B. Rouse (2009)	Organization	emergence, complexity	simulation, Theory
		Safarzyska, K. and J. C. van den Bergh (2010)		Diversity, Path, Dependence/lock-in, co-evolution, bounded, rationality, Diffusion	Simulation, Theory, ABM, Computation

Topic	Era	Author/Date	Organizational Theory Focus	Systems/Scientific Theory	Analytic Theory/Method
Organization	1960-1980	White, H., S. Boorman and R. Breiger (1976)	Social, Structures	connectivity/networks	Blockmodels/Algorithms
		Simon, H. A. (1980)	Individual	Adaptation	
	1980-2000	Anderson, P. (1999)	Organization	non-linearity, self-organization, Complexity	Cellular, Automata, ABM, Genetic, Algorithms
	After 2000	Scott, W. R. (2004)	Organization	Adaptation, network theory, Creation, of, New, Order, bounded, rationality	
		Argote, L. and H. R. Greve (2007)	Organization, Theory of the Firm	bounded, rationality	Simulation/Case Study
		Nissen, M. E. (2007)	Organization, structure		Simulation
		Morgan, J. H., G. P. Morgan and F. E. Ritter (2010)	Organization, group size	co-evolution/reflexivity	Simulation, ABM
Turnover	1980-2000	Cotton, J. L. and J. M. Tuttle (1986)	group size, Individual Traits, Turnover		Meta-Analysis
		Carley, K. (1992)	Organization Structure, Individual, Turnover	Learning	Simulation
	After 2000	Griffeth, R. W., P. W. Hom and S. Gaertner (2000)	Individual Traits, Turnover		Meta-Analysis
		Kitts, J. A. and P. T. Trowbridge (2007)	Individual, socialization, Turnover	interdependence, diffusion	Simulation
		Mohr, D. C., G. J. Young and J. F. Burgess, Jr. (2012)	Group oriented culture, Group size, Individual, Turnover		Survey
Career Stages	1960-1980	Levinson, D. J. (1978)	Individual, Career Stages		
	1980-2000	Ornstein, S., W. L. Cron and J. W. Slocum, Jr. (1989)	Individual, Career Stages		
		Savickas, M. L. (1997)	Individual, Career Stages		
	After 2000	Holton, E. F., III (2001)	Individual, Career Stages		
		Moynihan, D. P. and S. K. Pandey (2007)	Individual, Career Stages		
		Low, C. H. and P. Bordia (2011)	Individual, Career Stages		

Appendix B - ABM Model I. Source Code

```
;---------------------------- Model of Workforce Departure without Replacement of Workers -------------------------------------------|

turtles-own [
  satisfaction              ; measure of satisfaction
  stopped?                  ; attrbute of whether the turtle hasn't moved
  nearby-workers-satisfaction    ; average satisfaction agentset of turtles within some specified radius
  nearby-workers            ; agentset of turtles within some specified radius
  total-distance-moved      ; total distance moved by the turtle
  previous-patch            ; patch the turtle was previously on, used to establish distance traveled
  group-size                ; counting the collection of agents within the satisfaction radius
  group-id                  ; establishes groups of linked agents
    ]

patches-own [ non-usage ]

globals [

  model-result       ;; assessment of why model stops

  ;----------------Measuring workers exiting workforce ---------------------
  attrition-rate
  attrition-satisfied-rate
  attrition-committed-rate
  attrition-undecided-rate
  attrition-unsatisfied-rate

  attrition-satisfied
  attrition-committed
  attrition-undecided
  attrition-unsatisfied

  attrition-ratio-satisfied
  attrition-ratio-committed
  attrition-ratio-undecided_unsatisfied

  attrition-ratio-satisfied_current
  attrition-ratio-committed_current
  attrition-ratio-undecided_unsatisfied_current

  attrition-composition-range-factor

 ;----------------Other Observations ---------------------
  average-satisfaction            ; average satisfaction of the workforce
  average-migration          ; average distance traveled of the workforce

 ;----------------Grouping Variables ---------------------
  mate_sizes                ; list of number of co-workers for each worker
  group_lists               ; list of turtle ids in each extended group
  group_sizes               ; list of number in each extended group
  GroupCount                ; Number of groups
  GroupSizeAverage          ; Average Groups Size

]


to setup                    ; Clear all // create workers // reset time

  ca
     make-workers_undecided
     make-workers_committed
     make-workers_satisfied
  reset-ticks

end


to go

 ;------------------------Stopping Conditions----------------------------------

  if count turtles = 0 [set model-result ( -1 )   ]
  if count turtles = 0 [ stop ]
  if model-result = 1 [ stop ]

;----------------------------Data Monitors for attrition-------------------------------------------------------------
set attrition-rate (workers-satisfied + workers-committed + workers-undecided - count turtles)
                  /(workers-satisfied + workers-undecided + workers-committed)

set attrition-satisfied ( count turtles with [satisfaction >= workers-satisfied_minimum_satisfaction] - workers-satisfied)
set attrition-committed ( count turtles with
  [satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction] - workers-committed)
set attrition-undecided ( count turtles with
  [satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction] - workers-undecided)
set attrition-unsatisfied ( count turtles with
  [satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction] )


set attrition-satisfied-rate ( count turtles with
  [satisfaction >= workers-satisfied_minimum_satisfaction] - workers-satisfied)
   /(workers-satisfied + workers-undecided + workers-committed)
```

```
set attrition-committed-rate ( count turtles with
  [satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction]
    - workers-committed)/(workers-satisfied + workers-undecided + workers-committed)
set attrition-undecided-rate ( count turtles with
  [satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction]
    - workers-undecided)/(workers-satisfied + workers-undecided + workers-committed)
set attrition-unsatisfied-rate ( count turtles with
  [satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction])/(workers-satisfied
    + workers-undecided + workers-committed)


ifelse (attrition-rate > 0)
  [set attrition-ratio-satisfied_current (attrition-satisfied-rate / attrition-rate)
  set attrition-ratio-committed_current (attrition-committed-rate / attrition-rate)
  set attrition-ratio-undecided_unsatisfied_current
     (( attrition-undecided-rate + attrition-unsatisfied-rate) / attrition-rate)

;----------------------------Evaluating if workers have stopped -------------------------------------
if all? turtles [stopped?]
  [set model-result ( 1 ) grouping-eval]  ; Calls the group function if all workers have stopped
  ]

  [ set attrition-ratio-satisfied_current (0)
    set attrition-ratio-committed_current (0)
     set attrition-ratio-undecided_unsatisfied_current (0)]

  ask turtles [

    set previous-patch patch-here  ;; establish starting position
    seek-satisfaction                ;; seeking satisfaction
   if not stopped?
   [set total-distance-moved (total-distance-moved + (distance previous-patch))] ;; calculate distance traveled
    ask links [ if link-length > satisfaction-radius [ die ] ]
          ]

  ; place limits on the satisfaction value
  ask turtles with [ satisfaction > 100 ] [ set satisfaction 100 ]   ; setting max satisfaction
  ask turtles with [satisfaction < 0 ] [ die ]      ; setting minimum satisfaction
  color-turtles

  if count turtles > 0 [do-plotting]
  if any? (turtles) [set average-satisfaction mean [satisfaction] of turtles]
  if any? (turtles) [set average-migration mean [total-distance-moved] of turtles]

tick

end

;---------------------------- Functions for the display of the workers --------------------------------

to color-turtles        ; Set worker color based on satisfaction
  ask turtles [ ifelse ( satisfied? ) [ set color 64 ]
                [ ifelse ( committed?) [ set color 66 ]
                  [ ifelse ( undecided?) [ set color 68 ]
                    [ set color gray ] ] ] ]
end


to paint-in-radius
  clear-patches
  ask turtles
    [ paint-agents patches in-radius satisfaction-radius ]
end

to paint-agents [agents]
  ask agents [ set pcolor [color] of myself - 2 ]
end


to clear-radius     ; Clears depiction of worker radius
clear-patches
end

;-------------------------------------Functions to create workers -------------------------------------


to make-workers_satisfied
   set-default-shape turtles "circle"
   crt workers-satisfied [set color 64 set satisfaction workers-satisfied_starting_satisfaction]

  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self
  ]
end

to make-workers_committed
   set-default-shape turtles "square"
    crt workers-committed [set color 66 set satisfaction workers-committed_starting_satisfaction]

  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self
  ]
end
```

```
to make-workers_undecided
  set-default-shape turtles "triangle"
  crt workers-undecided [set color 68 set satisfaction workers-undecided_starting_satisfaction]

  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self
  ]
end

;----------------------Function of seeking satisfaction based on neighboring workers---------------------------------------
to seek-satisfaction

  set nearby-workers (turtles in-radius satisfaction-radius) with [self != myself]
  ifelse any? nearby-workers  ;; check for surrounding workers and workers move if below satisfaction threshold
    [set nearby-workers-satisfaction mean [satisfaction] of nearby-workers

       ifelse   ( nearby-workers-satisfaction > satisfaction-threshold  ) ; if satisfaction of turtles within the radius
         [                                                                ; is below satisfaction threshold keep seeking
           set stopped? true                                               ;  otherwise stop
            set satisfaction satisfaction + satisfaction-growth-positive
            create-link-with one-of nearby-workers
            set group-size count link-neighbors
           ]
         [ fd Patches-per-Tick-Movement lt random 50 rt random 50
           set stopped? false
           set satisfaction satisfaction - satisfaction-growth-negative
                   ]
     ]
         [ fd Patches-per-Tick-Movement lt random 50 rt random 50   ; if there aren't workers nearby keep seeking
           set stopped? false
           set satisfaction satisfaction - satisfaction-growth-negative]
end


;--------Subroutine for evaluating groups-----------------------------------------------------------------------------------
;--------Based on routine provided in 3 Aug 2012 - "Color Flocking Model" by Norman Lee Johnson
;---------------------------------------------------------------------------------------------------------------------------

to grouping-eval

  let temp 0
  let fm 0
  let t-list 0
  let a-list 0
  let i-list 0
  let g-list 0
  let t-loop 0
  let a-loop 0
  let flocktmp 0
  let n-list 0
  let again 0
  set t-list []
  set g-list []
  set group_lists []
  set i-list []
  set t-list [who] of turtles
  set a-list []

repeat population [set a-list fput [] a-list] ; set up list with one entry per agent (t-list is convienent)
foreach t-list ;; create a list equivalent to agentset flockmate - called "a-list"
 [ set fm [nearby-workers] of (turtle ?) ;; returns agentset (not list as suggested in manual)
   set temp [who] of fm ; list of flockmates for ?
   if length temp > 0 [set a-list replace-item ? a-list (sentence ? temp)]
 ]

set n-list filter [length item ? a-list > 0] t-list

while [ length n-list > 0 ]
[

set g-list item (item 0 n-list) a-list
set again true

while [again]
[ set again false
|
foreach t-list  ;; Loop over all agents
 [ set t-loop ?
   set flocktmp item t-loop a-list
   if (not member? t-loop i-list and not empty? flocktmp)
     [ foreach flocktmp
         [ set a-loop ?
           if (not member? a-loop i-list and length item a-loop a-list > 1 and member? a-loop g-list)
           [ set g-list replace-item (position a-loop g-list) g-list (item a-loop a-list)
             set i-list lput a-loop i-list
             set g-list reduce [sentence ?1 ?2 ] g-list  ;; flattens list of lists
             set g-list sort remove-duplicates g-list    ;; remove duplicates
             set again true
           ]
         ]  ;; end foreach over g-list - at end - have a complete group list
     ]
 ] ;; end loop over t-list and if test
;print g-list
] ;; loop over while again - continue until no new agents added
```

```
 set group_lists lput g-list group_lists
 set temp reduce [sentence ?1 ?2 ] group_lists
 set n-list filter [not member? ? temp] t-list
 set n-list filter [length item ? a-list > 0] n-list
] ; loop over while n-list
; print list "group_lists" group_lists
set group_sizes sort map [ length ? ] group_lists
;print list "group sizes:" group_sizes
set mate_sizes map [ length item ? a-list] t-list
;; Reporters
set GroupCount length (group_sizes)             ;GROUP Variables
set GroupSizeAverage mean (group_sizes)         ;GROUP Variables
end


;------------------------------Reporters-------------------------------------------------------------------

to-report population
  report workers-satisfied + workers-committed + workers-undecided
end

to-report satisfied?
  report satisfaction >= workers-satisfied_minimum_satisfaction
end

to-report committed?
  report satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction
end

to-report undecided?
  report satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction
end

to-report unsatisfied?
  report satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction
end

to-report population
  report workers-satisfied + workers-committed + workers-undecided
end

to-report satisfied?
  report satisfaction >= workers-satisfied_minimum_satisfaction
end

to-report committed?
  report satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction
end

to-report undecided?
  report satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction
end

to-report unsatisfied?
  report satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction
end



;------------------------------Plotting--------------------------------------------------------------------

to do-plotting
  set-current-plot "Avg. satisfaction"
  set-current-plot-pen "satisfaction"
    plot mean [ satisfaction ] of turtles
  set-current-plot "Distribution of satisfaction"
  set-current-plot-pen "satisfied"
    plot count turtles with [ satisfied? ]
  set-current-plot-pen "Committed"
    plot count turtles with [ committed? ]
  set-current-plot-pen "Undecided"
    plot count turtles with [ undecided? ]
  set-current-plot-pen "Unsatisfied"
    plot count turtles with [ unsatisfied? ]
  set-current-plot-pen "Total Workers"
    plot count turtles
  set-current-plot "Attrition"
  set-current-plot-pen "Attrition"
    plot (workers-satisfied + workers-committed + workers-undecided - count turtles)
          /(workers-satisfied + workers-undecided + workers-committed)
 set-current-plot "Distribution of Migration"
  set-current-plot-pen "satisfied"
  if any? (turtles with [satisfied?])
   [ plot mean [total-distance-moved] of turtles with [ satisfied? ] ]
  set-current-plot-pen "Committed"
  if any? (turtles with [committed?])
    [plot mean[total-distance-moved] of turtles with [ committed? ]]
  set-current-plot-pen "Undecided"
  if any? (turtles with [undecided?])
    [plot mean[total-distance-moved] of turtles with [ undecided? ]]
  set-current-plot-pen "Unsatisfied"
  if any? (turtles with [unsatisfied?])
    [plot mean [total-distance-moved] of turtles with [ unsatisfied? ]]
  set-current-plot-pen "Total Workers"
    plot mean [total-distance-moved] of turtles
end
```

Appendix C - ABM Model II. Source Code

```
;------------------------------ Model of Workforce Departure with Replacement of Workers ------------------------------------------------|

turtles-own [
  satisfaction                  ; measure of satisfaction
  stopped?                  ; attrbute of whether the turtle hasn't moved
  nearby-workers-satisfaction    ; average satisfaction agentset of turtles within some specified radius
  nearby-workers            ; agentset of turtles within some specified radius
  total-distance-moved      ; total distance moved by the turtle
  previous-patch            ; patch the turtle was previously on, used to establish distance traveled
  group-size                ; counting the collection of agents within the satisfaction radius
  group-id                  ; establishes groups of linked agents

  age                       ; current age of worker
  starting-age              ; starting age of new workers
  new-worker-age            ; sets age of new worker age distribution
  worker-type               ; attribute to track whether the worker is new/added
           ]
patches-own [ non-usage ]

;--------------------------------------------- Global Variables ----------------------------------------

globals [

  model-result       ;; assessment of why model stops, only needed

  ;---------------- Worker Population and Replacement Variables ---------------------
  patch-location locationx locationy ; Captures the location of worker quitting to add new worker
  quitter   ; Counter of worker quitting to capture attrition statistics
  new-worker-count ; number of workers added due to attrition
  population ; number of agents
  attrition ; number of workers leaving work force
  average-satisfaction
  average-migration
  average-age
  ;---------------- Maintianing Model Time ---------------------
  Year                  ; current year
  Time-keeper-years       ; counts the number of years based on each ticks

  ;----------------Measuring workers exiting workforce ---------------------
  attrition-rate
  Attrition-Rate-Yearly  Attrition-Prior
  Attrition-Current      attrition-rate-current-year

  attrition-satisfied-rate        attrition-committed-rate
  attrition-undecided-rate    attrition-unsatisfied-rate

  attrition-satisfied      attrition-committed
  attrition-undecided  attrition-unsatisfied

  attrition_18to24  attrition_25to29  attrition_30to34  attrition_35to39
  attrition_40to44  attrition_45to49  attrition_50to54  attrition_30to54
  attrition_55to59  attrition_60orMore

  attrition_18to24_current_yr attrition_25to29_current_yr attrition_30to34_current_yr  attrition_35to39_current_yr
  attrition_40to44_current_yr attrition_45to49_current_yr attrition_50to54_current_yr attrition_30to54_current_yr
  attrition_55to59_current_yr attrition_60orMore_current_yr

  attrition_18to24_prior_yr  attrition_25to29_prior_yr  attrition_30to34_prior_yr  attrition_35to39_prior_yr
  attrition_40to44_prior_yr  attrition_45to49_prior_yr  attrition_50to54_prior_yr  attrition_30to54_prior_yr
  attrition_55to59_prior_yr  attrition_60orMore_prior_yr

  Population_18to24_prior_yr Population_25to29_prior_yr  Population_30to34_prior_yr  Population_35to39_prior_yr
  Population_40to44_prior_yr Population_45to49_prior_yr  Population_50to54_prior_yr  Population_30to54_prior_yr
  Population_55to59_prior_yr Population_60orMore_prior_yr

  attrition-rate_18to24_current_yr  attrition-rate_25to29_current_yr  attrition-rate_30to34_current_yr
  attrition-rate_35to39_current_yr  attrition-rate_40to44_current_yr  attrition-rate_45to49_current_yr
  attrition-rate_50to54_current_yr  attrition-rate_30to54_current_yr  attrition-rate_55to59_current_yr
  attrition-rate_60orMore_current_yr

  attrition-rate_18to24_cum  attrition-rate_25to29_cum   attrition-rate_30to34_cum   attrition-rate_35to39_cum
  attrition-rate_40to44_cum  attrition-rate_45to49_cum   attrition-rate_50to54_cum   attrition-rate_30to54_cum
  attrition-rate_55to59_cum  attrition-rate_60orMore_cum


  attrition-ratio-satisfied attrition-ratio-committed attrition-ratio-undecided_unsatisfied attrition-ratio-satisfied_current
  attrition-ratio-committed_current  attrition-ratio-undecided_unsatisfied_current


  ;----------------Grouping Variables ---------------------
  GroupCount  GroupSizeAverage GroupSizeMax GroupSizeMedian GroupSizeCount TransitioningIndividuals
  mate_sizes         ;; list of number of flockmates for each turtle
  group_lists        ;; list of turtle ids in each extended group
  group_sizes        ;; list of number in each extended group
  ;---------------- Age distrbution by satisfaction ---------------------

  worker-Committed-25 worker-Committed-26 worker-Committed-27 worker-Committed-28 worker-Committed-29
  worker-Committed-55 worker-Committed-56 worker-Committed-57 worker-Committed-58 worker-Committed-59

  worker-Dissatisfied-18 worker-Dissatisfied-19 worker-Dissatisfied-20 worker-Dissatisfied-21 worker-Dissatisfied-22
  worker-Dissatisfied-23 worker-Dissatisfied-24 worker-Dissatisfied-60 worker-Dissatisfied-61 worker-Dissatisfied-62
  worker-Dissatisfied-63 worker-Dissatisfied-64 worker-Dissatisfied-65 worker-Dissatisfied-66 worker-Dissatisfied-67
  worker-Dissatisfied-68 worker-Dissatisfied-69

  worker-satisfied-30 worker-satisfied-31 worker-satisfied-32 worker-satisfied-33 worker-satisfied-34 worker-satisfied-35
  worker-satisfied-36 worker-satisfied-37 worker-satisfied-38 worker-satisfied-39 worker-satisfied-40 worker-satisfied-41
  worker-satisfied-42 worker-satisfied-43 worker-satisfied-44 worker-satisfied-45 worker-satisfied-46 worker-satisfied-47
  worker-satisfied-48 worker-satisfied-49 worker-satisfied-50 worker-satisfied-51 worker-satisfied-52 worker-satisfied-53
  worker-satisfied-54
   ]
```

```
;---------------------------------------- Routines / Subroutines ---------------------------------------

;----------------Set up/Initialization ---------------------

to setup  ; Clear all // create workers // reset time

ca

  ;age distrbution by satisfaction (1998 distribution)
set  worker-Committed-25 (0.05903331689797781) set  worker-Committed-26 (0.05903331689797781)
set  worker-Committed-27 (0.05903331689797781) set  worker-Committed-28 (0.05903331689797781)
set  worker-Committed-29 (0.05903331689797781) set  worker-Committed-55 (0.09809957646031822)
set  worker-Committed-56 (0.09809957646031822) set  worker-Committed-57 (0.09809957646031822)
set  worker-Committed-58 (0.09809957646031822) set  worker-Committed-59 (0.09809957646031822)
set  worker-Dissatisfied-18 (0.017671855502680 4)  set  worker-Dissatisfied-19 (0.017671855502680 4)
set  worker-Dissatisfied-20 (0.03290233906019293)  set  worker-Dissatisfied-21 (0.03290233906019293)
set  worker-Dissatisfied-22 (0.03290233906019293)  set  worker-Dissatisfied-23 (0.03290233906019293)
set  worker-Dissatisfied-24 (0.03290233906019293)  set  worker-Dissatisfied-60 (0.06870943713312266)
set  worker-Dissatisfied-61 (0.06870943713312266)  set  worker-Dissatisfied-62 (0.06870943713312266)
set  worker-Dissatisfied-63 (0.06870943713312266)  set  worker-Dissatisfied-64 (0.06870943713312266)
set  worker-Dissatisfied-65 (0.02806974126534533)  set  worker-Dissatisfied-66 (0.02806974126534533)
set  worker-Dissatisfied-67 (0.02806974126534533)  set  worker-Dissatisfied-68 (0.02806974126534533)
set  worker-Dissatisfied-69 (0.02806974126534533)  set  worker-satisfied-30 (0.028798918252999 2)
set  worker-satisfied-31 (0.028798918252999 2)     set  worker-satisfied-32 (0.028798918252999 2)
set  worker-satisfied-33 (0.028798918252999 2)     set  worker-satisfied-34 (0.028798918252999 2)
set  worker-satisfied-35 (0.039789193269726 5)     set  worker-satisfied-36 (0.039789193269726 5)
set  worker-satisfied-37 (0.039789193269726 5)     set  worker-satisfied-38 (0.039789193269726 5)
set  worker-satisfied-39 (0.039789193269726 5)     set  worker-satisfied-40 (0.047860828645416 5)
set  worker-satisfied-41 (0.047860828645416 5)     set  worker-satisfied-42 (0.047860828645416 5)
set  worker-satisfied-43 (0.047860828645416 5)     set  worker-satisfied-44 (0.047860828645416 5)
set  worker-satisfied-45 (0.055853305255980 6)     set  worker-satisfied-46 (0.055853305255980 6)
set  worker-satisfied-47 (0.055853305255980 6)     set  worker-satisfied-48 (0.055853305255980 6)
set  worker-satisfied-49 (0.055853305255980 6)     set  worker-satisfied-50 (0.050393429379354 8)
set  worker-satisfied-51 (0.050393429379354 8)     set  worker-satisfied-52 (0.050393429379354 8)
set  worker-satisfied-53 (0.050393429379354 8)     set  worker-satisfied-54 (0.050393429379354 8)

  ;--------Creating Initial Worker Population---------
     make-workers_undecided
     make-workers_committed
     make-workers_satisfied

   set Population_18to24_prior_yr count turtles with [Group_18to24]
   set Population_25to29_prior_yr count turtles with [Group_25to29]
   set Population_30to34_prior_yr count turtles with [Group_30to34]
   set Population_35to39_prior_yr count turtles with [Group_35to39]
   set Population_40to44_prior_yr count turtles with [Group_40to44]
   set Population_45to49_prior_yr count turtles with [Group_45to49]
   set Population_50to54_prior_yr count turtles with [Group_50to54]
   set Population_30to54_prior_yr count turtles with [Group_30to54]
   set Population_55to59_prior_yr count turtles with [Group_55to59]
   set Population_60orMore_prior_yr count turtles with [Group_60orMore]


  set Attrition-Prior     0      ; set initial attrition
  set Time-keeper-years   0      ; set initial time
  reset-ticks

end

;---------------- Quitting Sub Routine ---------------------

to quit                                ;; Command to count workers that leave the workforce
   set quitter quitter + 1
   if Group_18to24 [set attrition_18to24 attrition_18to24 + 1]
   if Group_25to29 [set attrition_25to29 attrition_25to29 + 1]
   if Group_30to34 [set attrition_30to34 attrition_30to34 + 1]
   if Group_35to39 [set attrition_35to39 attrition_35to39 + 1]
   if Group_40to44 [set attrition_40to44 attrition_40to44 + 1]
   if Group_45to49 [set attrition_45to49 attrition_45to49 + 1]
   if Group_50to54 [set attrition_50to54 attrition_50to54 + 1]
   if Group_30to54 [set attrition_30to54 attrition_30to54 + 1]
   if Group_55to59 [set attrition_55to59 attrition_55to59 + 1]
   if Group_60orMore [set attrition_60orMore attrition_60orMore + 1]

  set pcolor [255 0 0] ; Displays location of where a worker quits
  set locationx pxcor
  set locationy pycor
  die

end

;---------------- New Worker Sub Routine ---------------------


to new_worker
  let age-list [ 65 66 67 68 69 60 61 62 63 64 55 56 57 58 59 50 51 52 53 54 45 46 47 48 49
                 35 36 37 38 39 40 41 42 43 44 19 18 30 31 32 33 34 25 26 27 28 29 20 21 22 23 24 ]

  let prob-table [ 0.002 0.005 0.007 0.009 0.012 0.016 0.020 0.024 0.028 0.032 0.041 0.050 0.059
                   0.068 0.077 0.092 0.106 0.120 0.135 0.149 0.169 0.189 0.209 0.229 0.249 0.270
                   0.290 0.311 0.332 0.353 0.376 0.398 0.421 0.443 0.465 0.489 0.513 0.538 0.564
                   0.590 0.616 0.642 0.677 0.711 0.746 0.781 0.816 0.852 0.889 0.926 0.963 1.000 ]

  let create-worker quitter - attrition

  repeat create-worker  ;

 [  let prob random-float 1.0
    let age-select length filter [? < prob] prob-table ;
    crt 1 [set color 15
           set satisfaction new-workers_starting_satisfaction ;Starting satisfaction is globally set
           set age item age-select age-list          ;Age is determined from the historical probability
           set worker-type "new"                     ;Distinguishes new workers from existing
    set starting-age age                             ;Captures starting age of new workers
    pen-up
    setxy locationx locationy
    set stopped? false
    set total-distance-moved 0
```

```
    set group-id self ]
  ]
  set new-worker-count new-worker-count + create-worker
end

;---------------------------Evaluating if workers have stopped/Maintaining Model Time----------------------
to go
  set Year Time-keeper-years
  set Time-keeper-years  floor (ticks / 52)

      ;Stopping Conditions

  if count turtles = 0 [set model-result ( -1 )   ]
  if count turtles = 0 [ stop ]

 ;------------------------------- Worker Commands to seek satisfaction and quit --------------------------------

  ask turtles [

    set previous-patch patch-here  ;; establish starting position
    seek-satisfaction                    ;; seeking satisfaction
   if not stopped? [set total-distance-moved (total-distance-moved + (distance previous-patch))] ;calculate distance traveled
    ask links [ if link-length > satisfaction-radius [ die ] ]
          ]

  ; place limits on the satisfaction value
  ask turtles with [ satisfaction > 100 ] [ set satisfaction 100 ]   ; setting max satisfaction
  set attrition quitter

  ask turtles with [satisfaction < 0 ]
  [  quit  ]

  if quitter > attrition [new_worker]                     ; Replacing workers

  color-turtles

 if count turtles > 0 [do-plotting]

 if any? (turtles) [set average-satisfaction mean [satisfaction] of turtles]
 if any? (turtles) [set average-migration mean [total-distance-moved] of turtles]
 if any? (turtles) [set average-age mean [age] of turtles]

;---------------------------Data Monitors for attrition-----------------------------------------------------
set attrition-rate (workers-satisfied + workers-committed + workers-undecided - count turtles)
                   /(workers-satisfied + workers-undecided + workers-committed)

set attrition-satisfied ( count turtles with [satisfaction >= workers-satisfied_minimum_satisfaction] - workers-satisfied)
set attrition-committed ( count turtles with
  [satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction] - workers-committed)
set attrition-undecided ( count turtles with
  [satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction] - workers-undecided)
set attrition-unsatisfied ( count turtles with
  [satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction] )

set attrition-satisfied-rate ( count turtles with
  [satisfaction >= workers-satisfied_minimum_satisfaction] - workers-satisfied)
   /(workers-satisfied + workers-undecided + workers-committed)

set attrition-committed-rate ( count turtles with
  [satisfaction >= workers-committed_minimum_satisfaction and satisfaction < workers-satisfied_minimum_satisfaction]
    - workers-committed)/(workers-satisfied + workers-undecided + workers-committed)
set attrition-undecided-rate ( count turtles with
  [satisfaction >= workers-undecided_minimum_satisfaction and satisfaction < workers-committed_minimum_satisfaction]
    - workers-undecided)/(workers-satisfied + workers-undecided + workers-committed)
set attrition-unsatisfied-rate ( count turtles with
  [satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction])/(workers-satisfied
    + workers-undecided + workers-committed)

ifelse (attrition-rate > 0)
  [set attrition-ratio-satisfied_current (attrition-satisfied-rate / attrition-rate)
  set attrition-ratio-committed_current (attrition-committed-rate / attrition-rate)
  set attrition-ratio-undecided_unsatisfied_current
     (( attrition-undecided-rate + attrition-unsatisfied-rate) / attrition-rate)

  if Year = 0
  [set Attrition-Prior 0
   set attrition_18to24_prior_yr 0 set attrition_25to29_prior_yr 0 set attrition_30to34_prior_yr 0
   set attrition_35to39_prior_yr 0 set attrition_40to44_prior_yr 0 set attrition_45to49_prior_yr 0
   set attrition_50to54_prior_yr 0 set attrition_30to54_prior_yr 0 set attrition_55to59_prior_yr 0
   set attrition_60orMore_prior_yr 0

   set attrition_18to24_current_yr  (attrition_18to24 ) set attrition_25to29_current_yr  (attrition_25to29)
   set attrition_30to34_current_yr  (attrition_30to34 ) set attrition_35to39_current_yr  (attrition_35to39)
   set attrition_40to44_current_yr  (attrition_40to44 ) set attrition_45to49_current_yr  (attrition_45to49)
   set attrition_50to54_current_yr  (attrition_50to54 ) set attrition_30to54_current_yr  (attrition_30to54)
   set attrition_55to59_current_yr  (attrition_55to59 ) set attrition_60orMore_current_yr  (attrition_60orMore)
      ]

  if Year < Time-keeper-years                                          ; Calculating Attrition
  [ set Attrition-Current (quitter - Attrition-Prior)
    ; Set Attrition by age group for the year
    set attrition_18to24_current_yr  (attrition_18to24 - attrition_18to24_prior_yr)
    set attrition_25to29_current_yr  (attrition_25to29 - attrition_25to29_prior_yr)
    set attrition_30to34_current_yr  (attrition_30to34 - attrition_30to34_prior_yr)
    set attrition_35to39_current_yr  (attrition_35to39 - attrition_35to39_prior_yr)
    set attrition_40to44_current_yr  (attrition_40to44 - attrition_40to44_prior_yr)
    set attrition_45to49_current_yr  (attrition_45to49 - attrition_45to49_prior_yr)
    set attrition_50to54_current_yr  (attrition_50to54 - attrition_50to54_prior_yr)
    set attrition_30to54_current_yr  (attrition_30to54 - attrition_30to54_prior_yr)
    set attrition_55to59_current_yr  (attrition_55to59 - attrition_55to59_prior_yr)
    set attrition_60orMore_current_yr  (attrition_60orMore - attrition_60orMore_prior_yr)
```

```
    set Attrition-Prior ( Attrition-Prior + Attrition-Current )
    set attrition_18to24_prior_yr ( attrition_18to24_prior_yr + attrition_18to24_current_yr )
    set attrition_25to29_prior_yr ( attrition_25to29_prior_yr + attrition_25to29_current_yr )
    set attrition_30to34_prior_yr ( attrition_30to34_prior_yr + attrition_30to34_current_yr )
    set attrition_35to39_prior_yr ( attrition_35to39_prior_yr + attrition_35to39_current_yr )
    set attrition_40to44_prior_yr ( attrition_40to44_prior_yr + attrition_40to44_current_yr )
    set attrition_45to49_prior_yr ( attrition_45to49_prior_yr + attrition_45to49_current_yr )
    set attrition_50to54_prior_yr ( attrition_50to54_prior_yr + attrition_50to54_current_yr )
    set attrition_30to54_prior_yr ( attrition_30to54_prior_yr + attrition_30to54_current_yr )
    set attrition_55to59_prior_yr ( attrition_55to59_prior_yr + attrition_55to59_current_yr )
    set attrition_60orMore_prior_yr ( attrition_60orMore_prior_yr + attrition_60orMore_current_yr )

     ; Set Attrition rate by age group for the year
    set attrition-rate-current-year (Attrition-Current / count turtles)

    ifelse Population_18to24_prior_yr > 0
    [set attrition-rate_18to24_current_yr attrition_18to24_current_yr / Population_18to24_prior_yr
     set attrition-rate_18to24_cum attrition-rate_18to24_cum + attrition-rate_18to24_current_yr ]
    [set attrition-rate_18to24_current_yr 0 ]

    ifelse Population_25to29_prior_yr > 0
    [set attrition-rate_25to29_current_yr attrition_25to29_current_yr / Population_25to29_prior_yr
      set attrition-rate_25to29_cum attrition-rate_25to29_cum + attrition-rate_25to29_current_yr]
    [set attrition-rate_25to29_current_yr 0]

    ifelse Population_30to34_prior_yr > 0
    [set attrition-rate_30to34_current_yr attrition_30to34_current_yr / Population_30to34_prior_yr
      set attrition-rate_30to34_cum attrition-rate_30to34_cum + attrition-rate_30to34_current_yr]
    [set attrition-rate_30to34_current_yr 0]

    ifelse Population_35to39_prior_yr > 0
    [set attrition-rate_35to39_current_yr attrition_35to39_current_yr / Population_35to39_prior_yr
      set attrition-rate_35to39_cum attrition-rate_35to39_cum + attrition-rate_35to39_current_yr]
    [set attrition-rate_35to39_current_yr 0]

    ifelse Population_40to44_prior_yr > 0
    [set attrition-rate_40to44_current_yr attrition_40to44_current_yr / Population_40to44_prior_yr
      set attrition-rate_40to44_cum attrition-rate_40to44_cum + attrition-rate_40to44_current_yr]
    [set attrition-rate_40to44_current_yr 0]

    ifelse Population_45to49_prior_yr > 0
    [set attrition-rate_45to49_current_yr attrition_45to49_current_yr / Population_45to49_prior_yr
      set attrition-rate_45to49_cum attrition-rate_45to49_cum + attrition-rate_45to49_current_yr]
    [set attrition-rate_45to49_current_yr 0]

    ifelse Population_50to54_prior_yr > 0
    [set attrition-rate_50to54_current_yr attrition_50to54_current_yr / Population_50to54_prior_yr
      set attrition-rate_50to54_cum attrition-rate_50to54_cum + attrition-rate_50to54_current_yr]
    [set attrition-rate_50to54_current_yr 0]

    ifelse Population_30to54_prior_yr > 0
   [ set attrition-rate_30to54_current_yr attrition_30to54_current_yr / Population_30to54_prior_yr
     set attrition-rate_30to54_cum attrition-rate_30to54_cum + attrition-rate_30to54_current_yr]
   [set attrition-rate_30to54_current_yr 0]


   ifelse Population_55to59_prior_yr > 0
    [set attrition-rate_55to59_current_yr attrition_55to59_current_yr / Population_55to59_prior_yr
      set attrition-rate_55to59_cum attrition-rate_55to59_cum + attrition-rate_55to59_current_yr]
     [set attrition-rate_55to59_current_yr 0]

   ifelse Population_60orMore_prior_yr > 0
    [set attrition-rate_60orMore_current_yr attrition_60orMore_current_yr / Population_60orMore_prior_yr
      set attrition-rate_60orMore_cum attrition-rate_60orMore_cum + attrition-rate_60orMore_current_yr]
    [set attrition-rate_60orMore_current_yr 0]

    ; Set Population basis by age group for the year
    set Population_18to24_prior_yr count turtles with [Group_18to24]
    set Population_25to29_prior_yr count turtles with [Group_25to29]
    set Population_25to29_prior_yr count turtles with [Group_25to29]
    set Population_30to34_prior_yr count turtles with [Group_30to34]
    set Population_35to39_prior_yr count turtles with [Group_35to39]
    set Population_40to44_prior_yr count turtles with [Group_40to44]
    set Population_45to49_prior_yr count turtles with [Group_45to49]
    set Population_50to54_prior_yr count turtles with [Group_50to54]
    set Population_30to54_prior_yr count turtles with [Group_30to54]
    set Population_55to59_prior_yr count turtles with [Group_55to59]
    set Population_60orMore_prior_yr count turtles with [Group_60orMore]
  ]

    if all? turtles [stopped?]
    [set model-result ( 1 ) ]
      ]

  [ set attrition-ratio-satisfied_current (0)
    set attrition-ratio-committed_current (0)
     set attrition-ratio-undecided_unsatisfied_current (0)]

 if Year < Time-keeper-years             ; Calls the group function at the beginning of each year
  [   grouping-eval ]                    ; Counting groups

tick

end
```

```
;--------------------------- Functions for the display of the workers -------------------------------
to color-turtles
  ask turtles [ ifelse ( satisfied? ) [ set color 64 ]
                [ ifelse ( committed?) [ set color 66 ]
                  [ ifelse ( undecided?) [ set color 68 ]
                    [ ifelse ( new-Worker?) [ set color 16 ]
                    [ set color gray ] ] ] ] ]
end

to paint-in-radius
  clear-patches
  ask turtles
    [ paint-agents patches in-radius satisfaction-radius ]
end

to paint-agents [agents]
  ask agents [ set pcolor [color] of myself - 2 ]
end

to clear-radius
clear-patches
end

;-----------------------------------Functions to create workers ----------------------------------
to make-workers_satisfied
   set-default-shape turtles "circle"
   crt workers-satisfied * worker-satisfied-30 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 30]
   crt workers-satisfied * worker-satisfied-31 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 31]
   crt workers-satisfied * worker-satisfied-32 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 32]
   crt workers-satisfied * worker-satisfied-33 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 33]
   crt workers-satisfied * worker-satisfied-34 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 34]
   crt workers-satisfied * worker-satisfied-35 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 35]
   crt workers-satisfied * worker-satisfied-36 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 36]
   crt workers-satisfied * worker-satisfied-37 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 37]
   crt workers-satisfied * worker-satisfied-38 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 38]
   crt workers-satisfied * worker-satisfied-39 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 39]
   crt workers-satisfied * worker-satisfied-40 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 40]
   crt workers-satisfied * worker-satisfied-41 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 41]
   crt workers-satisfied * worker-satisfied-42 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 42]
   crt workers-satisfied * worker-satisfied-43 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 43]
   crt workers-satisfied * worker-satisfied-44 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 44]
   crt workers-satisfied * worker-satisfied-45 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 45]
   crt workers-satisfied * worker-satisfied-46 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 46]
   crt workers-satisfied * worker-satisfied-47 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 47]
   crt workers-satisfied * worker-satisfied-48 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 48]
   crt workers-satisfied * worker-satisfied-49 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 49]
   crt workers-satisfied * worker-satisfied-50 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 50]
   crt workers-satisfied * worker-satisfied-51 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 51]
   crt workers-satisfied * worker-satisfied-52 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 52]
   crt workers-satisfied * worker-satisfied-53 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 53]
   crt workers-satisfied * worker-satisfied-54 [set color 64 set satisfaction workers-satisfied_starting_satisfaction set age 54]
   .

  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self
            ]

end

to make-workers_committed
   set-default-shape turtles "square"
   crt workers-committed * worker-Committed-25 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 25]
   crt workers-committed * worker-Committed-26 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 26]
   crt workers-committed * worker-Committed-27 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 27]
   crt workers-committed * worker-Committed-28 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 28]
   crt workers-committed * worker-Committed-29 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 29]
   crt workers-committed * worker-Committed-55 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 55]
   crt workers-committed * worker-Committed-56 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 56]
   crt workers-committed * worker-Committed-57 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 57]
   crt workers-committed * worker-Committed-58 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 58]
   crt workers-committed * worker-Committed-59 [set color 66 set satisfaction workers-committed_starting_satisfaction set age 59]

  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self

    ]
end

to make-workers_undecided
  set-default-shape turtles "triangle"
  crt workers-undecided * worker-Dissatisfied-18 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 18]
  crt workers-undecided * worker-Dissatisfied-19 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 19]
  crt workers-undecided * worker-Dissatisfied-20 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 20]
  crt workers-undecided * worker-Dissatisfied-21 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 21]
  crt workers-undecided * worker-Dissatisfied-22 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 22]
  crt workers-undecided * worker-Dissatisfied-23 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 23]
  crt workers-undecided * worker-Dissatisfied-24 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 24]
  crt workers-undecided * worker-Dissatisfied-60 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 60]
  crt workers-undecided * worker-Dissatisfied-61 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 61]
  crt workers-undecided * worker-Dissatisfied-62 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 62]
  crt workers-undecided * worker-Dissatisfied-63 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 63]
  crt workers-undecided * worker-Dissatisfied-64 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 64]
  crt workers-undecided * worker-Dissatisfied-65 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 65]
  crt workers-undecided * worker-Dissatisfied-66 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 66]
  crt workers-undecided * worker-Dissatisfied-67 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 67]
  crt workers-undecided * worker-Dissatisfied-68 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 68]
  crt workers-undecided * worker-Dissatisfied-69 [set color 68 set satisfaction workers-undecided_starting_satisfaction set age 69]
```

```
  ask turtles
  [ pen-up
    setxy random-xcor random-ycor
    set stopped? false
    set total-distance-moved 0
    set group-id self
    ]
end

;--------------------Function of seeking satisfaction based on neighboring workers-------------------------------------

; seeking satisfaction based on neighboring workers
to seek-satisfaction

  set nearby-workers (turtles in-radius satisfaction-radius) with [self != myself]
  ifelse any? nearby-workers  ;; check for surrounding workers and workers move if below satisfaction threshold
    [set nearby-workers-satisfaction mean [satisfaction] of nearby-workers

          ifelse age > 59 ;
               [
                ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-60ormore  )
                [set satisfaction satisfaction - satisfaction-growth-positive * Growth-Factor-60ormore
                  set stopped? true]
                [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-60ormore
                  fd Patches-per-Tick-Movement lt random 50 rt random 50
                  set stopped? false]
               ]

               [ifelse age <= 24
                    [
                    ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-18to24  )
                     [set satisfaction satisfaction - satisfaction-growth-positive * Growth-Factor-18to24
                      set stopped? true]
                     [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-18to24
                      fd Patches-per-Tick-Movement lt random 50 rt random 50
                      set stopped? false]
                     ]


                  [ifelse ((age > 24) and (age <= 29))
                     [
                      ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-25to29  )
                       [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-25to29
                        set stopped? true]
                       [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-25to29
                        fd Patches-per-Tick-Movement lt random 50 rt random 50
                        set stopped? false]
                     ] ;

                     [ifelse (age > 29 and age <= 34)
                      [
                       ifelse    ( nearby-workers-satisfaction > satisfaction-threshold  )
                        [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-30to34
                         set stopped? true]
                        [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-30to34
                         fd Patches-per-Tick-Movement lt random 50 rt random 50
                         set stopped? false]
                      ] ;

                        [ifelse (age > 34 and age <= 39)
                          [
                            ifelse    ( nearby-workers-satisfaction > satisfaction-threshold  )
                              [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-35to39
                               set stopped? true]
                              [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-35to39
                               fd Patches-per-Tick-Movement lt random 50 rt random 50
                               set stopped? false]
                           ] ;

                           [ifelse (age > 39 and age <= 44)
                             [

                             ifelse    ( nearby-workers-satisfaction > satisfaction-threshold  )
                               [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-40to44
                                set stopped? true]
                               [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-40to44
                                fd Patches-per-Tick-Movement lt random 50 rt random 50
                                set stopped? false]
                             ] ;

                             [ifelse (age > 44 and age <= 49)
                               [
                               ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-45to49  )
                                [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-45to49
                                 set stopped? true]
                                [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-45to49
                                 fd Patches-per-Tick-Movement lt random 50 rt random 50
                                 set stopped? false]
                               ] ;

                               [ifelse (age > 49 and age <= 54)
                                 [
                                 ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-50to54  )
                                  [set satisfaction satisfaction + satisfaction-growth-positive * Growth-Factor-50to54
                                   set stopped? true]
                                   [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-50to54
                                    fd Patches-per-Tick-Movement lt random 50 rt random 50
                                    set stopped? false]
                                  ] ;
```

```
                                [ifelse (age > 54 and age <= 59)
                                  [
                                    ifelse    ( nearby-workers-satisfaction > satisfaction-threshold-55to59  )
                                      [set satisfaction satisfaction - satisfaction-growth-positive * Growth-Factor-55to59
                                       set stopped? true]
                                      [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-55to59
                                       fd Patches-per-Tick-Movement lt random 50 rt random 50
                                       set stopped? false]
                                   ]

                                  [set satisfaction satisfaction + satisfaction-growth-positive ]
                                ]
                              ]
                            ]
                          ]
                        ]
                      ]
                    ]
                  ]
            create-link-with one-of nearby-workers ; displays links between co-workers

      ]
          ;;Losing satisfaction if not in a group
               [  ifelse age > 59 ;
                 [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-60ormore ]  ;
                 [ifelse age <= 24                                                                        ;
                    [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-18to24 ] ;

                    [ifelse ((age > 24) and (age <= 29))
                       [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-25to29 ] ;
                       [ifelse (age > 29 and age <= 34)
                           [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-30to34 ] ;
                           [ifelse (age > 34 and age <= 39)
                             [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-35to39 ] ;
                             [ifelse (age > 39 and age <= 44)
                               [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-40to44 ] ;
                               [ifelse (age > 44 and age <= 49)
                                 [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-45to49 ] ;
                                 [ifelse (age > 49 and age <= 54)
                                   [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-50to54 ] ;
                                   [ifelse (age > 54 and age <= 59)
                                     [set satisfaction satisfaction - satisfaction-growth-negative * Decay-Factor-55to59 ] ;
                                     [set satisfaction satisfaction - satisfaction-growth-negative ]


                                   ]
                                 ]
                               ]
                             ]
                           ]
                       ]
                    ]
                 ]

           fd Patches-per-Tick-Movement lt random 50 rt random 50    ;; if there aren't workers nearby keep seeking
           set stopped? false
        ]

      set age age + 1 / 52  ; each tick represents 1 week
      end

;--------Subroutine for evaluating groups-----------------------------------------------------------------------------------
;--------Based on routine provided in 3 Aug 2012 - "Color Flocking Model" by Norman Lee Johnson
;---------------------------------------------------------------------------------------------------------------------------

to grouping-eval

  let temp 0
  let fm 0
  let t-list []
  let a-list []
  let i-list []
  let g-list []
  let t-loop 0
  let a-loop 0
  let flocktmp 0
  let n-list []
  let again 0
  let agent 0

  set t-list []
  set g-list []
  set group_lists []
 set i-list []
  set a-list []
  set n-list []

  set t-list [who] of turtles
  set population count turtles + attrition + new-worker-count

repeat population [set a-list lput [] a-list] ; set up list with one entry per agent (t-list is convienent)
foreach t-list ;; create a list equivalent to agentset flockmate - called "a-list"
 [  set agent turtle ?

    if agent != nobody
    [set fm [nearby-workers] of (agent)]

  ifelse fm != 0
  [set temp [who] of fm] ; list of flockmates for ?
  [set temp ""]
   if length temp > 0 [set a-list replace-item ? a-list (sentence ? temp)]
  ]

set n-list filter [length item ? a-list > 0] t-list
```

```
while [ length n-list > 0 ]
[

set g-list item (item 0 n-list) a-list
set again true

while [again]
[ set again false




foreach t-list  ;; Loop over all agents
 [ set t-loop ?
   set flocktmp item t-loop a-list
   if (not member? t-loop i-list and not empty? flocktmp)
     [ foreach flocktmp                    ;; insert flock mates into a-list
         [ set a-loop ?
           if (not member? a-loop i-list and length item a-loop a-list > 1 and member? a-loop g-list)
           [ set g-list replace-item (position a-loop g-list) g-list (item a-loop a-list) ;; replace with list
             set i-list lput a-loop i-list
             set g-list reduce [sentence ?1 ?2 ] g-list  ;; flattens list of lists
             set g-list sort remove-duplicates g-list    ;; remove duplicates
             set again true
           ]
         ]  ;; end foreach over g-list - at end - have a complete group list
     ]
 ] ;; end loop over t-list and if test
;print g-list
] ;; loop over while again - continue until no new agents added

 set group_lists lput g-list group_lists
 set temp reduce [sentence ?1 ?2 ] group_lists
 set n-list filter [not member? ? temp] t-list
 set n-list filter [length item ? a-list > 0] n-list
] ; loop over while n-list
; print list "group_lists" group_lists
set group_sizes sort map [ length ? ] group_lists
;print list "group sizes:" group_sizes
set mate_sizes map [ length item ? a-list] t-list
;; Reporters
set GroupCount length (group_sizes)             ;GROUP Variables
set GroupSizeAverage mean (group_sizes)         ;GROUP Variables
set GroupSizeMax max (group_sizes)               ;GROUP Variables
set GroupSizeMedian median (group_sizes)         ;GROUP Variables
set GroupSizeCount length (group_sizes)         ;GROUP Variables
Set TransitioningIndividuals (count turtles - (GroupSizeAverage * GroupSizeCount))
end

;;------------ Reporters----------------------------------------


to-report satisfied?
  report satisfaction >= workers-satisfied_minimum_satisfaction
end



to-report committed?
  report satisfaction >= workers-committed_minimum_satisfaction
                  and satisfaction < workers-satisfied_minimum_satisfaction
end

to-report undecided?
  report satisfaction >= workers-undecided_minimum_satisfaction
                  and satisfaction < workers-committed_minimum_satisfaction
end

to-report unsatisfied?
  report satisfaction >= 0 and satisfaction < workers-undecided_minimum_satisfaction
end

to-report new-Worker?
  report worker-type ="new"
end

to-report Group_18to24
  report round age <= 24
end

to-report Group_25to29
  report round age > 24 and round age <= 29
end

to-report Group_30to34
  report round age > 29 and round age <= 34
end

to-report Group_35to39
  report round age > 34 and round age <= 39
end

to-report Group_40to44
  report round age > 39 and round age <= 44
end

to-report Group_45to49
  report round age > 44 and round age <= 49
end

to-report Group_50to54
  report round age > 49 and round age <= 54
end
```

```
to-report Group_30to54
  report round age > 29 and round age <= 54
end

to-report Group_55to59
  report round age > 54 and round age <= 59
end

to-report Group_60orMore
  report round age > 59
end

;--------------------------------Plotting-----------------------
to do-plotting

 set-current-plot "Avg. satisfaction"
   set-current-plot-pen "satisfaction"
      plotxy year mean [ satisfaction ] of turtles

 set-current-plot "Avg. Age"
    set-current-plot-pen "Age"
      plotxy year mean [ age ] of turtles

 set-current-plot "Distribution of satisfaction"
    set-current-plot-pen "satisfied"
      plotxy year count turtles with [ satisfied? ]
    set-current-plot-pen "Committed"
      plotxy year count turtles with [ committed? ]
    set-current-plot-pen "Undecided"
      plotxy year count turtles with [ undecided? ]
    set-current-plot-pen "Unsatisfied"
      plotxy year count turtles with [ unsatisfied? ]
    set-current-plot-pen "Total Workers"
      plotxy year count turtles

 set-current-plot "Attrition"
    set-current-plot-pen "Attrition"
      plotxy year attrition-rate-current-year

 set-current-plot "Attrition by Age Group"
     set-current-plot-pen "Attrition"
       plotxy year attrition-rate-current-year
     set-current-plot-pen "18to24"
       plotxy year attrition-rate_18to24_current_yr
     set-current-plot-pen "25to29"
       plotxy year attrition-rate_25to29_current_yr
     set-current-plot-pen "30to54"
       plotxy year attrition-rate_30to54_current_yr
     set-current-plot-pen "55to59"
       plotxy year attrition-rate_55to59_current_yr
     set-current-plot-pen "60orMore"
       plotxy year attrition-rate_60orMore_current_yr

 set-current-plot "Distribution of Age Groups"
    set-current-plot-pen "18to24"
      plotxy year count turtles with [ Group_18to24 ]
    set-current-plot-pen "25to29"
      plotxy year count turtles with [ Group_25to29 ]
    set-current-plot-pen "30to54"
      plotxy year count turtles with [  Group_30to54 ]
    set-current-plot-pen "55to59"
      plotxy year count turtles with [ Group_55to59 ]
    set-current-plot-pen "60orMore"
      plotxy year count turtles with [ Group_60orMore ]
    set-current-plot-pen "Total Workers"
      plotxy year count turtles
end
```

Appendix D - Systems Dynamics Model Equations

// Initialization parameters are based on the US Government workforce age distribution of 1998, and the average attrition rates and the new hire age distribution from 1998 to 2011.

```
Grp18to24(t) = Grp18to24(t - dt) + (NW18to24 - T18to24 - Q18to24) * dt
INIT Grp18to24 = 3279
INFLOWS:
NW18to24 = NewWorkerRate18to24*Attrition
OUTFLOWS:
T18to24 = Grp18to24 / 7
Q18to24 = Grp18to24*AttritionRate18to24

Grp25to29(t) = Grp25to29(t - dt) + (T18to24 + NW25to29 - Q25to29 - T25to29) * dt
INIT Grp25to29 = 6074
INFLOWS:
T18to24 = Grp18to24 / 7
NW25to29 = NewWorkerRate25to29*Attrition
OUTFLOWS:
Q25to29 = Grp25to29*AttritionRate25to29
T25to29 = Grp25to29/5

Grp30to34(t) = Grp30to34(t - dt) + (NW30to34 + T25to29 - Q30to34 - T30t034) * dt
INIT Grp30to34 = 8473
INFLOWS:
NW30to34 = NewWorkerRate30to34*Attrition
T25to29 = Grp25to29/5
OUTFLOWS:
Q30to34 = Grp30to34*AttritionRate30to34
T30t034 = Grp30to34/5

Grp35to39(t) = Grp35to39(t - dt) + (NW35to39 + T30t034 - Q35to39 - T35to39) * dt
INIT Grp35to39 = 11101
INFLOWS:
NW35to39 = NewWorkerRate35to39*Attrition
T30t034 = Grp30to34/5
OUTFLOWS:
Q35to39 = Grp35to39*AttritionRate35to39
T35to39 = Grp35to39/5

Grp40to44(t) = Grp40to44(t - dt) + (NW40to44 + T35to39 - Q40to44 - T40to44) * dt
INIT Grp40to44 = 14282
INFLOWS:
NW40to44 = NewWorkerRate40to44*Attrition
T35to39 = Grp35to39/5
OUTFLOWS:
Q40to44 = Grp40to44*AttritionRate40to44
T40to44 = Grp40to44/5

Grp45to49(t) = Grp45to49(t - dt) + (NW45to49 + T40to44 - Q45to49 - T45to49) * dt
INIT Grp45to49 = 17276
INFLOWS:
```

```
NW45to49 = NewWorkerRate45to49*Attrition
T40to44 = Grp40to44/5
OUTFLOWS:
Q45to49 = Grp45to49*AttritionRate45to49
T45to49 = Grp45to49/5

Grp50to54(t) = Grp50to54(t - dt) + (NW50to54 + T45to49 - Q50to54 - T50to54) * dt
INIT Grp50to54 = 17951
INFLOWS:
NW50to54 = NewWorkerRate50to54*Attrition
T45to49 = Grp45to49/5
OUTFLOWS:
Q50to54 = Grp50to54*AttritionRate50to54
T50to54 = Grp50to54/5

Grp55to59(t) = Grp55to59(t - dt) + (NW55to59 + T50to54 - Q55to59 - T55to59) * dt
INIT Grp55to59 = 12944
INFLOWS:
NW55to59 = NewWorkerRate55to59*Attrition
T50to54 = Grp50to54/5
OUTFLOWS:
Q55to59 = Grp55to59*AttritionRate55to59
T55to59 = Grp55to59/5

Grp60ormore(t) = Grp60ormore(t - dt) + (NW60ormore + T55to59 - Q60ormore) * dt
INIT Grp60ormore = 8618
INFLOWS:
NW60ormore = NewWorkerRate60ormore*Attrition
T55to59 = Grp55to59/5
OUTFLOWS:
Q60ormore = Grp60ormore*AttritionRate60ormore

Attrition = Q18to24+Q25to29+Q30to34+Q35to39+Q40to44+Q45to49+Q50to54+Q55to59+Q60ormore
AttritionRate = Attrition/Population
Population = (Grp18to24+Grp25to29+Grp30to34+Grp35to39+Grp40to44+Grp45to49+Grp50to54
                +Grp55to59+Grp60ormore)

AttritionRate18to24 = .275
AttritionRate25to29 = .05
AttritionRate30to34 = .05
AttritionRate35to39 = .032
AttritionRate40to44 = .023
AttritionRate45to49 = .012
AttritionRate50to54 = .011
AttritionRate55to59 = .052

AttritionRate60ormore = .167
NewWorkerRate18to24 = .232
NewWorkerRate25to29 = .174
NewWorkerRate30to34 = .129
NewWorkerRate35to39 = .105
NewWorkerRate40to44 = .112
NewWorkerRate45to49 = .099
NewWorkerRate50to54 = .072
NewWorkerRate55to59 = .045
NewWorkerRate60ormore = .032
```