A Method for Engineering Resilient Organizational Workforce Systems

simpathē :: Systems Integration of Manpower, Personnel, and Training for HSI Evaluations

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***Abstract*—At its core, *resilience* refers to the ability to resist and/or respond to a shock (internal or external stressor, disruption, disturbance, or challenge), and recover from the event once it has occurred. Organizations are complex adaptive systems whose capacity for resilience is embedded in a set of individual-level Knowledge, Skills, Abilities, and Other attributes (KSAOs), as well as a blend of organizational system-level cognitive, behavioral, and contextual capabilities. This paper applies complex systems theory and a Human Systems Integration (HSI) perspective to present a conceptual approach and computational model called *simpathē* (an acronym for Systems Integration of Manpower, Personnel, and Training for HSI Evaluations). The *simpathē* model aims to help assess organizational workforce resilience in two ways: first, it facilitates planning and preparations to help build organizational capacity to resist undesirable effects from system shocks; second, it enables rapid workforce trade-space evaluations to aid in developing situation-specific responses (and ultimately, transformative activities) that capitalize on disruptive events. This paper illustrates the *simpathē* model with a use case example that characterizes organizational workforce resilience in the face of a major technological perturbation within the system—namely, the large-scale (organization-wide) conversion to operating and maintaining a collection of new communication technologies.**

Keywords-organizational resilience; workforce; human systems integration; systems thinking; complex adaptive systems.

I. INTRODUCTION

The nature of change and uncertainty in the environment surrounding businesses associated with health, defense, crisis management and emergency services constantly challenges the resilience of organizations in these industries. Rapidly changing technology, intense competition, the stress of constantly having to do more with less, not to mention the need to be prepared for and respond to natural disasters, pandemic diseases, terrorist attacks or other man-made calamities, economic recessions, safety/security threats, equipment failures and general human errors are just some examples of how many different types of shocks can undermine the stability and security of an organizational system [1]. An organization's workforce—i.e., the resource pool of individuals engaged in or available for work—comprises a major nexus of resilience potential for organizations. Having appropriate numbers of people who possess the appropriate knowledge, skills, and attitudes to operate efficiently and effectively is critical to an organization's capacity to adapt to constant change, respond rapidly and adequately to organizational shocks, and thrive in dynamic and sometimes turbulent environments.

This paper leverages theories and concepts from industrial/organizational psychology, ecology, industrial systems engineering, operations research and management, complexity science, and Human Systems Integration (HSI). It then combines them with resilience research to develop a method for characterizing organizational workforce resilience as a function of interdependencies between *manpower* (the number of people available for work), *personnel* (the aptitudes of the people who work), and the *training* needed to prepare those people to perform the work.

The rest of this paper is organized as follows. Section II presents background and related research that briefly reviews the foundational theory, principles, and concepts employed in this research effort. Section III describes the technical methods for characterizing organizational workforce resilience, while Section IV introduces *simpathē*, a computational model that implements those methods. Section V closes with a use case example to demonstrate how *simpathē* can provide insights and solutions to organizational decision makers for both planning/preparation (i.e., static resilience) and for response/recovery (dynamic resilience).

II. BACKGROUND AND RELATED WORK

Recent years have seen a surge in resilience related research [2]. A considerable amount of this prior work is grounded in the context of disasters and other traumatic events [3]. Furthermore, much of the work is primarily concerned with understanding resilience from the perspective of either individuals or communities [4], with much less emphasis on understanding or characterizing resilience for sociotechnical systems at the organizational level.

The research effort described in this paper is distinct from the (albeit useful and informative) prior literature in both respects. First, the current work addresses the issue of resilience at a system-level in a unique way (exploring static and dynamic resilience associated with an organizational workforce system). Second, the focus is on a more general and pervasive type of organizational system shock (i.e., technological disruptions affecting an industry or business).

Such distinctions necessitate a brief review of exactly what the term *organizational workforce resilience* means in the this context, as well as what it means to refer to organizations as *complex adaptive systems* when referencing the specific domains of *manpower*, *personnel*, and *training* from the systems engineering sub-discipline known as Human Systems Integration.

A. *What is Resilience?*

The term *resilience* lends itself to interpretations that have relevance to a variety of research interests ranging from physical science disciplines like metallurgy and materials science, to natural science disciplines like ecology (where Holling's seminal 1973 publication linked the concept with an ecosystem's ability to absorb change and still persist [5]) to social sciences like individual and organizational psychology, and applied sciences like safety engineering [1]. Tracking the evolution of the definition of resilience through the years and across the disciplines gives an idea of the broad impact the concept has had to science in general, and helps shape the understanding of its use in this paper, which pairs it with organizational workforce systems.

Shortly following Holling's initial contribution to the field [5], the ecological literature began to reference two types of resilience: first, "ecological resilience" is consistent with Holling's original definition (the ability to absorb change and still persist after a shock); second, "engineering resilience" deals with the dual processes associated with a) building up *resistance* capacity to potential disruptions *a priori*, and b) enhancing the speed of returning to the pre-existing equilibrium [2][6][7]. As one might infer from the title of this paper, these concepts are important to the current effort.

For at least the past few decades, the economics literature has provided significant social science research contributions to the concept of resilience. In particular, Rose offers useful research from the perspective of economic resilience to natural and man-made disasters (c.f., [8][9]). Rose uses the term "static resilience", which refines the concept of resistance in engineering resilience to incorporate specific consideration for proactively developing the ability for maintaining core functions and performing essential tasks when shocked. Rose also introduced "dynamic resilience" to refer to the speed at which a system returns or bounces-back to a pre-shock state. Regional studies literature on resilience further cultivated the concept by calling attention to an important aspect of dynamic resilience: it is "an adaptive notion […] characterized by complex non-linear dynamics and an adaptive capacity that enables [systems] to rearrange their internal structure spontaneously" [10].

Progressing to the field of operations research and management, the concept of *organizational resilience* is instantiated as the capacity for an organization to resist shocks (by avoiding organizational breakdowns and failures) and return to a normal state—which may be the original state or some other new desired state [11][12]. Sheffi and Rice further emphasize that a resilient organization should incorporate a strategic initiative to build resilience by (preemptively, continuously) monitoring the organizational state, being sensitive to operations and having well-developed situation awareness, maintaining flexibility to create or reduce redundancy when and where needed [12]. Teixeira and Werther similarly advocate for organizations to be anticipatory responders—to anticipate potential challenges and disturbances and to adaptively adjust prior to a disruption [13]. Consistent with prior research [2], this paper synthesizes the above literature into a characterization of organizational resilience that embraces:

a) the concept of engineering resilience [6][7], with both static and dynamic resilience [8][9],
b) the perspective that organizations comprise complex adaptive systems and processes [10],
c) the notion that a system may "recover" by returning to its original state or to a new desired state [11][12],
d) resilience as a strategic initiative to be proactively evaluate organizational decisions [12], and
e) resilient organizations as anticipatory responders such that adaptation to a new desired state may occur ahead of a disruptive event [13].

With these tenants of organizational resilience in mind, *organizational workforce resilience* further focuses and scopes the current effort to considerations associated with the organization's human capital resources—i.e., the resilience embodied in the organization's staffing, tasking, and training of individuals responsible for the work associated with maintaining core functions and performing essential tasks within the organization. The concept of organizational (workforce) resilience is quite different from notions of individual resilience pervasive in psychology literature. Research in that domain is typically oriented around personal characteristics that serve as protective factors and/or promote a person's capacity to survive, bounce-back, and thrive when faced with adversity and crisis. Examples of factors discussed in psychology research include those related to self-esteem, self-confidence, self-efficacy, loci of control, adaptive coping and problem-solving strategies, flexibility and resourcefulness, personality (including the Big 5 and other ego-resiliency traits), emotional intelligence (including self-awareness and assessment), health, and social relationships (see [14]–[18]). A common misconception of organizational resilience is to perceive it as a sum total of individual capacities to be resilient [19]. However, organizations are complex sociotechnical systems that change and evolve not just based on individual orientations and actions but more so through the interactions that individuals have with each other and from interdependencies among the sub-systems and processes in the organization [20].

Whereas individual resilience is too narrow for the purposes of the current effort, the notion of community resilience is slightly too broad. Research in community resilience typically attends to the connections between neighborhoods and community-level organizations, and between a variety of local and non-governmental groups whose professions necessarily focuses on building and protecting places (e.g., engineers, urban planners, architects), as well as those focused on growing and maintaining healthy people (e.g., health care and public health professionals, emergency responders, social service providers, faith-based specialists, educators, law enforcement, etc.) [4][21]–[23].

A. What is the Complex Adaptive Systems Perspective?

The current paper provides a useful link between considering the resilience of individuals and the resilience of an entire community. This link is accomplished by taking an explicit complex adaptive systems perspective grounded in specific technical methods from systems engineering and HSI.

Edson [24] offers a helpfully concise formal definition of complex adaptive systems, with short descriptions of the important characteristics that make the perspective so well-suited for applications in organizational resilience research: *Complex adaptive systems are diverse, interconnected systems that exhibit self-organization (purposeful internal evolution), hierarchy (certainty created through structures that bring order and meaning), emergence (a coherent and integrated dynamic of innovation), and learning (planned application of experience to future events) based on environmental feedback in response to uncertainty* (p. 499).

Thus, a *complex system* is composed of a large number of comparatively simpler parts interacting with each other so that the emergent behavior of the whole is intrinsically difficult to predict based only on the behavior of any single part [25][26]. This is due to the nonlinear interactions, dependencies, and relationships among the parts, as well as between parts and the system's environment. Many complex systems are also *adaptive*, meaning they "respond to their environment and alter their behavior in such a way that they can maintain or improve their function, or so they can 'survive' (that is, continue to persist as organized systems)" [25].

The complex adaptive system perspective is a useful framework for conceptualizing organizational resilience because it captures the tenant of adaptability, as well as the nonlinear relationships between aspects of human capital within the workforce (the number and type of people, their aptitudes, their training), the work environment (workweek demands in terms of the dynamics of situationally dependent tasks required, resource availability, time apportioned), and so on [10][23][27]. The emergent nature of this perspective is in contrast to reductionist approaches, which attempt to understand the system as a whole by study individual pieces in isolation; again, the systems perspective emphasizes that the whole is not equal to the simple sum of its parts.

B. What is Human Systems Integration (HSI)?

The International Council on Systems Engineering (INCOSE), the Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS), and the Systems Engineering Research Center (SERC) jointly define Human Systems Integration as an interdisciplinary technical and management process for integrating human considerations with and across all system elements [28]. HSI incorporates the following domains as integration considerations: manpower, personnel, training, human factors engineering, occupational health, safety, habitability, and human survivability. Of these domains, the current effort of engineering organizational workforce resilience is principally concerned with the trade-offs related to manpower, personnel, and training. *Manpower* refers to the number and type of people who operate, maintain, support, and provide training for systems [29]. *Personnel* refers to the human aptitudes (such as knowledge, skills, abilities, attitudes) and experiences required to perform the jobs of operators, maintainers, and support staff [29]. *Training* prepares people to perform the tasks necessary to accomplish organizational goals and objectives [29].

III. CHARACTERIZING WORKFORCE RESILIENCE WITH THE *SIMPATHĒ* MODEL

Workforce resilience is an organization's ability to respond and adapt rapidly to threats posed to its workforce. Organizations that can build resiliency into their human capital are more likely to protect their most valuable resources and maintain continuous operations in the event of a crisis. In general, this paper conceptualizes workforce resilience as a function of the interdependencies between manpower, personnel, training, and the organizational context in terms of core functions and essential tasks. The technical foundation for establishing this context is the task analysis. I refer to this conceptual approach for evaluating aspects of organizational workforce resilience as Systems Integration of Manpower, Personnel, and Training for HSI Evaluations, abbreviated as *simpathē* (pronounced "sympathy").

A. Task Analysis

In HSI (from the human factors engineering domain), a task analysis involves the study of how a system goal or objective is accomplished. Task analysis includes a detailed decomposition and description of both manual and mental activities, timing/durations, frequency of occurrence, task divisions of labor and allocation (to some combination of one or more humans and/or technology), potential errors, information requirements (both inputs and outputs), requisite aptitudes for task performance, performance criteria, environmental conditions, and other factors involved in or required for one or more people to perform a given task (see [30] for a more complete list of task analysis elements used for various applications). The term *task* is often used interchangeably with activity or process.

The method presented in this paper relies on a minimum of three specific task analysis elements: hierarchical task list with descriptions, task timing (duration), and task frequency.

1) Task List and Descriptions. System functions (goals, objectives) serve as an initial hierarchical framework for further decomposition of goal-directed, step-by-step list of all essential tasks and activities needed to ensure the organization's core functions can be maintained. Ensure that all collateral duties (especially those particularly relevant for disruptive situations) be incorporated to the extent practical.

2) Timing. For each essential task activity, the task timing (durations) are needed in order to determine the labor requirements for ensuring core functions and essential tasks are maintained during organizational shocks. In the absence of direct observation, task times can be analytically derived using empirically-established human performance equations associated with human perceptual process, information and decision processing, and human body movements. For example, the Hick-Hyman empirical equation depicts motor reaction time (RT) in response to perceiving/processing information and making decisions as a logarithmic function of the number of alternative stimuli and responses. Fitts' Law is an empirical equation for movement time (MT), which describes the logarithmic relationships of distance traveled and required precision with the time to complete discrete movement. When combined, the equations above allow analysts to derive total task times (TT), which account for perceptual delays, decision delays, and movement durations:

$$\mathrm{TT} = a + [\, b * \log_2(N)] + k + [\, c * \log_2(\tfrac{2D}{W})\,] \qquad (1)$$

Where: a and b are empirically derived constants to account for perceptual and decision processing; N is the number of choices or attention items; k and c are empirically derived constants to account for times difference of specific body part movement (finger, wrist, arm, foot, etc.); D is distance of movement; W is width of target.

Another analytical method used in industrial and production engineering are Predetermined Motion Time Systems (PMTSs), also referred to as Predetermined Time Standards or Predetermined Time Systems (PTS). Methods-Time Measurement (MTM) is one such system useful for quantifying the amount of time required to perform specific tasks under defined conditions.

Because of the complex adaptive nature of organizational systems, it is often useful to understand the range and distribution of times associated with tasks. The Program Evaluation and Review Technique (PERT) [31] accommodates uncertainty by incorporating timing appraisals based on three point estimates: *optimistic time*: the minimum possible time required to accomplish an activity assuming everything proceeds better than is normally expected or that the task is performed by a highly proficient expert; *pessimistic time*: the maximum possible time required to accomplish an activity, assuming things go awry (excluding major catastrophes) or that the task is performed by an non-proficient novice; and the *most likely time*: the best estimate of the time required to accomplish an activity, assuming everything proceeds as normal or that the task is performed by a typical competent worker. The PERT distribution assigns very small probability to extreme values, and so the Modified PERT distribution introduces a fourth parameter, lambda (γ), that controls the weight of the most likely value in the determination of the mean and helps provide control on how much probability is assigned to tail values of the distribution:

$$\mu_{task} = \frac{a+\gamma b+c}{\gamma+2} \qquad (2)$$

Where: a is the minimum (most optimistic) time; b is the most likely time, c is the maximum (most pessimistic) time; γ is the distribution control parameter that becomes useful when (b – a) and (c – b) are very different magnitudes [32].

3) Frequency. In the absence of empirical data, task frequencies can be estimated or rated. For example, Subject Matter Experts (SMEs) reposnible for performing maintenance on the communications equipment for an organization might provide frequency ratings to estimate how often they typically perform certain maintenance tasks on a single piece of equipment. Ratings may be numerical anchors that represent the levels of granularity appropriate for the analysis, for example:

1 = the task is performed at least annually, but typically not more than twice per year.

2 = the task is performed at least semi-annually, but typically not more than monthly.

3 = the task is performed at least monthly, but typically not more than twice per week.

4 = the task is performed at least twice per week, but typically not more than twice per day.

5 = the task is performed at least twice per day, but typically not more than twice per hour.

6 = the task is performed at least twice per hour, but typically not more than once per minute.

B. Manpower Calculations

Using the data from the task analysis (task list, timing, frequency) in conjunction with information regarding numbers of systems and anticipated work-week labor, we can derive required full-time equivalents (FTEs) needed to maintain an organizations core functionality and essential tasks.

1) Equivalent Man-Week. The EMW equation combines the frequency ratings with the modified PERT times to obtain the estimated weekly labor associated with a particular task. For example, the equivalent weekly proportion for any task with a frequency rating of 1 (task is performed at least annually, but typically not more than twice per year) ranges between 1/52 = 0.01923 and 2/52 = 0.03846, because the frequency is bound between 1 and 2 times per 52 weeks. Thus, the EMW labor requirement for a task that takes 90 minutes, but only gets performed once or at most twice in a year is between 1.7307 minutes and 3.4614 minutes.

$$EMW_{task} = \mu_{task} * eqp_{task} \qquad (3)$$

Where: μ_{task} is the task-specific point estimate obtained from the modified PERT equation; eqp_{task} is the task frequency expressed as an equivalent weekly proportion.

2) Full-Time Equivalent. The FTE is obtained by the summing the EMW times for all tasks, and then dividing by prescriptive workweek labor (e.g., a 5 day workweek of 8 hours per day is 40 hours, or 2400 minutes). For large, longer-term rebuilding efforts, individuals cannot sustain overload/overtime schedules. FTE should therefore be scaled with "maximum workload buffers" to account for any proportion of time reserved by a utilization threshold. Typical guidance from the field of Human Factors Engineering *[33]* is to limit human utilization workloads to 75%, which improves organizational workforce (static) resilience.

$$FTE = \frac{\sum EMW_{task}}{workweek} * 0.75 \tag{4}$$

C. Personnel

For each of the core functions and essential tasks, a list of requisite KSAOs can be identified. Often, these KSAOs will be bundled together into specific job-roles. The degree to which the duties associated with specific job-roles occupy a person's time interacts with the manpower FTE estimates such that the FTE associated with a particular job-role can be formalized as:

$$FTE_{role} = \frac{\sum EMW_{task*role}}{workweek} * 0.75 \tag{5}$$

Additionally, a job-task analysis looks at the fit between the requisite KSAOs needed to accomplish the core functions and essential tasks for an organization versus the KSAOs of the people engaged in or available to perform those tasks. A KSAO mismatch (or "personnel gap") occurs when a task or some set of tasks require specific knowledge, skills, abilities, or other aptitudes that are not possessed by individuals working in the organization.

$$\Delta KSAO = KSAO_r - KSAO_p \tag{6}$$

Where: $KSAO_r$ represents the set of requisite knowledge, skills, abilities, or other aptitudes and $KSAO_p$ represents the set possessed by individuals in the organization's workforce. When ΔKSAO > 0 exists, organizations have a personnel gap. When ΔKSAO < 0 exists, organizations have overqualified personnel, which may lead to labor cost inefficiencies or retention issues. Furthermore, when the manpower and personnel domains interact such that there is a discrepancy between the number of role-specific FTEs required to perform all core functions and essential tasks and the number on hand, then the organization becomes less resilient due to either inefficiency (if over-staffed with too many role-specific FTEs) or inability to maintain organizational core functions (if under-staffed with not enough role-specific FTEs).

D. Training

In the ever changing environment of industry and business, an organization's human capital (employee KSAOs) must be constantly updated to keep pace with change. This is especially the case for the type of emblematic shocks organizations frequently encounter (i.e., responding to rapid changes in technology and marketplace shifts). Oftentimes, such organizational system shocks will necessitate either a) an entirely new set of core functions for the organization, or b) new essential tasks to maintain the *same* core functions, and potentially also c) rendering previous functions and/or tasks obsolete, or d) other adjustments and modifications that affect task timing/duration, frequency, or requisite KSAOs.

In complex adaptive systems like organizations, the training domain interacts (and is interdependent) with the manpower and personnel domains. Organizations can be anticipatory responders by identifying training gaps ahead of the crisis of workforce shortages or obsolescence.

IV. SIMPATHE: COMPUTATIONAL MODEL

The methods and techniques described in Section III for *simpathē* represent the conceptual approach for evaluating the interdependencies between manpower, personnel, training, and organizational context in a systematic and integrated way. A computational model that implements these methods and techniques is also useful to aid in more rapid exploration of the trade-space associated with such (nonlinear, complex) interdependencies. The *simpathē* computational model is available as either a standalone computer program (a script written in the Python programming language), or as an interactive browser-based Jupyter Notebook or JupyterLab application. All implementations allow for programmatic access to the models and techniques, but the Jupyter implementations have additional (non-programmatic) user interface elements that add web forms and control widgets to aid with data importing, exploration, and visualization. For example, analysts can use the browser-based JupyterLab application to select an existing task analysis data file, run the program, and view tabular and graphical summaries for manpower requirements associated with all functions and tasks designated in the task analysis. Optional sub-groupings are enabled as well: manpower requirements by personnel, if roles are designated within the task analysis, by hierarchical function or functional area, or by other desired groupings (for example, see the use case example described in the next section). If data is available regarding the organizational system's existing workforce structure, *simpathē* will also assess any potential manpower (and optionally personnel) mismatches between the human capital resources required according to the task analysis versus what is available in the extant workforce, and likewise presents summaries in interactive tables and graphical formats.

V. USE CASE EXAMPLE: TECHNOLOGICAL DISTRUPTION

The United States military is a national defense oriented organization that precisely meets the criteria of being a complex adaptive system, and decision makers regularly apply resilience-thinking to their organizational decision processes. This organization uses an assortment of specialized communications equipment for a large variety of situations. The organization not only operates these specialized communication devices, they must also conduct much of the maintenance for them. As one might imagine, the technology associated with range of these types of devices is widely varied, and is constantly evolving. Such technological innovations, advances, upgrades, or replacements are the source of disruptions for the organization's MPT situation. In an effort to mitigate the negative impacts on manpower, personnel, and training (MPT) for technological disruptions, the organization used *simpathē* to assess MPT risks and potential courses of (COAs). First, *simpathē* helped summarize the FTE requirements for all functions and tasks associated with the maintenance journeymen, supervisors, and support technician roles for designated levels of maintenance (organization-level versus depot level) for one or more selected types of communications equipment (e.g., radio types X, Y, and Z out of a set of 17 types of hand-held, vehicle mounted, or backpack carried communication devices). These FTE requirements were then compared to the extant MPT situation for over 1,000 different maintenance units within the larger organization such that current over- and under-staffing situations were identified. A range of possible technological changes that affected the maintenance functions and tasks were next assessed for their impact on the number and types of maintainers, their aptitudes, and their training. For example, some innovations made KSAOs related to analog communications less applicable, stressing aptitudes related to digital, satellite, and wired/wireless networking KSAOs.

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