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A Model of Psychosocial Factors for Long-Duration Spaceflight Exploration Missions

Lacey L. Schmidt, Ph.D. as guided by Lauren Blackwell Landon, Ph.D. and Holly Patterson, M.A. (representatives of NASA's Behavioral Health and Performance Research Element

National Aeronautics and
Space Administration

Johnson Space Center
Houston, Texas 77058

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Abstract

This report presents a semi-quantitative model, database of supporting studies, and a method to continue modeling the psychosocial factors most likely to influence and impact teams during autonomous, long duration and/or distance exploration missions (Behavioral Health and Performance, Team Gap 1). The model follows an Input-Process-Output framework with four layers of psychosocial factors: 1) Situational and Individual Inputs, 2) Hidden Aggregates and States, 3) Teamwork Processes, and 4) Team Performance Output. This model and modeling process are an attempt to integrate very discrepant data, study types, contexts, and theories into one conceptualization that may be used to inform NASA's future research decisions regarding which psychosocial factors might be most profitably addressed or leveraged given limited resources to support Long Duration Space-flight Exploration Missions (LDSEM).

Executive Summary

This report describes a model of psychosocial factors for long-duration spaceflight exploration missions (LDSEMs) as completed for NASA requisition number 4200527261 by Lacey L. Schmidt of Minerva Work Solutions, PLLC. Dr. Schmidt completed three milestones as described by the statement of work: 1) Conduct a Literature Review, 2) Draft a Theoretical Model, and 3) Create a Final Report. For milestone one, a literature review was conducted to identify the key factors and relationships relevant to team performance. As an additional deliverable for Milestone One, a categorization system and database was created to help record, sort and classify the literature into appropriate types of evidence and relevance to LDSEMs. For milestone two, Dr. Schmidt created a systematic method of using the sorted and classified literature to build a nomological model (i.e. infographic) that is visibly tied to the quality of evidence within the relevant literature. Using this method, a theoretical model was drafted to include a description of weights of factor relationships outlined in the model and the evidence for those weights. The final theoretical model follows an Input-Process-Output framework with four layers of psychosocial factors: 1) Situational and Individual Inputs, 2) Hidden Aggregates and States, 3) Teamwork Processes, and 4) Team Performance Output. The model visually describes the strength of relationships among 41 psychosocial factors, as well as four factor clusters of use for further LDSEM teamwork theory development. Qualitative rational for the model's conceptualization was based on over 200 relevant meta-analytic, longitudinal, and or context specific articles; while 94 of those articles also offered quantitative data that informs the rational for the model's factors and the strength and direction of relationships among those factors. The database (in the form of a Microsoft Excel workbook) and electronic copies of all articles within the database were provided on compact disc along with this report to the Behavioral Health and Performance Research Element. This final report acts to fulfill milestone three by detailing the methodology, model, and literature well enough to enable future users to duplicate or add to the model as needed. The final report also serves to summarize gaps and research recommendations listed by priority with rational. Note: updated visuals of the nomological model considering any additional data points are available upon request from the Behavioral Health and Performance Research Element.

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Introduction

Purpose of this Modeling

This model was created to facilitate a better understanding of the key threats, indicators, and life cycle of the team for autonomous, long duration and/or distance exploration missions (Team Gap 1). The model is based on the research findings to date, and is intended to inform current spaceflight operations and research and frame future research efforts. There were necessarily two main steps to generating this model: 1) a review of the literature resulting in a theoretical model of psychosocial factors in long-duration exploration missions, and 2) a collection of existing quantitative research and indication of gaps for future research studies to address. This model relies upon the general research of teams as well as the research on teams in space-flight analogous populations (e.g. isolated and confined environments, healthcare, the military, first-responders, and expeditioners) and studies conducted with teams on LDSEMs to create an evidential foundation for the model.

Important Conceptual Definitions

For a concept to be psychosocial means it relates to one's psychological development in, and interaction with, a social environment (of or pertaining to the interaction between social and psychological factors). This interaction necessarily occurs at the individual, group and/ or at situational levels and forms the basis for the model's variables. In the confines of this report, the model is especially interested in psychosocial factors, team processes, and team outcomes that ultimately ensure, promote, and maintain behavioral health and performance on a long-duration spaceflight exploration mission (LDSEM) (e.g. greater than or equal to six months in space). There are at least four layers of factors that must be sufficiently described by the model: a layer of individual and situational level psychosocial factors that influence a hidden layer of multi-level interactional and group factors leading either directly or indirectly to a processing layer that determines a final layer of outcomes. Layers should not be confused with levels. Levels indicate a unit of measurement (e.g. the team, the person, the week), while layers describe a perceptual plane of understanding (like the layers of an onion). Also, for the purpose of this report, the concept of a team is limited to the space-flight crew members that have daily contact with one another and who have direct influence on team performance outcomes (e.g. may be as small the team as astronauts within the vehicle, unless ground control has daily contact and influence on team performance outcomes) and the terms team and crew are used interchangeably. Team performance is operationalized as the completeness and accuracy of objectives met by the team before or within the specified mission timeframe.

Literature Review

Methodology

A multi-method approach was implemented to obtain a variety of literature for review and ensure all research relevant to teams in long-duration mission contexts was considered. The first method was to search existing public and scholarly databases that might contain relevant research publications from appropriate research fields. Ultimately ten (10) databases were searched, including *NASA STI*, the Department of Defense's Public *STINET*, the *Catalogue of US Government Publications*, *Google Scholar*, *PsycInfo*, *PubMed*, *EBSCO*, *Academic Search Premiere*, *OneSearch*, and *ScienceDirect*. Within these databases, eight (8) specific streams or fields of research were included: aerospace, military, sports, business, education, psychology, medical, and information technology.

In an effort to be thorough and complete, all of the following search terms were combined with the terms "team" and "teamwork" to search within each database.

Table 1: The List of Search Terms combined with "Team" and "Teamwork"

• Adaptation	• Executive	• Outcomes
• Arctic/ Antarctic	• Expedition	• Performance
• Asthenia	• Extreme Environment	• Pilot
• Astronaut	• Facilitation	• Problem solving
• Building	• Factors	• Project
• Cognition	• Failure	• Psychosocial
• Cohesion	• Firefighter	• Quality
• Collaboration	• First-responder	• Rescue
• Command	• Flight controller	• Resilience
• Communication	• Intervention	• Resources
• Conflict	• Isolated Confined Environment	• Risk
• Cooperation	• Knowledge	• Salutogenic
• Coordination	• Leader	• Science
• Countermeasure	• Leadership	• Skills
• Decision making	• Longitudinal	• Space
• Development	• Management	• Space Analog(ue)
• Diversity	• Measurement	• Success
• Effects	• Meta-analysis	• Technical
• Emergency	• Military	• Training
• Error	• Multilevel	• Wellness

The second method was to personally invite and appeal for unpublished or pending publications from the directors of laboratories, institutions, and universities known for contributing to the research on teams and teamwork in similar or relevant contexts. There were 43 departments at 28 such entities contacted including Rice University's Business and Psychology Departments, the University of Houston's Business, Psychology, and Cognitive Science departments, the University of Southern Florida's Psychology department, University of Central Florida's Business and Psychology departments and Simulations Center, Oklahoma University's Psychology Department, Oklahoma State's First-Responder Publications Center, the University of Texas's Leadership Center and Business and Psychology departments, the University of Texas' Medical Branch, the University of Texas' School of Public Health, Texas A&M's Business and Psychology departments, the University of North Texas' HR Management and Psychology departments, Michigan State's Psychology department, Bowling Green's Psychology department, Syracuse University's Psychology department, the University of California's (UCLA) Psychology department and Medical School, Pennsylvania State's psychology department, Harvard's Business and Medical schools, George Mason University's psychology department, Duke University's Psychology department, Aberdeen University's Center for Simulations and Team Research Lab, McGill

University's Center for Medical Simulations, John Hopkin's Center for Quality Improvement, Minnesota State University's Business and Psychology departments, Colorado State University's Business and Psychology department, Colorado School of Mines Human Factors and Engineering department, the American Research Institute, the Army Leadership Research Institute, the Navy Aeromedical Institute, and the Federal Aviation Administration's Human Factors Research group. These invitations resulted in the sharing of 15 articles in pending publication status and references to four (4) recently-made-public military/ technical reports.

The third method was to post generic appeals on various social media sites to all students, scientists, and authors to share any research citations relevant to factors influencing teamwork in operational environments over time. Such appeals were posted twice (once in September and once in October) on LinkedIn, Facebook, Twitter, and Google+, and resulted in roughly 300 recommended articles from many different research domains (e.g. psychology, education, critical care medicine, sports, engineering, computer science, human factors, cognitive science, rescue services, security, and oil and gas exploration and production).

From all three methods, over 1100 potentially relevant articles were initially identified, and from those 244 articles warranted reading beyond the abstracts. However, only three types of literature were considered further for this review. First, literature summarizing vast quantities of quantitative research, data collected through multiple methods, or longitudinal data (e.g. meta-analyses, longitudinal studies) regarding teamwork was considered irrespective of what teamwork context these studies involved. Second, important theoretical literature, multi-year literature reviews, and qualitative studies related to teamwork or team performance in spaceflight or similar operational contexts and populations was considered. Third, and most importantly, quantitative or correlational studies involving teams or teamwork in LDSEMs or analogs were retained for further sorting.

Categorization and Second Sorting Details

Articles meeting the basic requirements of the first sort (e.g. 244) were sorted into three categories: 1) longitudinal, multi-method, or meta-analytically informative to the model of the psychosocial factors impacting teams independent of context, 2) theoretically or qualitatively informative to the model (because of the article's integration of research across contexts or specificity to the long-duration space-flight exploration mission context), or 3) quantitatively informative to the model (because of the study's context and the study population's similarity to the spaceflight mission context or analogs). Figure 1 summarizes the categorization schema applied.

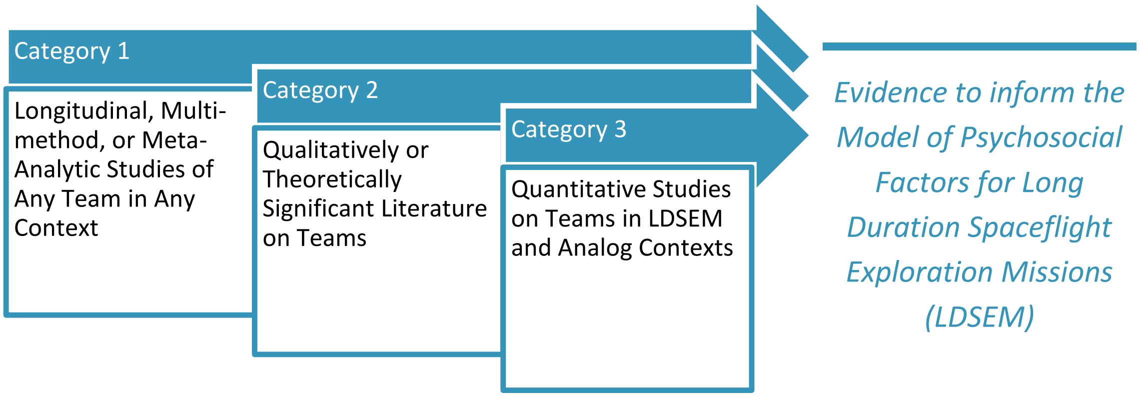

Figure 1: Categorization Schema

For the purposes of this literature review and categorization, spaceflight mission context was operationalized as any manned mission to or outside of lower earth orbit, and long-duration space flight context was operationalized as such manned missions lasting six months or longer. In general, analogs were operationalized as an environment or context that closely mimics one or more psychosocial aspect of spaceflight (e.g. Isolated, Confined, Extreme, and/ or Exploratory Objectives) and requires workers to work together as a team to achieve a similar mission and activities (e.g. explore, conduct scientific investigations, engineer systems). Long-duration analogs are operationalized as those that require teams to live and work together for six months or longer. However, the term analog also includes low-fidelity and short-duration analogs so long as they aim to investigate long-duration or team performance outcomes over time; such as a series of moon-base exploration games, intensive care unit simulations, military field exercises and simulations, or a series of business or operations management simulations conducted in class rooms. Table 2 provides further examples of the types of analogs that meet the operational definitions used to classify research for this project.

Table 2: Types and Examples of Analogs Included

Type	1st Example	2nd Example	3rd Example
ICE Analogs	Antarctic	Arctic	Submarines
Chamber Studies	HERA	MARS 500	TEKTITE
Extreme Team Analogs	Drilling Rigs	Fire Stations	Military Field Hospitals
Mission Analogs	Special Reconnaissance Field Missions	Wilderness Trek/ Patrol Missions	Flight Control Teams
Low-Fidelity Analogs	A Series of Flight Controller Simulations	Actual Management or Product Development Project	Military Unit Field Exercise Team Training Event

Qualitatively informative studies were operationalized as those that summarized across many years of team research, extrapolated on long-duration space exploration mission experiences and prior studies, or were based on qualitative research techniques that could not be reasonable converted to quantitative estimates (e.g. diary studies, case studies). Quantitatively informative studies were operationalized as those that used and reported on some type of predictive statistical results or correlations (or other descriptive statistics such as frequencies of observations that could be reasonably converted to quantitative estimates) for factors related to teams and teamwork.

As one example of categorizing articles using these operationalizations, the Sealab 45-day saturation dive sponsored by NASA (Pauli & Clapper, 1967) was classified into category two because it contained some insight into team members emotional response to teamwork in an analog environment (but no quantitative or correlational data significant to teams or teamwork). This categorization facilitated the structure of the resulting model such that connections supported by the third type of articles were given more weight than those connections only supported by the first and/ or second types; and connections supported by all three types were given the greatest consideration (more information about weighting follows in the section on modeling database methodology). Specifically, the sorting caused longitudinal and meta-analytics finds to be weighted by 1 (or as is) in the model, while quantitatively significant studies from spaceflight and analogs were weighted (multiplied) by 3 in terms of relevance in the model. Theoretically or qualitatively significant studies from spaceflight and analogs were not numerically fit into the model, but the 2 indicates that their findings were used as support for the inclusions of factors and clusters within the model. The original 244 studies identified were completely read and sorted into the three categories a second time, resulting in 224 articles (e.g. 20 studies did not meet categorization criteria upon closer reading).

This categorization and the first two sortings (resulting in 224 articles) were the first step in determining relevance and assigning weights within the model. Further weighting was determined by fully reading through the articles a second time to determine how similar the study population and context was to astronaut crews and the LDSEM context. The criteria for calculating these similarities is described and documented in a later section of this report related to model generation.

Nineteen (19) of the 224 articles left from the second sort did not have sufficient team or psychosocial applicability upon a second full reading. In the end, 205 total articles were sorted into the three categories and included in the construction of the model visual. Thirty-nine (39) articles inform the model at the first categorical level (quantitative meta-analytic, multi-method, or longitudinal). One hundred and eleven (111) articles inform the model at the second categorical level (e.g. only qualitatively). Fifty-five 55 articles inform the model at the third categorical level (e.g. quantitatively within some analog population and/ or context). A total of 94 articles (both category one and three) quantitatively inform the model's development, while a total of 111 articles provide qualitative support for the model. This means that nearly 46% (or 45.85%) of the final articles supporting the model provided quantitative evidence, while roughly 54% provided qualitative evidence or rational for modeling decisions and structure.

Each quantitative article included may inform more than one factor or relationship within the model as some articles reported correlations or effect sizes for multiple factors or multiple relationships. From the 94 total quantitative articles (e.g. categories one and three), 167 individual rows (or weighted correlations) of evidence were gleaned to build the spreadsheet detailing the quantitative evidence for the model.

Necessary Working Assumptions

Despite the exhaustiveness of the literature review process, the resulting model is not meant to be all encompassing—rather it is to inform a select type of user (aerospace medical and behavioral health and performance subject-matter-experts) of the current state of theory as it is directly applied to their unique context and future aspirations (e.g. long-duration spaceflight missions). As a consequence, some factors known to be important in other contexts were excluded from this model when there was not sufficient evidence from a spaceflight context or meta-analytic literature to determine their relevance (e.g. third quarter effects, transactive memory). Additionally, interrelationships among individual level psychosocial factors were ignored for modeling purposes if these interrelationships were not known to be important to monitoring or manipulating team outcomes for long duration missions. For example, personality and intelligence are correlated such that more conscientious personalities generally score higher on intelligence tests, but this relationship does not obviously influence the performance of a team (whereas conscientiousness alone may). In order to achieve a more parsimonious and useful model, the model was more concerned with how psychosocial factors impact team outcomes (like how team training impacts team performance), and less focused on how psychosocial factors are related to one another (like how trust is related to affect). For example, it is likely that leadership style and mission duration are at least correlated, but this interrelationship was not as important as determining how leadership and mission duration are each likely to influence team performance in an LDSEM context.

Finally, since negative outcomes (like errors and ill-health) cannot logically be predicted by most psychosocial research and observation methods, this model assumes that the greatest outcome of concern is team performance and that maintaining minimum levels of health and some ability to avoid and mitigate errors are important but unspoken prerequisites to team performance. Unless otherwise explicitly stated, team performance always means objectively measured team performance (e.g. number of goals accomplished, absence of errors, accuracy or viability of solutions, etc.) in this report.

A Literature Brief on Teamwork Modeling

Over the last 50 plus years, research has largely used an input-process-outcome (IPO) framework for studying team performance and effectiveness (J. Mathieu, Maynard, Rapp, & Gilson, 2008). Several empirically tested models of team performance exist (Dyer, 1986; Morgan Jr, Glickman, Woodard, Blaiwes, & Salas, 1986), but the most popularly applied across industries and by operational teams are the Team Effectiveness Model (Tannenbaum, Beard, and Salas 1993) and the subsequently developed Adaptive Team Performance Model (Burke, Salas, Prince, et al., 2010). The Team Effectiveness Model is presented in Figure 2.

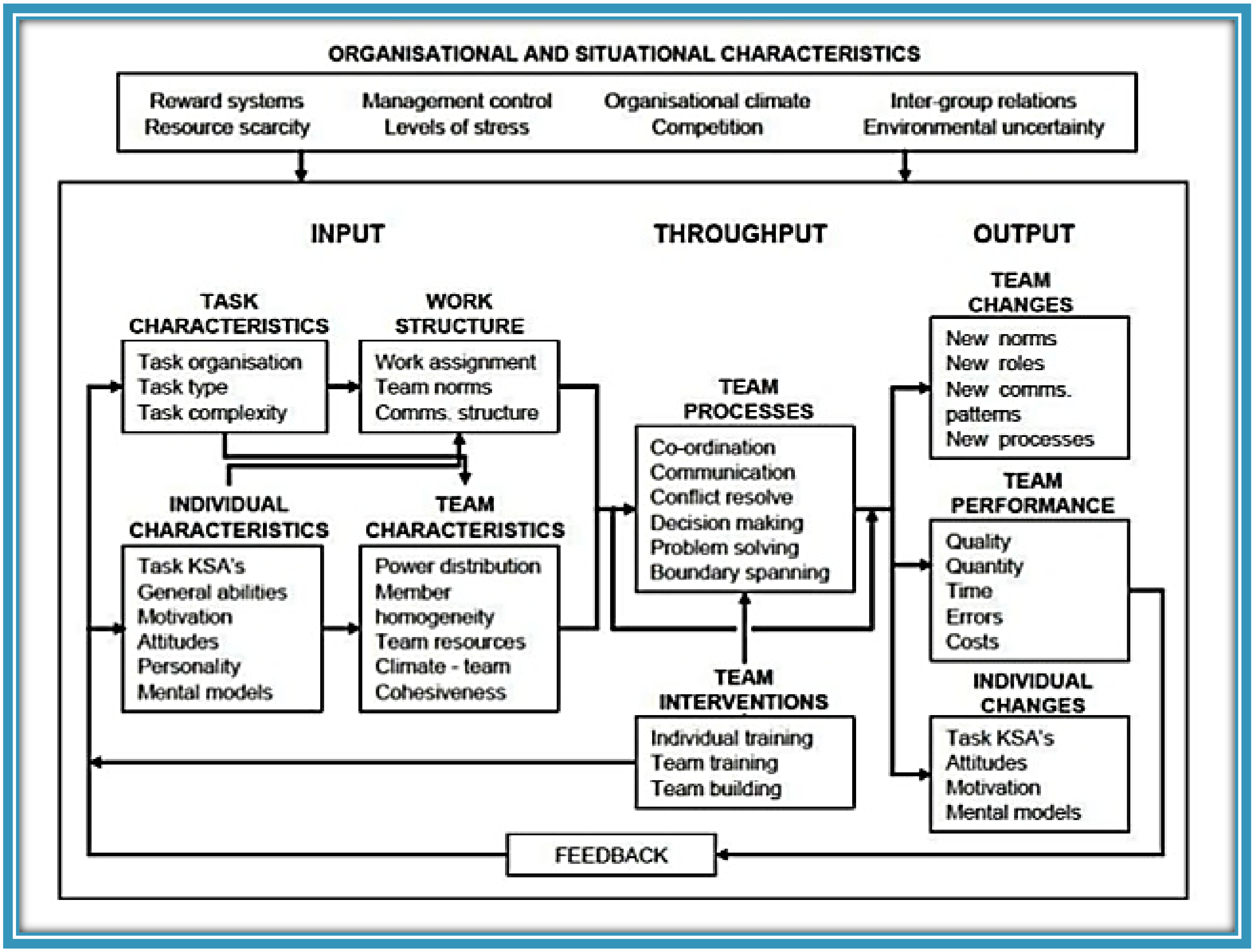

Figure 2: The Team Effectiveness Model

While the Team Effectiveness Model demonstrates that the IPO framework is suitable for conceptualizing psychosocial factors for teamwork in general, it struggled to represent the interconnectedness of relationships among factors within the model and the adaptive nature of human social groups in a meaningful way. This motivated the subsequently developed Adaptive Team Performance Model presented in Figure 3 and spurred another informative round of teamwork modeling theory within the general literature.

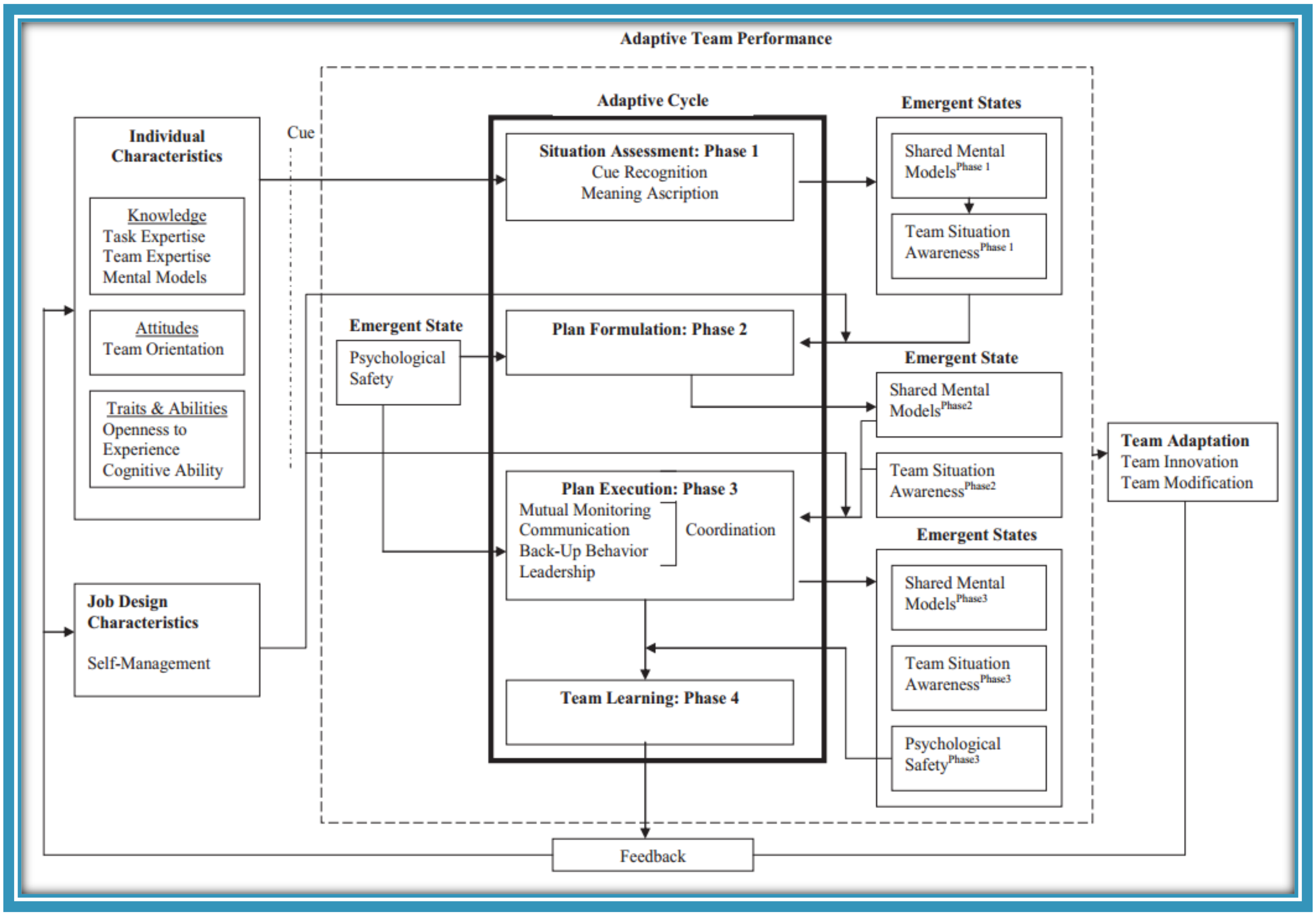

Figure 3: The Adaptive Team Performance Model

From these model structures and pursuant research applying the models to various contexts over the last decades, it appears that certain psychosocial factors are more important for some teams in certain contexts than they are for others teams; but how or why these factors morph over time and across contexts is not well enough understood to allow theorists to conceptually model them for particular contexts without more research specific to that context. For example, all of the four major theoretical approaches to team composition (e.g. person-role fit, additive ability, etc.) have merit, but which one is most useful for promoting performance depends upon the team's context, the duration of team performance required, and the time at which team performance is measured. In particular, the clarity of positions and where team structure is along the continuum of totally emergent to totally fixed appears to matter as much or more than individual team members' summative skills, abilities, or personality profiles (J. E. Mathieu, Tannenbaum, Donsbach, & Alliger, 2013). Given the likelihood of a totally fixed structure, position certain nature, duration of pre-mission training as a team, and extended duration of team performance requirements for LDSEM crews, none of the four major theoretical approaches to team composition appear likely to consistently work well in the LDSEM context.

On the flip side, teamwork modeling research does indicate that some psychosocial factors should be important for all teams, independent of or across contexts and cultures (J. Mathieu et al., 2008; Zhang &

Peterson, 2011). For example, an abundance of research indicates that social exchange quality, shared mental models/ team mental models, perceived organizational support for the team, teamwork knowledge and training as a team impact performance significantly and positively in most contexts. There is also some evidence of cyclical relationships applicable to many contexts. For example, success as a team increases cohesion and cohesion helps generate better team performance and team members' desire to keep working as a team.

Additionally, many operational and military teams consistently follow a multi-phasic "norming, storming, performing" evolution well enough to allow both researchers and management to use such evolutionary models to document and investigate team performance in real time or in the field (Beal, Cohen, Burke, & McLendon, 2003; Dyer, 1986; Grice & Katz, 2005; Hammerstrom, 2010; Marks, Mathieu, & Zaccaro, 2001; Morgan Jr et al., 1986; Salas, Bowers, & Cannon-Bowers, 1995). Morgan and colleagues (1986) offers the most comprehensive description of this team evolutionary path, in phases that at least conceptually parallel the phases that subject matter experts expect LDM crews to experience (Bishop, 2004; Fiedler & Carpenter, 2005; Flynn, 2005; Grether, 1962; Manzey, 2004; Sipes & Ark, 2005; Woolford, Mount, & Salvendy, 2006).

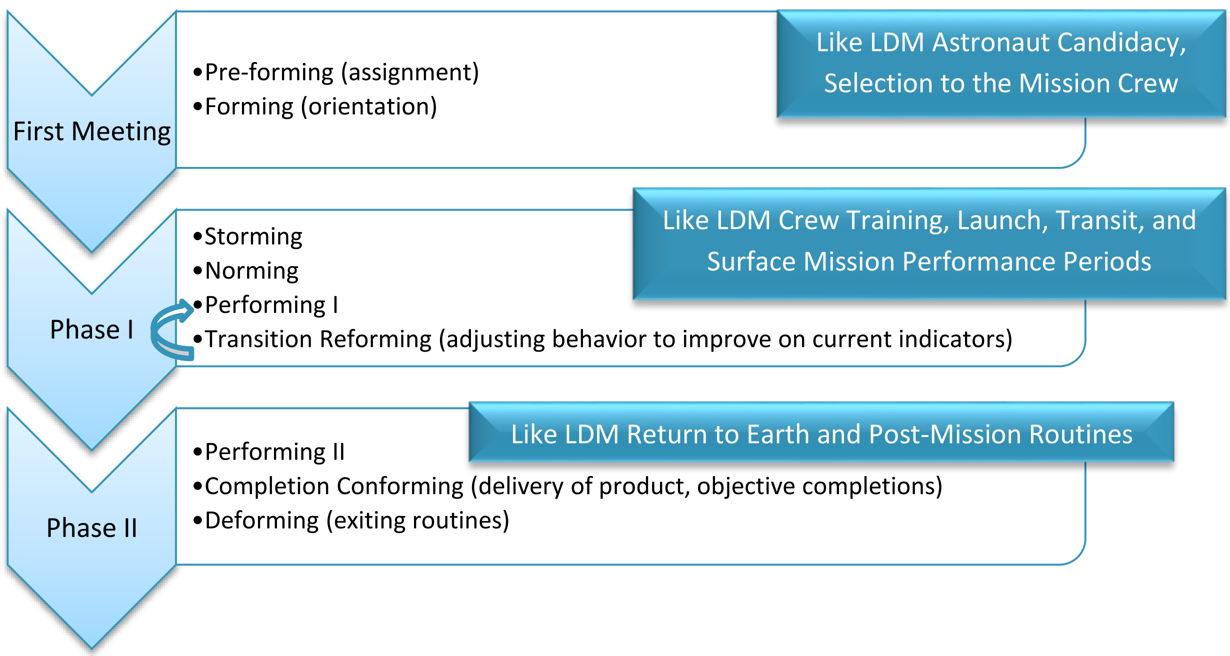

Figure 4: Morgan and Colleagues (1986) Team Evolutionary Path and LDM Parallels

The general literature on teamwork theory and modeling also offers holistic updates on the general state of team research and its broad readiness for application thanks to regular and systematic reviews provided across domains (Kozlowski & Ilgen, 2006; J. Mathieu et al., 2008; J. E. Mathieu et al., 2013; Resick, Dickson, Mitchelson, Allison, & Clark, 2010; Seibert, Wang, & Courtright, 2011). Kozlowski and Ilgen (2006) offer a table in their review (see Table 3), which with some modifications to include recent developments, serves as a useful summary and a solid theoretical start point for the development of this more contextually-specific and applied model of psychosocial factors for LDSEM.

Table 3: Team Processes and Emergent States Related to Team Effectiveness: Levers, Support, and Recommendations for Application

Process/ State	Levers	Support	Recommendations
***Team Cohesion**	• Not well specified • Shared Experience • Leadership	• Body of systematic theory and research • Meta-analytic findings	• Related to team effectiveness • Research antecedents • **Application ready**
***Team Efficacy and Group Potency**	• Training • Leadership • Mastery Experiences • Persuasion	• Body of systematic theory and research • Meta-analytic findings	• Related to team effectiveness • Research antecedents • **Application ready**
Team Conflict	• Interpersonal skills • Conflict Management skills • Trust	• Meta-analytic findings	• Research *how* impacts team performance and *factors that mitigate* conflict
Team Affect, Mood, Emotion	• Member similarity • Social contagion • Contextual influences	• Research and theory emerging	• Refine concepts • Integrate with research on *cohesion and conflict*
***Team Coordination, Cooperation, Communication**	• Design • Training • Leadership	• Body of systematic theory and research • Meta-analytic support for levers	• Refine levers • **Application ready**
***Team Member Competencies**	• Design • Training • Leadership	• Body of systematic theory and research • Meta-analytic support for levers	• Refine levers • **Application ready**
***Team Regulation, Adaptation**	• Design • Training • Leadership	• Body of systematic theory and research • Meta-analytic support for levers	• Refine levers • **Application ready**
***Team Climate**	• Strategic imperatives, goals • Leadership • Interpersonal interaction (social exchange) • Contextual influences	• Body of systematic theory, method, development, and research (including meta-analytic).	• **Application ready**
***Team Mental Models**	• Training • Leadership • Shared experience	• Body of systematic theory, method, development, and research (including meta-analytic).	• **Application ready**
Transactive Memory	• Familiarity • Face to face interaction • Shared experience • Digital aids	• Research and theory emerging	• Research to refine construct, assessment techniques, and antecedents

Note: This table is adapted from another publication (Kozlowski & Ilgen, 2006). "" Denotes the construct is application ready (meaning some research has already been done on applications with practical success).*

Based on these existing models and research reviews, a list of factors likely to be important within the LDM context and over time was drafted to help guide and document modeling decisions made for this project. The list of probably factors was used to ensure that all constructs known to be relevant to team performance were reviewed within the literature in the space-flight and associated analog domains. During the course of reading and re-reading articles collected from these domains, the list of probable factors was further amended and refined as described in the following section.

Probable Factors

Prior to calculating and visualizing the model, the following list of probable factors and their associated levels of measurement were initially gleaned from the literature during the first full read through of each article. In the interest of parsimony, the first listing tried to lump factors described in similar words into one combined factor whenever logically possible.

Table 4: Initial List of Probable Factors

	Initial Factor	Most Common Level of Measurement
1	Adaptation/ Regulation (including error management/ correction)	Group
2	Affect/ Mood/ Emotion	Individual, Group, Situational
3	Autonomy	Individual
4	Cohesion	Group
5	Command/ Hierarchy/ Matrix	Individual, Group, Situational
6	Commitment	Individual
7	Communication	Group
8	Communication Modality	Situational
9	Competition	Situational
10	Composition	Group
11	Conflict	Situational
12	Context/ Event/ Time (e.g. ICE, 3rd Quarter)	Situational
13	Cooperation	Group
14	Coordination	Situational
15	Confinement	Situational
16	Deep-level diversity (values, skills, tenure, etc.)	Group
17	Empowerment/ Sense of Control	Group
18	Environmental Uncertainty/ Danger/ Risk/ Threat conditions	Situational
19	Feedback (Availability, Frequency, Quality)	Group, Situational
20	Group Potency	Group
21	Inherent Stress/ Fatigue	Individual
22	Interdependence	Group, Situational
23	Isolation	Situational
24	Leader-member exchange	Individual
25	Leadership Style/ Model/ Process	Individual, Situational
26	Personality (including both profile types and factors like OCEAN)	Individual, Group
27	Profession/ Occupation/ Calling	Group, Individual

	Initial Factor	Most Common Level of Measurement
28	Proximity/ Physical Distance Between Team Members/ Virtual	Group
29	Resilience/ Grit/ Personal Growth (including salutogenesis)	Individual
30	Resource-Demand Balance	Group, Situational
31	Risk Tolerance	Individual
32	Role and Role Clarity	Individual
33	Self-Care/ Self-Management/ Self-Monitoring and Regulation	Individual
34	Self-Efficacy	Individual
35	Shared Mental Models	Group
36	Social Support	Group
37	Stress/ Stressors	Individual, Group
38	Surface-level diversity (race, gender, age)	Group
39	Task Type/ Task Characteristics	Situational
40	Team Climate/ Perceived Organizational Support	Group
41	Team Culture/ Collectivism	Group
42	Team Efficacy	Group
43	Team Self-Monitoring Process	Group
44	Team-member exchange	Group
45	Teamwork Knowledge/ Skill/ Competency Training	Individual
46	Technical Proficiency/ Operational Competency	Individual, Group
47	Token Status	Individual, Group
48	Trained as a Team	Group
49	Transactive Memory/ Knowledge Management	Group, Individual
50	Trust	Individual
51	Work-Life Balance	Individual
52	Workload	Group, Individual

These factors were most frequently mentioned and studied across all relevant literature; and were therefore specifically considered for inclusion in the model through the second and third complete readings of each article. However, this initial listing was modified and further condensed into a final listing as the articles were fully read and re-read, and more was learned about the historical naming trends associated with different factors (e.g. grit became toughness and then resilience and then resilience and grit both gained popular as terms describing the same concept over time in the academic and research literature). Some factors were reconsidered and renamed to better encapsulate concepts that were too closely related in the available body of evidence to justify naming them separately (e.g. interdependence was not really different from commitment to the team in a practical sense despite being at different levels of measurement theoretically as both were consistently measured at the individual level). Some factors, although heavily mentioned in qualitative literature were not specifically measured or quantified in any of the available evidence (e.g. competition, work-life balance) or not significant in quantitative terms in any of the evidence (e.g. isolation, confinement), and thus were not included in the final listing of probable factors used to build the modeling database. The final (second) listing of probable factors left 41 factors to pursue during the modeling phases of this project.

Table 5: Final (Second) List of Probable Factors

#	Final Factor	Other Related Concepts/Terms in Literature subsumed in this Factor	Common Level of Measurement
1	Affect	Mood, Emotion, Attitude	Individual, Group, Situational
2	Autonomy	Independence, Collective Autonomy, Sense of Control, Empowerment	Individual, Group
3	Cohesion		Group
4	Collectivism	Collective process of working together as a team over individual independence, Team's value of collectivist culture	Group
5	Commitment	Interdependence, co-dependence, attraction, wanting to stay a part of the team	Individual
6	Communication	Information exchange process within team	Group
7	Communication Modality	Includes written, visual, audial, etc.	Situational
8	Composition	Size, Fit, Average or aggregate of personalities, abilities, values, or tenures on a team	Group
9	Conflict	Task Conflict, Role Conflict, Relationship Conflict	Situational
10	Context	Event, Time, Duration, Quarter, Half	Situational
11	Cooperation	Boundary Work (spanning, buffering, reinforcing)	Group
12	Coordination	Briefing, Planning, Goal Specification Process	Situational
13	Deep-level Diversity or Similarity	Invisible differences or variances within the team (e.g. values, skills, tenure, etc.), Heterogeneity, Homogeneity	Group
14	Feedback	Debriefing, After Action Reviews (Includes Availability, Frequency, Quality)	Group, Situational
15	Health	Resilience, Grit, Personal growth, Salutogenic effects, Well-being, Satisfaction, Organizational Citizenship Behaviors	Individual
16	Leader-member exchange	Leader support, Leader helping behaviors, Leadership quality	Individual
17	Leadership Style	Model and Type of Leadership, Transformational, Transactional	Situational
18	Learning	Team adaptation, Regulation, Self-correcting teams, Error management, Error Correction, Error mediation	Group
19	Personality	Personality factors, Individual personality profiles	Individual
20	Purpose	Goal of team's existence, Initiating structure/ reason	Situational
21	Role	Role Clarity	Situational
22	Self-Care	Self-Management, Self-Monitoring and Self-Regulation	Individual
23	Self-Efficacy	Confidence	Individual
24	Shared Mental Models	Includes both similarity and accuracy of share mental models	Group
25	Social Support	Including emotional, informational, instrumental, and appraisal	Group
26	Stress	Includes emotional experiences (e.g. grief, tension), and perceived physical (e.g. time pressure, fatigue) stressors and	Individual, Group

#	Final Factor	Other Related Concepts/Terms in Literature subsumed in this Factor	Common Level of Measurement
		behaviors (e.g. turnover, select selection out), negative health symptoms (e.g. PTSD)	
27	Subjective Team Performance	Perceived performance (includes rating, grades)	Aggregate
28	Surface-level Diversity	Visible differences or variances within the team (e.g. race, gender), Heterogeneity	Group
29	Team Performance	Objective only (includes number of goal/ objective accomplishments, desired behavior counts/ frequencies, productivity measures)	Aggregate
30	Task Type	Task purpose, Task characteristics (e.g. Technical tasks, Creative tasks, etc.), Automation level	Situational
31	Team Climate	Team Culture, Perceived Organizational Support for the Team, Psychological Safety within team, Organizational Justice through team	Group
32	Team Efficacy	Team potency, Team effectiveness	Group
33	Team Self-Monitoring Process	Team goal monitoring	Group
34	Team-member exchange	TMX (infers quality of exchanges within team rather than process), Team resource sharing	Group
35	Teamwork Knowledge	Teamwork skill, Teamwork competency	Individual
36	Technical Proficiency	Operational competency, Technical skill	Individual, Group
37	Token Status	Includes position singularities like leader and odd-man out singularities	Individual, Group
38	Trained as a Team	Experience as a team/ working together as a team	Group
39	Transactive Memory	Working memory, shared memory, team task knowledge	Group, Individual
40	Trust	Willingness to collaborate	Individual
41	Workload	Work quantity, Job demands (includes objective and perceived)	Group, Individual

Modeling Methodology

A total of 94 articles (both category one and three) provided quantitative evidence, while 111 offered qualitative evidence or rational for modeling decisions and structure. The first step to generating a visual model that made full use of all of these articles was to create a database. The database was built in Microsoft Excel (2013) as to facilitate easy review by the broadest number of future users and the most potential exportability to the widest variety of statistical and processing software across academic and research domains (e.g. the data can be exported to SPSS, STATA, etc.). Similarly, Microsoft PowerPoint (2013) was used to draw the model visual using the information articulated in the database.

The following sections will generally describe the process for creating the modeling database and the model visual. More specific/ step-by-step instructions for editing or adding more evidence to the database and model were provided to the Behavioral Health and Performance Research Element as an appendix to this report and provided under separate cover to accommodate screen captures without burdening the length of this report.

The Modeling Database

As each qualitative article informs the model only once as a whole entity, while each quantitative article included may inform more than one factor or relationship within the model, it was logistically necessary to create two spreadsheets within the Microsoft Excel workbook to 1) track all articles as a whole contributor and 2) track the individual contributions and decisions made regarding multiple relationships from the same article. Thus the workbook (or database) consist of two spreadsheets: one detailing all references and what each reference is about (e.g. abstract, population, sample, estimated similarity to LDSEM context and populations, etc.) and a second listing all the instances of data considered from quantitative articles only and documenting how that information was used to create specific aspect of the visual model (e.g. the formulas for weighting relationships between factors, etc.). In finalizing the database, four additional tabs were created in the workbook. A front page or cover tab was created to warn future users that the database is associated with this report and there are resources available for learning how to use it. Three tabs other tabs were inserted after the two data spreadsheets to help database users remember the initial context and assumptions of this project as it was completed on April 16, 2015. The first of these three tabs is a copy of the final listing of probably factors along with an additional column noting the layer of the model were these factors were housed in the model visual. The second of these three tabs in a picture of the model visual as it existed on April 16, 2015, and the third is a broader and simplified picture of the model (e.g. with all individual linkages between factors removed) to give an overview perspective. The pictures captured in these last two tabs were also included in the next section of this report.

Procedure for Building the Database

Please remember, this is only a brief description of the rationale for how the database was constructed to support the visualization of a model of psychosocial factors for LSEM teamwork. Step by step instructions for adding new studies to the database and adjusting the model visual may be found in the appendix to this report (provided under separate cover to the Behavioral Health and Performance Research Element).

Sorting and Entering the Data into the First Spreadsheet

The first spreadsheet documenting all references was designed to capture both the essence and point of each study as well as enough details about the study to help determine its relevance to a model of psychosocial factors for LDSEM teams specifically. As such, the citation and abstract for each study was first entered into the first two columns of the spreadsheet and a reference identification number was assigned to the study based on that first order of entry (e.g. the first study entered was given a reference ID of 1) after the first reading. Information about each study's population of interest, sample, context (e.g. lab study, field study, office study, simulation, etc.) and duration (e.g. 1 day survey study, review of 10 years, 30 day simulation, etc.) was also recorded in the spreadsheet during the first read through of every article. After the first reading it became apparent that some (20) articles were not relevant to teamwork in any way and these were deleted from the spreadsheet before doing the second read-through of each study. As studies were re-read, the variables and outcomes with significant correlations or effect sizes were listed by name and the size of each correlation or effect was recorded in subsequent columns. The statistical approach, testing statistics and significance was also recorded. At this point in the data entry, it became obvious that another 19 articles did not offer theoretically or practically significant and relevant information about teams or psychosocial factors related to teamwork. These studies were deleted from the spreadsheet (but copies of the articles were maintained on compact disc and within an Endnote library provided along with this report to the Behavioral Health and Performance Research Element).

Finally, each entry in the database was reviewed for accuracy. Some studies were re-classified as category two studies (as no data recorded was quantitatively significant upon closer reading).

Recording Significant and Relevant Correlations/ Effects

While the details of the hypothesis testing statistics and their significance overall were recorded for each quantitative study in the spreadsheet, it was not always the relationships tested by the hypotheses that explained relationship between psychosocial factors within a study. Some studies incidentally noted correlations among psychosocial factors associate with teamwork (e.g. the study was actually designed to test physiological responses to emotional distress, but also measured and documented a correlation between commitment to the team and emotional distress over time). So if the correlations documented in a study were logistically relevant to teamwork and significant at a p-value equal to 0.01, then all such correlations were recorded in the first spreadsheet. Correlations and effect sizes also offered the easiest way to consistently quantify and documenting studies offering data from a variety of methods. Effect sizes from a meta-analysis are on the same scale and frequently reported as correlations and other studies usually report correlations as part of their descriptive statistic regardless of the statistical methodology used to test the hypotheses.

Once categories were sufficiently established for each study and all other data was present in the database for those classified as quantitatively valuable somehow (e.g. category one or three), then two estimates were made for each study regarding their similarity to LDSEM populations and contexts.

Determining Similarity

Both similarity estimates were judgments recorded on a percentage scale of zero to 100 (e.g. 90% similar to LDSEM populations/ astronauts). These judgments were necessary to help quantify the value of the studies even more closely within categories such that a category three study presenting data on International Space Station astronauts over six months of spaceflight could be numerically deemed more valuable than a category three study presenting data on United States Navy submariners over one week of voyage. The following table documents the anchors used to guide these similarity judgments within the database so that they may be repeatedly used consistently (or modified in total and re-applied to comprise an improved database).

Table 6: LDSEM Population and Context Similarity Anchors

Percent Similarity	Population and Context Similarity Anchors
0-10%	-Undergraduate student populations -In a general lab or class-based study involving teams or teamwork skills
11-20%	-Undergraduate students populations selected because of some similarity to astronauts (e.g. engineering majors with aerospace project experience) -In a lab or field study constructed to resemble some psychological aspect of space-flight or long-duration missions
21-30%	-Graduate student populations selected because of some similarity to astronauts -In a lab or field study constructed to mimic multiple psychological aspects of space-flight or long-duration missions
31-40%	-Adult populations screened to meet minimum basic astronaut standards (e.g. bed rest study participants) -In a low-fidelity long-duration analog that mimics at least one physical and one psychological aspect of spaceflight (e.g. head-down bed rest)
41-50%	-Adult populations screened to be of similar age, experience, education, personality, intelligence, etc. -In a medium-fidelity shorter-duration analog that mimics multiple aspects of spaceflight (e.g. week-long centrifuge training, week-long HERA)
51-60%	-Working adult populations (e.g. electricians, foremen, paramedics) -In a medium fidelity longer-duration analog that mimics multiple aspect of spaceflight (e.g. a two week trek in Antarctica, a year-long deployment to a field hospital in the middle east).
61-70%	-Working adult populations of similar age, experience, education, etc. (e.g. managers, executives) -In an operating context with multiple psychosocial aspects similar to long-duration spaceflight missions (e.g. working with a multi-cultural team to plan a long-term project for spaceflight or to control a robotic mission to space).
71-80%	-Professional populations consider comparable to astronauts in at least one fundamental way (e.g. pilots, engineers, scientists, physician, military officers) doing similar tasks or completing similar objectives -In parallel operating contexts or contexts of parallel complexity (but not living continuously in that context or living in large teams) (e.g. Trauma Surgery Units, Fire Stations, Coastguard Cutters, oil rigs, McMurdo station in summer).
81-90%	-Professional populations selected because of similarity to astronauts in multiple ways (e.g. pilots, engineers, physicians, military officers) doing similar missions in small teams -In parallel mid to short duration living and working contexts (e.g. aircraft carriers, submarines, oil rigs, summer over Antarctic stations) or official space agency analogs or missions of shorter duration (e.g. Desert RATS, Haughton Mars, HERA 30 days, NEEMO, Space Shuttle Missions, etc.).
91-100%	-Senior Flight Controllers, Station Training Leads, Flight Directors, Flight Surgeons, Astronaut Stand-Ins, Astronaut Candidates, Astronauts, Former Astronauts in small teams -In official BHP, NASA, or other space agency long-duration ICE analogs (e.g. MARS 500, winter-over Antarctic stations); long duration space missions (e.g. Skylab, ISS, MIR).

After both similarity estimates were recorded for each of the 205 studies in this first spreadsheet, then the correlations/ effects recorded for each study were reviewed on final time before transferring the quantitative data into a new/ second spreadsheet for further processing.

Transferring Quantitative Information from All References into the Quantitative Spreadsheet

At this point the reference identification number and citation for each quantitative study was copied and pasted into the two leftmost columns of the new quantitative spreadsheet once for each time that the study reported a significant association between two factors. Some information was also duplicated along with each entry to facilitate the weighting of the data, such as the similarity estimates and the evidence category.

Model Weight Calculation

Once a row was created in the quantitative spreadsheet for each association between two factors (and the relevant information about similarity was duplicated), then the correlation reported for that association was also copied into that row and then multiplied by 100 to put it into the same scale as the similarity estimates (in percentages). This converted correlation is recorded in an adjacent cell (column "*j*" on that row) (e.g. a 0.30 correlation becomes converted to 30.00).

The next two columns in each row contain levers specific to that study, one is that study's literature review classification (e.g. a 1 or a 3 for quantitative studies) and the second is a lever categorizing the sample size used to obtain the correlation from that study. Sample size in simply categorized 1, 2, or 3 such that 1 represents correlations supported by samples of 100 or less, 2 represents samples of 101 up to 200 and 3 represents samples of more than 200 or a meta-analysis effect size. These two levers (labeled "*k*" for evidence category class and "*L*" for sample class) are used to help estimate the weight of each association for modeling as summarized in the formula:

$$\text{Model Weight} = ((g*h)*j)*k*L$$

The two similarity estimates (percent similar to LDSEM populations and percent similar to LDSEM contexts as duplicated in columns "*g*" and "*h*" respectively) are first multiplied together, and then the product of "*g*" and "*h*" is multiplied by the converted correlation represented as "*j*" (in the formula in and the "*j*" column of the spreadsheet). This product is then multiplied separately, first by the evidence class (*k*) and finally by the sample class (*L*) to form the model weight.

Combining Weights

The ultimate goal of the database is to document the inductive process by which quantitative data was transformed into a visual conceptualization of the model in a repeatable manner. Some subjective judgments had to be made about what weights could reasonably be combined. These judgments were made based on the following stream of logic (in the order of presentation): 1) the weights speak to the same outcome variable, and 2) the weights speak to the same or similar input variables. Once all data was entered into the quantitative spreadsheet then it was sorted according to these criteria and judgments were made regarding which weights could be inductively justified. To help future users understand what factors were considered qualitative relevant two columns were added to the quantitative spreadsheet. One column was used to record (in consistent verbiage and based on the final listing of probable factors) the single probable factor name for the input variable and the other column recorded the single probably factor name for the output variable. The spreadsheet was then sorted a second time according first to the single output factor name and second to the single input factor name. Next the weights were each examined and colored based on the positivity of the relationship between factors such that beneficial relationships weights were colored in green font, neutral or of uncertain benefit in black, and detrimental relationships in red. For example, as a positive correlation (and hence weight) for autonomy and health indicates that more autonomy benefits better health this weight was colored in green font (as well as represented by positive weight).

Finally, a box was drawn around all of the weights associated with the same outcome factor and similar input factors and then these weights were additively combined (e.g. 1+2=3) and recorded in a new cell labeled combined weight. Of the 167 weights calculated corresponding to each row, 46 stood independently and could not be combined. The other 121 weights were able to be combined into 32 weights, leaving a total of 58 weights to use in draft the visual model of the psychosocial factors currently relatable to LDSEMs. The next section describes the logic and methodology for drawing the model using these weights.

The Visual Model/ Infographic

A neural network conceptualization within an IPO frameworks was chosen as the most logical means of representing a model with 4 potential layers of 41 factors commonly measured at multiple levels of measurement. A neural network is a system composed of processing layers operating in parallel whose function is determined by network structure, connection strengths, and the processing performed at individual nodes. Neural networks were inspired by the architecture of biological nervous systems, which use many simple processing elements operating in parallel, and have been successfully used to describe human cognition and social processes in multiple academic domains. Neural networks are usually diagrammed according to parameters in a trained neural network model based on actual data allowing the trained neural network to maintain only those relationships that matter significantly enough to the outcome to form a traceable and dependable path (see Figure 5), which often helps describe a parsimonious model without sacrificing any necessary and practical complexity.

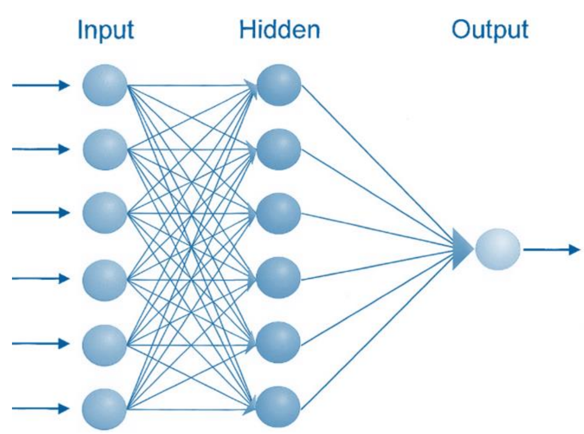

Figure 5: The Traditional Neural Network Conceptualization

The concept of a "neural network" style visualization or infographic was chosen to help conceptualize this model of psychosocial factors for three reasons: 1) it nicely parallels the nomological net approach that the American Psychological Association advocates for driving decisions about research priorities and applications, 2) it is easy to conceptually wed a neural network with the already popular input-process-output framework popular in team research in general, and 3) a neural network structure to the infographic may allow future investigators to more easily validate the model against a trained neural network model as soon as sufficient data becomes available within the LDSEM context. The following table describes the common components of neural networks and summarize the features that were leveraged in this conceptualization, along with some examples.

Table 7: Key Components and Features of a Neural Network Conceptualizatioon

Component	• Features	***Examples***
Layers = Conceptual Domains *(Universes)*	• Concepts within a domain are measured at the same level • Helps define scale and complexity	Input Layer Hidden Layer Process Layer Output Layer
Blocks = Common Clusters *(Galaxies)*	• Set of nodes within a layer indicate factors usually co-exist	Emergent States Block within the Hidden Layer
Nodes/ Neurons = Constructs/Factors *(Planets)*	• Common color indicates common level of measurement • Individual node demonstrates a discernable factor or variable	Trust Node within the Hidden Emergent State Block
Lines = Relationship paths/ functions/ laws *(Orbits)*	• Thickness indicates strength of relationship • Direction indicates causation or implied causation • Color indicates polarity	Line linking Trust Node to the Cohesion Node

Procedure for Building the Model Visual

This is only a brief description of how information from the database was used to conceptualize the data and build the model visual. Step by step instructions for adding new studies to the database and adjusting the model visual may be found in an appendix to this report (provided under separate cover to the Behavioral Health and Performance Research Element).

Drawing the Model

A picture of the model as it existed on April 16th, 2015 is included in this report (see Figure 6). The model visual was drawn using standard shapes and connection lines within the software, in order to make it practical and easy for others to change or update the visual as needed. The model's layers were first created using color gradient settings in the slide background. Four color gradients were set to define four layers (i.e. Input, Hidden, Process, and Output). The gray blocks representing factor clusters were then created using the standard text box drawing tools before each factor was created using the same tool in a white fill with a color outline representing its most common level of measurement (e.g.

green outlines represent factors measured most commonly at a situational or individual characteristic level, yellow outlines represent factors most commonly measured at a grouped level of measurement, blues outline factors most commonly measured over a series or process of measures or behaviors and objectives, while gray outlines indicate factors that are commonly measured at mixed levels). Factors were sorted into the appropriate layers and clusters according to decisions made during the review of data for entry into the database. Finally, links between factors were drawn using the line tool according to weights determined in the database such that each one unit of weight corresponded to 0.05 font point thickness for the line (e.g. a weight of 16 would result in a 0.80 point thick line for that relationship between factors). Consequentially, lines were not drawn for any weights of less than one quarter of one unit (i.e. 0.25 weights) in the model (as they would be in 0.01 point font or less and too small to easily see).

Lines were drawn in one of three colors to represent the positivity (e.g. good influence) of the relationship between factors, so that red lines represents a more negative relationship, black lines indicate a more neutral or undeterminable relationship, and green lines indicate a positive or beneficial relationship between factors (e.g. more trust is largely associated with better quality leader-member exchange within the evidence base considered here).

The Model Visual/ Infographic of Psychosocial Factors

Please note that the model as picture here (see Figure 6) is a static picture only. It is easier to see and examine specific parts of the model by using the zoom features in the Microsoft PowerPoint file where this picture was originally drawn.

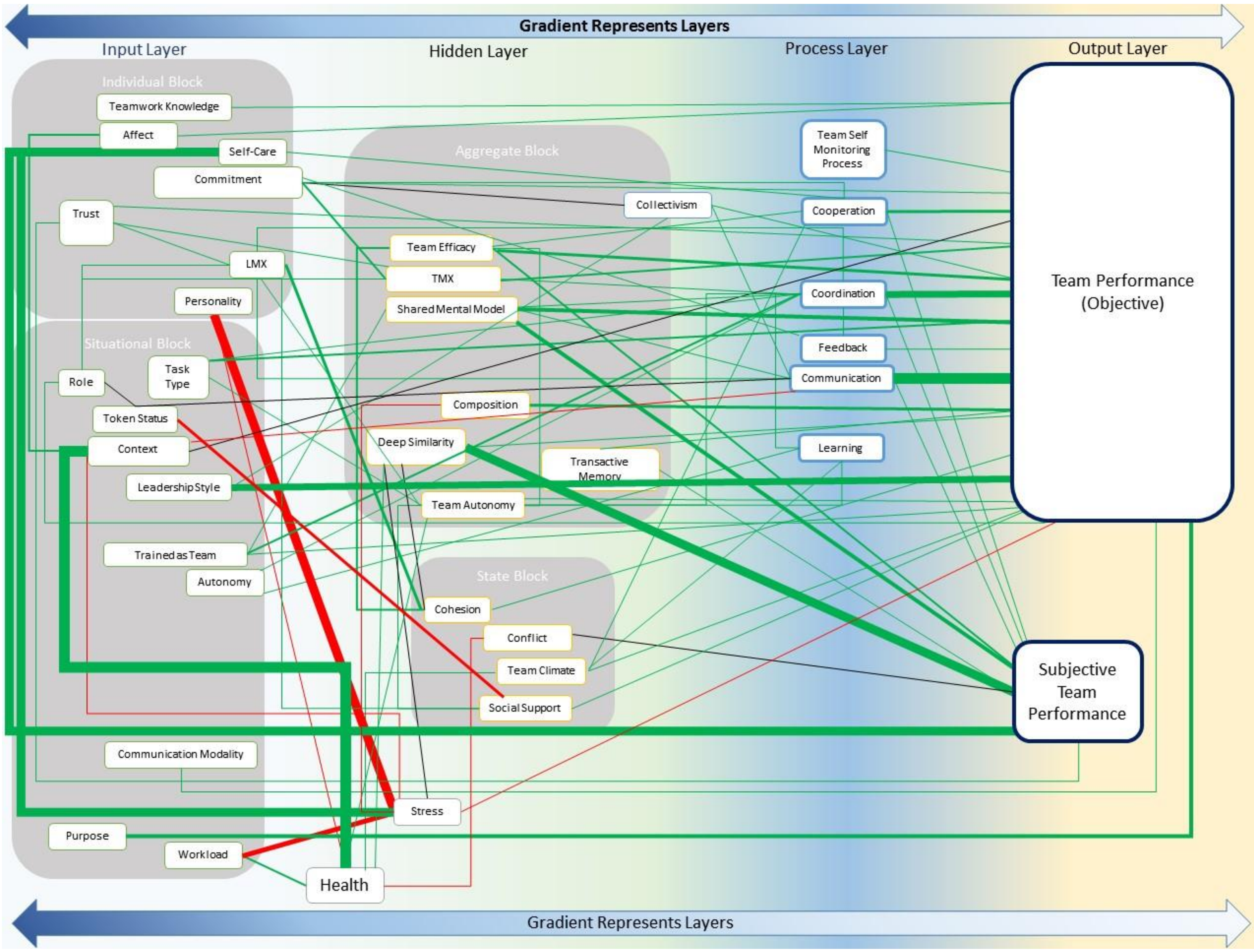

Figure 6: The Psychosocial Factors Model Visual/ Infographic

Model Description

There are 38 factors influencing team performance (the 39th factor) within the IPO framework of this model. There are also two blocks of factors within the input layer of the model (i.e. an individual block and a situational block) and two blocks of factors within the hidden layer of the model (i.e. a block of aggregate-type factors and a block of state-type factors). The situational block contains the greatest number (i.e. ten) of those 38 factors; while the states block contains the least number of factors (i.e. four). Two (2) of the 41 probable factors, surface-level diversity and technical proficiency, were not included in the final model even though there is some limited quantitative data to support their likely importance because it is still unclear if they are truly as relevant as other factors already well weighted within the list like deep-level similarity.

One thing to note, is that many of the factors in the team process layer are often treated as outcomes of interest in many contexts (e.g. military cohesion studies, studies when performance is not objectively measured); but this model assumes that while such processes may at times actually be desirable outcomes, they are not the ultimate outcomes of interest. Similarly, in other contexts or models of team performance, these factors have different relationships to performance (e.g. some models posit that the process of communication causes the state of conflict within the team); but these factors are modeled as they are here because the limited evidence available indicates that is how they apply to the long duration space-flight exploration mission context.

Conclusions

Four General Insights from All of the Evidence

The second and third read through of each article prompted the realization of four general insights. These insights were gleaned from a holistic mental processing across all categories of evidence (as was necessary to conceptualize the model).

1. Something similar to Maslow's hierarchy of needs appears to come into play in ICE and long-duration analogs (Harrison, 2005; Hellman, Witt, & Hilton, 1993; Kanas, 1998; Koscheyev, Roschina, & Makhov, 1994; Pleban, Valentine, & Thompson, 1987; Ramthun, 2014; Suedfeld, Brcic, Johnson, & Gushin, 2012; Suedfeld, Legkaia, & Brcic, 2010; Tafforin, 2013; Wood et al., 2005). . . basic needs are very salient (e.g. food and sleep) and drive daily moods, processes associated with socialization and esteem (such as communication and leadership) drive morale, and when mood and morale are satisfied then team members engage in more self-reflection and self-actualization of the team (and appear more willing to invest in bonding as team). Analog participants and astronauts both report experiencing salutogenic effects (even when basic needs are challenged) whenever more time working together has forged stronger team bonds. The highly motivated personalities typically involved in space flight and associated analogs also report strong desires to "not let the team down," as well as a reverence for the mission and the general purpose of exploration (Palinkas, 2003; Paton, 2006; Pattyn et al., 2009; Suedfeld, 2005; Thirsk, Williams, & Anvari, 2007). When enough individuals of a team report losing sight of the purpose of the mission or feel the team is not cooperating well, then mood and morale ebb enough to undermine performance (but not necessarily enough to lead to an objective performance error).

2. Such ebbs in mood, morale, and performance should probably be expected during the storming and reforming stages of phase I in the evolution of most teams. Ebbs in mood, morale and performance during the later stages of the second phase of the evolution of analog teams generally seems to drive down subjective team performance and leaves team members less willing to repeat the experience or work with other team members again in the future. If acute or excessive stressors or disasters do impact team performance, then it is most likely through a narrowing of team members' focus that in turns leads to missing social and teamwork cues important to maintain the processes (e.g. coordination) that are directly related to team performance (James E Driskell, Salas, & Johnston, 1999).

3. Being able to do meaningful work matters, as does constructive leadership in terms of bolstering team moral and performance in most conditions. In fact, leadership quality is significantly related to

cohesion within the team and may influence team performance in LDSEM context mostly through cohesion (even if it does not directly influence performance as it goes in most team contexts).

4. The third quarter effect is sometimes observed and sometimes not, and if it exists, then it is unclear what causes it to show for some teams and not others in the same contexts.

And Three Key Observations

Drawing the model and further processing led to three key observations. One critical aspect that the quantitative evidence does not sufficiently address is the evolutionary cycle of teamwork. Research does not tell us which factors, clusters, or layers are likely to be best leveraged at what points along the evolutionary paths of teams. Thus there is no easy way to understand how this model might relate or be visualized in respect to the evolutionary path that seems to best suit LDSEMs (see Figure 4).

Second, some psychosocial factors that were theoretically proposed to be significant are not or at least are not really very likely to impact either teams similar to astronaut teams or teams over time. Specifically, given the long-duration nature of space-flight exploration missions and the strength of the space-faring culture, there is generally enough time and motivation for these teams to learn and successfully adapt to both surface-level (e.g. gender, race) deep-level (e.g. value, experience) diversity prior to the mission− so long as team are afforded the opportunity to train together. However, if teams are not afforded the opportunity to train together before flight (as is largely the case with current International Space Station crews), then mission operations should expect that most teams will need the first three to six weeks in flight to adapt through deep-level diversity issues (and the pre-forming and forming stages of a team evolutionary path).

Third, other psychosocial factors that were theoretically proposed to be significant (e.g. stress, health, self-care, workload, token-status, personality) are significant but through such indirect associations as to be of practically little value for influencing teams in this very specific context in the immediate future. For example, excluding team members with personality disorders, an individual's personality type is not likely so informative as the mix of personality types within a team; and even the mix of personality types is difficult to manipulate given the greater influence of more direct factors (e.g. training as a team) and operating requirements (e.g. technical roles) related to team performance. Likewise, workload is another factor that looks differently than expected. Qualitative data suggests that astronauts expect and prefer a fairly heavy workload and report feeling happier and healthier when kept busy. The limited quantitative data supports this interpretation of workload being best when balanced on the busy side, so long as it allows the team adequate time to engage in coordination processes and team-members some time to co-recreate. However, when a heavy workload is imposed upon the whole team, then the quantitative evidence reviewed here shows that Post-Traumatic Stress Disorder symptoms are highly likely to result (even if they are directly related to team performance in return).

A Simpler View of the Model

In the interest of increasing the utility of this conceptualization, the very simplistic view of the model presented here may also be used (see Figure 7). This simple view grossly assumes that the more complex neural net conceptualization can be summarized back into the IPO framework with an ultimate overall directionality toward team performance. The hidden emergent states influencing team processes can be envisioned as a doorway leading from inputs, and inputs and processes should still be considered as having the ability to both directly and indirectly influence output/ performance.

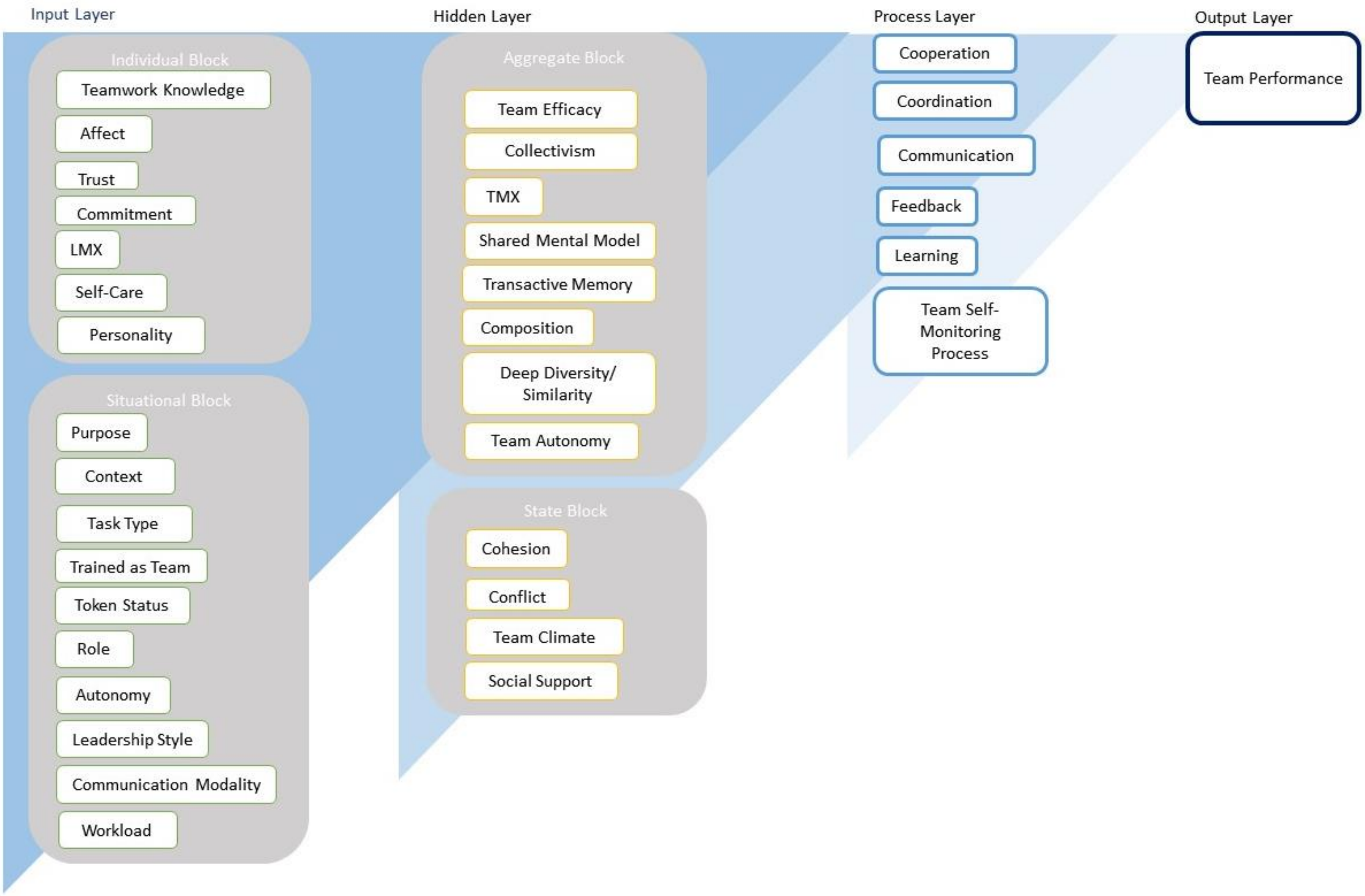

Figure 7: Simpler View of Psychosocial Factors Model for LDSEM Teams

It should be noted that health and stress factors are not included in this simpler view, despite both their relationships to other factors in the model and their importance for psychosocial adaptation. The reason for this is not sufficient quantitative evidence to link health and stress to team performance yet. Relationship lines in general were left out as a whole for this view, but any user of the model could forge a view to fit various purposes. For instance, stricter thresholds for including factors could be set to achieve even greater simplicity by eliminating any factors that do not directly link to team performance at least twice (e.g. from two different studies) in the evidence. Likewise, any user could choose to focus on a simplified sub-views of the model to suit various purposes (e.g. only the process and output layer, or excluding the situational block and the state block).

Recommendations

For Current Operations

First, there is ample evidence to support spending resources on training teams as a team as much as possible to support optimal team performance (Beaubien, Baker, & Holtzman, 2003; Bowers, Weaver, Urban, & Morgan Jr, 1997; Chen, Thomas, & Wallace, 2005; Hixson, 2014; Noe, Dachner, Saxton, Keeton, & EASI, 2011).

Second, training and countermeasures that improve the building of shared mental models and team processes (e.g. cooperation, coordination, communication, and feedback) are likely to give the greatest return on investment in terms of optimized team performance (Beaubien et al., 2003; Chen et al., 2005; Eddy, Tannenbaum, & Mathieu, 2013; Hammerstrom, 2010; Smith-Jentsch, Mathieu, & Kraiger, 2005); and based on the current state of knowledge, optimized performance might be the best way to promote health and reduce the team's risk of poor psychosocial adaptation for the immediate future.

Third, some design aspects (such as autonomy and communication modality) are both positively and negatively related to team performance quantitatively, but (based on a closer reading of all the supporting literature) these sorts of high-performance, well purposed teams (like astronauts) will (and are accustomed to) adapt to make best use of the teamwork as it operationally exists (Collins, 2003; Cowings et al., 2007; DeRue & Morgeson, 2007; James E. Driskell, Radtke, & Salas, 2003; Musson, Sandal, & Helmreich, 2004; O'Shea, Goodwin, Driskell, Salas, & Ardison, 2009; Pauli & Clapper, 1967; Pleban et al., 1987; Ramthun, 2014; Ritsher, Ihle, & Kanas, 2005; Suedfeld, 2005). In other words, it is likely that teams care about learning to work better with the level of autonomy and communication modality that are already available, and thus these design aspects may be of little practical concern to them. Behavioral health specialists may not need to ask about these aspects unless first mentioned by team members, and team instructors may need to spend more time helping the team strategize work-arounds to design limitations and system failures (e.g. if this communication modality fails, how can we use the remaining ones to keep up our coordination processes?)(Endler, 2004).

For Current Research Efforts

Strangely enough, the evidence suggests that longer duration mission are psychosocially better than shorter duration missions and that teams generally perform better (probably due to more practice opportunities) when given more time to perform (Stuster, Bachelard, & Suedfeld, 2000). This suggest that current research should strive to study teams for longer durations to in order to avoid making a mountain out a team's emotional mole hills. In the qualitative literature, expeditioners and astronauts frequently mention the ease of putting up with just about anything for two to six weeks (e.g. the team isn't adapting just ignoring); so study durations of less than six weeks are not as likely to allow investigators to see a good representation of a LDSEM team's evolutionary path or even full use of the teamwork processes we already have evidence to believe should be important to LDSEM team performance.

Traditional and cognitive team-level task analyses could be applied to all existing long-duration space flight teams, multi-team systems and analogs in order to help define temporal rhythms and influences associated with this context. Regardless, team-level task analyses would provide crucial data about which team members must do what when in order to support which team processes and achieve performance objectives that could be used to inform research into which training manipulations, countermeasures, and teamwork aids are most likely to support LDSEM teamwork specifically.

For Future Research Efforts

This is where the model is most beneficial—but research authorities will have to make a guiding decision about whether to promote a shore-up-the-knowledge-gaps approach or a leverage-the-knowledge-strengths approach to driving performance and minimizing risks. This will make it clearer for researchers where to spend limited time and resources. If the priority is on shoring up the knowledge gaps, then it is a matter of investigating the impact of negative (red lines) and/ or faint (less saturated lines) relationships in the model. If the priority in in leveraging knowledge strengths, then it is a matter of innovating and testing countermeasures and tools related to the positive (green lines) and/ or apparent (more saturated, evidence supported lines) in the model. Also, factors that are blocked together in the model are likely worth investigating as a set or cluster, since they are at least conceptually related and will probably co-influence most outcomes.

Second, given the increasing availability of tools and processes for teams to engage in self-monitoring and self-correction in real time, it is important to understand the implications of teams using these tools. Research to date does not indicate whether there is a stage or phase in team's lifecycle where it might be detrimental to apply such tools (e.g. is it safe for the team to self-correct during the storming stage?). Nor does research yet indicate clearly how the team may best manage the increase in cognitive loads sometimes associated with self-monitoring and introspection, or what is likely to happen to the team's performance if the tool or process gives team members incorrect or incomplete feedback. Basic laboratory style research could answer at least parts of these questions in the near future.

Third, since research does not yet tell us which factors, clusters, or layers are likely to be best leveraged at what points along the evolutionary paths of teams this bears more theorizing. Researchers could start experimenting with factors from the process layer (as those seem to fit in philosophically with the phases within a team's evolutionary path). For example, experiments could manipulate the communication path at different points in the evolutionary path of teams in labs and analogs to help better identify where to most successfully apply countermeasures intended to improve a team's communication process.

Most importantly, any future researcher(s) wishing to leverage this report and the model/ infographic offered herein should first endeavor to make both the database and the model entirely their own. The assumptions made here in order to help conceptualize this model will become less gross as concepts are argued, stretched, refitted, and reshaped to accommodate additional evidence (of all types). This current effort is best thought of as the first documented attempt to weave a working net.

Limitations

This modeling represents a semi-quantitative, mostly-qualitative conceptualization of the psychosocial factors most likely to impact teams during long-duration spaceflight exploration missions. As such many gross and subjective decisions were made about how to integrate very discrepant data and studies into one conceptualization. For instance, some studies categorized as qualitatively important (sorted into category two for this report) may be re-interpreted as quantitative (or category three) evidence by other professionals with better ideas about how to interpret the statistics they do report in relation to LDSEM teams or teamwork.

Please DON'T:

1. Consider or treat this as a meta-analysis, or truly quantitative study of any kind.
2. Use this conceptualization to argue against or dismiss any other conceptualizations.
3. Imagine this conceptualization holds true to any context other than long-duration spaceflight exploration missions.
4. Add or change any fields in any spreadsheet within the database without first consulting this final report and the appendix on how to add studies to the database.

Please DO:

1. Use the database as a starting point to help you re-conceptualize and evolve the model of psychosocial factors most likely to impact teams.
2. Make this database more quantitative by adding more objective data from the LDSEM context as it is collected.
3. Design and execute studies to test any and all aspects of this conceptualization and to replicate the relationships it notes and assumes.
4. Add data and insights into the database after consulting this final report and the appendix on how to add studies to the database (so that decisions remain consistent and become less gross and subjective as the database evolves).

A Final Note

Simply put, this report offers a framework and a process for semi-quantitatively conceptualizing the psychosocial factors related to teamwork for LDSEMs. It is best to think of it as a nomological net for ideological fishing and its final worth is entirely dependents on how well it serves, is applied, and is modified into a better nomological net by other going forward.

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13. ABSTRACT *(Maximum 200 words)*

This report presents a semi-quantitative model, database of supporting studies, and a method to continue modeling the psychosocial factors most likely to influence and impact teams during autonomous, long duration and/or distance exploration missions (Behavioral Health and Performance, Team Gap 1). The model follows an Input-Process-Output framework with four layers of psychosocial factors: 1) Situational and Individual Inputs, 2) Hidden Aggregates and States, 3) Teamwork Processes, and 4) Team Performance Output. This model and modeling process are an attempt to integrate very discrepant data, study types, contexts, and theories into one conceptualization that may be used to inform NASA's future research decisions regarding which psychosocial factors might be most profitably addressed or leveraged given limited resources to support Long Duration Space-flight Exploration Missions.

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