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Leadership/Followership for Long-Duration Exploration Missions Final Report

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Project Abstract

This report describes the work completed for the contract "Leadership/Followership for Long-Duration Exploration Missions (#NNJ13487783Q)," Michael D. Mumford, The University of Oklahoma, Principal Investigator. The project team completed five milestones in response to a request for providing a better understanding of effective leadership and followership for long-duration space missions. In Milestone One, a literature review was conducted to identify the key conceptual issues and empirical findings relevant for the present effort. The topic areas covered included: 1) relevant leadership content areas, 2) leadership in analog environments, and 3) leadership in analog job settings. As an additional deliverable for Milestone One, an integrated leadership model was developed outlining the key capacities needed for Mission Control and Astronaut Crew leadership. This integrated model subsumes four leadership sub-models including the collective leadership of scientists and engineers, socio-emotional leadership, crisis/emergency leadership, and dyadic leadership, as well as a role switching decision framework for changing between models. Milestone Two provides recommendations for improving leader and follower performance. These recommendations include critical cognitive and social attributes likely to contribute to effective Mission Control and Astronaut leadership, as well as potential interventions for enhancing performance for each attribute. The purpose of Milestone Three was to conduct interviews with NASA staff to receive expert perspectives on effective leadership (e.g., attributes, dynamics, and processes) for long-duration space missions. This information, in turn, was used to assess the plausibility of, and to further develop, the proposed models. Information from the interviews suggests that the leadership models developed are plausible. Upon completion of the interviews, a future research agenda was created for leadership and followership for long-duration exploration missions. This final report acts to fulfill Milestones Four and Five, which integrates conclusions from the literature review, evaluation, and operational assessment and proposes a research agenda for the Behavioral Health and Performance Element regarding leadership and followership.

Project Summary

> *The ISS was never developed to be an autonomous, self-running space station. The Station is meant to be controlled from the ground. The astronauts are just doing the flight director's mission. They are merely an extension of the ground control. Astronauts are 'tip of the spear.' This has been the mentality of NASA for 50 years but this will have to change for Mars*[1]. (Psychological Operations, Behavioral Health and Performance)

> *I've always described short missions as visiting space or taking a vacation in space whereas long duration flights involve living in space. Going into space is such a difficult thing to do and you want to operate at a high pace but you cannot do that for a mission that stretches months or years. It's a marathon, not a sprint. For those that don't pace themselves, they can become overstressed, fatigued, and that often translates into negative behavior.* (Astronaut)

Performance impediments caused by inadequate cooperation, coordination, communication, and psychosocial adaptation within a team are some of the largest concerns that need to be addressed before planning and undertaking long-duration space exploration mission such as the Mars mission. Additional constraints on communications between Mission Control and crew associated with extreme distances imply future missions will require significantly more autonomy and self-sufficiency than any current or historic spaceflight mission. Bearing these challenges in mind, it is becoming clear that major shifts in NASA's long-standing leadership and followership paradigms are required. Having a conceptually sound, empirically-based understanding of what creates and sustains effective leadership for long-duration missions will enable Mission Control and Astronaut Crews to have safer, more productive missions.

The purpose of the present effort is to identify the critical issues surrounding team leadership and followership and their effects on team functioning with a specific emphasis on three key issues. First, the types of leadership most likely to produce effective teamwork must take into account several issues unique to long-term exploration missions, including conditions of isolation, confinement, danger, high autonomy, and an extended duration, must be identified. Although

[1] This approximated quote and those to follow in this report are not verbatim, but they do reflect key points made during interviews with NASA staff. Minor wording changes or additions were necessary to provide context for each comment. Current or last position held is indicated in parentheses after each statement.

many of these specific variables may appear in extant models of leadership, no existing models fully cover all of these issues. Second, it is important to consider the effects of followership performance and well-being in the context of space exploration must be considered. Current knowledge about the effects of followership performance in this context is spread across a diverse set of literatures that has not been reviewed or integrated for many years. The third key issue emphasized in this report considers methods that improve leadership in teams working in analog environments. Although there is limited data concerning these key issues from in-flight research, many analog environments provide useful information and findings that may be generalizable to spaceflight.

To address the issue of leadership and followership in the context of long-duration space exploration, the current project took an approach that focused on four key deliverables. Corresponding with Milestone One, the first key deliverable was to conduct a thorough literature review on critical issues surrounding leadership and followership, where diverse literatures are integrated into tentative models and key variables are identified. In line with Milestone Two, the second key deliverable outlines approaches to improve leadership and followership performance based on the findings from the literature review. In tandem with Milestone Three, the third key deliverable summarizes findings from interviews conducted with current and former NASA personnel from various backgrounds and with high levels of expertise. Their interviews revealed many valuable perspectives on current and future leadership requirements at NASA and helped us to further develop out model. The completion of these three deliverables aided in the completion of the fourth key deliverable, which corresponds to Milestone Four. The fourth deliverable focused on creating a list of future research areas to validate and further refine the models, as well as provide specific interventions that may prove effective for enhancing leadership and followership in space.

Milestone One: Literature Review

> *NASA has spent the last 30 years breeding out leadership and breeding in management. Every leadership course I ever took was actually management training. As a result, NASA ended up with a lot of ineffective leaders at high level positions.* (Former Flight Director, Mission Control)

In accordance with milestone one, a literature review was performed to inform effective practices for team leadership and followership for long-duration exploration missions. Although much of the extant literature may be useful, several issues specific to NASA limit our ability to directly generalize from existing work. First, most leadership research assumes a clear distinction between leaders and followers (Baker, 2007; Uhl-Bien, Riggio, Lowe, & Carsten, 2014; Vanderslice, 1988). For long-duration space exploration missions, teams will necessarily be composed of individuals all fully capable of assuming leadership responsibilities. While there may be one Crew Commander, different crew members will serve different functional leadership roles depending on the tasks or conditions at hand. Second, most work in the general leadership literature assumes significant variation in the amount of domain expertise among individual members (Boone & Hendriks, 2009; Carmeli & Schaubroeck, 2006; Friedrich, Vessey, Schuelke, Ruark, & Mumford, 2009). For any NASA team, crews will be composed of scientists and engineers, implying that all members will possess high levels of expertise. Past work in this area suggests that leading scientists, engineers, and research personnel requires a different approach than managing or leading non-scientific organizational personnel (Mumford, Scott, Gaddis, & Strange, 2002). Third, cross-cultural issues are often addressed in a separate literature base, and are not typically integrated into more mainstream leadership models. Cross-cultural concerns will be of great importance to long-duration missions as members representing multiple nationalities will be involved. Unique coordination and communication challenges can emerge for culturally diverse crewmembers and international mission control. These three idiosyncratic aspects of any long-duration space exploration mission suggest that this project cannot rely solely on the extant leadership research. To address this issue, our task was to gain insights from multiple specific areas of past work and integrate them into a set of cohesive and useful models.

The literature review comprises three general categories. In total, 36 specific topics, each falling into one of the three categories, were identified and reviewed. The first category includes teams

and leadership content directly relevant to long-duration space exploration. These areas included collective leadership, leading scientists and engineers, crisis/emergency leadership, dyadic leadership, and socio-emotional leadership (Connelly et al., 2014; Gooty & Yammarino, 2011; Mumford, Friedrich, Caughron, & Byrne, 2007; Robledo, Peterson, & Mumford, 2012; Vessey, Barrett, & Mumford, 2011). All five of these leadership models are directly relevant to long-duration space missions. Thus, each model received significant attention.

The second category includes leadership in analog environments such as the Mir Space Station, Antarctica, and Submarines. These analog environments are assumed to contain certain elements of *the physical leadership environment* that parallel long-duration space missions. For example, many of these analog environments (e.g., submarines) are considered to be isolated, confined environments. These isolated, confined environments present unique challenges and dangers that are not encountered in most leadership settings, but that must be taken into account when providing recommendations for long-duration space missions. Therefore, specific topics relating to leadership in analog environments can provide value for the unique aspects of long-duration space missions that cannot be gained from existing leadership research and theory.

The third category covered leadership in analog job settings such as Special Forces, firefighters, and leading in joint force operations. In contrast to the analog environments, the analog job settings offer certain elements of *the occupation* that parallel long-duration space missions. Specifically, it was expected that certain elements of job analogs may provide insight into particular leadership models. The literature review provided mounting evidence for this as many of the job analogs directly mapped onto the leadership models identified. For example, the topic area of firefighters offered significant value and demonstrated direct relevance to the crisis/emergency leadership model.

In sum, the leadership models, analog environments, and analog jobs each offer a unique and valuable perspective on the challenges and difficulties of a future long-duration space mission. Research in these areas revealed a number of implications for regarding leadership for long-duration space missions.

Structure of Reviews

A summary report was prepared for each of the 36 individual topics related to leadership from the three broad topic areas. Each report was organized into five sections: 1) implications for leadership models, 2) implications for long-duration space missions, 3) implications for training, selection, and performance management, 4) key contextual variables, and 5) a general appraisal of the topic area's value to the project. The sections of each summary report covering implications for leadership models were further broken down into the five areas of leadership that are relevant to our proposed model: collective leadership, socio-emotional leadership, crisis/emergency leadership, dyadic leadership, and leading scientists and engineers. This section serves to provide literature-based information about leadership behaviors vis-à-vis crewmember interactions during long-duration spaceflight. More specifically, these recommendations are focused on a team-based approach including components such as team socialization, group cohesion, adaptive capability, performance quality, and leader support.

Section two, dealing with the implications for long-duration space missions, was broken down into recommendations with reference to crewmember, Mission Control, and cross-cultural interactions. Contact among crewmembers is inevitable, and therefore, summary report recommendations emphasize communication styles and techniques likely to prove useful. Due to the complex nature of multi-team systems (e.g., the Mission Control-crewmember interface), recommendations also focused on concepts related to communication, shared mental models, and conflict. Likewise, interaction between international crewmembers provides an increased probability of conflict and poor communication (e.g., Kanas, 1998). Therefore, recommendations about effective communication and potential conflict resolution were also included in this section of the summary report.

Section three of the literature summary reports covered suggestions regarding NASA's astronaut selection, pre-mission training, and performance management. Although many specific recommendations were identified, some of the more global issues include how NASA might want to select crewmembers for long-duration spaceflight with the specific personalities, knowledge, skills, and abilities as outlined in the summary reports. Additionally, it may be advisable to select crewmembers as a team as well as foster high group cohesion. Prior to any

long-duration mission, crewmembers may benefit from training as a team and practicing skills and protocols that may need to be implemented during the mission.

Also included in the summary reports are key contextual variables, which are variables that may require more specific attention. Furthermore, key contextual variables have the potential to significantly impact leadership. It is important to identify these contextual variables in order to help facilitate their detection in a given situation. To conclude each summary report, an overall evaluation was made about the topic area's parallelism and contribution to the understanding of leadership of astronauts on long-duration space missions. Some topics have greater availability in the literature and are more relevant than others to leadership of astronauts on long-duration space missions.

Leadership Content Areas that are Directly Relevant

Although there may not be research that bears directly on the question of long-duration space exploration, there does exist research that may still be of significant value. This category of literature summaries covers 17 areas, many of which were of particular value. Several topics had significant limitations that hinder their ability to apply to the present effort, such as crew vs. teams, where the way the literature defines crews does not fully align with what a crew will look like for a long-duration exploration mission. Others that may not be as valuable as they first appeared include assertiveness and crew resource management training. Many astronauts coming in may have already gone through training in these areas. Work on scientific autonomy is often dated or philosophical and polemical in nature, thus limiting its applicability. Other areas, such as the literature that makes distinctions among many specific team processes (e.g., Marks, Mathieu, & Zaccaro, 2001) and work on multi-team systems, are potentially of value but are more theoretically oriented and somewhat limited in their direct applications. Lastly, work on gender and cross-cultural work often provides generalizations that may be too broad when dealing with specific individuals (e.g., just because a crewmember is a female does not imply much about how that particular individual will lead). Other areas that were originally conducted as distinct reviews, such as "team leadership and adaptability" and "leadership and teams," as well as "conflict resolution in teams," and "conflict resolution in individuals," are best presented together.

Leadership vis-à-vis Stress. Stressful situations may be less of an exception and more of a normal state of affairs for long-duration missions. Stated another way, stress is likely to be a common constraint limiting the performance of the crew. Work by Lyons and Schneider (2009) suggests that leadership style is related to many important performance dimensions during stressful situations. They found that transformational leadership was associated with enhanced task performance, lower negative affect, and lower threat appraisals compared to transactional leadership. Other work by Offermann and Hellmann (1996) highlights the point that leaders are often unaware or severely biased in their estimates of how their actions influence the stress of subordinates. Their work suggest that leader delegation and subordinate participation were two areas that were most underestimated by leaders. More specifically, followers associated increased delegation and participation with reduced stress whereas leaders did not, perhaps due to an increased sense of control. Other scholars (e.g., Smith & Cooper, 1994) have argued that stressed leaders create stressed followers. Stress in that way may be contagious and very important for NASA to further explore. Crewmembers and Mission Control personnel cannot avoid stress, and will likely need to be able to cope with, recognize, and manage it, especially when levels are at a level where they impede job functionality.

Leadership, Teams, Team Leadership and Adaptability. The teams and leadership literatures have not always done well learning from each other. In spite of this disconnect, the intersection of these two areas is of great value for long-duration space missions. Having an adaptive team is a desirable goal that yields many positive outcomes (Burke, Stagl, Salas, Pierce, & Kendall, 2006) and is influenced by many variables such as cognitive ability and personality (LePine, 2003), but most importantly, leadership (Kozlowski, Watola, Jensen, Kim, & Botero, 2009). A team with high adaptive capacity is able to respond to unanticipated challenges more effectively than a team without adaptive capacity. Another key implication from this area is the importance of team composition. Adaptability is partially a function of individual differences (LePine, 2003) and, therefore, subject to personnel selection. Also, training is framed less as a specific event but more as a mindset where the team seeks to continuously improve both as individuals and as a team. The importance of shared mental models in achieving this mindset is commonly emphasized (DeChurch & Marks, 2006).

Conflict Resolution in Individuals and Teams. Conflict is going to be an inevitable reality of a long-duration space mission, for both Astronaut crews and Mission Control teams. With the understanding that conflict will occur, the question we need to ask is how to best resolve conflict between individuals and within a team. Many strategies are examined in this literature including problem solving, forcing, smoothing, confrontation, withdrawal, exist, or engagement. There is no one best strategy for all situations, that is, the situation will often determine what strategy will prove most effective (Jones & White, 1985). Although the literature does not point to one best strategy, several applications to long-duration missions seem warranted. One, smoothing (i.e., accommodating the issues and concerns of other people before your own) may not be an effective long-term strategy, as it avoids understanding. Problem solving may be more effective because it allows leaders and crewmembers to actively discuss issues rather than escalating or avoiding a conflict.

From team conflict, we see the distinction between task and relationship conflict. The former can be beneficial whereas the latter is often problematic. Past research in this area suggests task conflict should be avoided on routine tasks but can enhance performance on complex and non-routine tasks (de Wit, Greer, & Jehn, 2012; DeChurch & Marks, 2001; DeChurch, Mesmer-Magnus, & Doty, 2013) as long as it does not lead to interpersonal and relational conflicts. As the long-term cohesion of the crew is of significant interest (e.g., Tekleab, Quigley, & Tesluk, 2009), there may be value in taking steps to ensure collaboration and accommodation are emphasized instead of competition and avoidance when attempting to resolve task conflict. Competition and avoidance will ultimately undermine the cohesion and performance of the crew.

Ingroup/Outgroup Biases. The issue of in-grouping and out-grouping stands as an important issue for consideration regarding long-duration space missions. The potential danger is that various subgroups form and compete or conflict within a team, hindering the ability of the crew and Mission Control to execute their directives. For example, crewmembers will have many potential sources of identity, including their nationality, gender, age, education, religion, or job experience. Social fault lines may form across some of these identities, where people more closely associate, or disassociate, with those that share, or do not share, something in common

with them. Brewer (1999) argued that in-groups do not often have strong feelings of dislike toward an out-group, but rather exhibit preferential treatment toward other in-group members. This type of preferential treatment may cause resentment from out-grouped individuals.

The existence of potential in-grouping and out-grouping has important implications regarding the training of the crew and Mission Control. The crew may find benefit in training together to better form a collective identity. One potential scenario would be Americans training together and meeting the rest of the crew at a later date. This scenario would not be ideal in that a subset of the crew would have already formed a strong connection among themselves that would be difficult for other crewmembers to join. Additionally, the crew and Mission Control may want to consider spending time together beyond formal training to facilitate the development of a collective identity.

Team Composition. The composition of the team itself is likely to be of significant importance for how successful leadership can be. Bell (2007) found strong evidence for the value of collectivism, team minimum agreeableness, and team mean conscientiousness in field studies. Although some people may believe that the technical skills should be the first consideration when selecting the crew, Hollenbeck, DeRue, and Guzzo (2004) would argue that composing a team with necessary traits and teamwork skills may be more important than composing one with the required technical skills. One of the most noteworthy implications from this area is the value in selecting the crew as a team rather than as individuals. Team composition variables are highly related to team success (Baker & Salas, 1992; Stevens & Campion, 1994), and it would be best to take advantage of the findings from this body of work.

Emotion Regulation. Emotions and the regulation of emotions will likely be of great importance for long-duration exploration missions. Gross (1998) draws a distinction between antecedent regulation strategies, or those that occur before an emotional reaction/experience fully unfolds, and response-focused regulation strategies, or those used to later the nature or intensity of an emotional experience that has already occurred. In particular, Gross (1998) discusses four processes associated with antecedent-focused emotion regulation and one process associated with response-focused emotion regulation. These five processes each occur at distinct time

points and approach the manifestation of emotions differently throughout the emotion regulation process (Gross, 1998). Going back to the findings from leadership and stress literature, subordinates are sensitive to the state of the leader (Offermann & Hellmann, 1996). Although suppressing an emotional reaction may be easier initially, it may also be more transparent to other crewmembers and can have deleterious long-term effects on an individual's well-being (Gross & John, 2003).

Leadership in Analog Environments

Leadership in analog environments is one of the three topic areas that comprise the literature review. Topic summaries in this area include Antarctica, capsule habitats, Mir, NEEMO, Skylab, submarines, as well as physiological and psychosocial effects in space. Literature reviews on MIR, Skylab, submarines, and physiological effects in space did not add much incremental value to understanding leadership on long-duration space missions due to factors such as differences in crew makeup and a focus on biological and medical issues. However, the remaining analog environments contain physical similarities to the extreme space environment that will be experienced on a long-duration space mission. Furthermore, analogs provide information about the limitations and strengths of individuals in these environments and how these limitations and strengths impact leadership.

Antarctica. Utilizing research on Antarctic missions as an analog environment for long-duration space missions provides considerable value in terms of comprehending the psychosocial and psychological effects experienced in an isolated and confined setting. It will be beneficial for multiple crewmembers to fulfill informal leadership roles to help foster group solidarity and coherence (Johnson, Boster, & Palinkas, 2003). Moreover, having heterogeneous expertise among crewmembers will allow individuals to take on leadership roles as needed and will minimize the likelihood that multiple crewmembers needlessly occupy the same leadership role. Palinkas (1990) found that effective leadership is based on experience, goal articulation, flexibility, and interaction with other individuals in an isolated and confined environment.

Certain aspects of the mission have potential to affect the degree to which crewmembers successfully adapt to an isolated and confined environment for long durations (i.e., six months to

two years). More specifically, giving crewmembers a sufficient amount of autonomy, privacy, and meaningful work should assist in cultivating successful adaptation to this type of environment (Salam, 2012). However, in isolated environments, sensory deprivation often results in symptoms such as anxiety, depression, and aggression, which are likely to have a deleterious effect on group cohesiveness, work effectiveness, and leadership (Arias & Otto, 2011; Gunderson, 1966). In order to maximize social relations, minimize sub-grouping, and facilitate acclimation to the environment characterized by long-duration space missions, crewmembers may need to be selected and trained as a team unit (Salam, 2012).

Capsule Habitats. Using research on capsule habitats as an analog for long-duration space missions has noteworthy value in terms of understanding outcomes associated with living in an isolated and confined environment. Stressors resulting from capsule isolation often result in psychological stress resulting from exhaustion, general drowsiness, neurotic reactions, and information exhaustibility (Bluth & Helppie, 1986). Countermeasures to these capsule stressors can be made in order to prevent poor cognitive functioning, psychosomatic problems, and depression, which may weaken the ability for leaders to successfully handle crisis situations, cope with emotions, and effectively communicate (Smith, 1969). Therefore, all crewmembers will benefit from monitoring the symptoms of accumulating stress and can be trained to apply effective and appropriate countermeasures (Suedfeld & Steel, 2000).

Due to the intimate nature of capsule habitats, conflict is bound to occur among crewmembers or between leaders and followers. To prevent excessive conflict, it may be desirable for crewmembers to be selected as an interpersonally compatible team in terms of mission priorities, values, and goals (Gunderson, 1966). Crewmembers might find value in being able to effectively manage and resolve interpersonal conflict to maximize collaborative problem solving and group cohesion (Stuster, 1996). To facilitate this process, quality communication between crewmembers as well as between Mission Control and crewmembers would be helpful.

NASA Extreme Environment Mission Operations (NEEMO). The findings from work done at NEEMO provide considerable value in understanding long-duration space missions. It was found that all crewmembers should be involved in pre-mission and during-mission procedure

development and changes, as they will have a greater sense of the current environment and their own capabilities (Todd & Reagan, 2004). Not only were crewmembers trained together as a team, but an emphasis was be placed on building camaraderie and fellowship among all crewmembers (Chappell, Abercromby, & Gernhardt, 2013). Individuals who are troublesome during the pre-mission training period regarding issues such as cooperation and timeliness are likely to mimic the same behaviors on any actual long-duration space missions may not be optimal crew members for a long-duration space mission.

Potential for poor quality communication between Mission Control and crewmembers warrants having backup plans. This will likely be important given the long time lag in communications that will occur on long duration missions. It would be advisable to provide the crew with a detailed plan and the tools required to do the task at hand. Also, the crew might benefit from autonomously executing their tasks with a minimum of topside interference. Prioritizing objectives and procedures will help guide crewmembers' work in an autonomous setting (Todd & Reagan, 2004).

Psychosocial Effects in Space. Examining the literature in this area is of extremely high value because of its direct relevance to multiple critical issues regarding leadership on long-duration space missions. Of particular concern are issues that create tension between crewmembers, which can be amended by having informal group discussions (Kanas et al., 2009). Primary issues include disagreements between crewmembers and Mission Control over task overloads or crew activity regulations (Sandal, 2001). Furthermore, it would be beneficial to have personnel in Mission Control with the skills needed to assist astronauts in obtained informational resources.

Having extremely high or low levels of tension on long-duration space missions is problematic for leadership and for overall crew functioning. If tension is too high, it is more challenging to get complex technical work done, whereas if tension is too low, other issues such as groupthink and low motivation may emerge (Sandal, 2001). To combat this issue, Mission Control can objectively monitor group dynamics and tactics to deal with dysfunctional patterns. This monitoring can be done by examining characteristics in communication, such as talking speed, periods of prolonged silence, and duration of communication sessions (Sandal, 2001). However,

Mission Control might want to approach these types of situations delicately in order to prevent crew dissatisfaction and conflicts. It is possible crewmembers may unfairly displace their dissatisfaction toward members of Mission Control, which would be damaging to overall communication quality.

Psychosocial issues should also be considered for both selection and training. Many traditionally emphasized variables in personnel selection, such as cognitive ability, are of less concern when selecting astronauts due to the elite nature of candidates who already score high on such variables (Sandal, 2001). Past work has identified certain characteristics that have been found to predict successful adaptation to isolated and confined environments, including, but not limited to, low levels of depression, having a more introverted, cautious and trusting personality, as well as high levels of independence and self-sufficiency (Palinkas, 1990). Selection alone is not sufficient for minimizing risks associated with stress and mental health on long-duration space missions. Crewmembers may find utility in training to cope with stress associated with prolonged isolation by utilizing tactics such as biofeedback, meditation, and stress inoculation training (Palinkas, 1990). Regarding crew-oriented training, it may be advisable to focus on team-building within the crew, development of behavioral norms, identification of common mission goals, and anticipatory problem solving (Sandal, 2001) to refine communication among crewmembers.

Leadership in Analog Job Settings

The final topic area covered in the literature review was leadership in analog job settings. This topic area served to identify and summarize literature in job settings featuring similar leadership practices to those required for crews of long-duration space missions. Additionally, this topic area covered job settings in which teams interact in physically distant locations to better understand how Mission Control can communicate effectively with the crew. In total, 11 review areas were identified and summarized. The review areas included boredom, CERN Leadership, Command and Control, Emergency Room Teams, Family Businesses and Conflict, Family Conflict, Firefighters, Leading in Joint Force Operations, Mission Control, Police Dyads, and Special Forces. Six of these review areas added incremental value to our understanding of

leadership for long-duration missions. Relevant findings emerging from these review areas will be discussed in the following section.

Firefighters. The research on firefighters offers value particularly in terms of addressing crisis situations. The findings suggest that the effective exchange of information and attention to communication, even peripheral communication, will facilitate the resolution of a crisis situation (Camp, Hudson, Keldorph, Lewis, & Mynatt, 2000). Additionally, crisis situations may cause feelings of fear, which can dampen crewmembers' decision-making ability (Dearstyne, 2007). Therefore, crewmembers may need to assist each other in managing these feelings of fear to prevent a lapse in performance. Furthermore, a hierarchy may need to be established when a crisis situation emerges to ensure that information is effectively disseminated and crewmembers respond appropriately (Camp et al., 2000). Thus, this literature provides noteworthy implications for crisis situations, as crewmembers might find value in effectively communicating and keeping others calm under pressure when a crisis situation occurs.

Mission Control. A review of the current research on Mission Control assisted the project team in understanding the current operations in the flight control room. In particular, it was found that the Mission Control center consists of a front room featuring 16 flight controllers, which are each supported by a staff in the back rooms (Patterson, Watts-Perotti, & Woods, 1999). At any given time, these flight controllers monitor at least four voice loops. Because flight controllers listen to a minimum of four voice loops at a time, individuals that can successfully integrate information would be conducive for these positions. One noteworthy finding was the announcement of "Break! Break!" in the flight control room, which indicates that the attention of all flight controllers is required immediately and, most likely, that a crisis situation is developing (Patterson et al., 1999). Additionally, this area provided insight into a successful shift change in the Mission Control center, as an incoming flight controller must review log information and listen to voice loops to acquaint himself or herself with relevant current information (Patterson & Woods, 2001). Although this area offers little value regarding specific leadership implications, it provided a better understanding of the communication within Mission Control and, therefore, will offer a more accurate diagnosis of situations involving the Mission Control-crew interface.

Furthermore, interviews with Mission Control personnel provided additional information about the basic structure of Mission Control and its method of communication with the crew.

Special Forces. The findings emerging from the Special Forces research offer a number of implications for long-duration space missions, as members of these operations also work in extreme environments involving dangerous situations. Regarding crisis situations, this research suggests that crewmembers might want to consider approaching these situations in a systematic manner such that members prioritize key tasks and develop simple plans to minimize the potential for failure (Prusaczyk & Goldberg, 2002). Additionally, individuals who are successful in formulating solutions in these isolated, extreme environments are characterized by a distinctive profile including active engagement, a high level of commitment, internal motivation, willingness to accept challenges, and creating one's own sense of purpose (Bartone, Roland, Picano, & Williams, 2008). It should also be noted that this research suggests the value of selecting for hardiness, as these individuals are more likely to effectively adapt to extreme environments (Bartone et al., 2008). Both crewmembers and Mission Control personnel might want to consider minimizing aloofness in their interactions in order to build a sense of mutual trust between the two parties (Horn, 2004). With regard to training, crewmembers may find value in being cross-trained on different skills to ensure that multiple individuals are equally skilled in a given domain and can step in as needed (Prusaczyk & Goldberg, 2002).

Command and Control. The implications derived from the Command and Control literature suggest that Mission Control might want to consider the appropriate level of specificity and detail in prescribing plans for the crew based on the demands of the situation (Shattuck & Woods, 2000). Under certain circumstances, Mission Control may need to provide a fairly specific plan to allow the crew to accurately address the problem. Although, in other situations, the crew may need to exercise their autonomy while bearing Mission Control's intention in mind when executing a less rigid, less structured plan (Shattuck & Woods, 2000). Although these implications may appear to be logical and straightforward, the structure and details of plans may not fully be at the discretion of Mission Control considering the time lag and increased need for autonomy in a longer-duration mission. In fact, many of the interviews conducted with NASA personnel suggested that the current Ops concept will undoubtedly need to change for a Mars

mission, as crewmembers will need to be granted greater levels of autonomy due primarily to the increased time lag.

Police Dyads. Research on police dyads (partners) suggests that status and expertise can have significant effects on dyad relationships and collaborative problem solving (e.g., Gerber, 1996). Specifically, an individual's status should not negatively influence the partner relationship by causing an imbalance in power. Crewmembers will most likely have expertise in different areas and, therefore, should be expected to contribute in dyadic work conditions regardless of their perceived status levels. Alternatively, those members with greater expertise in a given domain should have an accurate assessment of others' domain-specific expertise and be willing to allow others to contribute when his or her expertise is required. While crewmembers may not actually have low and high status positions as members in police dyads do, the literature on police dyads ultimately suggests that crewmembers should be accepting of other crewmembers' various levels of domain expertise (Gerber, 1996). Also, this research suggests that Mission Control should monitor the problem-solving strategies reflected in crewmember interactions to prevent destructive conflicts from occurring (Van De Vliert, Nauta, Giebels, & Janssen, 1999). Dyads in Mission Control, such as the Flight Director – CAPCOM relationship, should be able to communicate and work together effectively while monitoring and interacting with crewmembers. Thus, research on police dyads offers moderate incremental value, as it provides direct support for one of the primary tenets of the proposed leadership model, namely, that members must accept leadership roles when their expertise is needed.

Family Business and Conflict. The review area Family Business and Conflict offered several implications for resolving conflict in a group setting. First, it is important to note that this literature does not suggest that conflict should be done away with entirely. Rather, a small amount of conflict may enhance decision-making quality and reduce the potential for premature consensus (Cosier & Harvey, 1998). The findings from this area suggest that members may need to remain actively aware of pending and ongoing conflict, and might find value in resolving the conflict by collaborating and focusing on the problem itself rather than the associated emotions (Sorenson, 1999). Additionally, mutual trust must be fostered in order to promote constructive conflict (Cosier & Harvey, 1998). This literature also suggests that training may need to

investigate how to effectively manage relationship conflict to ensure that it does not disrupt group functioning (Cosier & Harvey, 1998; Kidwell, Kellermanns, & Eddleston, 2011). In sum, this review area provides a few suggestions on managing conflict that are more nuanced than an all-or-none approach to conflict.

Leadership Models

Findings from these literature reviews, in conjunction with relevant information obtained from the interviews, indicate four key leadership domains that will be important for the success of long-duration space missions. The literature reviews acted as a first step for model development but also served to provide direction for a more detailed literature coverage that also informed the structure and content of our models. The interviews helped focus and direct attention to key issues that needed elaboration or discussion. The four leadership domains include: 1) collective leadership of scientists and engineers, 2) dyadic leadership, 3) socio-emotional leadership, and 4) crisis/emergency leadership. Regarding collective leadership of scientists and engineers, roles may be taken on by multiple individuals and switched among members of the team, depending on the emergence of individuals with the most relevant and appropriate skills and expertise for a given situation. Dyadic leadership involves two interdependent partners in a balanced relationship of giving and receiving. Socio-emotional leadership involves the criticality of leaders exercising such skills as social judgment, tact/diplomacy, emotion regulation, as well as their emotion management knowledge in order to help increase positive situational outcomes and mitigate negative situational outcomes. Types of emotion management include emotion awareness, norms, regulation, outcomes, recognition, regulation, appraisal, and expression. Leadership in crisis/emergency situations is critical when a change occurs and a solution needs to be developed to help solve a poorly understood event. These four domains were developed into theoretical models that appear to be relevant to both crew leadership and Mission Control leadership.

Integrated Model

An over-arching, or integrated, model was developed to better understand the relationship between collective, dyadic, crisis, and socio-emotional leadership. Each of these models is subsumed in this integrated model. Although the integrated model acts as more of a framework

for understanding the other leadership models, it should be noted that each leadership model will apply to both Mission Control and crewmembers on a long-duration space mission. A visual representation of the integrated model can be found in Figure 1, which also contains the other four leadership models.

In this integrated model, encompassing both Mission Control and the crew, the entities involved are viewed as a large collective. The crew and Mission Control also act as discrete collectives unto themselves. It should be noted that the collective leadership model should act as a default when one of the other three leadership models are not being utilized. Therefore, it is important that all crewmembers and members of Mission Control have an understanding of how to operate under the collective leadership model. The two arrows going from the crew to Mission Control and vice versa indicate both collectives will influence, and in turn, be influenced by, each other. Also, which collective is leading at a specific time will also change depending on the circumstances. Although NASA's current leadership environment emphasizes more unidirectional flow from Mission Control to Astronaut crews, greater leadership dispersion and bidirectional influence will be critical for the success of a long-duration space mission. This implication highlights the value of Mission Control and the crew developing interpersonal respect and trust for one another, in addition to changing the organizational climate regarding leadership among members of Mission Control and crewmembers prior to a long-duration space mission.

Within the realms of both Mission Control and the crew are dyadic, crisis/emergency, and socio-emotional leadership. Double-headed arrows between each of these three leadership models indicate potential switching between types of leadership depending on the circumstances that may arise on a long-duration space mission for both crewmembers and Mission Control personnel. It should be noted that there may be differences in switching for Mission Control and the crew due to the fact that the crew may need to adopt a different leadership model than Mission Control in a given situation. This model is not in and of itself testable, but rather, it should be viewed as a framework for understanding how the other models of leadership will relate and interact with each other.

Collective Leading Scientists and Engineers

> *As part of the selection process for astronauts, we run them through an experiential course/field exercise and look for competencies. During a ropes course challenge, they need to meet certain obstacles and are expected to change leadership positions after they meet each obstacle. We want to see if they are good leaders as well as good followers during this time. One of the things we are interested in is how can you be competitive but still be a good follower? And some can't give up being a leader. Broadly speaking, during this ropes course, we are looking at candidates' communication style, leadership, followership, and how good of a 'team player' they are.* (Psychological Operations, Behavioral Health and Performance)

This collective model serves as the default for operations under normal circumstances. The other three leadership models, including socio-emotional, crisis, and dyadic, all operate under specific or special circumstances. This collective model will likely be the dominant model operating over the course of any long-duration space mission. The foundation for this model comes from the integration of previous work on collective leadership (e.g., Friedrich, Vessey, Schuelke, Ruark, & Mumford, 2009; Mumford, Friedrich, Vessey, & Ruark, 2012), as well as work focused on leading scientists and engineers (Mumford, Peterson, & Robledo, 2013; Robledo et al., 2012). Although these models pertaining to collective leadership and leading scientists and engineers both have value under specific circumstances, they are not directly applicable to the type of leadership necessary for long-duration space missions because of the assumptions they make about the nature of the collective or structure of the group. The collective model, shown in Figure 2, can be broken down into four specific areas: the leader, the collective, the context, and the outcomes. Each of these four general areas contains many specific constructs, issues, or variables as well as specific linkages regarding their interplay. Lastly, as many of the nodes, or variable groups, presented in this model come from past work, this section serves more as a broad summary rather than a thorough treatment of all nodes and linkages among nodes.

Leader.

> *One of the most important aspects of being an effective leader is knowing what questions to ask. It's easy to come up with a plan when you are the expert in that area but you may not have technical expertise in certain areas. That means you need to know strengths and weaknesses of yourself and others. You need to gain an understanding of how to ask what other options are out there while still keeping the goal in front of the team. You need to make sure the whole picture is taken into account and that one piece doesn't mess up others.* (Psychological Operations, Behavioral Human Performance)

> *The most effective commanders that I have known have all ensured that every member of the crew had ownership of some significant aspect of the mission. For example, on my last flight, there were seven of us. The commander and pilot's duties are pretty well defined so that left us with five mission specialists on board. The commander tried to divide the tasks equitably. Four of us were doing space walks and the fifth did the robotic arm operation. Everybody had some significant role to play in the mission and the performance on these tasks was critical to mission success. No one was just a bit player.* (Astronaut)

In this model, when we refer to a leader, we are not referring to a static individual, but rather to the leader at a specific time or in a particular situation. The leader may be the person(s) with the most expertise in a given situation. Although this explanation may sound straightforward in principle, in practice, who should lead may be less clear. Ultimately, the leader must possess a set of attributes and the expertise that allows him or her to perform several behaviors we would expect out of a leader in a more traditional sense (Yukl, 2010), while also assisting in several collective tasks including work planning and collective sensemaking.

Leader attributes refer to a broad set of individual difference variables that have been demonstrated to relate to effective leadership. This category includes variables such as intelligence, creativity, experience, and wisdom (Gottfredson, 1997; Mumford & Gustafson, 1988). Without possessing acceptable levels of these attributes, the leader will be limited in his or her ability to be effective. As these variables are necessary but not sufficient for effective leadership, they serve as the starting point of our leadership box. These variables will directly influence how a leader will communicate with a collective and form the basis of any technical or social expertise a leader may have developed.

Leader expertise is separated from leader attributes because it acts directly on several nodes not directly influenced by other leader attributes. Expertise, both social and technical, is critical to leading creative people (Mumford, Scott, et al., 2002), and may in fact be the most important variable impacting the performance of this population (Andrews & Farris, 1967). Leader expertise includes direct paths to leader/team exchange, as well as the leader network, but more importantly, serves as the foundation for work planning.

The next node in the leader box is leader structuring, which refers to how well a leader is able to define and organize his or her role and the roles of followers, set an orientation toward goal attainment, and establish clear patterns and channels of communication (Fleishman, 1973; Judge, Piccolo, & Ilies, 2004). Actions such as strategic planning or resource management would be examples of a leader initiating structure. Following leader structuring comes defining the mission, which refers to such actions as defining a problem, clarifying objectives, and motivating followers (Mumford, Schultz, & Osburn, 2002). Ultimately, in these two steps, the leader works to articulate the boundaries of a given issue including what needs to be done and how a task can best be accomplished. These two nodes, leader structuring and mission definition, are the basis of collective sensemaking and the group forming a shared mental model around the work.

The final node in our leader box, team processes, can be defined as how team members interdependently work to utilize diverse resources to yield meaningful outcomes (Marks et al., 2001) and can include variables such as mission analysis, planning, systems monitoring, performance monitoring, coordination, affect management, and confidence building. Many of these variables are directly tied to activities performed by the leader, such as how they structure the work and communicate its purpose and goals. These processes will interact with team performance parameters to bring about the first outcome in the model, collective performance capabilities.

Collective.

> *In terms of assembling a team, it is important to bear in mind that you can only have one team in the end and everyone needs to serve that one team. You can't let anyone do what is best for their team at the expense of another team. You can have sub teams, but nothing should be done in service of sub teams without consideration of the big overall team. Everyone has one common goal; one common mission.* (Former Flight Director, Mission Control)

The collective box encompasses the individuals on a team that are not presently occupying the leader role. Although these individuals may not have the most relevant expertise for a given situation, they will still play an important part in addressing a problem. The general issue in this box relates to information and the communication of information. In the context of collective leading of scientists and engineers, all team members will have high expertise, which means that

while a leader may have the most expertise for a given problem, any individual may still have incremental expertise that may be helpful to reaching better outcomes.

Many of the key nodes in the collective box relate to how a team interacts, including through what methods they communicate, through what channels they communicate, and the nature and tone of the communication. Because of this significant emphasis on communication, it is at the center of the collective and has more connections than any other node. It is the tool through which information is exchanged and how expertise can be selectively utilized by the group. Without sufficient communication, information does not flow through the network and the collective will not take advantage of its resources. It has direct relationships with many important nodes and acts as the currency of the collective model (Friedrich et al., 2009). Regarding the methods of communication, we have leader/team exchange, which is how the leader interacts with the team. Examples include delegation, empowerment, voice, evaluation and feedback. Looking to what channels are used to communicate, we have leader network and team network, which refer to how the crew members are interconnected with one another. That is, how central to group functioning is an individual, connections between individuals, familiarity with other crew members, and boundary spanning. These networks are what information flows through. Lastly, we have team affective climate, which addresses the tone of communication. This node reflects the importance of emotions and affect (Amabile, Barsade, Mueller, & Staw, 2005; Brief & Weiss, 2002) and includes such variables as affective norms, group affect, and the regulation of group emotion.

Team expertise is the counterpart of leader expertise. As all members of a long-duration mission will possess high levels of expertise, it should not be surprising that team expertise is held to relate to many key nodes including work planning, collective sensemaking, leader/team exchange, and team network. Much of this model is based around selectively utilizing the various expertise of the collective, and the support actions necessary to recognize who has the necessary expertise in a given situation.

Work planning is one of two nodes that straddle the collective and leader boxes. This is because it is a leader directed activity that heavily relies upon the input of the collective. As the leader

has the most relevant expertise for the specific situation, they will serve as the primary input for work planning. This general variable encompasses scanning, elaboration, development, and appraisal (Robledo et al., 2012). The purpose of this node is for the collective to recognize an issue and help a leader begin to figure out how to address it. Three nodes influence work planning, including leader expertise, team expertise, and communication.

Collective sensemaking/building a shared mental model is the second node that crosses over between the leader and the collective boxes. Here, team members share knowledge to help find meaning and form a shared interpretation of a given situation (Weick, Sutcliffe, & Obstfeld, 2005). A leader will have already made sense of the situation, so his or her primary role in this node is to help others to interpret and make meaning of the situation in an effort to build a shared mental model (Mohammed & Dumville, 2001).

Team performance parameters are aspects of the problems, aspects of the team or leader, and team perceptions that can influence the performance of a team. This node includes variables like collaborative problem-solving, conflict management, and information sharing. To some extent, it can be viewed as the culmination of the collective box. The collective has worked together (or not) to identify a problem, make a plan, and determine how to best execute this plan.

Context. The context serves as recognition of the fact that any mission will not be operating in a vacuum. There are many situational factors relating to a specific problem, factors outside of NASA, as well as issues inside of NASA. These variables are not directly linked to any of nodes from the leader, the collective, or outcomes, but it is assumed that they may act to influence almost any node under the right circumstances. The first context node is problem context, which broadly refers to variables such as the complexity or ambiguity of a problem. Problem context would also refer to constraints on a specific situation, such as the amount of crew available at a given time. The external context refers to factors outside of NASA that may have an influence on the mission, such as public opinion and support or domestic and international concerns (e.g., conflicts on an international stage involving several countries involved in a mission). As any long-duration space mission will necessarily be high profile, this node may influence how decisions are made and what outcomes are acceptable. The final contextual factor is the

organizational context. This node refers to variables such as resource availability, support availability, and expertise/technology importation. Issues on the mission may require specific outside expertise that may be difficult to acquire or access on short timeframes, and there may be limited ability to contact or interact with Mission Control.

Outcomes. The first outcome is collective performance capabilities, or qualities of the collective that influence its ability to complete a task. This node is the most immediate outcome of the collective process and is the precursor of more distal outcomes. It includes such variables as adaptive performance, collective efficacy, and information sharing. The two primary inputs to collective performance capabilities are team processes and team performance parameters, as these nodes cover how well a team is working together and their collective ability to problem solve. If a team has successfully worked through the earlier stages in the model, the collective will have high performance capabilities. Implementation and short-term outcomes are a broad category that includes immediate outcomes such as decision acceptance, productivity, follower satisfaction, and follower trust. Long-term outcomes are outcomes that occur later, such as mission success or other organizational or collective outcomes. Many problems and issues will arise on a long-duration space mission, and the way in which these are addressed will ultimately determine whether the mission succeeds.

A primary implication of the collective model is that no individual crewmember or member of Mission Control will hold a leadership position during the entirety of a long-duration space mission. Rather, each crewmember and member of Mission Control operating under the collective model will serve as both a leader and a follower, depending on the demands of the situation at hand. Due to the flexible nature of switching roles in the collective model, there is no clear distinction made between leader and follower in this report.

Socio-Emotional Leadership

> *The most effective crew commanders that I have seen have made everyone feel that they were the most important person on the team. You need to be interested in what the person has to say. You need to be engaged and understand the big picture. You need to understand where other people are coming from, and you can do that by being CAPCOM and going to meetings. Another thing is you need to be egalitarian. You can't have a military mindset. You need to be involved with folks at every level.* (Former Flight Director, Mission Control)

A second leadership model was developed for the socio-emotional aspects of the mission. Promoting effective cooperation, coordination, communication, and psychosocial adaptation among the crew and Mission Control must be a key concern for long-duration space missions. The demands and challenges associated with a long-duration space mission will require diplomacy, negotiation and social skills, as well as the ability to manage stress and negative affect by crew members and Mission Control personnel. To address these concerns, a model for socio-emotional interactions for crewmembers and Mission Control was developed. The model is composed of six general areas and can be found in Figure 3. Five of these areas have direct linkages with each other, while the sixth category, situational influences, includes variables that may moderate the effects of the specific dimensions in the model. The remaining five areas are leader traits, leader skills, influence processes, relations-oriented leadership behaviors, and outcomes. While this model covers a broad range of capabilities, the importance of specific traits and skills and the patters required may differ somewhat for Astronaut Crews versus Mission Control personnel. This is something that will require more research.

Leader Traits.

> *There was one mission in particular where the crew had difficulty opening a drawer and the ground kept telling them they were doing it wrong. Finally, the crew had to take pictures to show what was wrong with the drawer. That lack of gravity affects how long it takes to open a drawer; it might take much longer just to complete a simple task. The people who get frustrated with the ground get frustrated with the mission so how do you teach the ground that some of these things are more difficult than expected? One thing that's important is providing appropriate feedback to the astronauts. They all have different personalities and shouldn't be compared with each other. They're like your children in that sense.* (Psychological Operations, BHP)

To effectively cooperate and coordinate with others, leaders need to possess specific traits. Having these traits will allow leaders to accurately assess the needs of others while allowing these individuals to personally cope with the demands of the mission and expectations of others. One such trait that may be of importance is self-awareness, which refers to the capacity to understand the emotions one is experiencing or identifying, and capitalizing on one's own strengths (Cooper & Sawaf, 1997). Another variable, empathy, may allow individuals to better understand the emotions that others are experiencing by personally feeling those same emotions (Salovey & Mayer, 1990). Empathy has been found to have a positive effect on perceived leadership, suggesting that effective leaders are able to personally understand, or even experience, the emotions of others (Kellett, Humphrey, & Sleeth, 2002).

The next leader trait that will be important for effective socio-emotional leadership is having emotionally stable dispositions. Emotionally stable individuals are more likely to feel confident and secure in their everyday functioning (Judge & Bono, 2001). Research suggests that leaders have a higher tendency to "derail" when they lack emotional stability (Kirkpatrick, Shelley & Locke, 1991). Additionally, a meta-analysis conducted by Judge and Bono (2001) found that emotional stability had moderate correlations with job satisfaction and job performance. In relation to emotional stability, leaders also need to possess the capacity to tolerate stress, also known as "hardiness." Individuals that exhibit a hardy disposition are better able to handle stressful experiences and are more resilient following the stressful event (Bartone, 2006).

Trust has also emerged as a key trait desired in leaders, as it has been linked to a number of attitudinal and behavioral outcomes including organizational commitment and organizational citizenship behaviors (Dirks & Ferrin, 2002). Also, humor can be used as an effective tool in the workplace for promoting a number of positive outcomes including group cohesiveness, creativity, and leadership (Romero & Cruthirds, 2006). Finally, self-monitoring is another key skill for leaders as it allows leaders to assess the requirements of the situation and adjust their own behavior accordingly (Zaccaro, Foti, & Kenny, 1991).

Leader Skills.

> *The most effective astronauts that I've interacted with have been really experienced, good CAPCOMs. The astronauts that have been a pain on orbit have never been a CAPCOM. Their ASCAN assignments never led them to work real-time operations in MC. One thing to bear in mind is that they are just one piece of the overall system. Flight Directors are also one piece of the system. Everyone is equally important.* (Former Flight Director, Mission Control)

In addition to possessing requisite traits, leaders also need specific skills to effectively interact with others. It is assumed that these skills are influenced by these leader traits and have a direct effort on influence processes. Interpersonal skills cover a broad range of behaviors under the domain of relational interactions, including having the ability to communicate effectively with others and maintain cooperative relationships. Research also found that leaders were more likely to derail when they lacked the necessary interpersonal skills (Van Velsor & Leslie, 1995). In contrast, successful managers were able to form meaningful relationships and cooperate with others (Van Velsor & Leslie, 1995). Related to the concept of interpersonal skills is the notion of tolerating the diverse opinions of others and keeping an open mindset. Leaders might be placed in situations in which crewmembers disagree on a particular task or subject. They must be open to considering alternative viewpoints and must, subsequently, integrate these opinions into one coherent solution.

The ability to recognize emotions in oneself and others may also be important to leader performance in interpersonal interactions (Connelly et al., 2014). Tied to this concept of recognizing emotions is emotion regulation, or having the capacity to alter the way in which one experiences and displays emotions (Gross, 1998). Gross and John (2003) compared the effects of two emotion regulation strategies, namely, reappraisal and suppression. These authors found that cognitive reappraisal, an antecedent-focused strategy, was more effective in promoting interpersonal functioning and well-being while suppression, a response-focused strategy, had weaker effects on these two outcomes (Gross & John, 2003).

In addition to specific emotion-based skills, several interpersonal skills need to be considered as well. The ability to effectively communicate with others is a key aspect of leader performance, as it may influence the extent to which an individual emerges as a leader as well as the followers'

satisfaction with that leader (Bass & Stogdill, 1990). In communicating to others, leaders need to understand the appropriate manner in which to present this information. Having high levels of social insight may assist leaders in assessing what types of behaviors are appropriate in certain situations (Yukl, 2010). The Ohio State studies of the 1950s offered insight into two essential skills required by leaders, consideration and initiating structure. Of these two skills, consideration, or showing concern for the needs of others and acting in an encouraging manner (Fleishman, 1953), is of particular importance for our socio-emotional model. Although some authors have suggested that these constructs have become relatively forgotten in recent years, meta-analytic findings suggest that consideration has strong correlations with follower satisfaction and motivation (Judge, Piccolo, et al., 2004).

Individuals that demonstrate high levels of integrity are more likely to act in ethical and trustworthy ways. Derailed leaders show a lack of integrity. Tending to focus on improving their own career prospects, whereas successful leaders exhibit integrity by showing interest in developing others (Lombardo, Ruderman, & McCauley, 1988).

Influence Processes.

> *If missions always went as planned, it wouldn't make a difference. When things go bad, trust is needed. I really think trust is crucial. The challenge for the ground is to provide a continuity of trust. Being able to ensure trust is present throughout the duration of a mission is critical. The plan will be sent up from ground, and the crew needs to have faith in that plan.* (Former Flight Director, Mission Control)

> *The Flight Director often brings recommendations to program management. Consultation with program management is to be expected, as many of the decisions are made at this level but this can also create a tension. The Flight Director can't get sent back to his flight control team from program management with a "No" too many times. It is expected that they should be able to come back with a "Yes" from program management at least every now and then.* (Former Flight Director, Mission Control)

In an interpersonal context, leaders need to exercise influence over followers to ensure that the goals of the collective are achieved. Leaders can influence followers in a number of ways (Yukl, 2010). The first influence process in our model is diplomacy, as leaders are expected to show concern for the interests and needs of others. As noted earlier, leaders will need to deal with the differing opinions of others. Thus, leaders must be able to act in a diplomatic manner to balance

these diverse opinions. Along related lines, leaders' negotiation skills will also be particularly important in interpersonal interactions. Possessing these skills will be vital in situations involving crew-Mission Control interactions, in which the two parties hold two differing opinions on how to approach a given situation. Leaders on both sides will need to consider and discuss potential solutions that can appease both parties.

Networking can assist leaders in solving problems and obtaining the necessary information to solve these problems. Leaders are often faced with uncertainty and thus, acquiring information from individuals within the network to reduce this uncertainty is vital for leader performance (Kanter, 1983). Related to this variable, when a leader requires an individual to complete a task, he or she may need to use a proactive influence tactic to ensure that the subordinate follows through with the task. Subordinates may be resistant to completing the task for one reason or another, and therefore, a proactive influence tactic such as rational persuasion or consultation may be required (Yukl, Seifert, & Chavez, 2008). As noted earlier, building trust in followers is particularly important to leader success, as it is likely to lead to a number of positive outcomes, including increased affective commitment and job satisfaction (Dirks & Ferrin, 2002).

Returning to the crew-Mission Control interface, boundary spanning will be important for these interactions. Each party will have unique pieces of information about a particular situation. Thus, leaders need to be able to gather information from the other party to solve a particular problem or issue. The final way in which leaders can influence followers is through emotional contagion. The positive or negative affect of a group can be spread through the influence of contagion and, in the case of positive emotional contagion, a number of positive group outcomes including reduced group conflict can result (Barsade, 2002).

Relations-Oriented Leadership Behavior.

> *The Flight Controllers, Flight Directors, and CAPCOMs will need to be trained on emotional support. They need to have an appreciation of the environments the astronauts are in. The astronauts get pissed off when flight controller, flight director, or CAPCOM says, 'I need to get home.' Nobody on the ground will go through what the crew is going through.* (Mission Operations Directorate, Mission Control)

In addition to influence processes, leaders need to influence the outcome of a group by exhibiting certain behaviors directed toward followers. These behaviors fall into two primary categories: supervisory and political. In the supervisory category, supporting, developing, and recognizing the needs of followers is critical to leader performance (Yukl, 2010). Leaders that demonstrate supporting behaviors show concern for the needs of others and are more likely to form positive interpersonal relationships with others. Leaders that utilize developing behaviors offer opportunities for acquiring skills and, in turn, advancing one's career prospects. Leaders that employ recognizing behaviors provide awards and praise when a subordinate performs well (Yukl, 2010). In the political category, building networks, negotiating means and ends, and maintaining diplomatic relations are also critical to leader performance (Ferris, Davidson, & Perrewé, 2005). Performing these behaviors will allow leaders to successfully navigate through the political labyrinth of an organization by utilizing others' knowledge and skills to achieve specific objectives.

Situational Influences. Certain components of the situation may moderate the relationships in this model. When a leader is faced with an uncertain situation, the influence processes and behaviors may be more important as followers require more direction. Additionally, stress and/or conflict can also influence leader performance as increased demands are placed on the leader. Judge, Colbert, and Ilies (2004) found that the relationship between intelligence and leader performance was moderated by stress, such that intelligence has a weaker effect on performance under high levels of stress. Timeframe is an additional variable that may place constraints on leader performance, as leaders need to effectively manage their time when faced with a task or responsibility (Webber, 1980). The complexity of the situation will be particularly important for leadership in long-duration space missions, as leaders will face situations that are not present in most leadership scenarios. In addition to the traditional demands of leadership, leaders will also encounter novel aspects of space travel that may diminish or alter the effectiveness of key behaviors.

An additional situational influence is the extent to which leaders and followers have aligned objectives. Effective leaders can align the goals of followers with the goals that leaders endorse (Klein & Kim, 1998). However, if these objectives are not aligned, the leaders' influence

attempts may be ineffective or futile from the perspectives of followers. However, the extent to which individuals feel de-individuated (i.e., lessened self-awareness and sense of individuality; collective mindset) in a group may affect influence attempts as well. Deindividuation can lead to group-think, an overemphasis on group goals, lack of questioning of group or leader decisions, and a lack of accountability (Postmes & Spears, 1998). Some balance of collective and individual mindset is required for the outcomes of influences attempts to be positive. Finally, the affective climate of the intragroup or intergroup relations is likely to moderate leader's influence attempts. Affective climate, or the collective mood of individuals toward their jobs and others, can diminish or promote leader effectiveness, depending on the valence of the climate (Ashkanasy & Humphrey, 2011). For example, a positive affective climate in which all members feel positively toward each other and the mission will likely foster the acceptance of influence attempts and objectives.

Outcomes. All reviewed areas will influence outcomes at both the individual and collective levels. In particular, the performance of individuals and teams is expected to be impacted by the traits and skills of the leader and the influence processes and behaviors executed by the leader. If the leader lacks these traits and skills and does not engage effectively in influence processes and behaviors depicted in the model, performance will suffer. Furthermore, the coordination within and between international space agencies will be influenced by these dimensions. If leaders cannot effectively communicate or extract relevant information, coordination among agencies will suffer. Additionally, the well-being of crewmembers and Mission Control personnel will also be influenced by the dimensions described in the model. If leaders cannot successfully influence others or behave appropriately, the satisfaction of others will likely decrease. Leaders need to successfully engage in these processes and behaviors to ensure that followers complete the objectives and do not become dissatisfied with the leader while completing these objectives. Along related lines, the final outcome is trust. Although trust was already discussed in two areas, we believe that the processes and behaviors that leaders engage in will also have an effect on the extent to which others trust the leader. If leaders cannot successfully engage in these processes and behaviors, others may lose trust in the leaders' ability to complete an objective or mission.

Crisis/Emergency Leadership

The crisis/emergency leadership model is of critical importance for long-duration space missions due to the high-risk nature of such an endeavor. Unexpected events that call for effective leadership are inevitable and require a leadership that is quite distinct from the collective, dyadic, and socio-emotional models. Of the four leadership models presented in this report, the crisis/emergency model is the only model that could be drawn almost directly from existing literature. More specifically, this model has been drawn from work focused on a model of leader cognition in crisis situations (Mumford et al., 2007; Mumford & Friedrich, 2009; Vessey et al., 2011), though even for this model, changes were made to both expand some aspects of the model and simplify others.

The key to the crisis/emergency model is sensemaking, or the process by which individuals understand and interpret experience (Weick, 1995). Through sensemaking activities, leaders create a cognitive structure for understanding and responding to a crisis situation. The steps outlined in this leadership model are concerned with a leader developing a prescriptive mental model of a crisis and passing this along to followers. Past work in this area suggests that crises of varying importance occur quite frequently in novel and ill-defined tasks (Drazin, Glynn, & Kazanjian, 1999), and how successfully a leader sensemakes is key to resolving these issues. Our model is shown in Figure 4 and can be broken down into three stages: the first is the selection of the leader or leaders, the second stage is sensemaking, and the final stage involves forecasting and planning.

Selection of Leader(s). Our model begins with the assumption that a problem has been recognized. Without problem recognition, the steps described in the crisis/emergency model will not be executed. This is not to say that a crisis is not occurring, but that due to the cognitive nature of this model, the steps will not proceed until a problem has been identified by the crew or Mission Control. Once a problem has been recognized, it can then be defined and assessed. This early assessment will likely be based on intuitive decision making (Eubanks, Murphy, & Mumford, 2010), or their ability to quickly make accurate decisions in complex and ambiguous situations. Assuming that the crew or Mission Control will be operating in a collective fashion at this point, the next steps in this part of the model involve a brief assessment of personal and

needed expertise, as well as immediate evinced constraints, such as external resources and socio-physical constraints.

Broadly speaking, the steps involved in the selection of a leader or leaders can best be described as a series of snap judgments about a crisis. How quickly will this issue have negative effects, and how severe will they be? What personnel are best equipped to address the issue? How many tools or resources are at our disposal that can help solve the problem? The answers to these questions will inevitably lead to the culmination of this stage of the model: Who should lead? Like the collective model, expertise is the primary attribute necessary to lead (Ericsson & Charness, 1994).

Sensemaking.

> *We don't currently have an Ops concept that works for Mars, as the crew will need to be more autonomous. But, we do know that the flight control team has hundreds of years of experience when you add them all up whereas the crew has much less experience. The knowledge depth here will be really critical.* (Psychological Operations, BHP)

Once a leader or leaders have been selected, the crisis/emergency model follows the model as described in earlier work (Mumford et al., 2007). The goal of this stage is to form an accurate prescriptive mental model. To start the sensemaking process, a leader must scan both the internal and external situation in the context of existing mental models (Ford & Gioia, 2000; O'Connor, 1998; Souitaris, 2001). Basically, a leader will use his or her expertise to gather and interpret information about the overall situation. This emphasis on expertise highlights why this variable serves as the basis of selecting the leader in a crisis. If any relevant issue or variable is not included in the leader's understanding of a situation, he or she will not include it in his or her prescriptive mental model. More specifically, the success of scanning is bounded by a leader's expertise, such that low expertise individuals will not know what they are looking for in the situation.

With their descriptive mental models activated, the leader will draw upon his or her case-based knowledge (Mumford, Blair, & Marcy, 2002). Case-based knowledge, also referred to as experiential knowledge, is knowledge that comes from past experiences. From these past experiences, leaders can recall positive and negative events. That is, in a past situation that bears

some similarities to the present crisis, how was the issue addressed? These cases will be assessed for several important variables such as causes, resources, restrictions, contingencies, goals, affect, actors, and systems (Strange & Mumford, 2005). Taking all these variables into account, a leader will then form a prescriptive mental model of the situation at hand. Based on his or her expertise and past experience, his or her prescriptive mental model provides the understanding for how to move forward and address a crisis. It includes the understanding of what caused a problem, and based on key aspects of the context in the current crisis, what needs to be done to address it. That is, the outcome of the sensemaking stage is not a solution to the problem but rather, a cognitive model to interpret and respond to the problem at hand.

Forecasting and Planning. At this point in the model, we have selected a leader or leaders, and a prescriptive mental model of the crisis has been formed. The final step in the crisis/emergency model is for the leader to use this prescriptive mental model to forecast and create plans for addressing the issue at hand. Forecasting is a complex form of prediction, where both the predictors and outcomes are not fixed (Byrne, Shipman, & Mumford, 2010). Building upon this forecasting, a leader will need to self-reflect, evaluate forecasts, and reflect on social systems. That is, he or she will attempt to predict future outcomes vis-à-vis potential courses of actions. The leader may draw on others, both from the crew and Mission Control, to conduct this forecasting process, highlighting why collective leadership is the core model in this report.

Taking the information from forecasting, the leader must form plans and backup plans (Xiao, Milgram, & Doyle, 1997). Planning calls for the use of skills, including the identification of key causes, restrictions, downstream consequences, as well as opportunistic implementation (i.e., adaptive flexibility) and environmental scanning (Giorgini & Mumford, 2013; Marta, Leritz, & Mumford, 2005). Planning and forecasting are strongly linked in the sense that plans are based off of forecasting. Plans act as the practical implementation based on the conclusions formed during forecasting.

Once all of these cognitive processes have been worked through by the leader or leaders, we reach the final step in our model: influence attempts. Now that the leader has a mental model of the crisis, as well as a plan for how to address it, he or she must sell this plan to his or her

followers, which is no small task (Yukl, 2010). At this point, the crisis will not have been solved, but the foundations will have been laid that will allow for the crew and Mission Control to make the best decisions in crisis situations.

Dyadic Leadership

The dyadic leadership model is the final of the three leadership models operating under the collective model. More specifically, this model operates under conditions where two individuals, a leader and a follower, interact with one another vis-à-vis giving and receiving. The foundation for this model comes from the integration of previous work on individualized leadership and dyadic leadership (e.g., Dansereau, 1996; Mumford, Dansereau, & Yammarino, 2000; Yammarino & Dansereau, 2002). The dyadic model developed for this report, as shown in Figure 5, can be broken into four specific areas: individual-level variables, dyad-level, situational moderators, and outcomes. These four general areas are comprised of several specific constructs. Certain linkages describe how these variables influence and interact with one another. Because many of the constructs in the model are drawn from previous work, this section provides a broad synopsis of these constructs.

Individual Level. This box includes variables that are internal to both the leader and follower. Not only do these variables impact outcomes of dyadic leadership, but they also influence dyad-level variables. All crewmembers will have unique skills and expertise, which gives them the credibility needed to be accountable in a leadership role. The primary issue in this box is concerned with feelings of safety, including openness, perceived common interests, as well as no personal risk or threats. For example, an amicable yet candid exchange of differing viewpoints and opinions may result in better problem solving. The match between the leader and follower with regard to needs, goals, and values will also influence feelings of safety (Schneider, Smith, Taylor, & Fleenor, 1998; Schneider, 1987). Not only are feelings of safety important when conflict arises between a dyad pair, but they are also relevant to the follower's security about approaching the leader with problems, concerns, or questions (Jones & Archer, 1976).

Once feelings of safety have been established, autonomy preferences should be addressed. Given the circumstances, the amount of preferred autonomy given by Mission Control, as well as dyad

leaders, may fluctuate throughout the mission. Leaders give followers autonomy and the opportunity to achieve at his or her desired level (Dansereau & Yammarino, 2007). During times where there is a high level of crewmember autonomy, the leader's inspiration for the dyad pair to do their best is important because boredom or complacency may occur during long-duration space missions. This inspiration has potential to increase self-efficacy which will help give the subordinate confidence in the ability to complete his or her specialized task (House, 1977; Likert, 1961).

Dyad Level. The dyad-level box is comprised of variables that impact the relationship between the leader and follower. Although some of these variables may have a greater effect on this relationship, all will still play an important part in shaping the dyadic relationship. The general issue in this box relates to the quality and characteristics of exchanges between the leader and follower. Different dyad pairs will have unique exchanges and have a distinctive relationship compared to other dyad pairs (Dansereau & Yammarino, 2002). In the context of long-duration space missions, different crewmembers will take on leadership roles when different situations arise, requiring flexibility in the dyadic leadership model.

Many of the factors in this box relate to the similarity between the leader and follower, including beliefs, values, needs, autonomy, and recognition of one another. The amount of similarity between a leader and follower will impact the formality of interactions, respect, and empowerment that take part in the exchanges that occur (Wallis, 1999). Furthermore, dyad partners are a part of a balanced relationship where the amount of giving and receiving for each individual is similar. If dyads lack balance, they tend to be unsuccessful and short-lived (Yammarino & Dansereau, 2002).

Another key component of this box is interdependence, which can be classified into either task or outcome interdependence. A strong and balanced leader-follower relationship of interdependence occurs when there is a high degree of agreement in the perceptions and behaviors between the dyad pair (Wallis, Yammarino, & Feyerherm, 2011). When considering task interdependence, due to the different skills each astronaut will possess, one individual may need to complete a certain part of a task adequately before the other can proceed with his or her work. Moreover,

dyad members may have to share task work concurrently. Regarding outcome interdependence, both members of the dyad should equally and fairly be given recognition and praise for high-quality task performance.

Both psychological distance and physical distance are important elements of the dyad relationship. Members of a dyad who are psychologically close might be more likely to provide greater amounts of communication, feedback, and support for self-worth (Bednar, Gawain-Wells, & Peterson, 1989). Some dimensions of this type of support include showing respect, cooperativeness, openness, as well as being task-centered, showing acceptance, and allowing self-responsibility (Wallis, 1999). Different types of leader behaviors can influence followers' evaluations of these behaviors depending on psychological distance. Depending on the context, physical closeness may also influence these evaluations.

Situational Moderators. There are many problems that may arise on long-duration space missions pertaining to issues with crewmembers, complications with equipment, as well as factors inside and outside of NASA. Although these variables are not directly linked to the leader, follower, or outcomes of dyadic leadership, these situational moderators have the potential to influence these other sections of the model under specific circumstances. Due to the variety of situational moderators, this model has many implications for both crewmembers and Mission Control.

Individualized leadership operates at the dyad level of analysis, whereas the group and collective levels of analysis provide context for when this type of leadership occurs (Yammarino & Dansereau, 2002). Elements such as political agendas, multiple goals and constituencies, as well as the nature of tasks and roles may change or influence individualized leadership. For example, when considering political agendas, an astronaut's self-identity with a particular culture or gender rather than his or her occupation may foster tension between dyad members. Individualized leadership may require external monitoring to ensure that there is adequate and productive performance from the perspective of third parties (Yammarino & Dansereau, 2002), such as Mission Control. Crewmembers may have to complete tasks that range from mundane and routine to complex and chaotic, which will require flexibility of leadership roles in the dyad.

Other factors, such as resource constraints, standard operating procedures, goal definition, and reward distribution may also play a role in dyadic leadership. Clearly defining goals and having fluid correspondence between members of a dyad ensures that all known information is communicated in order to promote quality performance on goal-relevant tasks (Dansereau, Graen, & Haga, 1975). Contextual changes will increase the need to develop and rely on dyadic leadership because a rapidly changing situation requires the initiation of trust-based interpersonal relationships to help maintain and enhance performance. The establishment of quality one-to-one leader-follower relationships will be critical for long-duration space missions.

Outcomes. Both dyad-level and individual-level variables simultaneously influence outcomes surrounding dyadic leadership. Individualized leadership has a primary focus on satisfying performance, which helps solidify the dyadic relationship (Berscheid, 1985). Differing degrees of communication, task delegation, and leader-member exchange (LMX) can be the result of or impacted by dyadic leadership. To increase the likelihood of whether a quality relationship will develop, there must be 1) mutual respect for the capabilities of both members of the dyad, 2) reciprocal trust, and 3) an expectation that a mutual obligation of giving and receiving will occur over time (Graen & Uhl-Bien, 1995). Several problems will need to be resolved, and several setbacks will arise on a long-duration space mission. The way in which a dyad pair addresses these issues will determine goal completion and mission success.

Role Switching Decision Framework

> *Everyone is an expert in a particular area. The leadership is shared due to technical expertise. In the end, you need a Flight Director as the ultimate decision maker, but each person is in charge of their area. The leadership needs to be very situational. Individuals will always need to adapt to circumstances, and unforeseen circumstances can arise where a member might need to step up. Leadership shows up in ways you don't anticipate and therefore, it is important to create an environment in which leadership can emerge.* (Former Flight Director, Mission Control)

As described in the previous sections, the demands and challenges of long-duration space missions will require multiple types of leadership. The use of four distinct leadership models implies that leaders will need to "switch" between models when the situation calls for a specific leadership approach. Thus, a model for switching from one model to another has been

developed. For example, leaders may need to switch from the socio-emotional model to the crisis/emergency model when an unexpected and potentially dangerous situation arises. Although there is no direct research on this "role switching decision framework," the basis of the framework is found in "diagnostic" theory. This theory states that key markers in the situation should be utilized to "switch" from one model to another. In the section that follows, the basic procedure for executing the role switching decision framework will be discussed.

Description of Model. A visual representation of this model can be found in Figure 6. The first basic tenet of the model assumes that the collective will be operating under a specific leadership model. The collective may be operating under the default model (i.e., collective) or one of the sub-models such as the socio-emotional model. Because it is assumed that the crew will be operating under a specific leadership model, the first primary occurrence is the perceived disruption to crew functioning. Of particular importance here is the *perception* of disruption, as certain disruptions may occur during a mission that crewmembers and/or Mission Control personnel do not perceive. If the disruption is not perceived, the crew and/or Mission Control cannot recognize the need to switch leadership models.

Although the visual representation suggests that a perceived disruption must occur for the role switching to take place, there will be instances in which role switching is necessary without the occurrence of a perceived disruption. For example, during times of low workload, the crew may want to build social relations, and therefore a switch to the socio-emotional model may be warranted. This role switching decision framework emphasizes the importance of a perceived disruption as a catalyst for role switches, however, it does not limit the role switches to these scenarios. The crew and Mission Control simply need to be cognizant of situations that require an alternative leadership model.

If the disruption is recognized, or a need for a different model is perceived, the crew and/or Mission Control must then define the problem. To understand the best way to approach the issue or situation, crewmembers must first understand the issue at hand. Once the problem has been defined, additional information must be gathered to gain a better understanding of the present situation. Problem definition may provide members with a general understanding of issues to be

addressed, but information gathering will allow members to extract necessary information to solve the problem.

Once this information has been gathered, members can then activate mental models to recall prior experiences in which similar issues were encountered. The activation of these mental models will likely lead members to similar instances in which the problem was solved successfully or not solved at all. After these mental models have been activated, members can then identify the key diagnostics from the leadership models. Extracting relevant information from prior similar cases vis-à-vis the mental models will assist individuals in identifying relevant aspects of the leadership models for addressing the current situation. Once the key diagnostics have been identified, members can then choose the appropriate leadership model. In this stage, it is assumed that multiple leadership models can be selected if the current situation requires such an approach. The key diagnostics should directly map onto specific leadership models and thus, should simplify the selection of a particular model.

After the appropriate leadership model(s) have been selected, forecasting of potential consequences and outcomes must occur. Based on the demands of the present situation and the leadership model selected, members can forecast potential outcomes. By forecasting these outcomes, the following three stages of the role switching decision framework will be simplified as a result. Following forecasting, an assessment of colleague skills must take place to assess who is best suited to solve the problem. An assessment must occur within the crew and within Mission Control. After these two parties have been assessed for the skills required, the appropriate party/parties must be selected to address the problem. It may be found that one party is better suited to address the problem, in which case, that party should individually solve the problem without the other's assistance. Although, in some situations, the expertise of both parties may be required and, thus, the two parties should collaborate to solve the problem, as each party would use their requisite skills to assist in addressing the issue. After the party and/or parties have been selected, the problem can be addressed accordingly, and the selected party/parties should attempt to solve the problem.

Tailored Models. Although these leadership models are grounded in literature, they have been tailored for NASA. More specifically, these models help clarify the processes and conditions under which Mission Control and crewmembers should operate for long-duration space missions. Furthermore, based on attendance at the 2014 NASA Behavioral Health and Performance Conference and consulting with the project manager, these leadership models were also used to distinguish fundamental capacities that must be possessed by those asked to take on leadership roles as crew for long-duration space missions or as staff for Mission Control. There are no currently existing models that sufficiently describe leadership and followership in the context of long-duration space missions. Because these leadership models were built specifically for long-duration space missions based on existing literature and theory, they will require extensive validation work and merit a number of future research efforts.

Depending on a given situation on a long-duration space mission, certain components of the leadership models will be more critical and, therefore, require greater emphasis. This situational dependency holds for both crewmembers and Mission Control. However, depending on the functional role of Mission Control and crewmembers in a given situation, different components may be more salient and critical for one group than they would be for the other. For example, forecasting may be more valuable for Mission Control than for the crew, whereas adaptability may be more useful for the crew as compared to those in Mission Control.

All Milestone One work has been completed. The available literature on leadership and followership has been appraised with respect to theoretical and substantive leadership models, leadership in analog environments, and leadership in analog jobs. This comprehensive literature review led to the development of four primary leadership models applicable to both crew and Mission Control. Furthermore, an integrated framework for organizing these models and switching between these models has been developed. These models serve as the foundation for work on Milestone Two.

Milestone Two: Improving Leadership and Followership

The primary objective in Milestone Two was to identify approaches for improving leadership and followership performance. Work in this area is speculative because the models of leadership and followership being formulated have not been validated. Moreover, numerous unique considerations are likely to influence selection, training, development, work practices, and work structure for long-duration space missions.

Although speculative, there are several implications of the models and conclusions from the literature review that can be drawn. More specifically, several variables appear in multiple models, suggesting that these variables are central to NASA's aims in long-term space exploration. Each of these central variables can be placed under one of two broad areas that were identified based on the work conducted in Milestone One: cognitive variables and socio-emotional variables. Additionally, to facilitate future work for long-duration space missions, a consolidated list of key variables underlying leader performance has been compiled. This list provides a key piece of infrastructure needed for future work examining leadership in long-duration space exploration missions. It is available upon request.

Cognitive Variables

The cognitive variables list contains variables representative of the cognitive abilities an individual needs to possess to execute various leadership capacities. The eight cognitive variables include: 1) planning, which refers to a leader's attempt at purposeful, future-oriented decision-making, and requires generation, assessment, and implementation of alternative courses of action, as well as the existence of values and goals (Hogarth & Makridakis, 1981); 2) forecasting, which refers to envisioning multiple different outcomes of alternative actions (Byrne et al., 2010); 3) experiential judgment, which plays a crucial role in planning and forecasting due to the fact that an individual's ability to process information is limited, and people are adaptive in certain situations (Hogarth & Makridakis, 1981); 4) problem definition, which involves an individual's ability to structure a problem and identify the goals, procedures, restrictions, and information required to help solve the problem (Mumford, Reiter-Palmon, & Redmon, 1994); 5) idea generation, which is the process of generating alternative solutions to problems (Lubart, 2001); 6) environmental awareness, which requires that individuals be aware of the nature of the

environment that they currently face and those environments which they may face in the future (Fahey, King, & Narayanan, 1981); 7) intelligence, which can be thought of as the ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, and to overcome obstacles by careful thought and consideration (Gottfredson, 1997); and 8) information analysis, also referred to as critical thinking, is the objective evaluation of an issue in order to help form a rational judgment or plan (Norris, 1985). NASA should use these variables to guide the selection of crewmembers and Mission Control personnel.

Socio-Emotional Variables

The socio-emotional variables list contains critical variables, which NASA could potentially utilize to select and train both crewmembers and Mission Control personnel. The eight socio-emotional variables include: 1) trustworthiness, which is an individual's assessment of the likelihood that another group or individual can be trusted to uphold duties inherent within a perceived social contract that exists between the two parties (Caldwell & Clapham, 2003); 2) emotional stability, which is a personality trait characterized by confidence and security in everyday functioning, as well as low levels of anxiety and depression (Judge & Bono, 2001); 3) emotional recognition, which involves the ability to accurately decode and interpret other individuals' expressions of emotions communicated via nonverbal channels (Rubin, Munz, & Bommer, 2005); 4) emotion regulation, which is the process by which individuals control which emotions they have, when they have them, and how these emotions are experienced and expressed (Wong & Law, 2002); this will enable a more rapid recovery from psychological distress; 5) stress tolerance, also referred to as hardiness, is an individual's ability to cope with stress (Atwater, Dionne, Avolio, Comobreco, & Lau, 1999) ; 6) social insight and awareness, which is an individual's ability to read people and groups accurately (Gardner & Stough, 2002); 7) negotiation skills, which are comprised of developing rapport with others, obtaining information from other parties, explaining policies to others, and making decisions on accounts based on needs of all individuals and groups (Phillips, 1993); and 8) open-mindedness, which is the willingness to critically evaluate an individual or group's ideas and routines and to accept new ideas (Calantone, Cavusgil, & Zhao, 2002). Each individual selected for long-duration space

missions should possess the characteristics represented in this variables list in order to fulfill various leadership capacities.

Condensed Variables

Variables in the condensed variables list are an aggregate of the most frequently occurring and fundamental variables that appear in more than one of the four leadership models (collective, dyadic, socio-emotional, and crisis leadership). This list also shows in what model(s) a variable appears. NASA should view this list as a core competency list, which is necessary for the next phase of research. More specifically, these variables can be used to direct content analysis of past documents and reports pertinent to real-world leadership, be the primary candidates for experimental studies, form the core of agent-based simulations, and other studies. As such, content analysis, experiments, simulations, and other methods, can be used to validate the leadership models (see details below).

Available upon request, the list of variables is sorted based on the type of characteristic (cognitive/socio-emotional), as well as into general categories including individual differences, team processes, or contextual/situational variables. This variable list also shows which variables are associated with each of the four leadership models.

Intervention Approaches

Based on the lists of key variables, a list of intervention approaches has been created to guide future work. Available upon request, the list contains a list of the condensed variables crossed with the intervention approaches. A multi-pronged approach has been adopted to address these variables. The types of intervention approaches include training, development, selection, work practices, work structure, feedback systems, and job aids. The following section will describe each approach and provide explanations justifying each approach.

Training can be defined as attempts to facilitate the attainment of knowledge, skills, or attitudes, which can be applied in the near future (Cascio & Aguinis, 2010). The benefits of training have been covered in a wide range of domains, from the acquisition of tacit skills to declarative knowledge (Aguinis & Kraiger, 2009; Arthur, Bennett, Edens, & Bell, 2003; Barber, 2004;

Taylor, Russ-Eft, & Chan, 2005). Focusing specifically on training for leaders, Collins and Holton (2004) studied the effectiveness of training programs for leaders and found substantial support with respect to their effects on knowledge and expertise. The results of these studies suggest that training is a viable approach for the acquisition of skills, knowledge, and attitudes for individuals involved in future long-duration space missions.

Development, a related yet distinct approach, refers to the attainment of competencies, which are intended for longer-term and broader application (Cascio & Aguinis, 2010). Although the two approaches are similar, development is a broader, less systematic approach that is more focused on one's personal growth and long-term use (Aguinis & Kraiger, 2009). Bearing in mind that individuals will be selected for a multi-year mission, the need to develop competencies is also warranted. Therefore, development, in addition to training, is a viable intervention approach for improving certain competencies that will be necessary for long-duration space missions.
The third intervention approach that may be useful for long-duration space missions is selection. Selection (Sackett & Lievens, 2008) is a plausible approach for certain variables, as it would reduce time and resources required for training and/or development efforts. Moreover, the skills and abilities required for a long-duration mission are advanced and high-level, and will necessitate a rigorous, systematic selection method to ensure that the most qualified individuals are selected. Specifically, selection procedures will be required for identifying individuals with expert technical skills, in addition to requisite cognitive and socio-emotional traits.

An additional approach identified is work practices, or more specifically, high performance work practices. Such work practices include compensation systems and performance management systems (Huselid, 1995). Support has been found for the utility of this approach in enhancing organizational performance and reducing turnover (Combs, Liu, Hall, & Ketchen, 2006). Furthermore, firms that effectively use compensation and performance appraisal systems are more likely to attract committed employees and more productive employees. In other words, if employees can see the potential benefits of producing high quality work consistently, they are more likely to remain committed to that organization and produce at a high level in expectation that the firm will reward them appropriately (Huselid, 1995). Therefore, these work practices can

be used to adjust an individual's behavior to improve performance in a given task domain by enhancing employees' commitment and productivity levels.

Work structure has been identified as another intervention approach that may prove of significant value. Support for the efficacy of this approach can be found in Job Characteristics Theory, which suggests that five job dimensions influence psychological states in workers (Hackman & Oldham, 1976). These psychological states, in turn, are assumed to influence personal and work outcomes. Three of the job dimensions (i.e., skill variety, task identity, task significance) affect the meaningfulness of one's work, while autonomy influences the level of responsibility experienced, and feedback impacts the knowledge of results (Hackman & Oldham, 1976). Thus, it is important to bear in mind how work is designed as it may affect an individual's investment.

A feedback system is an additional viable approach for influencing these variables. In a similar vein to work practices, providing individuals with feedback will allow them to adjust their behavior accordingly to improve their performance at a later time. Moreover, it is important to note that feedback is most effective when it is provided with respect to the task rather than the person (Kluger & DeNisi, 1996). Therefore, an individual's performance in a particular task domain can be improved by providing explicit feedback to the specific behaviors needed to attain a specified goal.

The final intervention approach is job aids. Job aids provide instructions to a user in the form of words, symbols, pictures, or other methods to assist performance in a particular task domain. Examples of job aids include step-by-step lists, decision tables, and flowcharts. These can be beneficial as they reduce time and cost associated with training (Lineberry & Bullock, 1980). Thus, job aids appear to be a practical intervention approach, as they will allow individuals to acquire the knowledge needed to complete a given task in a little amount of time.

Milestone Three: Interviews

The primary focus of Milestone Three was to conduct interviews with NASA staff that have experience and/or knowledge about past and future space missions[2]. The purpose of these interviews was to inform the development of the models and refine these models as needed. While the interviews were being conducted, model development was still in progress, which allowed the research team to adjust the models accordingly as pertinent information materialized from interviews. The project manager requested that we work in conjunction with Dr. Suzanne Bell, team composition principal investigator, due to the limited availability of NASA staff. Dr. Shane Connelly from our research team and Dr. Bell developed three interview protocols with respect to leadership/followership and team composition for long-duration space missions, one for Mission Control personnel, one for Astronauts/former Astronauts, and one for Support and Behavioral Human Performance personnel. In accordance with these joint protocols, Drs. Bell and Connelly alternated asking interview questions vis-à-vis their respective areas of expertise. The interviews varied in length from approximately one to one-and-a-half hours depending on the availability of NASA staff. Drs. Bell and Connelly adapted the interview protocol according to each interviewee's area of expertise. An interviewee background summary can be found in Table 1. These interviews often unfolded more as discussions, however many of the original questions in the protocol were covered ruing the course of these conversations.

It was assumed that each area of expertise would provide unique insight into current operations at NASA and the future of long-duration space missions. Interviews were structured to provide perceptions of leadership dynamics required for long-duration space missions as well as relevant critical incidents highlighting important factors to consider in Mission Control and crew

[2] *Acknowledgments: We would first like to acknowledge the NASA employees that enabled us to conduct these informative and engaging interviews. We would like to thank those who set up the interviews and the individuals that graciously offered their time to discuss their work and speculate on future missions. In particular, we would like to thank Holly Patterson for scheduling these interviews and allowing us to have insightful discussions with these individuals. The expertise possessed by these individuals provided us with unique insight that illustrate the reality and magnitude of past and future space exploration.*

leadership and team composition. It was our hope that these discussions would provide further insight and justification for the variables in our models.

Preliminary information from the interviews suggests that the models developed for leadership/followership are plausible. The interviews served as a general test of model development vis-à-vis the expertise of experienced NASA personnel and provided support for key variables and the overall structure of the models. The interviews served three critical functions for the current project and future research. First, the interviews confirmed the proposed models they are plausible and will benefit the leadership of long-duration space missions. Second, they allowed for refinement of the leadership models. Third, the interviews served as an impetus for a research agenda to validate the models themselves and investigate issues that may have significant implications on long-duration space missions.

In addition to informing the development of the models, the interviews also provided information about specific aspects of leadership relevant to NASA. These findings contextualized the current NASA leadership paradigm by providing useful information that may be beyond the scope of this report but nonetheless, was beneficial to understanding current leadership structure and operations at NASA. For example, an interview with a Missions Operations Directorate revealed that while the CAPCOM is not considered to be a formal leadership position, many important leadership functions are served by individuals in this role. A former flight director provided additional support for this point, indicating that the CAPCOM serves a key informal leadership role by influencing events that occur within the Mission Control Center. Accounts such as these provided the project staff with additional information to better understand operations within the Mission Control Center and NASA in general. Furthermore, these accounts informed the leadership/followership models and allowed the project staff to revise the models as required.

Several key findings or themes became evident throughout the course of these interviews and warrant a brief discussion to illustrate their importance in guiding the current project. These themes are not exhaustive, as these interviews provided such detail that could not be fully covered in the following section. However, these themes are some of the most relevant to the current project and future leadership operations at NASA.

The first major theme discussed was the need for a paradigm shift in the way leadership operations are executed at NASA for the success of future long-duration space missions. In multiple interviews, NASA personnel discussed the need for increased autonomy in the crew for long-duration space missions, as the increased time lag in communication with Mission Control will make it more difficult to control the mission from the ground. For example, an interview with a former Flight Director revealed that, in future missions, providing the crew with a general outline of the flight plan and increased latitude to execute that plan may be more practical than providing the crew with a structured plan featuring specific objectives and tasks. In support of this point, an interview with a Mission Operations Directorate suggested that the crew may need to have procedures in place for potential failures or emergencies, as Mission Control may not be informed of the situation until significantly after it has occurred. An interview with a former CAPCOM described this increased need for autonomy in terms of an analogue to pioneers colonizing America in that the crew will need to be self-sufficient and cannot always rely on the expertise of Mission Control. This increased time lag and autonomy is not to be ignored, as it will bear critical implications on crew functioning.

Interviews with NASA personnel also suggested a need for a more collective approach to leadership in which leadership roles are not rigidly assigned or designated. An interview with a member of the Psychological Operations Unit revealed that during the selection process, candidates are expected to demonstrate both effective leadership and followership. The ability to step into a leadership role, and also relinquishing the leadership role when necessary, are both vitally important in the selection process. An interview with a former Flight Director reinforced this notion as he suggested that effective leadership is more about consensus building and team management rather than tight-fisted control. Furthermore, he argued that everyone needs to be a technical expert in their specific area and needs to step up as needed. An interview with another Flight Director emphasized this collective approach to leadership as he noted that everyone involved is just one piece of the overall system. To be effective, he made the point that leaders cannot have a military mindset or an “in charge” mentality but rather, should be egalitarian with others. The general consensus among these NASA experts suggests that one authoritarian

member cannot execute these leadership functions, as the technical expertise of multiple individuals will be required for a safe and successful mission.

Milestone Four: NASA Research Agenda

Basic Research Plan

Included here are primarily validation studies of the leadership (and command and control) models asserted in the current report that are based on extensive literature reviews and, to some extent, informational/exploratory interviews with NASA personnel. The key goal is to implement a multi-source, multi-method, multi-study validation design that includes primary and secondary data from a variety of sources (e.g., current and former NASA personnel, past missions, experimental and laboratory studies, habitat studies, and agent-based computational models/simulations). This approach eliminates single-study and common-method bias potential, and provides cross-validation of results. Secondary goals of this work and the results are to provide a basis to potentially help in crew selection and training, and to help in the creation and implementation of key "countermeasures" to enhance long-term space flight for crew performance and well-being.

The planned research study sequence would be as follows:

1. Conduct a series of historiometric studies (see Friedrich et al., 2014; Ligon, Harris, & Hunter, 2012; Parry, Mumford, Bower, & Watts, 2014; Yammarino, Mumford, Serban, & Shirreffs, 2013) to identify the key constructs, variables, and parameters in the conceptual models and frameworks on which to focus in subsequent studies. The source documents here could include not only biographies of eminent leaders to validate general leadership model notions, but also NASA mission reports, including AARs (After Action Reviews), astronaut journal entries, and audio recordings from NEEMO and the ISS to validate specific NASA-related model aspects.

2. Using this information, and somewhat in parallel to the historiometric work, conduct a series of agent-based simulations/computational models (Dionne et al., 2012; Dionne, Sayama, Hao, & Bush, 2010; Fioretti, 2012; Sayama, Dionne, & Yammarino, in press) to validate the conceptual models and frameworks. The strength of the simulations is to model complex relationships, and to do so efficiently thousands of times, in an exploratory way based on simple notions and

parameter estimates from the established literature. This is helpful when the relationships are new, complex, and/or multi-level (see Dansereau, Alutto, & Yammarino, 1984; Dionne et al., 2014; Yammarino & Dansereau, 2011; Yammarino, Dionne, Chun, & Dansereau, 2005) in nature, as in the conceptual frameworks here. The drawback is that different starting points, assumptions, and parameter estimates can yield quite different results. As such, other methods below will also be used to cross-validate these computational modeling results.

3. Conduct a series of (a) semi-structured "probing" interviews and (b) on-line survey studies involving current and former NASA personnel (both astronauts and Mission Control) to identify and clarify any ambiguities resulting from the simulations and computational models. The sampling plan for the interviews and surveys, as well as access to the appropriate NASA and contractor personnel, will require NASA input and support and respective university IRB approvals.

4. Somewhat in parallel to the interview and survey studies, conduct a series of laboratory/experimental studies to identify and clarify any ambiguities resulting from the simulations and computational models. These studies, as they would focus on basic leadership notions in the conceptual models, could be "true" experiments using student participants with manipulations (e.g., NASA training exercises as stimulus materials) and pre- and post-measures. There is ample access to both undergraduate psychology and business students as participants at the universities involved. These studies will require university IRB approvals.

5. Conduct a series of refinement simulations (computational agent-based models) (Dionne et al., 2012; Dionne, Sayama, Hao, & Bush, 2010; Fioretti, 2012; Sayama, Dionne, & Yammarino, in press) based on the information and results from all the prior multi-method studies. These simulations would involve the core constructs and relationships from the comprehensive conceptual models, as identified in the above studies, and can be viewed as the more pragmatic leadership (and command and control) models for implementation. Key outcomes here could be not only crew and Mission Control performance, but also potential training and development program outcomes and important culture and culture-change outcomes. Multiple and varied outcomes and countermeasures at all levels of analysis (i.e., individual/astronaut, dyadic/sortie,

team/crew, collective/Mission Control) (see Dansereau, Alutto, & Yammarino, 1984; Dionne et al., 2014; Yammarino & Dansereau, 2011; Yammarino, Dionne, Uk Chun, & Dansereau, 2005) can be examined.

6. The results of all this validation work and these numerous studies can then be used to identify and specify markers for all key variables and relationships asserted in the conceptual models and frameworks. These markers are critical for any future and/or related research and for interventions for (a) training and development programs, (b) performance metrics and performance management, (c) building "expert systems" (see below), and (d) creating "forecasting systems" (see below). Essentially, the validated leadership models (at least the validated core components, constructs, and relationships) and resulting data can serve as the input for these programs and systems.

7. Although difficult to build and implement, ideally these markers, at least for the core components of the models involved, would then form the basis of a computer-based "expert system", or a series of expert systems, and training and development programs that could be implemented in the HERA and NEEMO. Such expert systems involve building a keyword "dictionary", then "seeding" the keywords with information (e.g., from on-line or archival communications between crew and Mission Control), executing a "learning" phase for the system, and then validating it, to ultimately produce, in this case, actual leadership (and command and control) online scores. Studies based on the expert systems could be both observational and experimental in nature involving astronauts and Mission Control personnel. The ultimate goal here is to enhance the performance of the crew and Mission Control, affect any culture change required to complete the mission successfully, and identify key countermeasures to implement to ensure a safe and effective mission.

8. Likewise, difficult to create and implement, the expert systems and scores (i.e., scoring system), at least for the core components of the models involved, could then form the basis of a computer-based "forecasting system", or a series of forecasting systems, and training and development programs that could be implemented in the HERA and NEEMO based on them. Essentially, leadership behavior forecasts would be produced online for planning, projection, and

adaptation purposes to enhance mission safety and success. Clearly, beyond long-time line requirements for creating and testing such forecasting systems, there is the need for extensive training on system use.

9. Finally, for both the expert systems and forecasting systems, although based on validated leadership (and command and control) models, there is a need to conduct direct appraisals of effects of the systems, including their actual use and practice, within the NASA leadership and command and control system. This phase of the research is essentially the "real-world" validation and check on all the prior research phases applied specifically to the NASA environment.

Supplemental Research

The basic research plan highlights some of the most critical and pressing of research needs. This supplemental research section serves to build off the basic research plan and some of the implications therein. Most notably, the basic research plan implies new models of leadership and new procedures for providing feedback about leadership, that is, an online forecasting system. Many of the supplemental research suggestions are based around clarifying and gaining a better understanding regarding some of the implementation requirements and implications of these new models and systems. Flowing from discussions regarding the needs for future research, with respect to long-duration space missions, a number of key principles have guided this research agenda. The key principles are: 1) that training models must be developed for each of the proposed leadership models, 2) training models need to be developed to manage the role switching decision framework and conflicts in this decision framework, 3) feedback systems must be developed, and 4) error management systems need to be developed vis-à-vis this feedback to minimize errors. These key principles lead us to specific short-, mid-, and long-term studies that will help guide future work

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Training models must be developed for each leadership model. As the context of leadership in long-duration space missions necessitated novel leadership models, so too will the training programs for these models require specific tailoring to enhance training transfer and effectiveness (Blume, Ford, Baldwin, & Huang, 2009; Gilpin-Jackson & Bushe, 2007). Specific

work will be needed to identify what variables from the models are most amenable to training, as well as what types of training will be most useful. It will be necessary to develop specific training models for Mission Control and the crew for all the proposed models.

Training models need to be developed to manage the role switching decision framework and conflicts in navigating the decision framework. Competition will naturally arise amongst individuals over assuming leadership roles and thus, two key issues need to be addressed to reduce this potential for role conflict (Jackson & Schuler, 1985; Rizzo, House, & Lirtzman, 1970). First, individuals must know the role preferences of others and be able to identify potential role conflicts that may arise before they become an issue. Second, Mission Control personnel and crewmembers must be trained to identify the markers attached to each leadership model to switch roles effortlessly. Each asserted leadership model bears distinct markers that can make it more clear what role to switch to. Also, there is a need to understand and switch between leadership models, which implies there will be conflict. Mission Control personnel and crewmembers must be aware of these potential conflicts and errors embedded within this integrated leadership model and be trained to preemptively identify and reduce these conflicts and errors.

The active online system to be developed suggests that reactions to feedback from the system will be critical to Mission Control and crew performance (Atwater & Brett, 2006; Atwater, Wang, Smither, & Fleenor, 2009; Weisband & Atwater, 1999). Moreover, a real-time system implies that the feedback will be ongoing and therefore, individuals using the system must know how and when to provide the feedback to maximize effectiveness. Individuals are expected to learn from the active online system, which implies that self-reflection and forecasting are needed (Byrne et al., 2010). Taken together, this principle implies significant value in developing a better understanding how and when to best deliver feedback through the active online system to encourage feedback acceptance and understanding.

Error management systems must be developed vis-à-vis this feedback to minimize errors to ensure that the system can provide incremental value to performance. Leader errors refer to an avoidable action or inaction selected by a leader, which leads to an outcome outside the leader's

original intent, goal, or prediction (Hunter, Tate, Dzieweczynski, & Bedell-Avers, 2011). Past work on this topic points to various situational factors, such as process overload, that can lead to negative performance (Eubanks & Mumford, 2010). Therefore, Mission Control personnel and crewmembers would benefit from training on understanding the feedback provided by the online forecasting system and how to respond appropriately to this feedback. Bearing in mind these four key principles several short-, mid-, and long-term studies seem warranted.

Short-Term Studies

- Develop training for models, for Mission Control and crew, for collective, crisis/emergency, dyadic, and socio-emotional leadership
- Identify switching diagnostics
- Develop leader-team interaction model, for Mission Control and Crew
- Identify leadership feedback and adaptation models
- Integrate leadership and team models
- Identify model conflicts and resolution strategies
- Identify procedures for appraising leaders based on numerical feedback
- Identify procedures for negotiating leadership roles
- Identify errors made in appraising feedback on leadership
- Identify conditions giving rise to collective, dyadic, socio-emotional, and crisis/emergency models
    - Self-reflection and forecasting vis-à-vis models' principles

Mid-Term Studies

- Field test (i.e., collect empirical evidence, not necessarily from NASA personnel) training models, including collective, crisis/emergency, dyadic, and socio-emotional leadership
- Develop training models for diagnostics and switching
- Develop Mission Control and crew interaction models
- Field test feedback and adaptation of models
- Identify system markers for Mission Control and crew vis-à-vis forecasting
- Develop models for integration of leadership and teams

- Field test conflicts and resolution strategies
- Identify errors made in feedback appraisals
- Formulate procedures for providing feedback concerning leadership
- Identify conflicts and errors in feedback
- Field test role negotiation
- Field test errors made in responding to feedback
- Field test conditions
- Field test self-reflection and forecasting training

Long-Term Studies

- Refine operational training model, including collective, crisis/emergency, dyadic, and socio-emotional leadership
- Field test training models for diagnostics/switching
- Refine training models for diagnostics and switching
- Field testing Mission Control and crew interaction models
- Refine operational feedback and adaptation models
- Develop feedback systems
- Field test integration of leadership and teams
- Train models for managing conflict and resolution strategies
- Develop techniques for error management
- Field test individual feedback procedures
- Field test techniques for monitoring conflicts and errors
- Develop feedback and error training program
- Develop programs for inducing collectivity
- Develop self-reflection and forecasting training

Other Research Ideas

Included here are additional research studies suggested by the current report and the informational/exploratory interviews that are not necessarily validation related, but may warrant attention in future leadership (and command and control) work. Generally, most of this research

would occur subsequent to (but also perhaps somewhat in parallel with) work outlined in the prior section. That is, after the leadership (and command and control) models have been fully validated, refined via the expert systems and forecasting systems and HERA and NEEMO studies, and implemented. The focus here could be on various antecedents, outcomes, and countermeasures that, while perhaps not central to the conceptual models and frameworks, can nevertheless impact mission safety and success.

Short-Term Studies

- Integrate all leadership models to better illustrate and understand the dynamics of the leadership models
- Study the impact of contextual factors on feedback delivery systems
    - Examine the influence of psychological factors (e.g., burnout, anxiety, and loneliness) on feedback acceptance
    - Identify and examine the effectiveness of consultation strategies used by leaders
    - Identify and examine the aspects of the work environment that foster effective consultation
- Conduct experiments and correlational research of dyadic performance
    - Examine the main and interactive effects of disruptive factors such as time pressure, task ambiguity, criticality of consequences, and clarity of expertise
    - Identify the key dyadic team processes that promote effective performance under disruptive versus routine conditions
    - Examine the effects of personal history between dyad members on proximal and distal performance
    - Investigate the influence of formality of exchanges on dyadic performance
- Investigate the effects of variations in the interpretation of standard operation procedures
    - Examine how mismatch of interpretation influences task outcomes
    - Identify interventions to increase procedure compliance
- Conduct social network analyses of Mission Control and crew relationships and performance
    - Compare and contrast how network centrality is related to individual performance and well-being
    - Identify the key causes and outcomes of clique formation

    - Examine how changes in social network structure over time relate to performance

Mid-Term Studies

- Convert all leadership models to process models, as opposed to causal models, to facilitate training
    - Work out processes for executing dyadic and socio-emotional leadership models
    - Determine what the collective needs to be doing and what the leader (individual-level) needs to be doing to assist in the development of process models
- Develop interventions to understand differences in how Mission Control and crew interpret information
    - Examine Mission Control and crew responses to hypothetical prompts
    - Train and evaluate Mission Control and crew on feedback acceptance
- Examine the effect of family stability on leadership performance
    - Investigate proximal and distal effects of significant family events
    - Identify outcomes of prolonged absence of familiar support
- Investigate interventions to build trust and camaraderie
    - Identify effective formal and informal methods to achieve optimal levels of cohesion
    - Examine the outcomes of enhanced feelings of collectivity
- Conduct emotional-priming studies of socio-emotional leadership
    - Examine the effects of emotions such as anger or frustration on performance
- Study the effects of boredom on leadership performance
    - Examine effects of short- and long-duration periods of inactivity on performance
    - Identify countermeasures to reduce effects of boredom

Long-Term Studies

- Use quantitative results from pre-mission training to influence culture
    - Identify optimal method for inducing cultural changes in Mission Control and crew
- Create training tools using simulated outcomes to demonstrate comparisons between optimal and chosen paths
    - Identify effective methods to reduce differences between optimal and chosen paths

    - Determine the most effective method to relay this feedback to trainees
- Train personnel in the use of forecasting system before and during mission
    - Identify methods to adapt or change forecasting system
    - Determine optimal system design to reduce need for training
- Refine and evaluate leadership training and development interventions
    - Review recent literature and update programs

Conclusions

This report serves to summarize the work done for contract #NNJ13487783Q concerning leadership/followership for long-duration exploration missions. In accordance with the contract five milestones were completed: 1) conducting a literature review, 2) identifying and evaluating methods to improve leadership and followership, 3) interviewing experts regarding pertinent issues related to this contract, 4) creating a draft of the final report, and 5) creating a final report.

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Table 1

Interviewee Background Summary

Position	Area	Interviewed	Years Experience	Area of Expertise	Notable Missions
Psychological Operations	BHP	1	20+	Selection, providing psychological support	Shuttle/Mir, ISS
Mission Operations Directorate	Mission Control	1	30	Training teams	ISS
Psychological Operations, Flight Management	BHP	1	Information not obtained	Training crews and flight controllers	ISS
Flight Director	Mission Control	2	20+; 20	Ensuring crew safety and success	Space Shuttle, Shuttle/Mir; Shuttle/Mir, ISS
Psychological Operations, Psychiatry	BHP	1	8	Psychological countermeasures	ISS
Mission Operation - Russia	Mission Control	1	20+	Physiological countermeasures, cross-cultural issues	Shuttle/Mir, ISS
CAPCOM	Mission Control	1	Information not obtained	Providing crew support	ISS
Astronaut	Astronaut	2	15+; 20+	Mission execution	Mir, ISS; Mir
Jet Propulsion Laboratory, Planner	JPL	1	Information not obtained	Planning	Mars rover

Figure 1: Integrated Model

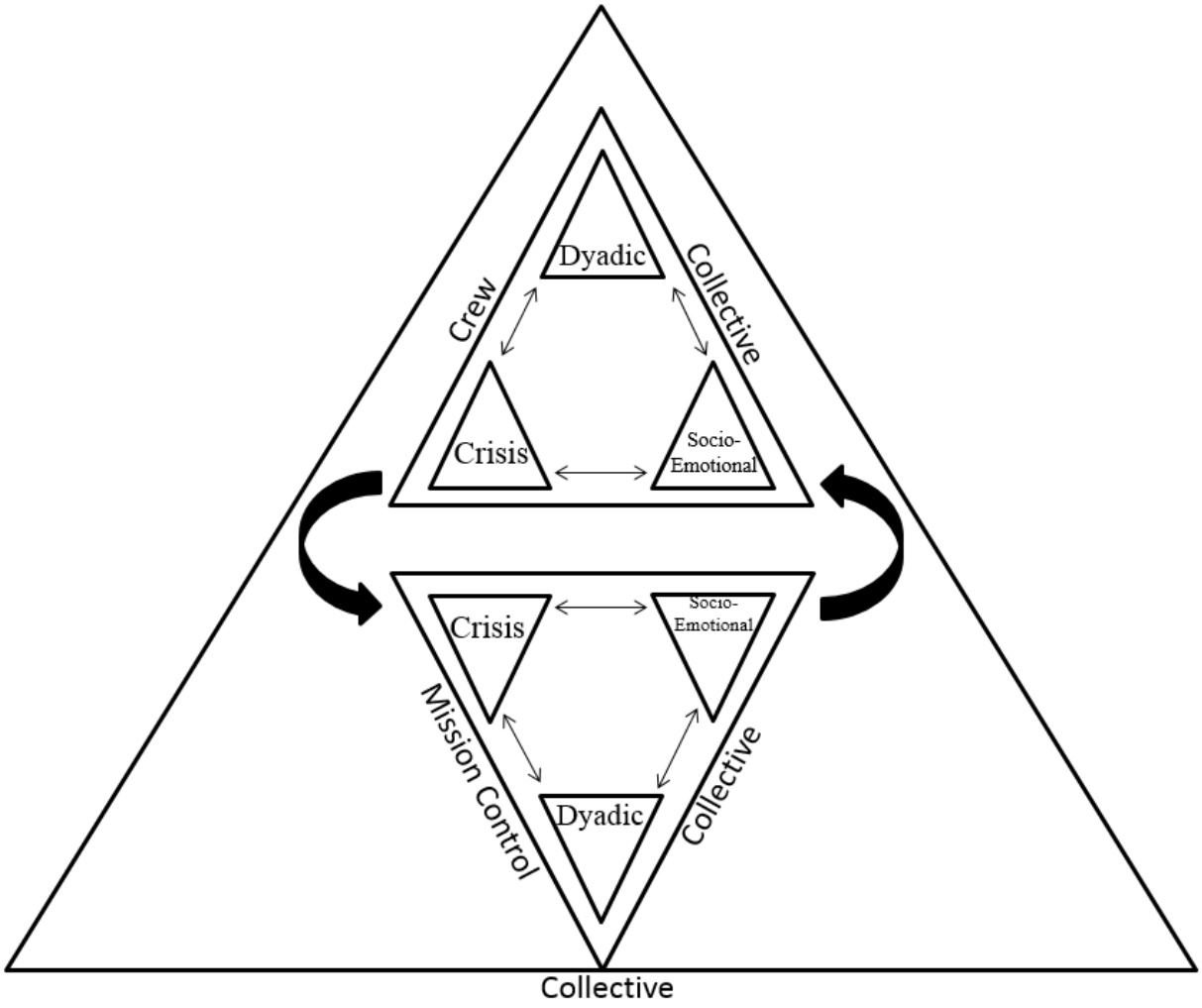


Figure 2: Collective Leadership of Scientists and Engineers

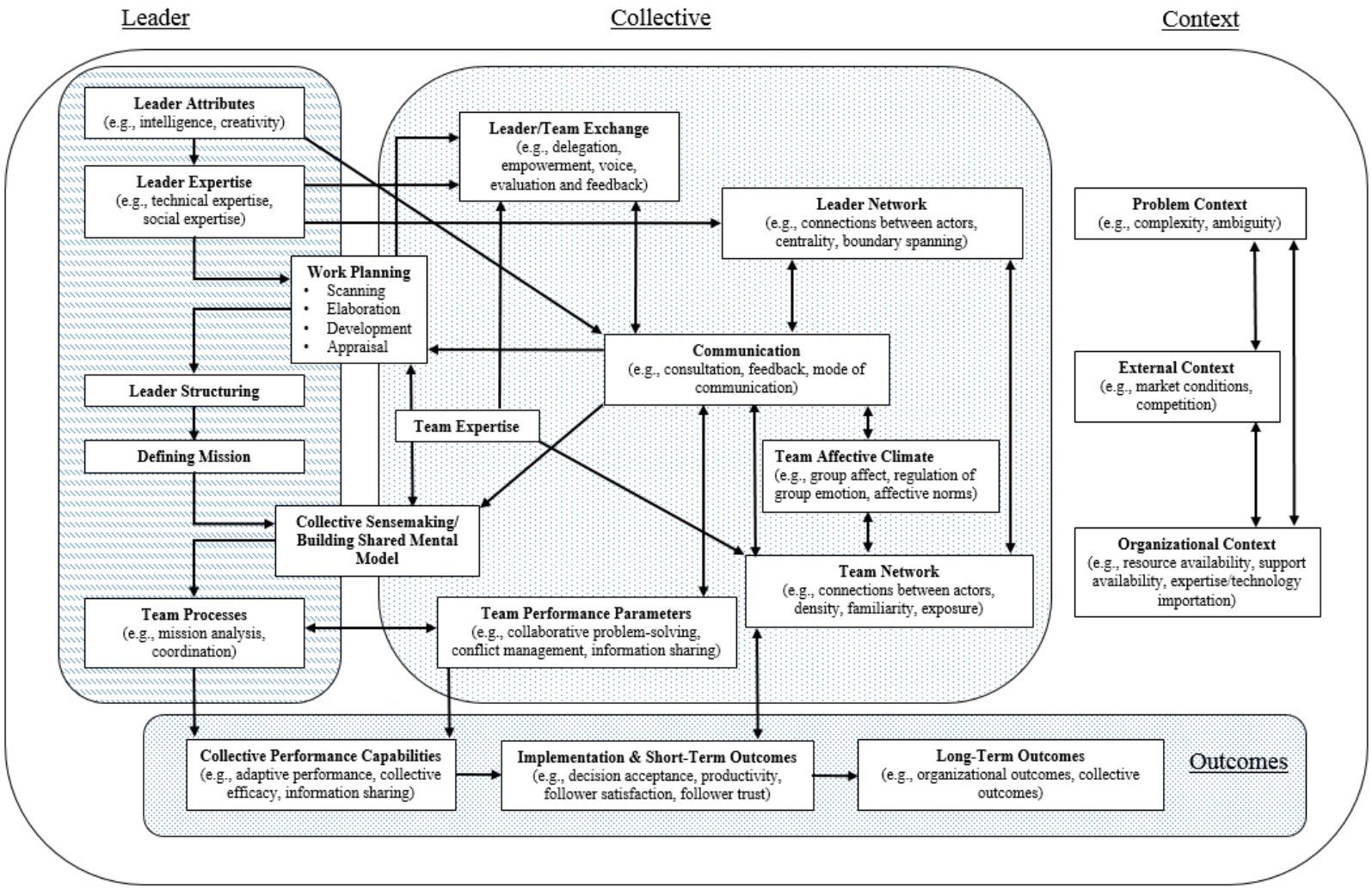


Figure 3: Socio-Emotional Leadership

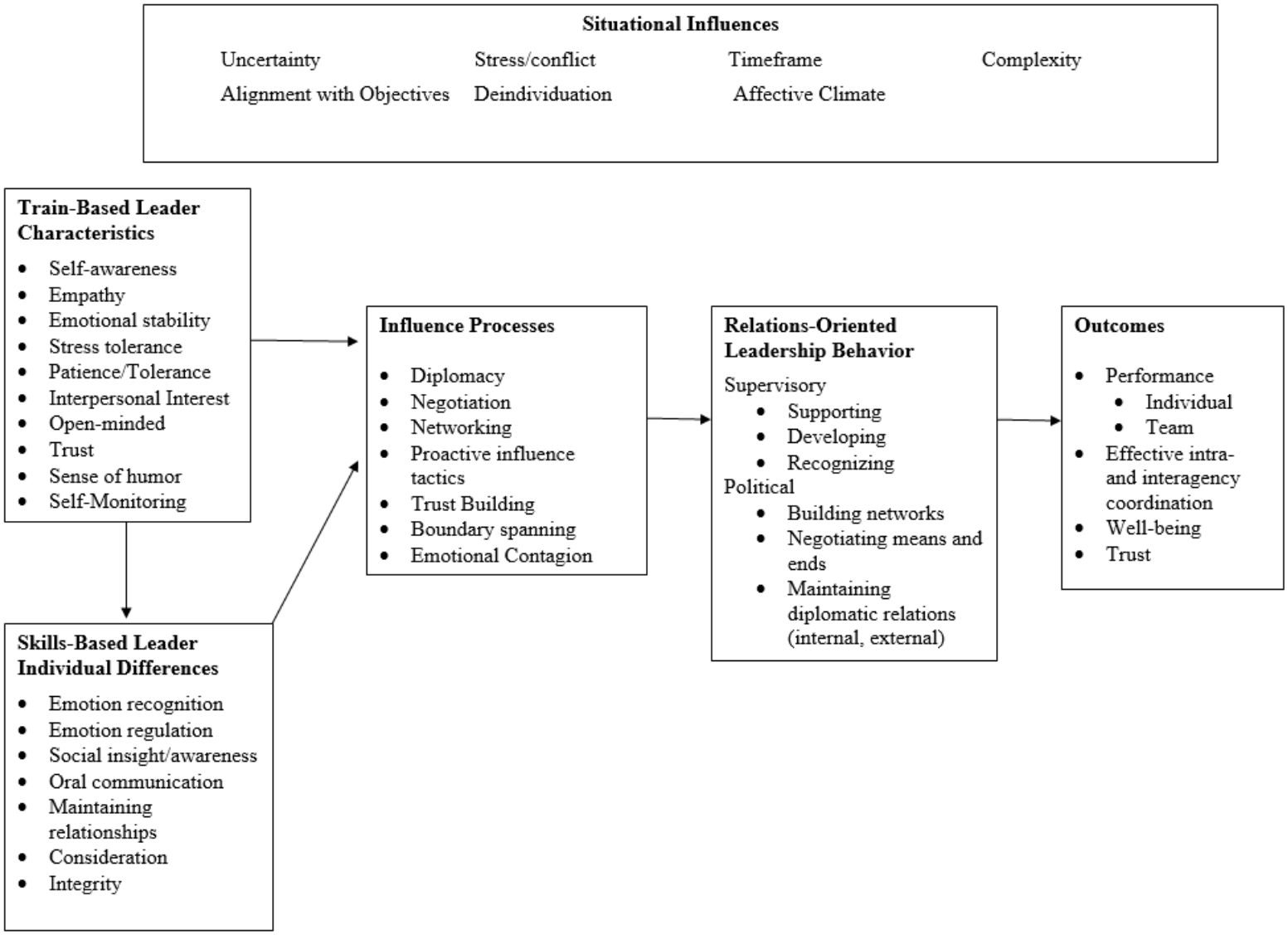


Figure 4: Crisis/Emergency Leadership

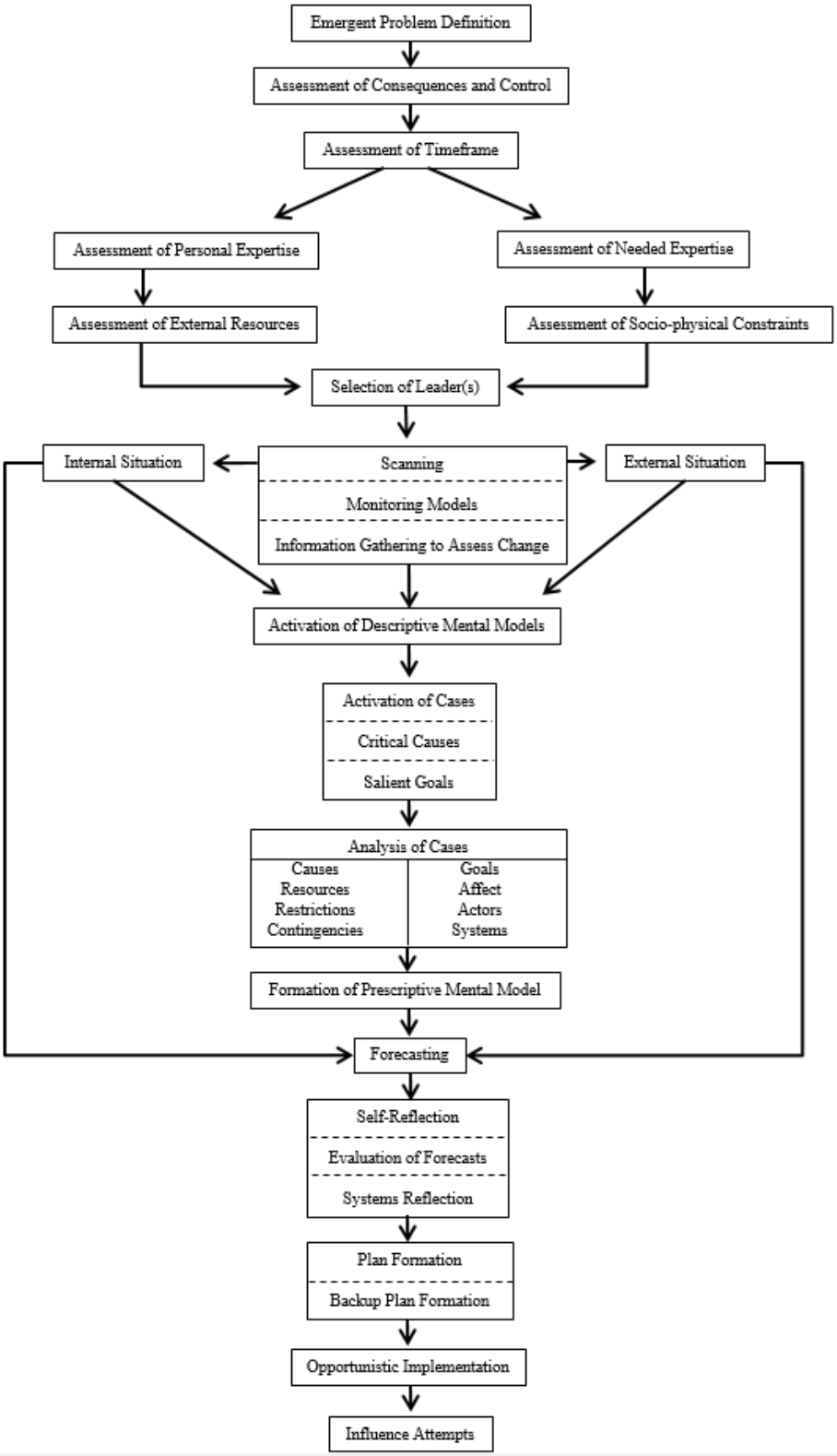


Figure 5: Dyadic Leadership

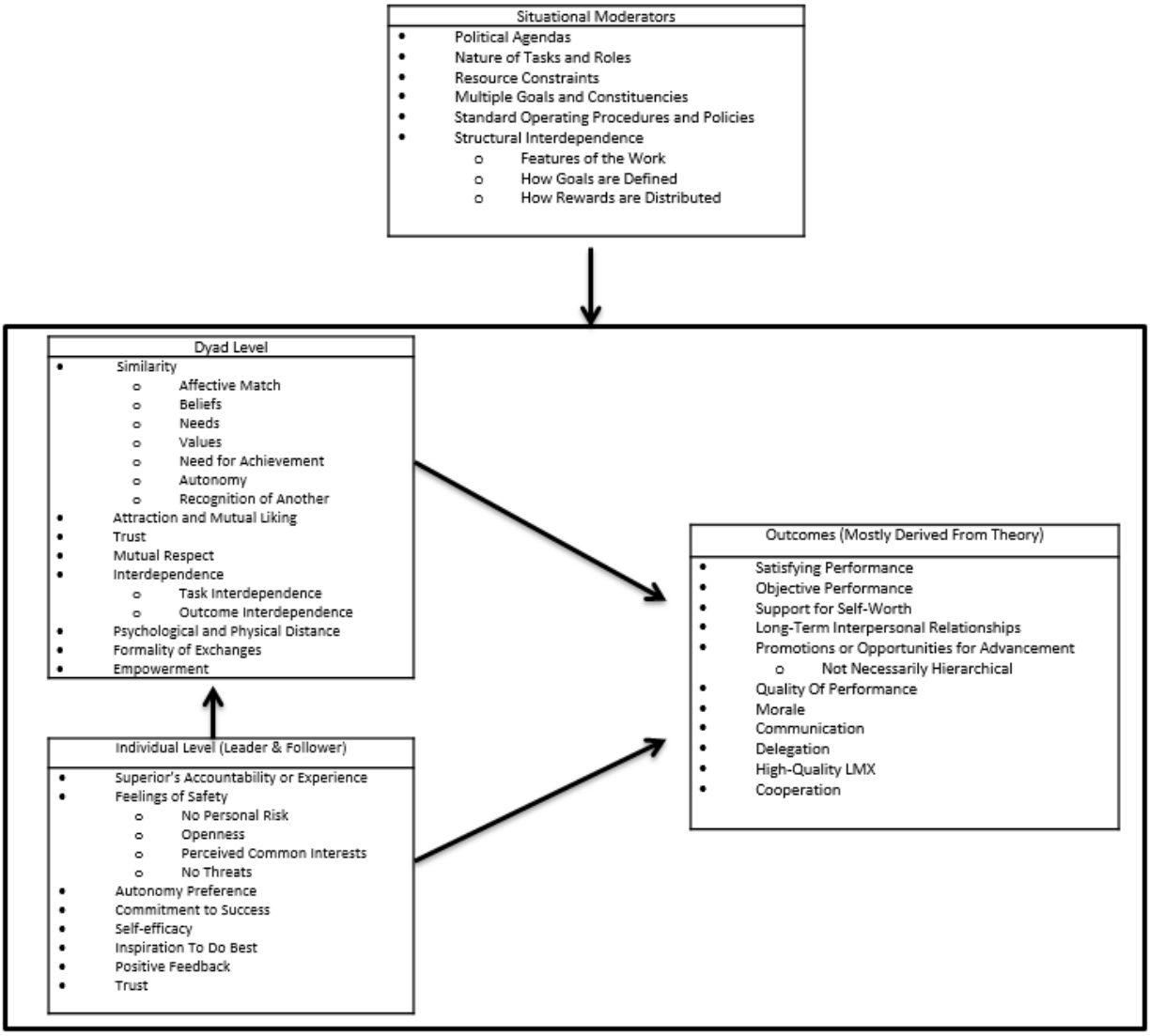
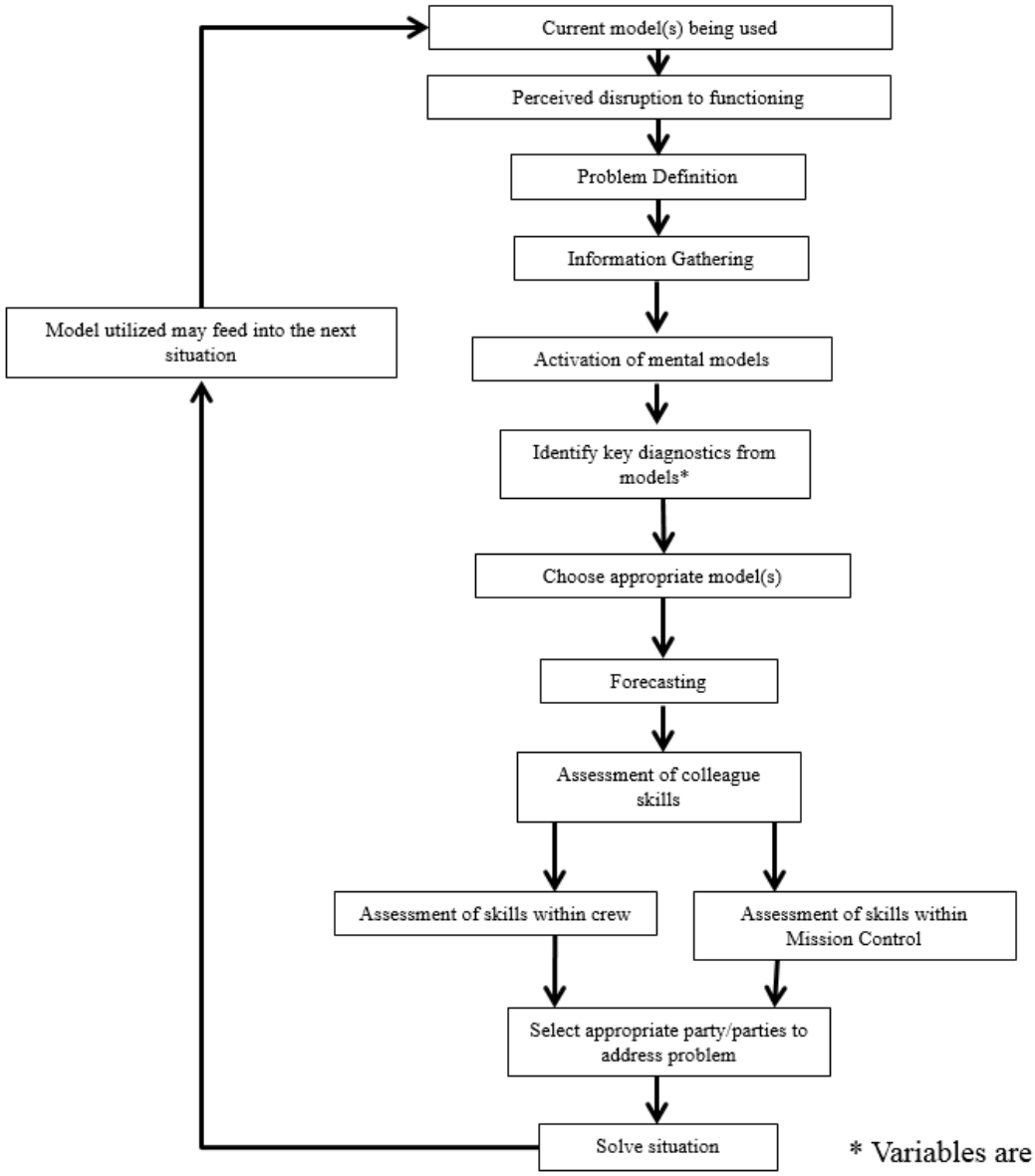


Figure 6: Role Switching Decision Framework



* Variables are listed; markers of these variables are not at present known

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13. ABSTRACT *(Maximum 200 words)*
This report describes the contract "Leadership/Followership for Long-Duration Exploration Missions (#NNJ13487783Q)," Michael D. Mumford, The University of Oklahoma, Principal Investigator. To start, a literature review identified the key conceptual issues and empirical findings with a review of: 1) relevant leadership content areas, 2) leadership in analog environments, and 3) leadership in analog job settings. Building from this review, an integrated leadership model was developed outlining the key capacities needed for Mission Control and Astronaut Crew leadership. This integrated model subsumes four leadership sub-models including the collective leadership of scientists and engineers, socio-emotional leadership, crisis/emergency leadership, and dyadic leadership, as well as a role switching decision framework for changing between models. We then provide recommendations for improving leader and follower performance. These recommendations include critical cognitive and social attributes likely to contribute to effective Mission Control and Astronaut leadership, as well as potential interventions for enhancing performance for each attribute. To supplement the literature review we conducted interviews with NASA staff to receive expert perspectives on effective leadership for long-duration space missions. This information, in turn, was used to assess the plausibility of, and to further develop, the proposed models. Upon completion of the interviews, a future research agenda was created.

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