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Factors Influencing the Effectiveness of Managing Human–Robot Teams

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Walden University
2022

Abstract

Factors Influencing the Effectiveness of Managing Human–Robot Teams

by

Theodore B. Terry

MS, Webster University, 2004

BS, McKendree University, 1996

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Management

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Abstract

Certain factors can influence the capabilities of a robot–human team by affecting their social and behavioral dynamics in a work environment. But these factors were not known due to the progressive nature of human–robot partnerships and a lack of peer-reviewed literature on the topic. This e-Delphi study aimed to identify and understand these unknown influential factors based on the participants' insights. The overarching research question asked about the need to determine factors that might influence the effectiveness of managing human-robot teams. The basis for the conceptual framework for this study was the theory of communication used in organizational management. Twelve participants with backgrounds in management, software engineering, robotics, or a combination answered open-ended and closed-ended questions in three data rounds through SurveyMonkey. Excel and Python were used to analyze the data. Eight factors, and 10 subfactors emerged from the analysis and showed a relationship to the influential dynamics in communication, trust, sociostructural entanglement, and decision-making, which are integral to organizational and human–robot workforce management. Human–robot workforce management is a new paradigm in organization management. The results of this study may engender positive social change by augmenting human capabilities, such as assisting vulnerable or challenged individuals who require continuous assistance, performing activities detrimental to human life, and performing lifesaving measures, such as search and rescue.

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Dedication

To dream and have hope are intrinsically woven together with the desire to establish and pursue goals—the embracement of purpose. We all have goals. Some goals are personal, and others are, shall I say, more social in nature. These are the ones created to invoke positive social change to make this world better for everyone.

When you and I examine the current social climate of our local, regional, and global communities, we find that change is necessary because of generations of instituted inequalities. To invoke positive social change, we must have hope, we must have faith, we must have a plan, and we must have involvement. Otherwise, a dream is nothing more than a dream where prayers are exercised without faith, and faith perishes because there is no evidence of work, better known as empty rhetoric.

I would like to dedicate this dissertation in memory of my dad and mom, Elgia and Pearl Terry, who passed away several years ago. They always inspired and encouraged me to aim high and press toward my goals with grit and determination. As educators, they made a positive impact on people from all walks of life. As lifetime learners, they stood on the shoulders of our ancestors and others who came before them. They always were my role models for what purpose looked like.

Acknowledgments

First, I want to thank GOD, the merciful and graceful Creator of the universe, for His unconditional and endless love. Thank you, LORD, for ordering my steps as I set out on this journey, for providing me with the endurance to run this academic marathon, and the vision to see beyond the barren desserts, mountainous terrain, and endless forest of distractors and obstacles.

Thank you prayer warriors for your faith and continuous prayers as I endeavored to complete this academic journey.

I want to express my most profound appreciation and gratitude to the members of my dissertation committee: Dr. Robert Levasseur, Dr. David Gould, and Dr. Kimberly Anthony, for their overwhelming support. Thank you for your enthusiastic encouragement, invaluable guidance, and mentorship throughout this research.

I also want to thank my sisters, Diane, Paula, Eileen; my brother, Bruce; and my children, Tamara, Tasha, Bernard, and Chloe. Thank you for keeping the faith and patience and me on my toes.

A special thanks to all the people who participated in my research. This work would have been null and void without your subject matter expertise.

I would be remiss not to mention my cheering squad; thank you for your thoughtful and comprehensive criticism and words of encouragement; we made it!

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Chapter 1: Introduction to the Study

Various research studies on robotics have referred to the development and use of robot platforms or robotic systems, with simple renditions and uses of mechanical and steam/pneumatic-powered robotic systems development appearing as early as 1023-957 BC (Goodrich & Schultz, 2007; Iavazzo et al., 2014; Yates et al., 2011). Today, the concept of using autonomous robots as collaborative teammates is an emerging dynamic in the management of human–robot teams or hybrid teams (AFOSR, 2018; Hoffman, 2019). There are unknown factors that can influence the effectiveness of managing human–robot teams, though known influential factors already exist within the dynamics of human teams' environments. The complexity of interaction between team members contribute to the success of the organization by (a) the cross-pollination of ideas; (b) the sharing of knowledge on best practices; (c) continuous education and training programs; and (d) promotion of organization unity and identity through institutionalized practices (Barnard 1938/1968; Bolden, 2011; Levi, 2001). Intuitively driven working relationships, including spontaneous collaboration, are immeasurable influential factors that are part of the social, environmental dynamics within a formal or informal organization (Barnard, 1938/1968; Bolden, 2011; Levi, 2001).

Chapter 1 contains a description of the background of the problem, the purpose, and the research question that provides direction for the research study. Additionally, this chapter includes the conceptual framework, assumptions, limitations, and restrictions in association with the research foundational to this study and a concluding summary.

Background of the Study

The definition of a robot is an autonomous intelligent entity that is collaborative and socially adaptive, capable of self-learning and self-governing, with the "ability to alter its work environment" (National Science Foundation, 2020, p. 1). A human–robot team consists of one human entity and one robot entity (Chauncey et al., 2016). The teaming ratio may consist of many human entities and one robotic or robot entity, one human entity and many robot entities, or many human entities and many robot entities (Chauncey et al., 2016; Nikolaidis et al., 2015).

The concept, development, and use of robot platforms or systems have been around for centuries. Early renditions of robotic, mechanical, and steam/pneumatic-powered, systems development appeared as early as 1023-957 BC (Goodrich & Schultz, 2007; Iavazzo et al., 2014; Yates et al., 2011). Robotic systems were functioning well before Isaac Asimov in 1942 coined the term robotics "to describe the study of robots" (Yates et al., 2011, p. 1708). Yan Shi (1023-957 BC), Aristotle (322 BC), Ctesibius (250 BC), Heron of Alexandria (10-70 AD), and Leonardo Da Vinci are potential contributors to the concepts in Karel Capek's 1920 play entitled, "R.U.R.: Rossum's Universal Robots," which introduces the Czech term *robota*, meaning artificial people or mechanical agents (Iavazzo et al., 2014; Yates et al., 2011).

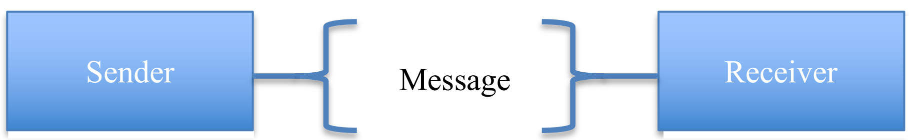
There is no definitive answer on what exactly a robot is (AFOSR, 2018; Yates et al., 2011) or how a robot should function within a human-robot team or society. LaFrance (2016) provided some insight by stating that a robot is a mechanical or virtual system capable of mimicking certain human physical behaviors or executing decisions through data collection programming or intellectual selection using artificial intelligence. Yates et al. (2011) stated how such systems of automation could function with some degree of intelligent autonomy for medical purposes, allowing surgeons to execute more precision and less taxing procedures, particularly in areas requiring robot-assisted surgery. Christoforou and Müller (2016) proposed human-like features as described in Capek's Rossum's Universal Robots play, extending the possible inclusion within mainstream society. The perception that a robot must bear some human resemblance, to include the functional capacity to existing, is purely fictional or limited due to the immaturity of the technology (Amici, 2015; Melis & Semmann, 2010; Nguyen et al., 2018; Zak, 2017). As the need for autonomous robots or robotic platforms or systems increases, so will the reduction in repetitive tasks, and improvements in precision of delicate medical procedures (Iavazzo et al., 2014; Yates et al., 2011).

The trend in robot or robotic systems evolution, from the genesis of mechanical and steam/pneumatic power to current robot or robotic systems of today, promotes the concept of building and managing human–robot teams (AFOSR, 2018; Iavazzo et al., 2014; NSF, 2020; Yates et al., 2011). But discussions over the centuries on the potential usages of robots and robotic systems have not included discussions of factors that might influence the effectiveness of managing human–robot teams. Not knowing these influential factors can have a profound effect on understanding the teams'collaborative behaviors on managing task assignments. Specific factors of cohesion, such as belonging within a homogenous human team, differ significantly for a heterogeneous human–robot team due to the absence of emotional intelligence and self-awareness in autonomous robot systems (Dautenhahn, 2007; Floreano & Mattiussi, 2008).

The complexity of interactions within a social and collaborative environment requires some form of communication, specifically within a team, regardless of the team composition (AFOSR, 2018; Levi, 2001; NSF, 2020). The basic form of communication, as derived from Levi (2001) and Shannon (1948) is a sender transmitting a message to a receiver, and a receiver receiving the message (see Figure 1).

Figure 1

Sender Receiver Communication Model



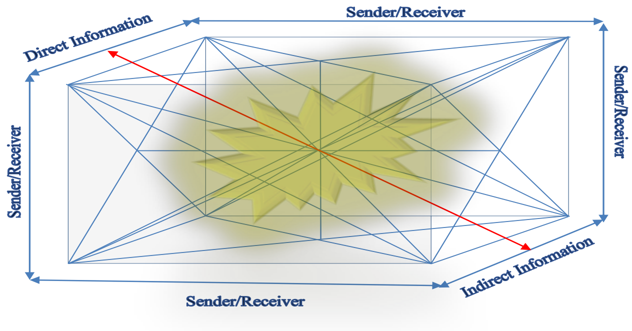
Note. The transmission of a message by a sender to a receiver is unidirectional.

Communication (Shannon, 1948) and information sharing (Hartley, 1928; Weaver, 1949/1964) are essential for the establishment and sustainability of any relational interactivity to occur between two or more members of a team, including a homogenous team of an autonomous robot and human teammates. The foundational premise of information sharing is to convey a message that elicits a quantifiable response from the recipient (Hartley, 1928). Barnard (1938/1968) and Hartley (1928) further stated that information is either direct or indirect, depending upon the sender, contents of the message, the audience or receiver, the methods of message conveyance, and speed of delivery. The complexity of communication dynamics (see Figure 2), as derived from

Levi (2001) and Shannon (1948), centers around the transmission and reception of direct or indirect information and the behavior responses between entities (Hartley, 1928).

Figure 2

Information and Communication Dynamics



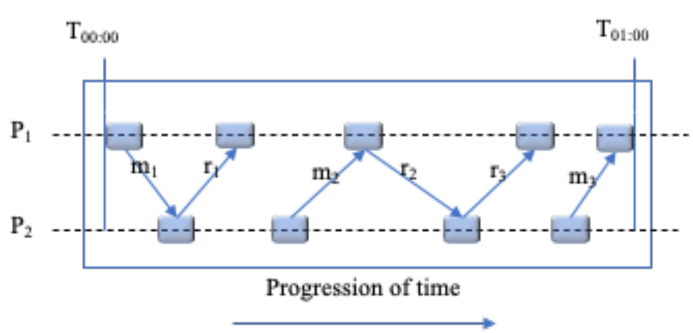
Note. The communications dynamic model showing how external influences may impact the transmission of information between two entities.

The dynamics in communication activity between two individuals or two points might also result in message spillover, where recipients within proximity may unintentionally receive messages sent to others (Hartley, 1928). Message spillover, along with the cross-contamination of noise from a variety of sources may alter or interrupt signal transmissions, causing a misunderstanding or content in the message reception (Hartley, 1928). Noise, in the transmission of information is external interference that causes a degradation in signal quality and is almost impossible to eliminate (Hartley, 1928). The dimensions and directional complexities of information and communication dynamics are subject to environmental influences, such as noise, which can affect the receiver's interpretation of the message, include any responses as a result of the receiver's perception of the content of the message.

Effective and meaningful communication within a socio-geospatial environmental grouping of team members results in better collaboration, social cohesion, and reduction in isolation (Baluska, 2010; Barnard, 1938/1968; Schulz-Bohm et al., 20158). How the cohesiveness of information exchange relates to the effectiveness of managing human-robot teams remains unknown (AFOSR, 2018; NSF, 2020). In contrast, subject related literature on team composition, team dynamics, and relational team management is widely available for regular human teams (Garfield et al., 2020; Guo et al., 2021; Levi, 2001). The modeling of information exchange (see Figure 3) within a given time slice is a regular occurrence of communication between two people, where P_n = person, m_n = message, r_n = response to a message, which is a derivative of Hartley's (1928), Levi's (2001), and Shannon's (1948) definition of communication and transmission of information.

Figure 3

Interactive Conversation Event Model



Note. The interactive conversation event model shows the dynamics of information exchange between two individuals over a course of time, where P_n = person, m_n = message, r_n = response to a message.

An autonomous robot, as a collaborative team member, is suitable for activities such as search and rescue, search and recovery, assisted social living, disaster relief, and hazardous environment exploration (AFOSR, 2018; NSF, 2020). The influential factors leading to the identification of successes and failures of managing human-robot teams is unknown due to the absence of literature on the subject, including environmental studies (AFOSR, 2018; NSF, 2020). The lack of literature is a concern as government and non-government agencies identify and implement technical agendas that incorporate the use of artificial intelligence and advanced analytics and modeling toward the employment of robots or robotic entities for collaborative work. Knowing what influential factors that may influence the effectiveness of managing human-robot teams requires interviewing subject matter experts in the research and development areas of advanced analytics and modeling, data management, modern software engineering, artificial intelligence, and robotic systems.

Problem Statement

Hybrid teams consisting of human agents and advanced intelligent robotic or advanced intelligent machine agents, without the ability to communicate with one another, remain ineffective. The composition of any well-functioning heterogeneous or homogeneous team requires consistent communication to foster trust and influence (Shannon, 1948; Weaver, 1949/1964). The ability to identify, process, and comprehend environmental influences through interactions (Van Ruler, 2018) can potentially distort or enable the effectiveness of a human-robot team (Deutsch, 1958). The accuracy and interpretation of information (Thomaz et al., 2016) can dynamically impact the effectiveness of decision-making processes (Michael, 2016; Pfeifer & Scheier, 1999). The general management problem was that the factors influencing the effectiveness of managing human–robot teams within a human–robot work environment are not clear (Hoffman, 2019; Lucci, 2013; Martius et al., 2013; Pfeifer & Scheier, 1999). The specific problem was that managers lack knowledge of the factors influencing the effectiveness of managing human–robot teams within a human-robot work environment, as human–robot teams do not yet exist (Baude & Sachs, 2017; Cominelli et al., 2018; Shannon, 1948; Weaver, 1949/1964). This may affect managers' ability to manage these human–robot teams effectively as they are developed.

Purpose of the Study

The purpose of this e-Delphi technique study was to gain insight into factors that could influence the effectiveness of managing human–robot teams within a human–robot work environment by using the opinions from experts in the field of robotics. The e-Delphi technique involves questionnaires, feedback, and correspondence with participating expert panel members through various types of electronic media, like email and other online methods, rather than the face-to-face or group interviews used in the classical and modified Delphi techniques (Davidson, 2013). The classic Delphi technique involves using an iterative data collection and analysis process consisting of three to five rounds of data collection, beginning with an open-ended questionnaire, followed by two to four questionnaires stemming from the responses to the questionnaire. The modified Delphi differs from the classic Delphi method. The former involves using face-to-face interviews or a focus group to gather responses based on a review of relevant literature, while the latter "requires panel members to remain anonymous to each other" (Davidson, 2013, p. 55). The electronic-Delphi technique or e-Delphi technique is an electronic extension of the modified Delphi, a variant of the classic Delphi (Davidson, 2013).

Research Question

What factors influence the effectiveness of managing human–robot teams within a human–robot work environment?

Conceptual Framework

The conceptual framework for this study was grounded in Chauncey et al.'s (2016) co-adaptive human–robot interaction framework, Ito's (2020) theory of human–machine metacommunication, and Shannon's (1948) and Weaver's (1949/1964) mathematical theory of communication. The co-adaptive human–robot interaction framework relates to how relational dynamics and hierarchal interactions occur between a human and a robot entity (Chauncey et al., 2016). The theory on human–machine metacommunication conveys a conceptual perspective on how communication should occur between humans and robots (Ito, 2020). This communication theory focuses on the generation, transmission, and reception of information between two points or two entities, or a combination of the two (Shannon, 1948; Weaver, 1949/1964).

Shannon's (1948) and Weaver's (1949/1964) theory on communication also explain how signals of information are formulated, transmitted, and interpreted between a point of origin and a reception point. Communication conveys a message of some type, whether, in music, direct speech, gestures, or writing contains relevant information consisting of symbols (e.g., characters, words, or motion) transmitted and received at varying rates (Hartley, 1928). The relevance of Shannon and Weaver to the framework on co-adaptive interaction between human and robot entities is the information exchange between a human and a robot entity, including the ability to understand certain gestures and body language (Chauncey et al., 2016). Ito (2020) theorized that such an exchange of information between a human and a robot entity invokes a behavioral stimulus and response naturally occurring in the same conversational manner or interpretation of gestures and motions between two human entities.

Nature of the Study

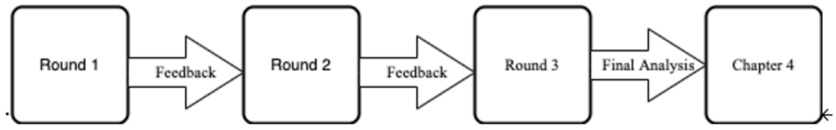
Using the e-Delphi technique in this qualitative study enabled the identification of factors that might influence the effectiveness of human–robot teams, a new concept in human–robot workforce management. The qualitative method is best suited for research projects or studies where quantitative data or results from prior research are unavailable. The qualitative methodology provides an understanding of social realities and phenomena through exploration research, allowing the use of flexible and interpretative methods to develop insight into a phenomenon (Corbin & Strauss, 2015). Using the e-Delphi technique helped gain insight into how to manage human–robot teams based on factors that might influence their effectiveness by gathering information from an expert panel using online questionnaires, feedback, and topic-related research (Ametepey et al., 2019; Davidson, 2013). Investigating factors that influence the effectiveness of managing human–robot teams may revolutionize human-robot workforce management.

The data for this research came from a panel of 12 subject matter experts. The RAND/UCLA Appropriateness Method User's Manual recommended using nine subject matter experts for representation of professional backgrounds and small enough for managing a diverse group (Fitch et al., 2001). However, there are no set criteria on the number of panelists (Ametepey et al., 2019; Davidson, 2013, Fitch et al., 2001). I sought the opinions from subject matter experts for this exploratory e-Delphi design who have at least 1 or more years of managerial experience managing research and developing teams and projects in the domains of science, technology, engineering, and mathematics, particularly in robotics and artificial intelligence.

I conducted three rounds of data collection from 12 panelists who are subject matter experts. Round 1 consisted of a questionnaire (see Figure 4). Rounds 2 and 3 consisted of a questionnaire and a survey with a 7-point Likert scale for a more accurate representation of the responses from the respective previous rounds. The goal was to develop a consensus from the subject matter expert panel. The data collection and analysis for this research required three iterations before arriving at an acceptable consensus (Diamond et al., 2014; Warner, 2017). Consensus is achieved by either setting an a priori threshold value which, if reached, would terminate the e-Delphi technique process or accepting the analysis from the final round as the consensus (Diamond et al., 2014). The use of an a priori threshold value can only occur when prior knowledge and expectations exist before starting the e-Delphi technique data collection and analysis process. However, expectations and previous understanding of factors that could influence the effectiveness of managing human–robot teams within a human–robot work environment are unknown. As a result, this research did not involve the use of an a priori threshold value.

Figure 4

e-Delphi Process Flowchart



Note. The e-Delphi process flowchart is an interpretation of Ametepey et al. (2019), Diamond et al. (2014), Hasson et al. (2000), and Hsu and Sandford (2007) procedures using the Delphi methodology.

Round 1 consisted of open-ended questions stemming from the literature reviewed for this study (Davidson, 2013; Hsu & Sandford, 2010). A content analysis and thematic analysis of the data collection from Round 1 will form the basis of question development in the next round (Ametepey et al., 2019; Diamond et al., 2014; Hasson et al., 2000). The difference between content analysis and thematic analysis is that the latter is a process that extrapolates meaning from identifying and analyzing patterns in data; the former determines the frequency of occurrence of text in the message characteristics (Saldana, 2016). In Round 2, the expert panelist received a summary of analysis from the previous round and a structured questionnaire containing questions stemming from the analysis summary of Round 1 (Davidson, 2013; Hsu & Sandford, 2010; Warner, 2017). In Round 3, the expert panelist received a summary of analysis from Round 2 along with a questionnaire containing questions stemming from the analysis summary of Round 2 (Davidson, 2013; Hsu & Sandford, 2010; Warner, 2017). The final analysis and the summary of analysis from all three rounds appeared in Chapter 4.

SurveyMonkey was the preferred platform to share and collect responses with the panelist because the platform is secure, stable, and widely used in research to collect data. Using the analytical features of coding and statistical analysis in SurveyMonkey reduced the time necessary to analyze incoming data. As data integrity is paramount, I stored all data downloaded from Survey Monkey related to this project in a secure location.

Definitions

Anti-choice: The argument of being against something or a specific option presented in a choice (Baude & Sachs, 2017; Lepora & Pezzulo, 2015; Smaldino & Richerson, 2012).

Artificial intelligence: The concept and development of computer/robotic systems capable of performing tasks requiring the application of knowledge to ingest and process information in the same capacity as human intelligence (Floreano & Mattiussi, 2008; Kakas & Michael, 2016; Pfeifer & Scheier, 1999).

Artificial general intelligence: An advanced level of artificial intelligence that can theoretically learn and self-govern in the same manner as a human entity (AFOSR, 2018; Floreano & Mattiussi, 2008; Kakas & Michael, 2016; Pittman & Soboleski, 2018).

Deep learning: Deep learning is a part of machine learning and artificial intelligence that uses neural networks for ingesting and processing information for knowledge and intellectual development to include perceptual analytics and computer vision (Kakas & Michael, 2016; LeCun et al., 2015; Shipp, 2016).

Entity: An intelligent entity capable of making decisions based on the presented information and is possibly able to engage in activities of self-learning, self-governing, and is reflective, adaptive, and ethical behaviors, and so on (AFOSR, 2018; Dautenhahn, 2007).

Machine learning: The capability of a machine that uses artificial intelligence for learning and knowledge development by ingesting and processing information using pattern recognition and analysis (Kakas & Michael, 2016; LeCun et al., 2015; Shipp, 2016).

Pro-choice: The argument of being for something or a specific option presented in a choice (Baude & Sachs, 2017; Lepora & Pezzulo, 2015; Smaldino & Richerson, 2012).

Relational trust: Relational trust is the consequence of the longevity of interpersonal exchange related to trust between two entities (Barnard, 1938/1968).

Self-learning: An intelligent based system that is capable of learning in an unsupervised environment and excels in a supervised learning environment with the capability of evaluating competency (Baude & Sachs, 2017; Dautenhahn, 2007; Lepora & Pezzulo, 2015; Smaldino & Richerson, 2012).

Self-governing: An intelligent based system capable of exercising self-discipline, making decisions, and assess levels of competency disregarding social influences (Baude & Sachs, 2017; Dautenhahn, 2007; Lepora & Pezzulo, 2015; Smaldino & Richerson, 2012).

Social intelligence: The ability to be socially aware of and knowledge of environmental surroundings, including the ability to interact with animate objects in a heterogeneous society (Keller, 2014; Morency, 2010).

Social-intertwining: The ideology that every person in the world is inter-connected, despite subtle differences and are part of the universal community (Abel, 1998; Barnard, 1938/1968; Borenstein et al., 2006; Morency, 2010).

Socio-dynamic: Social-dynamic or social-dynamics is the dynamic interactive behaviors based on socio-environmental influences (Abel, 1998; Barnard, 1938/1968; Borenstein et al., 2006; Morency, 2010).

Socio-relational: Relating to socio-dynamics in which social/community relationships evolve and are maintained, either through professional, social, or personal connection (Abel, 1998; Barnard, 1938/1968; Borenstein et al., 2006; Morency, 2010).

Supervised learning: A teaching or instruction method used by a user to supervise the learning process of an AI-enabled machine that can learn from and about the data provided (Floreano & Mattiussi, 2008; Pfeifer & Scheier, 1999).

Trust: Trust is the exercise of faith or belief in some animate or inanimate objects based on integrity, reliability, and character (Amici, 2015; Melis & Semmann, 2010; Zak, 2017).

Trust reciprocity: The exercise of trust in return, usually occurring between two people based on acceptance of the other person's integrity, reliability, and character (Amici, 2015; Melis & Semmann, 2010; Zak, 2017).

Unsupervised learning: The ability of an AI-enabled machine to learn without supervision (Floreano & Mattiussi, 2008; Pfeifer & Scheier, 1999).

Assumptions

There were three underlying assumptions for this study. The first assumption was that the participants come from within the United States and have varying levels of experience and education. Many of the participants ideally possess a diverse skill set ranging in the areas of robot and robotics development, software engineering, mathematics, and advanced concepts design and development in artificial intelligence to include computer vision, natural language processing, management, and predictive modeling.

The second assumption was that participants of this e-Delphi technique research study would be willing to participate in all three survey rounds. Davidson (2013) stated that “three rounds have been the traditional number” (p. 56) in any genre of Delphi study, but not necessarily a standard requirement. The Delphi process is iterative, such that any number of rounds will do, providing it satisfies the research study. The third assumption was that participants would exercise integrity in answering questions and surveys. Lack of integrity or biased opinion due to misinformation would skew the data causing inaccurate research findings. The use of online surveys and questionnaires and possible one-on-one video conferencing were used due to geographical separation.

Scope and Delimitations

The scope of this e-Delphi technique study was to investigate factors that could influence the effectiveness of managing human–robot teams. The design and use of human–robot teams through human–robot workforce management is a concept with little or no supporting peer-reviewed literature. This study addresses the gap in the literature by aggregating, analyzing, and reporting data that identifies unknown factors from subject matter experts. The panel of subject matter experts consisted of individuals who had experience developing and deploying applications in artificial intelligence, software engineering, and uses in robot or robotic platforms. The use of online tools such as surveys, questionnaires, and video conferencing to include email was necessary to reach the expert panelist (Davidson, 2013). Maintaining anonymity between panel members was essential to mitigate biases that may influence other panel members' responses to questions and surveys (Ametepey et al., 2019).

There was a possibility that panel members may have to withdraw from the study due to unforeseen circumstances. Ametepey et al. (2019) suggested using two or more rounds to collect data using two or more participants, not to exceed 100. The plan was to recruit nine to 12 subject matter experts from around the United States using social media platforms to mitigate any issues with panel members withdrawing or ending their participation before completing the study. Three rounds are sufficient in the traditional sense of the Delphi method (Davidson, 2013).

Limitations

The e-Delphi technique, like other methodologies, has some inherent limitations. One of the most significant limitations in using the e-Delphi technique was the reliability on internet communications (Habibi et al., 2014). Other limitations about this research were time, the number and the availability of eligible participants, and the integrity of responses to the surveys. Time affects all the other concerning limiting areas, such as the amount of time it takes to recruit subject matter experts as participants, develop and deploy questionnaires and surveys, and analyze data collections and report findings.

Significance of the Study

The significance of this study was to mitigate the literature gap on factors influencing the effectiveness and collaborative efforts of human–robot teams through human–robot team management. The study of collaboration and other influential factors affecting a human–robot team is an advanced concept in human–machine partnership and team management (AFOSR, 2018; NSF, 2020). There was a significificate amount of peer-reviewed literature on team dynamics and management involving human subjects, yet there was no peer-reviewed literature related to the dynamics of a human–robot team or managing human–robot teams. The significance of this study was to help mitigate concerns on the use of managing an autonomous robot or robotic systems in the workforce environment.

There were unknown factors that could influence the effectiveness of managing human–robot teams. The revelation of these factors helped in the understanding of how human–robot partnerships evolve. Partnerships must exist for a human–robot team to function successfully. Factors in managing human–machine partnerships are unknown because the factors that influence the effectiveness of managing human–robot teams is also unknown. This research may aid in the revelation of these unknowns that may lead to better human–robot workforce management and a life assistance partner.

Significance to Theory

An approach for this research on the effectiveness of influential factors involving the managing of human–robot teams was to use Rogers' (2008) relational communication theory, Van Ruler's (2018) communication theory, and Barnard's (1938/1968) influences of information as the primer foundation. The uncertainties of communicated information within a dynamic work environment require intelligent entities to synthesize and deduce information to make and adequately execute decisions (Armbruster & Delage, 2015; Lucci, 2013; Meder et al., 2013). In a human–robot partnership, communication efforts are necessary to develop and maintain a teaming environment (AFOSR, 2018; NSF, 2020; Rotenberg, 2018) from a humanistic perspective. Teaming and managerial relationships require team members to contribute to the team's success regardless of the task or event (Barnard, 1938/1968; Castro et al., 2017; Levi, 2001).

Significance to Practice

Identifying unknown influential factors related to managing human–robot teams' effectiveness was critical to understanding the social and behavioral dynamics of autonomous robots. By understanding these influential factors, advancement in the development and deployment of artificial intelligence, robot, and robotic applications can occur and amplify human capabilities in both social and work environments, and assist individuals with varying disabilities (AFOSR, 2018; NSF, 2020). The knowledge from this research may also contribute to the adaptive and continuous improvement of artificial intelligence, robot and robotic systems, and development of human–robot workforce management policies.

Significance to Social Change

The significance of social change was an understanding of the effectiveness of factors that influence the behaviors in managing human–robot teams. The identification and understanding of these factors amplify the evolution of a human–machine partnership leading to the possible benefits toward individuals who suffer from some degree of impairment, such as anxiety, physical, autism, or diminished sight (AFOSR, 2018; NSF, 2020). The design of such socio-robotic devices, such as Kaspar and Milo (RoboKind, 2018), provide behavioral therapy and companionship to children with autism and other behavioral challenges (Hertfordshire, 2018; RoboKind, 2018), which differ from nonrobotic personal assistance units, such as Siri and Jibo (Fowler, 2017). These robotic systems have some autonomy and learning capabilities (Haber & Sammut, 2013; LeCun et al., 2015; Michael, 2016). The results from this study could improve the design of the intelligent robot and robotic devices, such as the Phoenix, an intelligent exoskeleton that aids individuals with walking disabilities, sensing physical movements from its host (Abel, 1998; Bemelmans et al., 2015). The results of this study may also promote the societal acceptance of robotic assistants for individuals who have physical challenges or disabilities (Christoforou & Müller, 2016; Dautenhahn, 2007; Fehr & Fischbacher, 2004).

Other beneficial applications for the use of autonomous mobile robotic entities include assisting in search and rescue, search and recovery, and the discovery and identification of hazardous artifacts (AFOSR, 2018; Etzioni & Etzioni, 2017; Sapaty, 2015). By addressing the issue of social benefits, humanity may be more willing to accept the capabilities and assistance of a robotic entity, particularly in the areas of social assisted living, agriculture, security, crime prevention, search and rescue, and pollution reporting through persistent surveillance (AFOSR, 2018; Hoffman, 2019; NSF, 2020).

Summary and Transition

The impetus of this qualitative study was to understand factors that influence the effectiveness of managing human-robot teams. Research on human–robot teams or human–robot team management is an advanced concept with little to no peer-reviewed literature available. The revealing of two identifying issues was a gap in the literature and factors that are influential in the behaviors of a human-robot team, including human-robot workforce management. The approach to resolving these underlying issues is to use the e-Delphi technique, which requires the use of subject matter experts due to the vacancy in peer-reviewed literature. Chapter 2 is an exploration and review of the literature relevant to the subject of factors that influence the effectiveness of a human-robot.

Chapter 2: Literature Review

Managers lack knowledge of the factors influencing the effectiveness of managing human–robot teams within a human–robot work environment, as human–robot teams do not yet exist (Baude & Sachs, 2017; Cominelli et al., 2018; Shannon, 1948; Weaver, 1949/1964). This may affect managers' ability to manage these human–robot teams effectively as they are developed. The purpose of this e-Delphi technique study was to gain insight into factors that could influence the effectiveness of managing human–robot teams within a human–robot work environment, using the opinions from experts in the field of robotics. Relational dynamics between two or more entities within a team's composition, cannot exist without some influential factors that affect a team's behaviors (Barnard, 1938/1968; Hartley, 1928; Rogers, 2008). How this translates into a human–machine partnership or human–robot team remains unclear but is critical to the development and management of human–robot teams. More specifically, researchers do not know what verbal and nonverbal communication may affect a human-robot team's effectiveness.

This chapter contains a review of the literature relevant to the factors that influence the effectiveness of managing human–robot teams. A compilation of literature using keywords about the relational dynamics and potential factors, such as communication, highlights the possibilities for factors that might influence a human-robot team's effectiveness. The exploration of relevant peer-reviewed literature elucidates the composition and potential purpose of a human–robot team or human-machine partnership. The chapter summary includes the essential elements of the literature review, including identification of the knowledge gap and the importance of this research to filling that gap.

Literature Search Strategy

The literature search strategy for this study used the wording within the title, *Factors Influencing the Effectiveness of Managing Human–Robot Teams*, as a guide for selecting keywords. The keywords' ontology presents a thematic approach toward expanding the list of keywords that are relatable to the research title. Though not part of the initial keywords' expansion set, *Delphi* or any variant as a keyword was a necessary inclusion into the search pattern for Delphi research and studies. Using various combinations of the keywords, I conducted searches of library and online repositories to gather relevant articles, chapters, and books. Library repositories used in this research effort included Walden University, Google Scholar, ProQuest, Santa Fe Institute, St. Louis University – Pius XII Memorial, and McKendree University. The ERIC database and the following journals, *Frontiers in Neuroscience*, *Psychology*, *Robotics, and AI*, *Foundations and Trends in Human-Computer Interaction*, *Computational Biology*, *International Journal of Tech Management*, and *The Bell Systems Technical Journal* were accessed as part of this research effort. The keywords were used to find the literature in the study, including literature on the foundational theories on communication by Shannon (1948) and information (Hartley, 1928; Weaver, 1949/1964).

I used a two-tier search pattern, where the first set of dates was from 1900 to 2013, and the second set of dates was from 2014 to 2020. This search strategy led to the discovery of classic foundational theory related articles, with close attention to literature written between 1900 to 1930—the publishing period of most foundational concept/theory related articles—as well as the current peer-reviewed articles necessary to capture the relevant thinking in the rapidly evolving research area of robotics and artificial intelligence. I included literature from such disciplines as sociology, management, neuroscience, and computer science to ensure the relevancy of literature to the purpose of the study as reflected in the keywords in Table 1.

Table 1

Literature Search Overview

Research Title	Derived Keywords	Expanded Keyword Search
Factors Influencing the Effectiveness of Managing Human-Robot Teams	Communication	trust, influence, group dynamics, information, data
	Robotics	artificial intelligence, machine learning, deep learning neural net
	Cognition	perception, reactivity, freewill, autonomy, self-learning, self-governing, competency awareness
	Management	organizational behavior, social behaviors

Conceptual Framework

The conceptual framework on factors influencing the effectiveness of human–robot teams stemmed from the combination of the theories of Chauncey et al. (2016), Hartley (1928), Ito (2020), Shannon (1948), and Weaver (1949/1964) on interactive communication. Chauncey et al. and Ito both theorized that human and robot interaction could only occur through interactive communication. Hartley argued that communication conveys a message of some type, whether in music, direct speech, gestures, or writing, because a message contains relevant information consisting of symbols, words, or motion. The rates of transmission and reception of information, as Hartley stated, varies based on influential factors such as the environment. Shannon and Weaver, as referenced in their mathematical theory on communication, stated that environmental anomalies affect the transference accuracy between the transmitter and receiver.

Interactive communication (Chauncey et al., 2016; Ito, 2020) extends and expounds on Shannon's (1948) and Weaver's (1949/1964) communication theory, where information exchange between two individuals occurs when one individual sends a message and the other receives the message. The recipient of the message responds accordingly, usually within a specific timeframe. How factors influence human–robot teams' effectiveness remains unclear (Hoffman, 2019; Lucci, 2013; Martius et al., 2013; Pfeifer & Scheier, 1999), and a team's effectiveness without some form of communication remains questionable, because communication is necessary for information transmission.

The communication theories of Chauncey et al. (2016), Hartley (1928), Ito (2020), Shannon (1948), and Weaver (1949/1964) also relate to Parks' (1977) theory on relational communication. Relational communication theory consists of a professional or non-professional relationship between two or more individuals that is translational and reflective using forms of verbal and nonverbal methods of communication to transmit and receive information (Parks, 1977). The phenomenon occurring in interactive communication is essential to the development and effectiveness of human–robot teams

(Chauncey et al., 2016; Ito, 2020). What is central to interactive communication is not just the line or lines of communication but also the message's content, including the generation, transmission, reception, and interpretation of information (Hartley, 1928). Behavioral responses often occur in conversations between two entities (Ito, 2020). The reception, translation, and meaning of the information within the message are essential to understanding the factors capable of influencing the effectiveness of human–robot teams' behaviors, specifically regarding the environmental dynamics.

The foundational work for this research project, specifically toward identifying factors influencing the effectiveness of human–robot teams and managing human–robot teams, stems from Barnard's (1938/1968) research on social behaviors, organization theory, systems theory, and management theory within a corporation. Barnard described the necessary components of a collaborative arrangement as consisting of, at a minimum, the environment and two individuals. Work environments evolve dynamically through the interactions and influence of individuals within the environment (Barnard, 1938/1968). Barnard investigated an individual's independence within a socio-interdependent environment on individuals within the organization. Within the organization, the individuals exercise free will with a conscious objective of forming alliances with other individuals with the objective of becoming part of something greater than themselves (Barnard, 1938/1968; Lavazza, 2016). Barnard shared that the functional operations of an organization consist of many interacting components and processes that must work together according to the organization's purpose but within the socio-ecosystem. Managing resources within an individual's control using a general set of rules is a relational process requiring responsiveness within an organization (Barnard, 1938/1968). Making decisions could, at times, be burdensome, a task that some individuals find both perplexing and cumbersome. Every individual must manage within their limitations yet find ways to achieve success for themselves and the organization (Barnard, 1938/1968).

I used the combined works of Chauncey et al. (2016), Hartley (1928), Ito (2020), Parks (1977), Shannon (1948), and Weaver (1949/1964) on the theories of communication and relational communication in this research to further understand factors that influence individual and team behaviors. I also combined Barnard's (1938/1968) contributions to organization, systems, and management theories in this research to further understand social and organization behaviors within the dynamics of a team and how such factors could influence human–robot team dynamics. There are certain factors that are influential in the effectiveness of managing human–robot teams that can significantly impact a team's performance. Social relationships evolve through the dynamics of interactive communication within the framework of evolutionary systems biology, specifically in the evolution of interaction and behavior (Chauncey et al., 2016; Ito, 2020). Interaction between two entities invites change on the dynamics of evolution by selection (Deutsch & Marletto, 2015; Hartley, 1928; Lewicki et al., 2006). By selection or an election, what is meant by development is the transfer and reception of information for action or reaction purposes toward the resolution of some issue or cause (O'Malley et al., 2015). The algorithmic processes, which lean toward the development and growth of shared concepts and the advancement of some form of instructions or ideology, evolve on accepting data/information both as the transmitter and receiver (Barnard, 1938/1968; Popper, 2010). The conveyance of information and data, depending on the interpretation of message content, establishes some desire for action as part of the decision-making experienced by individuals (Moussaid et al., 2013). However, every source of information does not contain all the necessary information components to derive a proper response (Lewis & Weigert, 1985).

Literature Review

The complexity of identifying factors influencing the effectiveness of managing human–robot teams required scrutiny of relevant topic related literature. The inquiry toward the discovery and introduction of questions, possible answers to those questions, concepts, and theories, is necessary to provide some practical understanding of the topic (Charmaz, 2014; Corbin & Strauss, 2015; Moen, 2006; Nakkeeran, 2010). The basis for human and robot teaming is a concept of tomorrow's collaborative augmented workforce and human-robot team management that is well suited for today (Adams et al., 2012; AFOSR, 2018; NSF, 2020; Sapaty, 2015). The literature review consists of four subsections: influential dynamics in communication, influential dynamics in trust, influential dynamics in socio-structural entanglement, influential dynamics in decision-making.

Influential Dynamics in Communication

Communication, using signals, requires some degree of acknowledgment or awareness of and between two individuals for the occurrence of information exchange (DeDeo, 2018; Patricelli & Hebets, 2016; Shannon, 1948; Weaver, 1949/1964).

Chauncey et al. (2016) and Ito (2020) referred to this as interactive communication, which is a necessity in team dynamics. Levels of interaction between individuals is a choice based on each individual's perspective of the other, including known information and the individual's acceptance of the other (Smaldino & Richerson, 2012; Van Ruler, 2018). Interaction as a choice rests on fulfilling a want or a need to satisfy a desire to connect for an undetermined amount of time (Barabasi, 2003; Barnard, 1938/1968). Humans do not to exist in isolation; they are part of a "complex universal puzzle" that interacts dynamically (Barabasi, 2003, p. 7). The compounded nonlinear three-dimensional spatial interactivity between two or more entities within any environment, regardless of distance and radius, makes communication multi-dimensional (Moussaid et al., 2013; Yukalov & Sornette, 2014). Communication also becomes multidirectional with a dynamic path that is either linear or nonlinear or a variation of both (DeDeo, 2018; Hartley, 1928; Shannon, 1948; Weaver, 1949/1964). Foundationally, this is the key to understanding socio-environmental relationships (Morency, 2010). Social interactions are intrinsic to the decision-making processes with influences through information exchange using various communication forms, such as oral, auditory, written, or body language, or a combination (Morency, 2010).

Social cognition and communication interactivity is the process of an individual being socially aware of their work environment (Meadows et al., 2014). The relevance of social cognition is how an individual chooses to receive and process information (Ceunen et al., 2016; Hartley, 1928; Shannon, 1948; Stoffregen & Bardy, 2001; Weaver, 1949/1964). The composition of information before transmission is a "group of physical symbols, consisting of words, dots, and dashes, or the like" (Hartley, 1928, p. 536) to convey some acceptable meaning to the recipient. The transmission and reception theories on information are the perception and processing of information and signals between individuals (Moutoussis, 2017; Schad, 2016). The adoption of these theories by sociologists, psychologists, and behavioral researchers establishes a foundation for understanding behavioral communications within work environments (DeDeo, 2018; Hartley, 1928). An individual's ability to process information received requires the individual to evaluate the content's meaning and dynamics before executing and delivering any response (Baude & Sachs, 2017; Keller, 2014).

Social interactivity between individuals and inanimate objects such as messaging boards, billboards, emails, and the like, are a daily occurrence (Barnard, 1938/1968; Hartley, 1928; Meadows et al., 2014). Researchers have argued that the systems of messaging delivery or general communication applications is unidirectional (Patricelli & Hebets, 2016; Weaver, 1949/1964), whereas others contended that social interactivities and messaging between individuals within a work environment are bidirectional (Rogers, 2008). Hartley (1928) proclaimed that every individual is an active participant in the reception and transmission of information daily through social interactivity within their respective work environment. Barnard (1938/1968) argued that implicit or explicit bias occurs because of individual differences between the receiver and the communicator. Bandura (1991) and Barnard also argued that agreements due to preference are not always the opinion between individuals but is somewhat of organization acceptance.

Social interactivity requires the exchange of communication signals between two entities (DeDeo, 2018). An entity's perceptual point of view may differ on current information exchange due to available knowledge and social experiences, including cultural and religious beliefs (Prabhakaran & Gray, 2012; Sharpee et al., 2014). Cultural understanding occurs through social interactivity and the acceptance (Meadows et al., 2014). The perspective of acquiring knowledge through personal beliefs, culture, and education, allows an individual to formulate some form of thought and opinion through reasonable comprehension and critical thinking (Meadows et al., 2014).

The centrality of Hartley's (1928), Shannon's (1948), and Weaver's (1949/1964) communication and information theories is the transmission and reception of information through signals and connectivity. Hartley's two-fold discussion was the interactivity between people and the transfer of information and data using the telegraph. Shannon's (1948) study on communication differs from Hartley's not using the telegraph, but by the transmitter's transmission mechanisms to the receiver. Weaver (1949/1964) defined what information is and why communication is necessary to enable cooperation between two entities. Shannon mathematically modeled the transmission and reception of data executed by a transmitter and a receiver. Connectivity is a necessary activity and component in communication before the transmission and reception of any information can occur (Rogers, 2008; Shannon, 1948; Van Ruler, 2018).

There are some exceptions to this rule. These exceptions require some level of intelligence, such as communicating some form of information (Abel, 1998; Pfeifer & Scheier, 1999). The ability to receive transmitted signals from an originator with some degree of perception and the ability to transmit signals of some variation is a quantifiable form of intelligence (Pfeifer & Scheier, 1999). Not all forms of life exhibit the same level of intelligence, nor do they communicate in the same way (Gilroy et al., 2018; Schulz-Bohm et al., 2018). For example, a flower may radiate a scent and coloration to attract some insects for pollination purposes (Baluska, 2010; Stoffregen & Bardy, 2001). In contrast, a human being may become attracted to the flower's beauty of color and aromatic fragrance (Stoffregen & Bardy, 2001). A flower's design is to radiate a signal as a means of attracting a receiver to fulfill a purpose (Baluska, 2010; Gilroy et al., 2018; Schulz-Bohm et al., 2018; Stoffregen & Bardy, 2001). A flowering plant may also emit some signal of distress to neighboring plants and insects (Baluska, 2010; Gilroy et al., 2018; Schulz-Bohm et al., 2018) of impending danger.

The meaning of information, the transmission and reception of signals, and intentional use, as referenced by Hartley (1928) and Weaver (1949/1964), originated before the 17th century in the *sense* of the word (Ceunen et al., 2016; Stoffregen & Bardy, 2001), where the definition is about the conveyance or perception of meaning. Perception is about proximity awareness using the senses. Burge's (2010) viewed perception as the reception of information and data through varying sensory-perceptual modalities, which either establishes an action or inaction based on social or internal influence. Schad (2016) referred to this as the "mechanism of perception" (p. 1), which causes an action to occur within a specific time resulting from the environmental stimuli. Ceunen et al. (2016) referred to this sensory-perceptual of modalities as interoception. Information signals influence an individual's emotional state, decision-making dynamics, detection, and reporting of pain and health concerns, including time measurement. The views of Ceunen et al. (2016), Burge (2010), and Stoffregen and Bardy (2001) on perception relate to the origins of *sense*, circa 17th century, in which the actual meaning based on theory did not surface until Hartley's (1928) introduction, as applied to transmission and reception, and then again by Weaver (1949/1964) in application to communication.

Hartley (1928), Shannon (1948), and Weaver (1949/1964) postulated that acknowledgment, as a response, can only occur after the receipt of information or data, which comes after the establishment of connectivity. However, the transmission of response becomes null and void when the communication link between the receiver and communicator is severed or disconnected (Armbruster & Delage, 2015; Hartley, 1928). Communication disconnects are usually a result of distracting influences, communication crossflow, or signal dropping or cancelation (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964). Ceunen et al. (2016), Burge (2010), and Stoffregen and Bardy (2001) viewed the cause of this type of communication disconnect as a misperception. Hartley (1928) earlier defined discombobulating communication as misinterpretation.

Hartley (1928) contended that acknowledgment dynamics occur in broadcasting information, such as radio transmission and distributed information and data. In contrast, Hartley (1928) and Weaver (1949/1964) injected the idea that subtle body language gestures serve as the transmission of acknowledgment, based on the perception of the message. Ceunen et al. (2016) assessed that when a speaker speaks in-person to a live audience, as in delivering a sermon at a morning church service, individuals in attendance often signal gestures of agreement or disagreement.

An entity's acknowledgment of awareness recognizes some other entity's existence but not always to exchange information (Meadows et al., 2014). The choice of being aware of some entity is a choice and a decision not to exchange information or engage in any activity (Lynch & Hagner, 2014; Meadows et al., 2014). However, some degree of connectivity and some information exchange has taken place (Morency, 2010). From another perspective, Ceunen et al. (2016) and Stoffregen and Bardy (2001) asserted that the choice of being aware of environmental surroundings is about an individual's perception and how well the presence of something or someone can be interpreted. The exchange of information, albeit brief and nonverbally, is an acceptance of awareness that another entity exists within proximity of sensory perception (Shmueli et al., 2014). Recognizing some object's existence is primarily being socially aware of environmental surroundings absent of interactivity (Meadows et al., 2014; Sharpee et al., 2014).

How individuals interact without regard to formality is a daily occurrence of communal complexity (Barnard, 1938/1968; Rogers, 2008). Awareness of this type, an acknowledgment without purpose, as an informal organization, is a primer function occurring when individuals congregate (Barabasi, 2003; Barnard, 1938/1968); another form of interactive communication Chauncey et al. (2016) and Ito (2020. There is some degree of interaction between entities in an informal organization, but without purpose (Barnard, 1938/1968). Some encountering and interactions are by accident, others by choice (Barnard, 1938/1968). Morency (2010) stated that this is a highly interactive process in which communication (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964), with or without purpose, functions as a means of communicating verbal and nonverbal messages. Barnard (1938/1968) and Morency (2010) viewed the prospect of nonverbal communication as a general form of communication between two or more individuals regarding connectivity without any measure of purpose. The purpose of interaction without cause does require some understanding of social interaction, or as Meadows et al. (2014) stated, "without conscious effort" (p. 87).

The simplicity of a subtle nod is a gesture made after two individuals make eye contact is an example of an event in time, often without any conscious effort (Amici, 2015; Morency, 2010). Sharpee et al. (2014) discussed that connectivity and communication activities between two or more entities, albeit the discussion, are related to plants and microbes: Exchanging information through signaling. The commonality between Sharpee et al. (2014), Meadows et al. (2014), and Barnard (1938/1968) is the connectivity between two or more entities and messaging activities or communication, where communication is nothing more than the transmission and reception of signals (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964).

Signal transmission through connectivity is subjective to the recipient in which the contents of the signal may or may not serve a purpose (Hartley, 1928). Hartley (1928) stated that some information might not be for every individual. Shannon (1948) and Weaver (1949/1964) suggested that such information falls into either the category of data or noise. However, the data or noise spillage may influence the behaviors of individual bystanders (Hartley, 1928; Weaver's (1949/1964). Spillage, in this context, is the summation of Hartley's (1928), Shannon's (1948) and Weaver's (1949/1964) definition of communication crossflow to the masses using varying methods such as written text, spoken words, or two-dimensional or multi-dimensional signaling used in video streaming.

Purposing connectivity for the conveyance of information exchange (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964) through interactivity (Meadows et al., 2014; Sharpee et al., 2014) promotes resolution of conflicts or the stimulation of intellectual and social growth (Popper, 2010), or the evolution of innovative concepts, or the promotion of disputes, the degeneration of intellectual and social development (Popper, 2010), or the retrogression of innovative concepts (Barnard, 1938/1968; Pfeifer & Scheier, 1999). Acknowledgment with purpose addresses the question of why two entities would choose to connect for a certain length of time. However, the purpose does not address the influential factors that could positively or negatively affect the connectivity. Barnard (1938/1968) reasoned that the length of connection time, for a specific purpose, can occur for a few seconds to several hours.

Complexity in acknowledgment stems from the interactive dynamics of why two entities would choose to connect and exchange information (Lynch & Hagner, 2014; Meadows et al., 2014; Michael, 2016). Barnard (1938/1968) defined this relational dynamic as an organization's purpose, whether formal or informal. The exchanging of information as a form of action between two entities to achieve a goal in a collaborative effort (DeDeo, 2018) serves as a purpose for the formation of temporal relationships (Barnard, 1938/1968). Barnard (1938/1968) viewed temporal relationships as the connectivity or unity between two or more individuals for a purpose within a chosen timeframe for the transmission, reception, and interpretation of signals. In particular, the ingesting and application of information for further interactivity or engagement requires cooperation within the relationship between the two entities (Melis & Semmann, 2010; Riolo et al., 2001). If information corresponds to the proper syntax or language structures before transmission, which permits proper interpretation, then the context of the information received can be appropriately interpreted for actional application (Hartley, 1928).

However, not all signals are absolute and, therefore, are not perceived appropriately upon reception (Gilroy et al., 2018; Hartley, 1928; Lynch & Hagner, 2014). The influence of noise and other distractions can distort signal reception. (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964) Ceunen et al. (2016), Burge (2010), and Stoffregen and Bardy (2001) viewed that perception is the interpretation of signal reception and processing from another source. Therefore, issues related to miscommunication ensue, resulting in wasted resources, such as time, energy, and potentially damaging influential factors (Barnard, 1938/1968; Hartley, 1928).

The formation of an organization between two or more entities, whether formal or informal, cannot occur unless the acknowledgment of connection exists, and the purpose is clear, specifically in terms of reasoning, time, and space, with the motive for the exchange or conveyance of information (Hartley, 1928). Barnard (1938/1968) referred to this social connectivity or relationship as cooperation. Another view is that collaboration is a shared experience in the coevolution of cognition in which two or more entities establish some form of organization to accomplish some tasks (Santos & West, 2018). Axelrod and Hamilton (1981) and Bandura (1991) suggested that this type of collaborative effort occurs under the guise of self-organization due to the sharing of information or knowledge through social interactions. The genesis of understanding the purpose is in the reasoning of establishing the communication connectivity between two or more entities (Ceunen et al., 2016; Meadows et al., 2014; Michael, 2016; Yang & Narayanan, 2014, September). The influential desire to connect with other entities of similar likeness satisfies the need to understand and address current community issues that may or may not influence community members (Axelrod & Hamilton, 1981; Bandura, 1991; Barnard, 1938/1968).

In their study of information flow, Wu et al. (2004) identified that "individuals tend to organize formally and informally into groups" (p. 327) based on the velocity and flow of information, subject to the contents of the message, and the targeting audience. Wu et al., (2004) perspective on information flow is directly related to Barnard's (1938/1968) discussion on the formation and congregation of homogeneous relationships and communities and Hartley's (1928), Shannon's (1948), and Weaver's (1949/1964) theories on communication and information. Barnard (1938/1968) asserted that homogeneous relationships and communities are not as utopian as some individuals would hope. Relationships between two individuals within a community differ on skills, cultural and religious beliefs, education, and even insight making the connection or community more heterogeneous. Insight, or an understanding, is a matter of perception (Burge, 2010; Ceunen et al., 2016; Stoffregen & Bardy, 2001). The inception of information and data is a matter of connectivity before the reception and interpretation of information, in which all individuals interpret information differently (Hartley, 1928). Bandura (1991) injected the premise that necessary and straightforward information is, in general, interpreted the same with every individual, with some exceptions, according to Barnard (1938/1968), are due to physical or psychological challenges.

The importance of connectivity is for the conveyance of information with the possibility of some measurable response, where responses from received messages, including broadcast messages, occur if the receiver can relate to the transmitter or communicator. (Rogers, 2008). The reciprocal is the communicator's ability to connect to and even perceive the receiver's reception and behavior of the message's contents (Burge, 2010; Ceunen et al., 2016), assuming the communicator is an eyewitness of the receiver's actions. Direct or indirect connectivity is a vital link for information or data to flow between the transmitter and receiver (Barnard, 1938/1968; Hartley, 1928; Shannon, 1948; Weaver, 1949/1964). Connectivity between two people begins with a simple recognition of the exchanging of signals or subtle gestures, such as eye contact.

Miscommunication results from crossing or misaligning signals (Shannon, 1948; Weaver, 1949/1964). Consequently, the misinterpretation of information (Hartley, 1928) leads to the distortion in understanding purpose. The distortion of purpose or meaning is disruptive to the initial reasoning behind the acknowledgment's purpose: The reason for connectivity between two individuals (Michael, 2016; Yang & Narayanan, 2014). Ceunen et al. (2016), Burge (2010), and Stoffregen and Bardy (2001) referred to this as misperception, similar to Hartley's (1928) misinterpretation of information. Barnard

(1938/1968) referred to the miscommunication or misperception (Burge, 2010; Ceunen et al., 2016) as a detriment to the organization's effectiveness between two or more individuals, where clear communication is central to the thematic purpose of why the organization exists. Rather, the organization between two individuals, whether formal or informal, requires some form of communication, no matter how subtle the message is (Barnard, 1938/1968; Chauncey et al., 2016; Ito, 2020).

Miscommunication may occur between the transmitter and receiver, vary from lack of attention to various environmental influences (Barnard, 1938/1968; Burge, 2010; Ceunen et al., 2016; Hartley, 1928). Shannon (1948) referred to Hartley's (1928) disturbance in the transmission before the reception of signals as part of the noise to signal ratio. There is a certain amount of disruption in the signal's sinusoidal frequency between the transmitter and receiver. The entanglement of attentiveness and the environment centers on a continuous point of connection between two individuals during the communication session without signal disruption (Burge, 2010; Ceunen et al., 2016). Ceunen et al. (2016) and Burge (2010) stated that misperception occurs by the misinterpretation of signaling reception, most likely due to signal interference. One of the causes of signal interference is the environmental disturbances through which the signal must travel (Hartley, 1928; Weaver, 1949/1964). Because the environment is not free of contaminants or obstructions, concerning the spatial dynamics between the transmitter and receiver, signals are tainted by various movements of various types of molecular structures, forming a community of geo-spatiotemporal anomalies (Burge, 2010).

Van Ruler (2018) incorporated Shannon's (1948) communication theory in discussing conversation interactivity between two or more individuals. Shannon (1948) stated that the unidirectional flow of information is vital in communication. Van Ruler (2018) injected the idea that unidirectional flow does not promote organic circular growth in exchanging ideas in an evolving conversation. Hartley (1928), Shannon (1948), and Weaver (1949/1964) believed that with the incitement of communication crossflow, noise contamination degrades the quality of the signal exchange between the transmitter and receiver. Barnard (1938/1968) stated that at this point, no one is listening, and communication within an organization becomes null and void. However, regulating the bidirectional flow and the crossflow of information is the subject of the conversation and is necessary to maintain proper interactivity and growth (Van Ruler, 2018). Ceunen et al. (2016) and Burge (2010) viewed that proper interactivity in the growth of the conversation (Popper, 2010) can only occur if the perception of the exchange of ideas and thoughts in the conversation is proper; otherwise, the meaning and direction of the conversation becomes distorted and even meaningless.

In social gatherings or social meetings, individuals connect to converse on various topics, thereby creating a relational network to exchange information (Barnard, 1938/1968; Rogers, 2008; Yang & Narayanan, 2014, September): A form of interactive communication (Chauncey et al., 2016; Ito, 2020. Such social encounters or social relationships fall into either a professional or non-professional relationship (Barnard, 1938/1968). Barnard (1938/1968) defined social relationships as "the mutual reaction between two human organisms as a series of responses to the intention and meaning of adaptable behavior" (p. 11). The distinction between a social gathering versus a social meeting is a determinant of size and location in which Barnard (1938/1968) defined as a *simple, non-complex organization* or *complex organization*. A *simple, non-complex organization* may consist of a small group of individuals meeting for a short amount of time for a practical purpose (Barnard, 1938/1968); this purpose is relational dynamic. Each individual at the meeting or gathering has an ample reason for attending, usually to participate in exchanging ideas and the conversation's intellectual growth (Barnard, 1938/1968; Popper, 2010; Van Ruler, 2018). A *complex organization* differs from a *simple, non-complex organization* due to the size or number of participants and the temporal interactions between different departments or units by individuals within the organization (Barnard, 1938/1968).

There must be some form of communication for relationships to exist, discounting proximity, which includes short and long-distance professional and non-professional relationships (Ito, 2020; Rogers, 2008). What makes social relationships dynamic is the fluctuation in the connectivity between two individuals, which stems from the selection of choice and the timing of choice execution made during the communication process (Barnard, 1938/1968; Lucci, 2013; Rogers, 2008). Lucci (2013) defined this type of decision-making dynamic as an intertemporal choice, which is the time difference between the decision of choice and choice execution decision. The decision of choice execution becomes the consequence of the conclusion (Fiske & Taylor, 2008; Lucci, 2013). The fluidity of intertemporal choice is inherent in bio-intelligent species' social norms, which are the standard behaviors established by shared beliefs, such as religious, or cultural (Fehr & Fischbacher, 2004).

The combining of relationships and communication creates what Rogers (2008) referred to as relational communication. The length of time and the purpose of the connectivity, which is the basis for exchanging information, requires entities to make decisions relevant to their desire (Barnard, 1938/1968; Lucci, 2013; Rogers, 2008). *To connect or not to connect* is the question that every entity must ask before the activity of exchanging information (Lavazza, 2016; Lepora & Pezzulo, 2015; Meder et al., 2013; Smaldino & Richerson, 2012). Barnard (1938/1968) stated that this is the foundation toward collaboration within a corporation. Relational communication also relates to relational dynamics, where the information exchange differs from data in which the content of the signals received from the transmitting source has applicable meaning, influencing some degree of behavioral change, if any (Hartley, 1928; Van Ruler, 2018). Some socio form of a relationship must exist before any communication can begin (Rogers, 2008).

Synergy is the reflective behaviors in relational dynamics resulting from individuals working together for the corporation’s common good, rather than working separately and without communication (Barnard, 1938/1968). A corporation is nothing more than two or more individuals working together to fulfill a mission stemming from a vision (Barnard, 1938/1968; Lynch & Hagner, 2014; Meadows et al., 2014). The idea that a goal is something set by an individual or group of individuals within a corporation to accomplish a mission referencing a vision or shared vision using relational or interactive communication as a mechanism for the conveyance of thought (Barnard, 1938/1968; Chauncey et al., 2016; Ito, 2020; Rogers, 2008). Ranging from simple to complex, the pursuing of a goal to accomplish a mission is the genesis of relational dynamics and relational communications, which requires an understanding of the purpose and the acceptance of certain influential factors between individuals, particularly in a teaming environment (Barnard, 1938/1968; Rogers, 2008).

Contrastingly, individuals often establish personal goals to reach some life's objective (Amici, 2015; Barnard, 1938/1968; Melis & Semmann, 2010). Influences from social encounters and interactions contribute to an individual's growth (Lepora & Pezzulo, 2015; Moussaid et al., 2013). Barnard (1938/1968) stated that the power of choice and the exercise of free will is often limiting and paralyzing due to available opportunities, in which Fehr and Fischbacher (2004) stated, could have a "positive or negative side-effect" (p. 185) on an individual. Unequivocally, "social norms are standards of behavior that are based on widely shared beliefs" (Fehr & Fischbacher, 2004, p. 185) by an individual and by a community of individuals (Barnard, 1938/1968). The perception of others and the interoception of how an individual perceives himself or herself influences the acceptance of social norms where relational dynamics contribute to the evolution of social norms (Burge, 2010; Fehr & Fischbacher, 2004; Smaldino & Richerson, 2012).

Collaborative teams consisting of humans and robot entities must be able to share or exchange information and data that is either informative or critical to the decision-making processing structures (AFOSR, 2018; Gray et al., 2002; Hoffman, 2019; NSF, 2020). Barnard (1938/1968) stated that information sharing is critical to the cooperation's success. Information sharing from the communicator to the receiver forms a temporal relationship where the receiver may choose to accept or discard the use of all or some of the information (Barnard, 1938/1968; Hartley, 1928). The transmission and reception of information are subject to environmental influences (Shannon, 1948; Van Ruler, 2018; Weaver, 1949/1964).

Notably, Barnard (1938/1968), Hartley (1928), Shannon (1948), Van Ruler (2018), and Weaver (1949/1964) assumed that information sharing would be between human entities. There must be bidirectional acceptance between each team member for any relational dynamic to occur within a human-robot team (Lewis & Weigert, 1985; Nguyen et al., 2018; Soh et al., 2018; Wu et al., 2016). The means of communicating freely with one another is a continuation of Barnard's (1938/1968) aspect on cooperation, Hartley (1928), Shannon (1948), and Weaver's (1949/1964) perspective on communication and information broadcast, and Van Ruler's (2018) perspective on communication strategy and theory. The sharing of information during relational communication engagement will permit continuing activities by having some influence on the behavior dynamics of each team member (Barnard, 1938/1968; Rogers, 2008). The absence of emotional intelligence from the robot entity's perspective vacates the notion of any potential hostility from the robot entity itself, thereby establishing a more peaceful environment (AFOSR, 2018; Cominelli et al., 2018; Floreano & Mattiussi, 2008; Pfeifer & Scheier, 1999). Consequently, the robot entity would need to seek answers to questions as a means of ascertaining the true meaning of the message rather than have to decipher the context of the message (AFOSR, 2018; Dautenhahn, 2007).

Managing any team, regardless of composition and distance, requires interactive communication and a recognizable hierarchal structure (Barnard 1938/1968; Chauncey et al., 2016; Ito, 2020). The effectiveness in managing human-robot teams is conceptually the same as managing homogenous teams consisting of human entities that are inherently complex. Integrating human-robot teams into the general workforce requires managers to examine the potential advantages and disadvantages. Influencing diverse teams consisting of human entities requires managers to engage in interactive communication, inspiring teammates to succeed regardless of the assignment (Homan et al., 2020).

Interactive communication is vital to managers who manage small to large teams as a means of understanding the team's operational environment (Garfield et al., 2020; Guo et al., 2021). The relationship between managers and team members is essential and effective when relational communication is prevalent (Barnard, 1938/1968). To that end, managers must understand the dynamic driving factors in three environments: their team's environment, the environment of their organization, and their unique environment, as a principle of good leadership (Barnard, 1938/1968; Garfield et al., 2020; Guo et al., 2021). The juxtaposition of these three environments may require managers to adjust their style of leadership accordingly to meet organization requirements and mission or task objectives. Managers must continuously evolve, especially in leading diverse teams (Barnard, 1938/1968; Garfield et al., 2020).

A diverse team consists of members who have “a variety of different demographic backgrounds, personalities, values, knowledge, and expertise” (Homan et al., 2020, p. 1102). A human-robot team, by definition, is a diverse team. Managers and team leaders must openly embrace interactive and relational communication within the social work environment. Interactive communication is essential to forming, sustaining, and managing collaborative human-robot teams, incorporating a dynamic hierarchal structure (Barnard, 1938/1968; Chauncey et al., 2016; Ito, 2020). Relational communications, like interactive communications, allow managers and team members to gain a better understanding of each other (Rogers, 2008).

Influential Dynamics in Trust

Trust development between two individuals depends on the relational and communication activities, including the importance and truth of the information (Barnard, 1938/1968; Levi, 2001; Rotenberg, 2018). The attributes of trust, in most cases, are the commonality of cultural and religious beliefs and the acceptance between two individuals (McKnight & Chervany, 1996; Rotenberg, 2018; Zak, 2017; Schwerter & Zimmermann, 2019). To trust or not trust an entity invokes decision-making processes that require an individual to pursue evaluation methods and then choose whether to accept or reject the entity (Deutsch, 1958; Lavazza, 2016). Lewis and Weigert (1985) reflected on trust as “a cognitive process which discriminates among persons and institutions” (p. 970). Differences and ignorance are attributes of cognitive distrust that is reflective of social norms in some communities and social circles (Barnard, 1938/1968; Lewis & Weigert, 1985). Barnard (1938/1968) and Lewis and Weigert (1985) also argued that relational communication (Rogers, 2008) might eradicate cognitive distrust due to ignorance and relational dynamics, while differences will remain due to the composition of the individual's background.

Shared values and other commonalities referencing identity are the basis of hope and the foundation of unity in the embracement of trust toward the humanity of a community or civilization (Barnard, 1938/1968; Fiske & Taylor, 2008; Meadows et al., 2014). The consequence of truth or the lack of truth, as an influential factor, in a dispersed or conveyed message, can, and in most cases, upset the balance in trusting another person or entity (Hartley, 1928; Lucci, 2013; Meadows et al., 2014). Hartley (1928), Barnard (1938/1968), and Lewis and Weigert (1985) stated that the contents of information tend to either promote or destroy trust. The communication of such information can be in the form of body language, personal actions, and other forms of media, to include the displaying of symbols in writing, such as words (Hartley, 1928; Rogers, 2008; Van Ruler, 2018; Yang & Narayanan, 2014, September).

Even with no formal introduction, the conveyance of information by the communicator to a recipient, because of cultural shared beliefs and identity, can often establish a bond or linkage rather quickly (Barnard, 1938/1968; Levi, 2001). Blind confidence or faith is the catalyst for trust during times of uncertainty: When there is a fear of the unknown or the prevalence of doubt (Zak, 2017). The acceptance of robot entities by human counterparts within a mainstream society requires some degree of trust in order for a human and robot entity to collaborate on tasks and function as a team (Wu et al., 2016).

The prospect of trust dynamics between individuals is either unidirectional or bidirectional (Nguyen et al., 2018; Rotenberg, 2018; Zak, 2017). Equilateral or symmetrical trust is utopian, contrasting to asymmetrical trust is more of a common occurrence, but to what degree remains an elusive measurement of which a closely related model exists between uniformed officers of the peace, war, and fire, especially during heighten crises (Rotenberg, 2018; Zak, 2017). However, the specificity of trust as unidirectional or asymmetrical almost certainly applies to inanimate objects (McKnight & Chervany, 1996; Rotenberg, 2018; Zak, 2017). Exercising the decision to trust or not trust requires an individual to rely on a decision-making process derived from interactions, behaviors, and interdependence levels.

Trust is vital to managing a diverse team of any size, specifically when managing human-robot teams (Homan et al., 2020). Diverse teams tend to become closer and are more successful when trust exists between team members; as leaders, managers are part of the team (Barnard, 1938/1968; Homan et al., 2020). What makes team members embrace and gain trust for each other is participation in interactive and relational communication, including member acceptance (Homan et al., 2020; Rogers, 2008). The evolution of trust within an organization begins with managers investing in the well-being of their team members to include other managers and team leads within the organization (Barnard, 1938/1968; Homan et al., 2020).

Environmental influences, external to the team, leading to changes of behaviors of a team member can either support the evolving state and growth of trust or contribute to the erosion of team trust (Armbruster & Delage, 2015; Homan et al., 2020). Managers and team leaders can continuously influence trust by maintaining open communication, listening to their team members, and having a genuine concern for their welfare (Guo et al., 2021; Homan et al., 2020). Dependencies toward the evolution of trust are subject to internal and external influences affecting adaptive leadership. Managers are responsible for adapting to a changing operations climate and leading their team with integrity, courage, passionate service, and empowerment (Guo et al., 2021).

Guo et al. (2021) and Homan et al. (2020) reflected on the effectiveness of managers using adaptive leadership styles of management in a dynamic operational environment. The success of diverse teams, specifically human-robot teams, requires managers to adjust appropriately to the complexity of the internal team environment in conjunction with the organization's operational environment. The encouragement of collaboration between human-robot teams and other more homogenous teams is essential to building team and organizational trust, focusing on acceptance. Guo et al. (2021) stated that managers must work toward the operational "efficiency of the whole team within a specific environment" (p. 1) by upholding and living by an ethical value system that focuses on integrity with a passion for being the best. Homan et al. (2020) stated that "diversity management is inherent to leading teams" (p. 1101) because team members have a diverse background that encompasses Barnard's (1938/1968) seminal work in addressing the question, "what is an individual?" (p. 8). Guo et al. (2021) and Homan et al. (2020) indirectly anticipated managers managing human-robot teams by being proactively adaptive in providing leadership in a complex adaptive organization.

Influential Dynamics in Sociostructural Entanglement

Socio-structural entanglement stems from the flow or exchange of relational information between two or more individuals in a community where active and passive connectivity co-exists (Moussaid et al., 2013). Being influential requires an individual to consciously persuade another person to perform some behavioral modification to accomplish some tasks or participate in some event (Lepora & Pezzulo, 2015; Moussaid et al., 2013; Tang et al., 2016). Synergistically, the ability to influence or become influential can be subliminal or even subtle (Moussaid et al., 2013). Persuasion is subjective, with a thematic objective derived from the persuader's environment, culture, beliefs, and biases (Barnard, 1938/1968; Hartley, 1928; Morency, 2010). The persuader's message's primer element is the dynamics in the communication and the message's content (Hartley, 1928). The aligning or misaligning of the message content (Burge, 2010; Ceunen et al., 2016; Hartley, 1928), according to an individual's belief or desire for change (Barnard, 1938/1968), or the passion for a successful outcome of some event becomes actionable based on the receiver's interpretation, and the receiver's level of comprehension which will most likely excite some quantifiable response (Burge, 2010; Ceunen et al., 2016; Hartley, 1928).

Although Barnard (1938/1968) defined cooperation as a group of individuals using relational communications (Rogers, 2008) in a social network where everybody is different and that no two individuals are identical, but have varying skills and talents. Bernard (1938/1968) further stated that no two individuals could occupy the same geo-spatiotemporal coordinate concurrently. Abel (1998), Barabasi (2003), Barnard

(1938/1968), and Morency (2010) viewed that every person in the world is dynamically and passively connected regardless of differences and systemic beliefs: cultural, religious, etcetera. Social entanglement differs from social networks in that everyone, regardless of their respective communities or geospatial and temporal location (Abel, 1998; Moussaid et al., 2013; Shmueli et al., 2014). Abel (1998) viewed that cultural and ecological systems evolve dynamically, impacting every biological entity. Collectively, communities are passively connected. However, individuals using various communication methods within each organization or sub-organization within the community may have some universal connectivity allowing information exchange interactively (Abel, 1998; Chauncey et al., 2016; Ito, 2020; Moussaid et al., 2013; Shmueli et al., 2014). Abel (1998) argued earlier that entanglement is a complex system that stems from evolutionary biology (O'Malley et al., 2015), community ecology (Nakkeeran, 2010; Schulz-Bohm et al., 2018), social dynamics, and behavior development (Sharpee et al., 2014), and the understanding of cognitive reasoning and learning mechanism between humanity and computer systems (Michael, 2016).

Social entanglement encompasses the differential dynamics of a homogenous community that transposes into a state consisting of a heterogeneous population (Abel, 1998; Barnard, 1938/1968). Barnard (1938/1968) championed the construct that everyone is different. Hartley (1928) stated that everyone interprets and comprehends information differently. Social norms and human corporations are the principal foundations of humanity, purposing on social involvement dynamics, including communities and cliques (Fehr & Fischbacher, 2004). How these factors influence a human-robot team's collaborative efforts depends on the unknown influential factors impacting the effectiveness of the team's coexistence within a heterogeneous population, mainly where acceptance is of concern.

Soraa et al. (2021) focused on the social dimensions of domestic robots under the guise of gerontechnology. The social entanglement of acceptance by prospective recipients of such advanced robotic technologies may lead to some measurable apprehension, or not, even though change is inevitable, accompanied by benefits. From Soraa et al.'s (2021) perspective, robot technology that would conceptually work well in meeting the basic needs by assisting aging adults and caregivers within their respective homes must encompass cognitive, social, practical, and symbolic behavioral abilities. The pairing of a robot specifically designed to aid aging adults and caregivers of the elderly signifies the formation of a team, where one team member cares for the wellbeing of the other. The management of robots in gerontechnology and assisted active living is a new paradigm in robotics management; where robotic entities will operate in dynamic environments, often oscillating between simple and complex conditions (NSF, 2020; Soraa et al., 2021; Thommes et al., 2020).

An issue of concern for managers of robots within an assigned human-robot team is that robots will have the ability to operate autonomously without a governing entity nearby, reflecting on the acceptance of a robot as a teaming partner (Soraa et al., 2021; Thommes et al., 2020). Organization values, according to Domanska-Szaruga (2020), are a set of values that "help define the culture of a given organization" (p. 271), including a code of ethics, innovativeness, mission, and vision, and a drive toward excellence.

Thommes et al. (2020) reflected on this social entanglement as necessary for team members to operate independently, maintaining organizational values. Thommes et al. further stated that team and organizational effectiveness depend on the team's ability to adapt. Rigidity by managers can reduce the effectiveness of an organization and team; therefore, managers must remain flexible, particularly in the acceptance of new and advanced technologies (Barnard, 1938/1968; Guo et al., 2021; Homan et al., 2020; Thommes et al., 2020).

Influential Dynamics in Decision-Making

Decision making is both mandatory and voluntary, using conscious and subconscious control mechanisms on a dynamic prioritization scale where information catalyzes influence (Lucci, 2013; Prabhakaran & Gray, 2012). Lucci (2013) viewed that intertemporal choices are an integral part of the decision-making process, which is significant to Bandura's (1991) perspective on self-regulation and social cognition. Lepora and Pezzulo (2015) echoed this argument that the urgency of decision-making through choice selection is necessary to resolve an immediate issue. Bandura (1991) earlier reflected on social influences as a contributor to self-regulation, and the selection of choices are reflective of time and occurrences of events. Self-regulation is an active decision-making process that requires individuals to carefully review all informative options, select the most appropriate choice, and then execute the choice using algorithmic processes (Bandura, 1991; Lepora & Pezzulo, 2015; Lucci, 2013). Every bio-intelligent entity interacts and navigates differently within its environment, with each having the ability to make selective choices (Floreano & Mattiussi, 2008; Lepora & Pezzulo, 2015;

Prabhakaran & Gray, 2012). The occurrence of relational dynamics, the election of choices, or establishing goals require individuals or entities to engage in decision-making activities (Lucci, 2013; Prabhakaran & Gray, 2012; Rogers, 2008).

No intelligent entity can make and execute an appropriate decision without proper and adequate information (Lucci, 2013; Pfeifer & Scheier, 1999; Prabhakaran & Gray, 2012). During times of uncertainty, individuals would have a challenging time in making and executing decisions when preference information is incomplete or absent (Armbruster & Delage, 2015). The dimensions in decision-making usually have one-to-many correlations with available information sources, including data, which is the foundation and composition of some form of knowledge (Hartley, 1928). Sources of information are not merely vocal and body language communication methods between two individuals, such as sharing ideas and thoughts, but are prevalent in other media sources, such as radio or television broadcasting, and symbols or text on paper (Hartley, 1928). These sources are a form of media that a transmitter or communicator uses to reach a potential receiver or recipient (Hartley, 1928; Shannon, 1948; Weaver, 1949/1964).

The execution of choice is reflective of Bandura's (1991) viewpoint on cognitive awareness when an individual chooses to ingest and process information or data that is available from the communicator or communicator's media source (Lucci, 2013). Not every communicator or transmitter of information is the originator or primary source of information (Hartley, 1928). Hartley (1928) and Shannon (1948), as reflected in Pfeifer and Scheier (1999), Burge (2010), Popper (2010), and Smaldino and Richerson (2012) stated, that every source of information stems from another source; and, that every source builds upon other sources. There is the assumption that not every source of information is from a credible source. Hartley's (1928), Shannon's (1948), and Weaver's (1949/1964) theory on communication and information, information, whether new or old, or indifferent, stems from how transmitters or communicators present information with the injection of their thoughts and beliefs to influence the behavioral change of the recipient. The communicator's spurious actions, whether deliberate or not, could spawn or excite negative behavior within the recipient, such as distrust or volatile action against other entities (Hartley, 1928; Lavazza, 2016; Rogers, 2008). However, if the recipient of the information has insufficient reason to doubt the validity of the information and trust the communicator, then the communicator's credibility remains intact (Hartley, 1928; Lavazza, 2016; Rogers, 2008). In contrast, if the communicator has reason to believe the information is inaccurate and quickly moves to inform the recipient of the error, then the action by the communicator to promptly correct the mistake adds to his or her credibility (Hartley, 1928; Lavazza, 2016; Rogers, 2008). The behavior model of credibility and trust is the basis for having human-robot collaborative teams (AFOSR, 2018).

Information is a stimulus that, upon reception, can excite some measurable response in the recipient Hartley, 1928; Lavazza, 2016; Pfeifer & Scheier, 1999; Rogers, 2008. Pfeifer and Scheier (1999) stated that environmental influences stimulate intellectual thought and social development. The consequence of executing a decision is choosing the best option to execute, using the selection criteria stemming from information about an event or issue. An issue is the consequence of a failed event that requires a discussion and solution (Lucci, 2013).

Temporal priorities in finding a resolution require an individual to evaluate the urgency of the issue concerning the event failure (Lucci, 2013). Social events occur in time, relevance, or correlation to social activities (Barnard, 1938/1968). The social activity requires individuals' interaction (Bandura, 1991; Barnard, 1938/1968) who must decide whether to interact or not interact at a point in time (Lucci, 2013). Choosing when, where, and how to interact determines whether an individual needs or desires to socialize with others (Barnard, 1938/1968; Hartley, 1928; Lewis & Weigert, 1985). AFOSR (2018) and Ardiny et al. (2015) elevated the idea of human and robot or robotic entities collaborating on a task, project, or event where trust is a significant factor in the team's behavior. The genesis and composition of any relationship require at least trust and communication or connectivity between two or more individuals (Barnard, 1938/1968). Conceptually, this type of collaborative relationship is a requirement in the success of any human and robot team, where the human element must be willing to accept the decisions from an intelligent entity (Brown et al., 2015; Goodrich & Schultz, 2007; Meadows et al., 2014; Wu et al., 2016).

Meder et al. (2013) found that "uncertainty permeates all aspects of real-world decision problems, from construction the action and outcome space to inferring the probabilities sand values of outcomes and predicting the behavior of others" (p. 257). Specifically, individuals make and execute numerous decisions daily in relevance to environmental influences (Lavazza, 2016; Lucci, 2013; Meder et al., 2013). Decision-making is a three-part process (Meder et al., 2013; Parmigiani & Inoue, 2009; Yukalov & Sornette, 2014). There is the process of selecting the best option and selecting the option before executing (Burge, 2010; Lavazza, 2016; Lucci, 2013; Meder et al., 2013). The desire to execute a particular option of choice depends on whether the consequence of the execution is acceptable (Lavazza, 2016; Lucci, 2013). The execution of a decision is impossible without the availability of options stemming from the information (Lucci, 2013; Meder et al., 2013).

Technology has not immensely evolved to the state where artificial intelligence-based mobile systems can exercise self-learning and self-governing autonomously (Moniz, 2013). Robotic or robot mobile systems capable of self-learning and self-governing operating as autonomous intelligent entities exist, but limitations in their self-governing abilities require supervised learning and operations, leading to slow development of cognitive skills (Meadows et al., 2014; Pupo, 2014). As self-learning and self-governing, an entity's autonomy is the ability to exercise free will under social and cultural acceptance, remains limited (Lavazza, 2016). The basis of independence is the capacity to exercise limited free will as permitted under specific social and environmental influences and constraints, such as the freedom to choose and the freedom to exercise decisions based on the choices selected from available options (Lavazza, 2016; Moussaid et al., 2013). Other constraints, such as social, cultural, and legal limits, may restrict an entity's capacity to exercise some free will without detrimental consequences (Moniz, 2013; Salomons et al., 2016; Smaldino & Richerson, 2012). Choices of options are limited based on information derived from situational awareness, situational intelligence, and environmental influences, depending on the flow of input, processing, and information output (Pfeifer & Scheier, 1999).

Artificial intelligence and artificial general intelligence may have the ability to perform tasks equal to or beyond human capabilities, are indeed limited due to the current maturity levels of robot components (AFOSR, 2018; Floreano & Mattiussi, 2008; Kakas & Michael, 2016); the capacity to exercise rational and critical thinking. Because of the limiting factors in current artificial intelligence applications, in which no critical or rational thinking capabilities are available, the exercise of teaching such artificial intelligence-based systems occurs through supervised learning activities (Floreano & Mattiussi, 2008; Kakas & Michael, 2016; Pfeifer & Scheier, 1999). Applications and platforms which exercise machine learning, deep learning, and computer vision are subsidiaries of the artificial intelligence discipline (AFOSR, 2018; Floreano & Mattiussi, 2008; Kakas & Michael, 2016; Pittman & Soboleski, 2018). These applications and platforms function in a supervised and unsupervised capacity (LeCun et al., 2015; Pfeifer & Scheier, 1999; Shipp, 2016) to learn from their supervised experiences. Another limiting factor in artificial intelligence and robot application is the absence of blended learning capabilities through sensory processing (Michael, 2016). Supervised learning has the potential to teach certain biases that are favorable to the supervisor of the training (Floreano & Mattiussi, 2008; Kakas & Michael, 2016; Sammut, 2012). Such preferences may prove to be socially unfavorable and even detrimental to the public on the acceptance and growth of advanced robot entities of human-robot relationships within specific populations (Bartneck et al., 2018). Managers must ensure such biases are dismissed in the training curriculum to promote social equality and equity for robot entities in a human-robot team (Barnard, 1938/1968; Bartneck et al., 2018; Kaivo-Oja et al., 2017).

Managers are responsible for ensuring their teams' overall effectiveness and well-being and must rely on each member's intellect, strengths, capabilities, and ability to thrive in a multicultural environment (Thommes et al., 2020). Barnard (1938/1968) stated that "no organization can exist without people" (p. 83). The people who form the organization must operate with a sense of unity and the desire and drive to ensure the organization's success (Barnard, 1938/1968; Guo et al., 2021; Homan et al., 2020). By empowering members of the organization to effect change in a dynamic environment, decision making becomes part of the lowest point in the hierarchal structure of the organization, irrespective of the individual's area of responsibility. Conceptually, managers and human team members must be willing to accept decisions made by their robot counterparts (AFOSR, 2018; NSF, 2020; Soraa et al., 2021).

Influential Dynamics in Methodology and Design Selection

The RAND Corporation developed the Delphi method to forecast future events and phenomena (Ametepey et al., 2019), including understanding undeveloped and advanced technologies, robotics, artificial intelligence concepts, and social and organizational dynamic behaviors (Davidson, 2013; Hsu & Sandford, 2010; Warner, 2017). The Delphi method consists of multiple rounds of controlled data collection and feedback sessions with the subject matter experts (Davidson, 2013; Diamond et al., 2014; Hsu & Sandford, 2010; Warner, 2017). While there is little or no scientific evidence supporting an optimum number of rounds, the average Delphi study requires three iterations or rounds to reach a consensus (Davidson, 2013; Diamond et al., 2014; Hsu & Sandford, 2010; Warner, 2017).

The Delphi method originates from the Oracle at Delphi to determine the outcome of future events and resolving complex topics (Ametepey et al., 2019). According to Greek mythology, the Oracle at Delphi is an omnipotent forecaster with infallible authority to deliver prophecies on moral, spiritual, and philosophical topics (Ametepey et al., 2019; Davidson, 2013; Salcido, 2016). Davidson (2013) stated that “a research study that simply seeks people’s experience is not a Delphi study” (p. 62). A Delphi study also requires researchers to examine current and past events to improve or predict the future.

The are many variants of the Delphi method, consisting of classical, modified, policy, decision, real-time, e-Delphi, technological, and disaggregation (Davidson, 2013). The research approach for the proposed study is the e-Delphi technique. The e-Delphi replicates the classical Delphi technique. The primary difference between the e-Delphi and the classical Delphi is that all events, correspondences, transactions, feedback, and so forth, occur online in the former. In contrast, the latter requires face-to-face interaction (Davidson, 2013). The basis for choosing the e-Delphi technique over other Delphi approaches was the insufficient availability of data, the non-existence of human-robot teams in the general workforce, and the absence of any literature on human-robot team management.

Human-robot workforce management is a new concept in organizational management. While there are sufficient peer-reviewed articles available on standard workforce management, very little has been written on human-robot workforce management. The reason for using the e-Delphi technique is to forecast or explore what may or is likely to happen in the future when insufficient information is available to address a specific problem (Davidson, 2013; Hsu & Sandford, 2010; Warner, 2017). The concern in this study is that managers lack knowledge of the factors influencing the effectiveness of managing human-robot teams within a human-robot work environment, as human-robot teams do not yet exist (Baude & Sachs, 2017; Cominelli et al., 2018; Shannon, 1948; Weaver, 1949/1964). Using the e-Delphi technique in this qualitative study enabled the identifications of factors that might influence the effectiveness of human-robot teams, a new concept in human-robot workforce management.

Summary and Conclusions

The classic work of Barnard (1938/1968) on organization theory provided the foundation to the literature of this research on factors that could influence managing a human-robot team's effectiveness, including interactive communication (Chauncey et al., 2016; Ito, 2020). Relational communication (Rogers, 2008), ubiquitous connectivity (Shannon, 1948), and information (Hartley, 1928; Weaver, 1949/1964) are central theories and perspectives towards Barnard's (1938/1968) contributions, relative to Chauncey's et al. (2016) and Ito (2020). Development of the conceptual framework from the critical areas of the study title: communication, robotics, cognition, and management became part of the literature search strategy using Hartley (1928), Shannon (1948), Weaver (1949/1964), and DeDeo (2018) theories on information and communication. Managing human-robot teams is a new paradigm, particularly in the areas of gerontechnology and active assisted living, (NSF, 2020; Soraa et al., 2021; Thommes et al., 2020). The absence of peer-reviewed literature to identify and understand any influential factors influencing human-robot teams or human-machine partnerships is the prevailing gap in the universal body of knowledge, prompting the use of the e-Delphi technique as the methodology and design for this research.

Chapter 3 includes the selection and usage of the e-Delphi technique as a methodology toward the aggregation of data from subject matter experts to form a consensus on influential factors that could impact human-robot behaviors. The subject matter experts came from within the United States and had varying academic degrees and experience in the areas of computer and data sciences, robotics, software engineer, artificial intelligence, management, and mathematics. The process of data collection, data analysis, and data interpretation provided essential insight into the potential evolution and the understanding of how influential factors could affect the collaborative efforts of a human-robot team (Corbin & Strauss, 2015; Dautenhahn, 2007; Goodrich & Schultz, 2007). An exploration into any concerns in potential conflicts of interest, bias, or ethics is part of the researcher’s requirements includes full disclosure and explanation occurs in Chapter 3 (Charmaz, 2014; Corbin & Strauss, 2015).

Chapter 3: Research Method

The purpose of this e-Delphi study was to gain insight into factors that could influence the effectiveness of managing human–robot teams within a human–robot work environment, using the opinions from experts in the field of robotics. Teaming robots with human agents as teammates, including the idea of assisted-living caretakers, is an advanced concept (Nikolaidis et al., 2015; Thomaz et al., 2016; Wu et al., 2016; Zak, 2017). Using the e-Delphi technique was ideal for this study of the effectiveness of human–robot teams and future best practices in managing human–robot teams' effectiveness (Davidson, 2013). I attempted to identify and understand the factors that influence human–robot teams' efficacy and fill knowledge gaps in human–robot team management, including team dynamics and team composition (AFOSR, 2018; NSF, 2020). Understanding the factors that influence human–robot teams may positively affect social change, particularly in accepting robots as contributing members to a dynamic society, such as aiding individuals with challenges like poor sight or other physical impairments.

Research Design and Rationale

The driving research question was "What factors influence a human–robot team's effectiveness within a human–robot work environment?" The concept from the research topic and question centered around Chauncey et al.'s (2016) co-adaptive human–robot interaction framework, Ito's (2020) theory of human-machine metacommunication, and Shannon's (1948) and Weaver's (1949/1964) mathematical theory of communication, where a human–robot team consists of one or more human entities and one or more highly advanced intelligent independent performing robot entities (AFOSR, 2018; Brown et al., 2015; NSF, 2020; Tang et al., 2016). Regardless of composition, the team's synergy can conceptually excite certain behaviors within the team's relationship (Barnard, 1938/1968; Levi, 2001).

Understanding the influential factors in managing the effectiveness of human–robot teams required using the qualitative methodology and the e-Delphi technique. The choice of using the e-Delphi technique for this research study over other qualitative methods is the need for consensus on the insight into factors that could influence the effectiveness of managing human–robot teams within a human–robot work environment, using the opinions from experts in the field of robotics (Ametepey et al., 2019; Davidson, 2013; Habibi et al., 2014). Human–robot teams, as described in Chapters 1 and 2, are ideal for engaging in specific work environments, such as public safety, loss of biodiversity, search and rescue/recovery, discovery, and identification of hazardous artifacts, as well as assisting individuals with some degree of impairment (AFOSR, 2018; NSF, 2020). An advanced independent robot's challenge is to determine the level of competency needed as a team member to navigate and comprehend the socio-dynamics and physical compositions of their work environment (AFOSR, 2018; Castro et al., 2017; Wu et al., 2016). Specific navigational challenges may ensue depending on the overall composition of the work environment and the robot entity's competency and mobility (AFOSR, 2018; Christoforou & Müller, 2016). Some measurable degree of influence, which remains elusive, is part of the foundational cornerstones of any human–robot teaming relationship (Castro et al., 2017; Levi, 2001; Rogers, 2008; Zak, 2017). The ability to influence harmony with the social norms is culturally dependent (Tang et al., 2016). The exercise of free will becomes free will with constraints due to social, judicial, and environmental laws (Lavazza, 2016).

Further, team relationships, particularly in a high functioning and well-organized team, are communication dependent (Barnard, 1938/1968; Levi, 2001). Communication between two entities within an organization is a foundation for establishing and maintaining a relationship (Barnard, 1938/1968; Levi, 2001; Rotenberg, 2018). The ability to exert some form of influence relies on communication and trust development (Rotenberg, 2018). Individuals' decision-making dynamics are information dependent (AFOSR, 2018; Prabhakaran & Gray, 2012; Rotenberg, 2018; Wu et al., 2004). A simple act of communicating information from one entity to another requires identifying one as the source/sender and the other as the destination/receiver (Shannon, 1948; Weaver, 1949/1964). The complexity of communication increases as the distance between two entities increases, requiring the introduction of various computing technologies to maintain communication linkage (Hartley, 1928; Shannon, 1948). How this relationship evolves is dependent on the interactive dynamics between a human and a robot or robotic entity (Castro et al., 2017; Dautenhahn, 2007; Hoffman, 2019; Rotenberg, 2018).

Role of the Researcher

My role for this research study was to collect and analyze the study data and present my findings in a way that may lead to further research on the factors influencing the effectiveness of human–robot systems. As the principal researcher, I ensured all procedures or methods performed in this research are acceptable, transferable, and reproducible (see Corbin & Strauss, 2015). My role as the researcher was to identify and select participants who were conversant with the development and deployment of advanced software and data science applications, including artificial intelligence and robotics, and have some management experience. My role also included managing the data collection processes and analyzing the data using SurveyMonkey as an instrument to collect data within a virtual environment. The rules of engagement in using the e-Delphi technique followed the same rules of engagement of the classic Delphi and modified Delphi, using electronic medium to share information and the collection of data (Davidson, 2013).

My plan included using data collection methods and processes for analysis consistent with the standards in performing qualitative research, specifically using the e-Delphi technique. The data collection method consisted of capturing and analyzing responses from nine to 12 participants in at least three data capturing sessions (Ametepey et al., 2019; Davidson, 2013). Participants for this research were experts and practitioners in the areas of organizational development, development and deployment of robotics and artificial intelligence applications, including a background in areas such as computer and data sciences, advanced automation and systems design, biology, engineering, mathematics, and management.

Methodology

Methodology is a set of principles and procedures in studying some event or fact of social or scientific interest that other researchers can replicate (Corbin & Strauss, 2015). The factors that would affect the robot–human team's effectiveness are inherently unknown. Consequently, the methodology that best fit this scientific inquiry is the qualitative methodology using the e-Delphi technique.

The lack of topic-related, peer-reviewed documents and books and data and the low level of maturity of autonomous robot systems was influential in choosing the qualitative methodology, specifically the e-Delphi technique for this research study on identifying factors influencing human–robot teams' effectiveness. The use of statistics, numerical analysis, and other forms of mathematical algorithms on collected data for objective measurement of the relationships between variables to explain a phenomenon is the foundation of quantitative methodology (Howell, 2013). But the lack of datasets, peer-reviewed articles, and technical solutions on self-governing mobile robot systems as teaming partners made the use of quantitative research methods unsuitable. I also dismissed the idea of using mixed methods combining quantitative and qualitative methodologies for this research as a viable option because data sets for this research are nonexistent (Charmaz, 2014; Corbin & Strauss, 2015; Goulding, 2002; Howell, 2013). In contrast, researchers use qualitative research methods involving the collection of qualitative data from participants to interpret social phenomena, using content and factor analysis for theory development (Corbin & Strauss, 2015; Howell, 2013).

After studying the features and requirements of ethnography, case study, phenomenology, the narrative approach, grounded theory, and the e-Delphi technique, I decided that using qualitative methodology was the only viable approach for this research (Ametepey et al., 2019; Davidson, 2013; Goulding, 2002; Howell, 2013). Data collection of each of these methods is similar, involving either direct one on one interaction with an individual, or multiple individuals, in a group setting or through observation and document analysis (Ametepey et al., 2019; Charmaz, 2014; Corbin & Strauss, 2015; Goulding, 2002; Howell, 2013). But the purpose of each of these methods differs depending on the type of study and the analysis of data (Charmaz, 2014; Corbin & Strauss, 2015; Goulding, 2002; Howell, 2013). Ethnography focuses more on the context of a culture or organization, requiring researchers to immerses themselves into the research activities while conducting unstructured interviews (Trochim & Donnelly, 2007), which is the gaining of knowledge through experience (Howell, 2013). The case study is used to explore a bounded system, such as a person, group, or organization (Trochim & Donnelly, 2007). Individual experiences, the sequence of events, and stories captured from documents are ideal for using the narrative approach (Moen, 2006). Phenomenology is the study of individual participants' experiences with a phenomenon (Sokolowski, 2008). The reason for choosing the e-Delphi technique was to analyze data from a panel of experts over a series of data collection rounds to establish a consensus on factors influencing the effectiveness of managing human-robot teams. On average, three rounds of data collection, analysis, and feedback are necessary to reach a consensus without the use of an a priori threshold value (Ametepey et al., 2019; Davidson, 2013; Diamond et al., 2014; Hsu & Sandford, 2012).

Participant Selection Logic

I invited 15 subject matter experts (SMEs) using email who had a background in managing information and technology projects, including research and development in artificial intelligence, such as computer vision and machine learning, robotics, or working in collaboration with others in these areas. The potential SMEs for this research were not in any organization that would require a letter of partnership or sponsorship. The selection of participants were at least 18 years old (Corbin & Strauss, 2015). Though individuals at the age of 16 are considered minors, the average legal age of operating a motor vehicle in most states within the United States is 16 (USDOT-FHWA, 2018). Therefore, if a 16-year-old can accept the responsibility and be held responsible for operating a motor vehicle on roadways, the average 16-year-old can accept an advanced technological entity as a team member. This line of thought also applies to 18-year-old young adults or the 18–22-year-old grouping of young adults. They are in the armed forces maintaining advanced weaponry or guarding munitions or high-priority targeted areas at locations overseas such as U.S. Embassies, munition dumps, and weapon and fuel delivery platforms (Marines, 2020). A maximum age limit was not a factor in smartphone usage. Pew Research (2019) reported that 53% of senior citizens 65 and over within the United States are using smartphones in the same manner as individuals between the ages of 18–29. However, for this research, I only collected data from participants who met the qualifications and were at least 18 years old.

The expected number of expert participants for this research was nine to 12 subject matter experts. Managing a human–robot team is an advanced concept requiring consensus from a panel of subject matter experts on such a team's composition and behavioral characteristics. Habibi et al. (2014) suggested that using a panel consisting of nine to 12 members is sufficient, although there is no requirement for a precise number. To ensure security and protect participants' identities, I only corresponded with participants who volunteered and had completed their consent forms. Disposal of all the study data will occur 5 years after the completion of the study.

Questions used to collect demographic data, such as age, gender, education, and level of expertise in computing technologies, was part of the Round 1 questionnaire session containing the open-ended questions. Data about an individual's sexual orientation, ethnicity, race, religious beliefs, health, and income level was not part of this research study and, therefore, was not part of the data collection process. This information's exclusion has no bearing or relevance on the acceptance and use of advanced robotic technologies (Anderson, 2017; Kaivo-Oja et al., 2017).

Instrumentation

The questionnaire questions for this research stemmed from the primary problem and question in Chapter 1 and the initial literature search of this qualitative study. Some of the characteristics of a good questionnaire is that the questionnaire is free of any bias, valid, able to answer the primary and subsequent questions, highly reliable, and aligns with the conceptual or theoretical framework (Singelton & Straits, 2005). The use of survey instruments must have clear and definite instructions to eliminate confusion (Davdison, 2013).

The choice of instrument for data collection was an online survey platform that would allow participants to enter their responses remotely to questions online while concealing their identity. The survey platform, SurveyMonkey, is a stable and cost-effective platform for collecting and analyzing data and was ideal for all three rounds of data collection. The plan was to use the open-ended questionnaire in Round 1 to collect the panel of subject matter experts' written thoughts. MAXQDA Analytics Pro and Excel, including SurveyMonkey's analysis suite, are standard tools for qualitative research and could be used to process and analyze the data from Round 1. As an instructor of data science and computer science courses, creating a Python script solution for analyzing participants' textual answers was a possible solution as an academic exercise for infusion into the computer programming curriculum. Python scripts written to analyze data from participants are in the appendixes.

The data from Round 1 helped identify some initial factors that are influential in a human–robot team's effectiveness, which was vital to developing human–robot workforce management principles. The use of open-ended questions permitted participants to provide answers freely without any directed guidance. The purpose of Round 1 was to collect and process data from the panel of experts, then the process of generating questions for Round 2 (Diamond et al., 2014). In Round 2, the panelists received a summary of the analysis of Round 1 data and a questionnaire. The questionnaire consisted of questions stemming from the analysis summary that enable data collection relative to understanding factors that could influence the effectiveness of human–robot teams within a human–robot work environment. The rationale for Round 2 was to collect and process data from the panelist, then use the summary analysis to generate questions for Round 3. In Round 3, the panelists received a summary of the analysis of Round 2 data and a questionnaire stemming from the analysis from Round 2 for data collection.

Rounds 2 and 3 were more quantitative than qualitative as the questions derived from the previous round. Each panelist received a summary of analysis from each round or iteration along with a questionnaire for review and scoring, with the option to provide feedback on the summary of analysis from the previous round (Davidson, 2013; Diamond et al., 2014; Hsu & Sandford, 2010; Warner, 2017). The e-Delphi technique data collection and analysis process changed from qualitative to quantitative in Round 2 because statistical analysis of the responses was essential to understanding consensus stemming from the analysis summary (Hsu & Sanford, 2012). The panelists provided in Rounds 2 and 3 the data needed to compute the level of dispersion and central tendency measurements (Diamond et al., 2014; Hsu & Sandford, 2012). A level of dispersion consists of standard deviation and interquartile range, and the measurements of central tendency include the mean, mode, and median (Hsu & Sandford, 2012).

The use of completed surveys from participants helped to understand the factors that influence the effectiveness of managing human-robot teams within a human-robot work environment (Holgado-Tello et al., 2016; Wang et al., 2015). Participants gave their informed consent before data solicitation (Corbin & Strauss, 2015). Participants consented to the data collection process and agreed that their survey inputs were solely for this specific research study, as suggested by Corbin and Strauss (2015).

Pilot Study

Conducting a pilot study was essential for testing the initial research feasibility and testing the study procedures (Corbin & Strauss, 2015). A pilot study should increase the study's credibility by testing the sufficiency of the data collection and analysis processes from the interviewing of three to five participants (Corbin & Strauss, 2015). Participant requirements for this research study were not subject to the conditions in the Participant Selection Logic section. The rationale of testing random individuals without the proper subject matter expert credentials was to test the instruments and the data collection and analysis processes.

The pilot study's overall performance evaluation from start to finish ensured no ambiguity existed in the instructions, terminology, and questions (Corbin & Strauss, 2015). The pilot study used the same questionnaire for the primary research for Round 1. The Round 1 questions are open-ended questions designed for use in the survey instrument. The generation of questions for Round 2 came from the responses and feedback of Round 1. The responses and feedback from Round 2 guided me in generating the questions for Rounds 3. A revisit to the same three to five participants from the pilot test was essential for feedback purposes to make any necessary improvements before the main study launch.

The use of SurveyMonkey was the platform service of choice for data collection. Using this service platform allowed participants to participate in this study at a location of their choice and convenience. Such an option enabled anonymity between participants.

Procedures for Recruitment, Participation and Data Collection

The selection of participants for this research came from various social media platforms (e.g., Facebook, LinkedIn, and Twitter), with whom I do not have a direct working relationship, ensuring that data collection remained unbiased and that no conflict of interest occurred. The steps necessary for recruitment are:

1. The participants will have the opportunity to read the flyer advertising the study.
2. To learn more and to potentially give consent, the prospective participate will click on the link in the flyer to reach the initial questionnaire page/site, which is the consent form.
3. After reading the consent form, the participant, if agreeing to participate, will acknowledge his or her consent by entering their email address, and then click on "yes," before clicking on the "next" button to proceed to the questionnaire.
4. Participants declining to participate can simply close their browser or simply click on "no" and then click on "next" which will take them to the "Thank you" page.
5. Participants who have started the questionnaire, may end the questionnaire at any time by simply closing the browser.
6. Participants who have completed the questionnaire and would like to continue in the research study may do so by clicking on "yes" before submitting and exiting the questionnaire.

The e-Delphi technique requires three rounds of data collection, which is consistent with most Delphi studies, which average three rounds. The data collection process from Round 1 using the initial set of open-ended research questions, which requires, upon completion and submission by the participant, collating and summarizing data, and taking a descriptive statistics approach to analyzing data to develop questions for Round 2 and Round 3. The generation of questions for each of these rounds uses the

7-point Likert Scale and includes a summary of the data analysis from the previous round. The use of feedback analysis and descriptive statistics guides the researcher in the general observation and data collection process.

Questions for this research study are in the question map (see Table 2), which shows how the questions in the initial questionnaire map to the research questions. Generation of questions for Rounds 2 and 3 stemmed from the initial responses from Round 1. Conducting a pilot test of the questionnaire with two or three participants was necessary to ensure that instructions and questions are clear and understandable before executing the main study (Corbin & Strauss, 2015). The revelation of any ambiguity or potential ambiguity within the questions or instructions would necessitate changes to the instructions or questionnaire.

Table 2

Research Question and Initial Questionnaire

Research Question	Initial Questionnaire Questions
What factors could influence the effectiveness of managing human-robot teams within a human-robot work environment?	1. What factors could influence the effectiveness of managing human-robot teams within a human-robot work environment? 2. In what ways, might these factors influence the effectiveness of managing human-robot teams within a human-robot work environment?

Where the Data Will be Collected?

Data collection occurred within the United States, where the subject matter experts reside. By collecting data from around the country, data saturation was more quickly achievable due to the availability of numerous potential participants working in this area.

Many of the individuals sought for this research most likely supported First Robotics and other robotics competitions and have broad exposure to robotics, to include supporting scholastic sponsored robotics teams. Also, most of these individuals may have developed artificial intelligence-based applications. On average, most individuals for this research possess a Bachelor of Science degree in the areas of physics, engineering, computer science, mathematics, data science, or other science technology engineering mathematics-related discipline. This selected population is ideal for this research study. With IRB approval, I sent an email invitation to a few randomly selected individuals who have similar background to test the data collection and analysis process and then randomly recruit participates for the actual Delphi data collection sessions for actual study data.

Who Will Collect the Data?

I collected the data from qualified individuals around the United States using social media platforms once approved by the IRB. The formal process of collecting the data, including the coding processes and data analysis, and any other procedures conducted, must be repeatable. No human experiments, psychological or physical, occurred during the data collection process.

Frequency, Duration, and Recording of Data Collection

Data collection at a chosen location occurred three times, with reservations to verify the transcription through the use of an electronic survey. An application or device capable of recording for later transcription was the desirable method of capturing audio notes during interview sessions. The pilot study provided an average approximation of how long survey sessions would occur. Concealing the identity of participants by use of reference numbers ensured the confidentiality of the participants and their information. A database on a separate system containing the cross-reference list consisting of the participant's reference number and the participant's contact information was a clandestine method that ensured confidentiality of the participant's identity (Corbin & Strauss, 2015). SurveyMonkey captured the participant's responses to the open-ended questions in Round 1. Participants received a summary, for quality review, of their entries with an invitation to freely make changes to reflect their responses more accurately (Corbin & Strauss, 2015). The responses from Round 1 generated the questions for Round 2. The responses from Round 2 generated the questions for Round 3. Before the start of Round 3, the participants had the opportunity to view their responses. Involving participants in the quality assurance process significantly reduced or eliminated data discrepancies (Corbin & Strauss, 2015). Showing the participants, the results of their answers in comparison to other entries was part of the research debriefs.

Follow-up Plan if Recruitment Results in Too Few Participants

As a follow-up, in the event there were not enough participants to meet the minimum requirement for this study, I would continue soliciting participants on various social media platforms until the required minimum number of participants was met. Approximately four to 12 weeks is generally the timeframe necessary to collect data from all three rounds from nine to 12 participants, and the data collection is of good quality, and further data collection becomes unnecessary (Corbin & Strauss, 2015; Goulding, 2002).

Data Analysis Plan

What, when, and how certain factors evolve in and affect a robot-human partnership are daunting questions whose answers remain elusive (Levi, 2001). Use of the e-Delphi technique in the study of influential factors of the robot-human team requires collecting and analyzing data from responses in Round 1 on topic related open-ended questionnaire (Corbin & Strauss, 2015). The plan was to use electronic surveys using SurveyMonkey's services for data collection. The use of electronic surveys was more advantageous to participants due to geographical separation and ease of use. After the completion of each survey, participants received a copy of the summary to ensure the accuracy of their inputs before starting the analytical processing. Verification of the survey's accuracy was crucial in eliminating errors and allowing the participant to make appropriate corrections as necessary during the verification process. The process of analyzing the responses from Round 1 before coding and labeling was to observe patterns, addressing the relevance of the responses to research questions, as well as drawing linkage to relevant concepts (Corbin & Strauss, 2015). Analysis of the data from Round 1 informed the generation of questions for Round 2. In Round 2, the expert panelist received a summary of analysis from Round 1 and a questionnaire containing questions stemming from the summary analysis. The analysis from Round 2 informed the generation of questions for Round 3. In Round 3, the expert panelist received a summary of analysis from Round 2 and a questionnaire containing questions stemming from the summary analysis. Corbin and Strauss (2015) suggested avoiding the pitfalls and dangers in waiting to "collect all of the data at once" (p. 69) for processing. The possibility of life-changing events of the researcher was a possible factor. Therefore, the processing of transcripts occurred immediately following the participants' verifications.

Software Selected for Analysis

I used Microsoft Excel including SurveyMonkey's analysis capabilities for processing and analyzing the data for this research study. Excel and SurveyMonkey's analysis suite are software applications that are in use today by the qualitative research community (Corbin & Strauss, 2015). Organizing and coding unstructured collected textual data from the Round 1 survey was the first step after verifying the accuracy of the inputs with participants. The revelation of a central theme may occur during the textual analysis of responses from participants. The use of the selected software previously mentioned helped in the identification of such a theme, central to factors that are influential in the effectiveness of human-robot workforce management. The process of analyzing the data from the surveys required using algorithms in Excel and SurveyMonkey's analysis. The option of developing a Python script, while not necessary, was suitable for performing data analysis on the data collected from qualitative, quantitative, and mixed methods. Python scripts developed for the analysis of data in conjunction with this research study are in the appendixes. Subsequent steps for Round 2 and Round 3 are the same steps for Round 1, to ensure accuracy of data.

Coding of Data

The transformation of raw data from Round 1 into data for analytical purposes requires inductive analysis, open coding, and labeling of data reflecting categories connected to the research and questionnaire during the ingesting process (Corbin & Strauss, 2015). The exercise of open coding is to ensure proper coding in the developing and designing of categories while examining patterns of similarity, difference, frequency, sequence, correspondence, and causations (Charmaz, 2014; Corbin & Strauss, 2015; Saldana, 2016). The use of open-ended research questions in interview sessions is essential for coding of transcriptions for ease in applying labels to words and phrases (Saldana, 2016). Axial and theoretical coding help in identifying relationships that emerge from the data during and after processing, after the execution of open and in vivo coding (Corbin & Strauss, 2015). Survey responses from Round 2 and Round 3 did not require coding as the responses were quantitative.

Issues of Trustworthiness

The issue of trustworthiness premises on the ethical responsibilities of the researcher mapping to quantitative credibility and validity of the research (Corbin & Strauss, 2015). Deficiencies in any of these areas undermine the structural integrity of the research (Corbin & Strauss, 2015). Such ramifications have the potential of being costly in terms of resources and the reputation of the researcher and institution (Corbin & Strauss, 2015).

Credibility

Credibility in conducting research and the reporting of research results, as described by Charmaz (2014) and Goulding (2002), refers to the integrity of the procedures exercised in the collection, interpretation, and representation of data. The concept of theory development is the goal of this qualitative research on the use of advanced robot systems as collaborative team members (Corbin & Strauss, 2015). The use of constant comparison allows for the comparing of data during the ingesting process to existing data allowing for the interpretation and revealing of new findings (Corbin & Strauss, 2015), particularly for Round 1. Quantitative analysis of data collections from Round 2 and Round 3 was necessary as participants scored responses to questions. Using approved and acceptable data collection and analytical processes established confidence in the research results (Charmaz, 2014; Corbin & Strauss, 2015).

As a software engineer, data scientist, and research engineer, exercising quality assurance is a daily practice, which will meet the quality requirements necessary for this research study. Quality assurance requirements exist for the prevention of mistakes or defects during the data collection and analysis process (Corbin & Strauss, 2015). The integrity of the process prevented the distortion of the findings. Exercising quality assurance is necessary throughout the research process (Corbin & Strauss, 2015).

Transferability

Transferability is about establishing reproducible evidence (Corbin & Strauss, 2015). Evidence of this research study is dependent on the consensus of subject matter experts that will trend toward reproducible modeling of responses that can contribute to understanding a collaborative team's environment. Social unity, the uniting of entities for a common cause or purpose, requires examination of influential factors that have an effect on the behaviors of human-robot teams or human-machine partnerships. Consequently, by carefully documenting the research processes of this study, the research study itself becomes transferable, including the methods and statements, but not necessarily the findings of the study (Corbin & Strauss, 2015).

Dependability

What makes data in research reliable is the stability and consistency in the inquiry and collection processes (Corbin & Strauss, 2015). Adherence to acceptable rules and practices of quality assurance in the data collection further establish dependable results from research conducted (Corbin & Strauss, 2015). The context in understanding the use of human-robotic teams or human-machine partnerships, in general, is an evolving process. The dependability of this research is reliant on the integrity of the research process (Corbin & Strauss, 2015).

Confirmability

Confirmation of research results by peer researchers further establishes credibility and solidifies the integrity of the research study (Kelly et al., 2014). An interrogative approach by subject matter experts into the content of the research methodology and compliance toward ethical standards ascertains the integrity in the data collection and analysis processes, and research results (Charmaz, 2014; Corbin & Strauss, 2015). The confirmation of a research study by peers further ensures the vetting of a thorough investigation of the research question (Corbin & Strauss, 2015).

Ethical Procedures

Integrity is an integral part of ethics (Corbin & Strauss, 2015). Integrity is the ethical responsibility of the researcher to exercise integrity to the participant, the profession, and self in "producing the highest quality of work" (Corbin & Strauss, 2015, p. 14). The exercising of ethical responsibility by the researcher is to ensure compliance with the Institutional Review Board's directives and rules for research engagement (Corbin & Strauss, 2015). Walden's Institutional Review Board (IRB) approved this study before the start of the identification and collection of data for this research project. With IRB approval, questionnaire used open-ended questions found in Appendix D. Participants selected met the criteria identified in Appendix C. An anonymous approach in the collection of data, whereby personally identifiable information was not part of the data collection process, minimized potential risks in revealing the identity of participants. The recruiting of participants for this study began upon approval from the IRB. Other than a participant's name, age, gender identification, level of education, years of experience with computing technologies and use or development of artificial intelligence applications, no further requirements for additional personally identifiable information was necessary.

There were no medical, psychological, or physical testing activities required for this study (Corbin & Strauss, 2015). The distribution and collection of questionnaires occurred in a virtual setting that was accessible to the subject matter experts and not within their respective daily work environments. Participants were encouraged to exercise free will in deciding if they would desire to participate or not. There were no other ethical concerns concerning the research on identifying and understanding factors that were influential on the effectiveness of human-robot teams or human-machine partnerships.

Summary

The question of what influential factors involving the effectiveness of managing human-robot teams or human-machine partnership exist, including assessing the efficacy of these influential factors dynamically, remains elusive, requiring input from a board of subject matter experts. The justification, research methodology, and research design on the selection and use of the e-Delphi technique and the researcher's role is the theme in this chapter. This research study involved three rounds of data collection to generate a consensus, starting with the first round using open-ended questions. The responses from Round 1 generated closed-ended questions for Round 2, and the responses from Round 2 generated closed-ended questions for Round 3. I conducted a pilot study to test the research procedures before commencing the main study.

Survey responses were solicited from a selection of participants with a background in computer and data sciences, mathematics, physics, and engineering, and some knowledge of, or working experience with robotics or artificial intelligence, at a location of their choosing (Corbin & Strauss, 2015). Data were captured and derived from the survey data, capturing events for analysis and modeling propose toward the generation of a consensus in understanding the influential factors and dynamics of a human-robot or human-machine collaborative relationships (AFOSR, 2018; Corbin & Strauss, 2015).

The use of acceptable qualitative research methods, particularly in data capturing and analysis, ensured the study's credibility and confirmability (Corbin & Strauss, 2015), including the maintaining of ethical standards. Chapter 4 includes a description of any changes to the questionnaire and process, the data collection and analysis process, the study results, and evidence of trustworthiness. Chapter 4 concludes with summarizing the study, leading to the discussion, conclusion, and recommendations found in Chapter 5.

Chapter 4: Results

The purpose of using this e-Delphi technique was to investigate factors that can influence the effectiveness of managing human–robot teams. The gap in literature on human–work management represents incomplete knowledge on the factors that influence the effectiveness of human–robot teams, leading to a lack of clarity (Hoffman, 2019; Lucci, 2013; Martius et al., 2013; Pfeifer & Scheier, 1999). The specific problem was that managers lack knowledge of the factors influencing the effectiveness of managing human–robot teams within a human–robot work environment, as human–robot teams do not yet exist (Baude & Sachs, 2017; Cominelli et al., 2018; Shannon, 1948; Weaver, 1949/1964). The lack of knowledge in managing a human–robot workforce environment may affect managers' ability to manage these human–robot teams effectively as they are developed.

A panel of subject matter experts assembled for this research consisted of individuals who have professional experience and an academic background in science, technology, engineering, mathematics, team or organization management, and other science or technology related disciplines. The panel of subject matter experts participated in three e-Delphi data collection rounds guided by a series of open-ended and close-ended questions to arrive at consensus regarding the effectiveness of influential factors impacting the human–robot workforce environment—specifically, human–robot teams. In this chapter, I describe the research setting, participant demographics, data collection procedures, data analysis, procedures, evidence of trustworthiness, and results of the research, concluding with a chapter summary and transition.

Pilot Study

A pilot study was conducted using three randomly selected participants and the Round 1 open-ended questionnaire to test the feasibility and procedures for this research using the SurveyMonkey platform. My analysis of the pilot study verified the effectiveness of the data collection and analysis processes. I used the pilot to test the SurveyMonkey platform, the data collection and extraction, and the data analysis processes. The overall performance evaluation of the pilot study from start to finish ensured no ambiguity existed in the instructions, terminology, and questions (Corbin & Strauss, 2015). No additional testing was necessary because of the success of the pilot.

Research Setting

The e-Delphi technique was used as the methodology for this research, in which the surveys and correspondence occurred online. Other than having internet connectivity, there were no other environmental restrictions or specific requirements for participation. The subject matter experts were free to take the survey at their place of choice. Thus, how, when, or where the participants chose to complete the survey was immaterial. Although nine participants were needed for this research, 15 participants were sought. A total of 12 subject matter experts responded and participated in all three rounds of data collection.

Demographics

A total of 15 subject matter experts (SME) were invited to participate in this research, and 12 accepted. The absolute minimum of participants for this research was nine, as recommended by the RAND corporation (Fitch et al., 2001). Subject matter experts were expected to have a degree in management, science, technology, engineering, or mathematics with experience in analyzing and solving complex problems, managing teams, and project management. The assembled panel of subject matter experts were between the ages of 25 and 66 and consisted of eight women and four men. The education levels varied as outlined in Table 3. In addition to their formal education, the subject matter experts had a wealth of experience in managing projects and teams; designing, developing, testing, and implementing systems, including developing artificial intelligence applications; and coaching teams in robot competitions.

Table 3

Education Level of Subject Matter Experts

Bachelor's Degree			
Type of Degree	YE	G	N
Business Management	10+	F	1
Aeronautical and Astronautical Engineering	10+	M	1
Public Affairs and Community Service	11+	M	1
Management Information Systems	10+	F	1
Master's Degree			
Type of Degree	YE	G	N
Business Administration	8+	F	1
Computer Science/Mathematics	10+	F	1
Management Information System	12+	F	1
Science Administration w/Concentration in Business	10+	F	1
Management Information Systems - Human-Centered Computing	10+	F	1
Doctor's Degree			
Type of Degree	YE	G	N
Computer Science	12+	F	1
Juries Doctorate	10+	M	1
Physics	14+	M	1

Note: YE = Years of Experience, G = Gender, N = Number of Participants

Data Collection

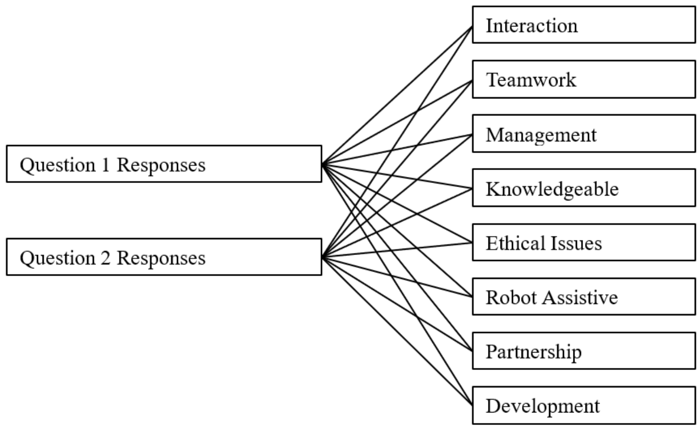
In each of three rounds over a 15-week period, I collected data from 12 subject matter experts. Round 1 consisted of two open-ended questions. Round 2 and Round 3 consisted of closed 7-point Likert style questions. SurveyMonkey was used to distribute questionnaires and collect responses. By using SurveyMonkey, anonymity was maintained between participants. The survey was easily administered online. Collected data was then analyzed using Excel.

Overview of Round 1

In Round 1, the subject matter experts were given two open-ended questions on influential factors that would affect a human–robot team leading to the potential understanding of a human-robot workforce environment (see Appendix B). A consensus was not reached in their responses (see Appendix C). Their responses, collectively, led to the generation of eight different themes (see Figure 5). Theme-related questions, in relation to the literature in Chapter 2, were then generated for Round 2; the same questions were used in Round 3 (see Appendix E). The only difference in the questionnaires between Round 2 and Round 3 was that the Round 2 questionnaire did not contain any statistical data or participants' previous responses. The Introduction page reflects the purpose of Round 2 (see Appendix E).

Figure 5

Responses to Categories



Overview of Round 2

In Round 2, a questionnaire containing 48 questions grouped under the appropriate themes from Round 1 was sent to 12 participants. The participants were asked to rate each question using a 7-point Likert scale ranging from *strongly disagre*e to *strongly agree*. The participants were provided an option at the end of the survey for additional comments. Sufficient time was allotted for responses, with 100% of the participants completing Round 2. The data were analyzed to provide statistical analysis for Round 3.

Overview of Round 3

In Round 3, a questionnaire containing the same 48 questions in Round 2, grouped under the appropriate themes, was sent to the 12 participants. The questionnaire sent to the participants contained the group's statistical responses and their response from Round 2 with each question. The participants were asked to rerate each question using a

7-point Likert scale ranging from *strongly disagree* to *strongly agree*. If participant changed their response, they were asked to provide a reason for the change. The participants were provided an option at the end of the survey Round 3 for additional comments. Extended time for each participant was permitted as the review and rescoring of Round 3 required more time. One hundred percent of the participants completed Round 3, with 33% reporting *no change* in their responses from Round 2.

Data Analysis

My aim in the data analysis was to determine if a level of consensus existed among the subject matter experts. The participants were provided a set of open-ended questions in Round 1 and closed-ended 7-point Likert scale questions in Round 2 and Round 3. SurveyMonkey was used as an instrument to distribute the surveys and collect data to and from the participants. Data from all three rounds were downloaded from the SurveyMonkey site and loaded in Excel for analysis.

Analysis of Round 1

The responses from both questions in Round 1 were analyzed, producing eight themes (see Table 4). Each theme was created by scanning the participants' responses twice before choosing the best appropriate categorical synonym, reflecting the meaning of the participants' responses segmented into sentences. The themes were then rechecked against the participants' responses to ensure a relationship and measurable consistency existed.

Table 4

Theme Frequency Distribution

Theme	Code	Question 1	%_R1	Question 1	%_R2
Interaction	A	10	13%	12	13%
Teamwork	B	10	13%	13	14%
Management	C	14	18%	19	21%
Knowledgeable	D	14	18%	10	11%
Ethical issues	E	8	10%	11	12%
Robot assistive	F	4	5%	4	4%
Partnership	G	10	13%	15	17%
Development	H	7	9%	6	7%
Total		77	100%	90	100%

Note. Thematic frequency distribution survey of question 1 and question 2, where R1 = Proportional Response to Question 1, and R2 = Proportional Response to Question 2.

A code was then assigned to each theme as part of the coding process. The participants' responses were reevaluated and coded (see Appendix D) and then reviewed for consistency. The theme frequency distribution shows the frequency of the codes. The relationship between the code frequency and the participants' responses is shown in the R1 and R2 columns. The R1 and R2 columns represent the proportional responses, numbered according to the questions. The calculated percentages measure the degree to which participants responded in favor of the category.

I developed the questions for Round 2 based on the themes. As I developed questions for each theme, I examined them for conciseness, redundancy, and alignment in conjunction with the participants' responses, which resulted in 48 questions. See Table 5 and Appendix F.

Table 5

Number of Questions per Theme

Theme	Number of questions
Interaction	3
Teamwork	6
Management	9
Knowledgeable	6
Ethical issues	5
Robot assistive	6
Partnership	6
Development	7
Total	48

Note. Number of questions per theme reduced based on the code frequency average

The questions generated for Round 2 were based on the primary research question, the newly created themes, and the participants' responses. The questions were then reevaluated for proper thematic alignment. The questions were converted to closed-ended statements rather than have the participants respond to open-ended questions, and a 7-point Likert scale was assigned for rating purposes.

Analysis of Round 2

In Round 2, the generated questions from Round 1 were reexamined to ensure conciseness and thematic alignment, including eliminating any questions that seemed redundant. The questions were then uploaded into SurveyMonkey, and a 7-point Likert scale ranging from *strongly disagree* to *strongly agree* was set up for each question. I tested the questionnaire through SurveyMonkey while awaiting approval from the IRB. The test I performed on the questionnaire was successful, from scoring the questions to downloading and analyzing the data. The IRB approved the questionnaire. The questionnaire was distributed to the 12 subject matter experts who were given approximately 3 weeks to complete the questionnaire. All the participants completed the questionnaire within the allotted time frame.

The data were downloaded from SurveyMonkey and uploaded into Excel. On the initial examination of the data, I determined that the participants completed all the requirements in answering the questionnaire. I then computed the mean, mode, median, and standard deviation, and interpreted the results for each question. A consensus threshold was not computed to determine the level of consensus, as it was not clear how the participants would respond in Round 3.

Analysis of Round 3

The same questions in Round 2 were used for Round 3. The introduction to the questionnaire, the participant's previous rating, and the group data analysis were the only significant differences between Round 3 (see Appendix E) and Round 2 (see Appendix D) questionnaire. After receiving IRB approval, I created 12 different questionnaires on SurveyMonkey, each populated with the participant's rating of the question from Round 2. Each questionnaire was sent to the participant with their ratings of the questions.

The purpose of Round 3 was to allow participants to review and compare their rating of a question against the analysis of the group's rating of the same question. After reviewing their initial response from Round 2, the participants could change their rating or keep the same rating. All participants completed the requirements with 33% (four of the 12) not changing their Round 2 ratings and 66% (eight of the 12) changing one or more of their ratings.

The Round 3 data were downloaded from SurveyMonkey and entered into Excel for analysis. Twelve downloads from SurveyMonkey were required. Each download was uploaded and consolidated into one Excel worksheet. Upon completing the uploads, the mean, mode, median, and standard deviation for each question were calculated for purposes of interpreting the results (see Appendix E).

Evidence of Trustworthiness

Trustworthiness in the credibility, transferability, dependability, and confirmability premises on the ethical responsibilities of the researcher (Corbin & Strauss, 2015). The role of ethics was an integral part in maintaining the structural integrity and trustworthiness of the research. The procedures used in the data collection and analysis were carefully outlined and then exercised in the pilot to ensure removal of any biases of the researcher, documenting each step as an added check and balance. In the actual data collection using subject matter experts, the same procedures were used with no deviation. The added quality assurance met the standards of trustworthiness used in a qualitative study.

Credibility

I collected data from creditable subject matter experts for this research by following the procedures outlined in Chapter 3. Credibility in conducting research and the reporting of research results, as described by Charmaz (2014) and Goulding (2002), refers to the integrity of the procedures exercised in the collection, interpretation, and representation of data.

Transferability

Transferability for this study was about establishing reproducible evidence that can used in other forms of research related to human-robot workforce management (Corbin & Strauss, 2015). I used the standard e-Delphi technique procedures in conducting this research to maintain research integrity. By exercising this level of integrity, the procedures and results of this research can be transferred to similar research projects. Yet, findings will not be transferable given the small and nonrandom sample size.

Dependability

The focus on dependability in this research was reflective of the reliability and integrity in the procedures of inquiry and data (Corbin & Strauss, 2015). To ensure the integrity of dependability, I carefully outlined the procedures in participant recruitment, instrument utilization, and data analysis. I achieved this level of dependability by using a set of structured questionnaires consisting of closed and open-ended questions, and Likert-scaled responses, that is consistent with qualitative and quantitative research. The strategy used in soliciting subject matter experts was outlined in Chapter 3, with no change in the qualification.

Confirmability

The confirmability of procedures and results used in this research followed the acceptable standards of practices in research where peer researchers can agree on the findings of the research through duplication of effort (Kelly et al., 2014). I followed the procedures outlined in this Chapter 3 to maintain the integrity of the research including data collection and analysis. Researchers who have a vested in interest in human-robot workforce environment should have no problem in confirming the results of this research.

Study Results

In this study, I explored the unknown factors that can influence the effectiveness of managing human-robot teams by consulting with subject matter experts. An initial 15 subject matter experts were invited to participate in this research study using email. Only 12 subject matter experts responded by completing the Round 1 questionnaire. The same 12 subject matter experts agreed to participate in Round 2 and Round 3.

Analysis of Round 1

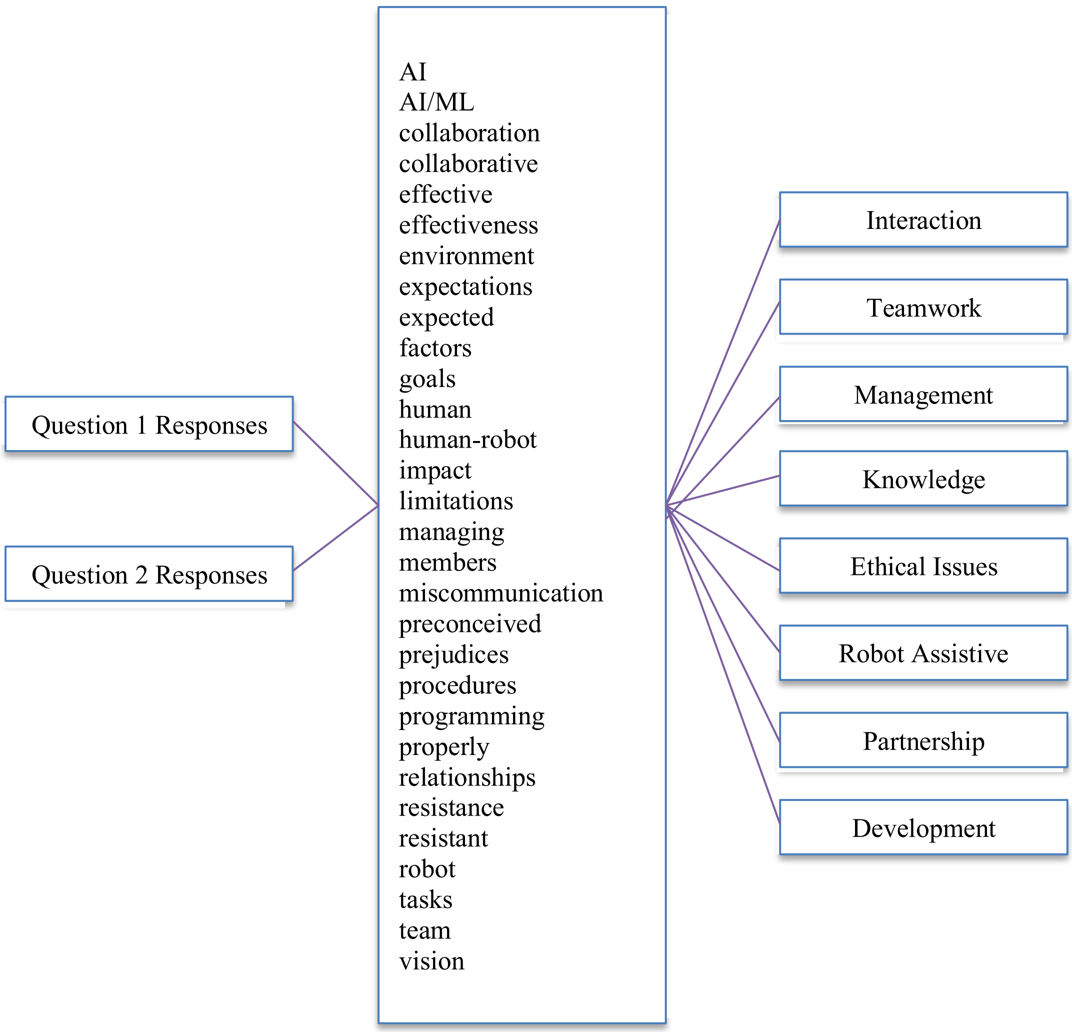
The goal of Round 1 was not to ascertain a consensus but rather to gather and evaluate the experiences of subject matter experts on factors that could influence the effectiveness of managing human-robot teams using open-ended questions. I used the exploratory method to analyze the participants' responses consisting of 700 words. The responses were scrubbed to remove pronouns, conjunctions, and grammatical punctuations using an application I wrote using Python with Natural Language Processing (NLP) components of Artificial Intelligence (AI) (see Appendix H). The Python program reduced the number of words from 700 to 173, with an approximate processing time of 3 seconds.

The reduced participants' responses were then compared to the keywords located in the two open-ended questions. After comparing the two data sets, the participant's responses were further reduced to 91 words. The scrubbed list of words was then consolidated into a list of 30 keyword, achieved through the examination of how the words were related synonymously or similarly. For example, the word *robot* appeared as *robot*, *Robots*, and *robots*.

Regardless of plurality and usage, the number of occurrences of the words related to *robot* except for words such as human-robot or human-robotic was totaled under the word *robot,* and the words *robots* and *Robots* were removed. Similarly, human-robot and human-robotic were combined into human-robot, and the quantities were totaled. The 30 words were then converted into eight themes by examining the relationship between the words, the participants' responses, and the keywords from the two open-ended questions. The thematic connection between the themes and the raw responses was reexamined and coded (see Appendix D). The coding assignments did not represent any kind of ranking order but rather as a connector to the theme.

Figure 6

Responses to Themes



The distribution frequency between the participants and the themes did not reveal a consensus (see Table 3). However, the quantities per theme in the distribution frequency table (see Table 3) were used as a baseline for creating the Round 2 draft questions. The draft questions were then reevaluated against the participants' responses per theme and the number reduced based on evidence of redundancy (i.e., similarity) and relevancy (see Table 4).

Analysis of Round 2

The questionnaire consisting of 8 themes and 48 Likert-styled questions was sent to the 12 participants who chose to continue in this research study. All participants completed and returned the questionnaire within a reasonable timeframe. An initial examination of the data revealed no empty cells in the participants' entries.

Table 6

Cronbach's Alpha and Internal Consistency

Cronbach's Alpha	Internal Consistency
$\alpha \geq 0.9$	Excellent
$0.9 \geq \alpha \geq 0.8$	Good
$0.8 \geq \alpha \geq 0.7$	Acceptable
$0.7 \geq \alpha \geq 0.6$	Questionable
$0.6 \geq \alpha \geq 0.5$	Poor
$0.5 \geq \alpha$	Unacceptable

Note. Cronbach's alpha is used to measure the reliability and internal consistency of a Likert scale data set (Glen, 2022).

The data were then analyzed to determine if a consensus was reached. Research findings suggested a consensus was achieved in all eight categories based on the central tendency calculations (see Table 5). The central tendency's column results are a correlation between the $\bar{x}$ and the computed range of the 7-point Likert scale:

$$\bar{x} = \frac{\sum xi}{N}$$

Note. $\bar{x}$ = results of the computation, N = number of values, xi = sum of all data points

To assess the reliability of the participants' responses, I performed an additional analysis using Cronbach's alpha equation (see Equation 2). The Cronbach's alpha equation is used to determine the reliability of a Likert scale data set. The resultant of the equation is then correlated with the range in Cronbach's alpha and internal consistency table to determine the reliability (see Table 6). After calculations, the Likert scale data set from the participants was then correlated with the internal consistency or reliability resulted in an α rating of 0.91 or *excellent* (see Table 7).

$$\alpha = \frac{N}{N-1}\left[1 - \frac{\sum s^2 y}{s^2 x}\right]$$

Table 7

Cronbach's Alpha Reliability Test for Round 2

Variables	Description	Values
N	Number of items	48
$\sum s^2 y$	Sum of Variance	71.60
$s^2 x$	Variance Total	658.22
α	Cornbach's Alpha	0.91
Internal Consistency/Reliability		Excellent

Analysis of Round 3

The questionnaire sent to the 12 participants who chose to continue in this research study consisted of eight themes and 48 Likert-styled questions using the same questions in Round 2. Each question was accompanied with the participant's Round 2 responses. All participants completed and returned the questionnaire within a reasonable timeframe. An initial examination of the data performed in Round 3 revealed no empty cells in the participants' entries.

The data were then analyzed using the same procedures in Round 2 to determine if a consensus was reached. Research findings for Round 3 suggested a consensus was achieved in all eight categories based on the central tendency calculations (see Table 6). The central tendency's column results are a correlation between the $\bar{x}$ (see Equation 1) and the computed range of the 7-point Likert scale.

I used the same process in Round 2 to perform an additional analysis of the participants' Round 3 responses using Cronbach's alpha equation (see Equation 2) to assess the reliability of the data set. The Cronbach's alpha equation was used to determine the reliability of a Likert scale data set (see Table 7). After calculations (see Table 7), the Likert scale data set from the participants was then correlated with the internal consistency or reliability resulted in an α rating of 0.81 or *good* (see Table 8).

Table 8

Cronbach's Alpha Reliability Test for Round 3

Variables	Description	Values
N	Number of items	48
$\sum s^2 y$	Sum of Variance	55.47
$s^2 x$	Variance Total	270.58
α	Cornbach's Alpha	0.81
Internal Consistency/Reliability		Good

Summary

In Round 1, the goal was not to achieve consensus from subject matter experts but to gather their experiences on influential factors in managing a human-robot workforce. Human-robot workforce management is a new paradigm in organizational workforce management. The Round 1 questionnaire was sent to 15 subject matter experts, with 12 participants responding with completed surveys. These same 12 participants actively participated in Round 2 and Round 3. There were some differences between the data sets of Round 2 and Round 3. Nine participants, or 67%, made changes in their Round 3 responses but did not indicate why they made changes in some of their responses. Four participants, or 33%, kept the same Round 2 answers in their Round 3 responses. A difference was observed in the final statistical analysis when comparing the Round 3 responses to Round 2 of each section (see Appendix G). In Chapter 4, the research findings and results were described. Chapter 5 includes discussion, limitations of the study, recommendations, and conclusions.

Chapter 5: Discussion, Conclusions, and Recommendations

My aim with this e-Delphi study was to explore unknown factors that can influence the effectiveness of managing human–robot teams by using the expert opinions of subject matter experts. The pairing of robots, entities that can alter their environment, with humans as teammates to perform various tasks is an advanced concept in human–robot team development and workforce management. Investigating the factors that may influence the effectiveness of managing human–robot teams may revolutionize human–robot workforce management.

Participants in this study were asked to identify and describe influential factors that may impact the performance of each member of a human–robot team within a heterogeneous organization. Organizations currently lack policies, regulations, and guidelines governing the social integration and use of robots as viable components of an organization's workforce strategy. The consensus from the participants revealed eight themes centered around organizational development and team management toward the integration of robots as team members within the workforce and community social structure.

Interpretation of Findings

The participants mostly agreed that managing a human–robot team in a dynamic environment requires interaction, teamwork, and knowledge, addressing ethical issues and how robots can participate in work environment events as necessary (see Table 9). The observed consensus also reflects how participants collectively scored in each section, indicating how managers may influence the human–robot workforce environment.

Table 9

Table of Consensus

Theme	Calculated Mean	Consensus
Interaction	6.28	Strongly Agree
Teamwork	5.26	Somewhat Agree
Management	5.72	Agree
Knowledge	6.46	Strongly Agree
Ethical Issue	5.77	Agree
Robot Assistive	5.40	Agree
Partnership	5.98	Agree
Development	5.66	Agree

Twelve qualified participants participated in all three rounds of the data collection process. There was a measurable consistency in each of the three rounds stemming from the participants' responses. The overall goal in Round 1 was not to determine the existence of a consensus but to gather the participants' expert opinions using a set of subject-related questions (see Appendix C). A deductive approach was used in analyzing the participants' responses using the literature in Chapter 2 as a foundation. Eight themes emerged after studying the participants' responses. Participants were then asked to rate a set of Likert scaled theme-related questions in Round 2. A preliminary consensus emerged from the analysis (see Appendix G) but was inconclusive because human and robot teaming is a concept of tomorrow's collaborative augmented workforce (AFOSR, 2018; NSF, 2020). In Round 3, participants were then asked to reevaluate their responses from Round 2 using the same Likert questions from Round 2 considering the results of Round 2. The Round 3 data were collected and analyzed (see Appendix G), and then compared to the results from Round 2 and Round 1, and then compared to the conceptual framework found in Chapter 2.

Interaction

Communication emanated as the common thread among all three rounds. Managing a team, regardless of composition, requires interactive communication, where interactive communication is the information exchange between two or more individuals (Barnard, 1938/1968; Chauncey et al., 2016; Ito, 2020). The participants in this study *strongly agreed* that interaction is essential to organizational management and team dynamics. Interaction between two or more individuals requires some form of communication, either direct or indirect. Without communication, managers or team leaders can neither lead nor manage resources appropriately.

The integration of robots as part of the modern workforce will require employees at various stages and levels within the hierarchal structure of the organization to accept and engage robots in a manner that is beneficial to the organization. The participants in this study advocated that interactive communication through employee interaction is necessary for robots to learn and adapt to the organization's principles of operation. An organization's culture is not always defined as a written rule but is implicitly embraced, allowing an organization to fulfill its purpose.

Teamwork

Whether formal or informal, teamwork is necessary to complete tasks within a purpose of an organization. What excites individuals to collaborate is a matter of choice with a sense of purpose and an inner desire to contribute to the team's or organization's success (Barnard, 1938/1968; Levi, 2001). The participants *somewhat agreed* on the collaborative effort. However, the participants were hesitant because of unknown factors and limitations involving the integration of advanced robot systems into the workforce, simply because such systems do not exist. Still, the participants agreed that heterogeneous teams should work in collaboration, regardless of composition, to complete tasks and project assignments. Homogenous teams, consisting of only human entities, are already comprised of individuals with diverse skill sets. As defined in Chapter 1, the bonus of having robots on the team will lessen the burden or risk to human life in situations such as eliminating repetitive and mundane tasks or investigating chemical leaks or explosive devices.

Management

The participants *agreed* that management should have an invested interest in integrating advanced robot systems into the workforce. Managers should have the vision and insight to embrace the capabilities of robot systems to advance the implementation of such systems into the corporate work environment. Managers are responsible for the organization's development and overall operations, including the organization's employees (Barnard, 1938/1968), which coincides with how the participants viewed the role of the manager or team lead in managing human-robot teams.

Knowledge

Education and knowledge sharing is critical to workforce development. The participants *strongly agreed* that all employees, regardless of position within the organizational structure, should have at least a general understanding of the robot's capabilities. Additional and in-depth education and training are necessary for individuals who will have direct contact with the robot entity. The acceptance of these robot entities by individuals who will be teaming with them will stem from their knowing the robot entity's capabilities and capacity to learn from them and their social and physical environments.

Ethical Issues

The application of ethics is twofold in that humans on the team will need to govern themselves according to the ethical standards of their organization. In contrast, robot entities will need to learn to manage themselves consistently regarding the organization's code of conduct and general rules of behavior. Some rules of behavior in society are not written but learned through social interactions, such as treating someone with respect regardless of the person's identity (i.e., race, gender, religious beliefs, and so on). The participants unanimously *agreed* that ethical issues are an area that requires further research, including that each human teammate will need to conduct themselves by following established guidelines.

Robot Assistive

Participants *agreed* that robots can assist individuals with physical challenges or disabilities (Christoforou & Müller, 2016; Dautenhahn, 2007; Fehr & Fischbacher, 2004). The participants' responses further indicated that robots could assist in various capacities to free their human teammates to do other more important tasks. Robots could perform search and rescue missions; assist individuals requiring continuous assistance, such as geriatric patients; provide crime prevention monitoring and other security services; and provide pollution reporting through persistent surveillance (AFOSR, 2018; Hoffman, 2019; NSF, 2020). The participants also agreed that robots should be able to assess, assist, or direct their human counterparts in task assignments, especially in dangerous or life-threatening situations. The participants reached a consensus that robots should have the capability to assess the health and well-being of their human teammates.

Partnership

There was a consensus among the participants that open communication is essential to forming and sustaining a viable human–robot or human–machine partnership. The role of such a revolutionary partnership will erode any potential barriers that would prohibit the learning and exchange of information between all team members. The participants agreed that robot entities should be able to identify and understand problems as they occur and share in the delivery of viable solutions that will benefit the team and organization.

Development

Organizational development and the training of employees within an organization are essential to the development and integration of human-robot teams. The participants in the study advocated for knowledge sharing and in-depth training sessions as human–robot teams become more prevalent in the workplace. The participants also shared that open lines of communication should exist between developers, engineers, roboticists, and end-users as autonomous mobile robot systems evolve with, at some point, the ability to provide feedback.

Limitations of the Study

There are some inherent limitations in using the e-Delphi technique. The most significant limitation was time, from recruiting subject matter experts, developing questionnaires, distributing questionnaires after IRB approval, and collecting and analyzing data. The aggregation and analysis of data took the most time since the participants did not complete and submit their questionnaires simultaneously. The number and availability of eligible participants, including the integrity of their survey responses, was a limiting factor. I invited 15 qualified individuals to participate in this study, and 12 participated. These same 12 participants participated in all three rounds of the data inquiry sessions. The participants for this study resided in various communities around the United States, so using the Internet for commutation purposes was essential.

Another limitation affecting this study on the factors influencing the effectiveness of managing human-robot teams was the availability of peer-reviewed resources. Reflecting on the definition of *what a robot is* from Chapter 1, there were no written policies, laws, procedures, or rules of engagement on the employment, management, and use of robots in the modern workforce environment. The lack of policies governing robots in the human-robot workforce environment is because such an inclusive environment is a new paradigm in organization workforce management. Consequently, there were no case studies of actual human-robot teams or human-robot interactive events available due to the unavailability of robot technologies as defined in Chapter 1. Secondary data sets on robots or robotic entities' interactions are limited. No secondary data sets exist for this research on human-robot team management.

Recommendations

Communication is central to any form of organization, regardless of composition, whether formal or informal and is key to organization management (Barnard, 1938/1968;

Levi, 2001). The influential factors in managing teams consisting of human entities may not be synonymous with those for managing human-robot teams. The primary difference is the emotional intelligence component in human entities, which does not exist in robot entities (Dautenhahn, 2007; Floreano & Mattiussi, 2008). In analyzing the participants' responses, their emotions, experiences, and beliefs were an integral factor in how they responded to the surveys. Prabhakaran and Gray (2012) and Sharpee et al. (2014) stated that how individuals respond to surveys often reflects on their experience and knowledge. There are competing negative factors, such as lack of focus, low motivation, state of mind, location not conducive to taking a survey, and length of time, that will influence the outcome of the survey results.

Effective managers and team leaders must clearly understand available resources under their control and the teams they lead to manage expectations and organizational operations. Managing expectations of an organization can only come from open communication, the communication of purpose, including explaining or conveying policies and regulations, accompanied by self-discipline, both from the leader and the teammates (Barnard 1938/1968; Chauncey et al., 2016; Ito, 2020). Rules of engagement, social regulation, and cultural policies are not always written but assumed and embraced as social norms within an organization. In contrast, employees or teammates must have a clear and firm understanding of the written and unwritten rules and regulations governing an organization's daily operations. Some unwritten social rules may be controversial and discriminatory due to petty differences between individuals due to systemic beliefs and misinformation propagation. Managers, leaders, and team members must take an active approach to identify and eliminate such controversies and discriminatory practices that will retard the progression and unification of an organization, regardless of organization size and composition (Barnard, 1938/1968).

Exploring the management of self-aware mobile robot entities, see robot definition in Chapter 1, that are not capable of displaying, expressing, or exercising emotional intelligence presents new challenges in the development and integration of the modern workforce. Developing and deploying human-robot teams to support organizational missions or joint agency tasks is a new paradigm in organization management. Further research on the relational dynamics of collaborative mobile robotic entities is necessary to ensure the successful integration and management of human-robot teams in the workforce of the future.

How managers and team leaders influence, develop, and integrate human-robot teams into their respective organizations are predicated on how well the eight influential areas identified by the participants in this study (see Table 8) are advanced in a social robot's competency awareness development and executed within the organization's managerial sphere. A subset of factors (see Figure 8) derived from each area in the Table of Consensus (see Table 8) requires additional research since the strengths, limitations, and weaknesses will dynamically vary and impact the robot's competency awareness development.

Figure 7

Subset of Influential Factors

Factors	Sub Factors	Group Dynamics	Free Learning	Augmentation	Behavioral Analysis	Adaptive Behavior	Planning	Participative	Navigation	Coordination	Causality
Interaction		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Teamwork		Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Management		Y	Y	N	Y	Y	Y	N	N	Y	Y
Knowledge		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ethical Issues		Y	Y	N	Y	Y	Y	Y	N	Y	Y
Robot Assistive		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Partnership		Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Development		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Note. Y = Yes and N = No in factoring the relational depth of research between the factors and sub factors.

Each element in the subset presents a unique challenge in the evolution of organizational management toward including robots as viable team members (see Figure 8). While not mentioned in any of the participants' responses, the causality element is significant in the human-robot team's development and the robot's evolution. Supposedly, every team member should have the competency to understand and explain the causes of problems and the effects (Popper, 2010). The complexity of a problem may vary. However, knowing and accepting a problem without understanding the cause and effect requires an inquiry into the origins of the cause to understand the effects. The robot's competency awareness is essential if the robot to become a viable teammate. Managers will need to understand that the complexity of social interaction between two or more entities, specifically within a human-robot team, encompasses the dynamics of trust and decision-making, the influential dynamics of communication, and the socio-structural entanglement of an organization.

The implementation trajectory of autonomous mobile robot entities into an organization’s daily operations is not so much a question of if as when it will happen. Those drafting organizational policies, procedures, and regulations should consider the integration of autonomous mobile robots as entities capable of free learning under the guise of direct or indirect human supervision. As team members, autonomous mobile robots should have the ability and opportunity to learn and ask questions as necessary. Future research in the robot evolution involving organization management should focus on developing and integrating independent mobile robot entities as team members without restrictions on the robot’s capabilities.

Implications

The implications for social change within the boundaries of this research area are in the influential areas identified by the subject matter experts (see Figure 8). As reflected in Chapter 1, the social change is the adaptation of a human-robot socio-relationship within the society where one human entity and one robot entity, at a minimum, are paired together as a team. The social dynamics within a team or group are to collaborate on various tasks toward completion or assist each other when a team member needs assistance. Managers and team leaders already understand how to manage a homogenous workforce, which should enable them to overcome any problems with managing a heterogeneous workforce. The difference between a homogenous and heterogeneous workforce is the former consist of human entities only, whereas the latter is a workforce combining human and robot entities.

Managers and team leaders should have a basic understanding of the identified factors (see Figure 8) that will influence the behaviors in managing human-robot teams. The role of management in integrating robots into the modern-day workforce can positively impact social change relative to the managerial inclusion of robots within a horizontal and vertical organization structure. Integrating robots into society or an organization requires systemic adaptation bound by interaction and knowledge, absent of biases. As defined in Chapter 1, robot entities will require human interaction to become socially aware of their environment, allowing them to assist at will or when an individual calls for assistance.

The influential factors identified by the research participants amplify an aspect in the evolution of a human-robot or human-machine partnership, where individuals who suffer from some degree of impairment, such as anxiety, physical, autism, or diminished sight, will benefit (AFOSR, 2018; NSF, 2020). The design and deployment of existing socio-robotic devices, like Kaspar and Milo (RoboKind, 2018), already provides behavioral therapy and companionship to children with autism and other behavioral challenges (Hertfordshire, 2018; RoboKind, 2018). These robot devices differ from non-robotic personal assistance units, such as Siri and Jibo (Fowler, 2017).

Further development of autonomous robot entities capable of independent activities will afford more environmental stability for socially and mentally developmentally impaired or impacted individuals. Robots with some or unrestricted autonomy and self-learning strategies can improve the performance and design of the intelligent robot and robotic devices, such as the Phoenix, an intelligent exoskeleton that aids individuals with walking disabilities, sensing physical movements from its host (Abel, 1998; Bemelmans et al., 2015). Robots partnering in an assistive living environment can assist individuals who require constant monitoring and assistance, from simple to complex tasks.

Integrating robots into the military and civilian workforce will positively impact social change. The human-robot team will can aid in persistent surveillance, long-term border protection of military installations and compounds, search and destroy improvised explosive devices (IED), search and recuse or recovery mission, and joint taskforce drug interdiction. When there is a threat to human life, intelligent mobile robots can or should continue in their task and assigned roles, absent of any human management oversight, until such a threat has been neutralized. Other areas in the non-military sector are aiding in the search and rescue of the missing and lost due to events or natural disasters.

The eight influential factors and 10 subfactors (see Figure 8) are not definitive and remain inconclusive. However, the findings from this research promote social change in an area that centers around acceptance through communication. Managers will have a meaningful role in integrating robots into existing teams as teammates. The integration of robots is not a replacement for humans but an augmentation or extension of human capabilities, specifically within a human-robot team. The consequence is that humanity unilaterally benefits from the acceptance and integration of the robot’s capabilities to assist, particularly in the areas of social assisted living, agriculture, security, crime prevention, search and rescue, and pollution reporting through persistent surveillance (AFOSR, 2018; Hoffman, 2019; NSF, 2020).

The Delphi Technique was used in this study to inquiry selected subject matter experts in pursuit of finding answers to the posed research question. Three rounds of data collection were used to aggregate and analyze data to satisfy the curiosity in identifying influential factors necessary to manage human-robot teams. This study indicated eight factors and 10 subfactors (see Figure 8) that managers and team leaders can use to influence human-robot collaborative teams, including robot entities as viable team members. The relational and managerial dynamics between entities in a human-robot group within a formal or informal organization translate well in an assisted living environment, where robot entities would be able to provide assistance; however, and whenever needed. The participants in this study concurred that managing robot entities is a new paradigm in organization management, specifically as such entities lack an emotional component.

The overarching element that surfaced from using the Delphi Technique is the embodiment of relationships between entities within an organization. Whether formal or informal, relationships in an organization evolve as each person or entity learns from each other within a teaming environment. More importantly, relationships can influence an organization's behavior and capabilities. Managers, team leaders, and team members, from a humanistic perspective, should embrace the idea that autonomous mobile robot entities will exist to augment human capabilities, not replace them.

Conclusions

The discussion on learning and understanding the factors that are influential in managing human-robot teams within a human-robot work environment centers on the ability to communicate within the team structure between two or more entities. The notion of managers or team leaders managing autonomous mobile robots that satisfy the definition in Chapter 1 (i.e., can alter its environment at will) as team members is a new paradigm in organizational and human-robot workforce management that undoubtedly will make some managers or team members uncomfortable. The conspiracy or myth of robots replacing human entities can incite fear or perhaps rage in some people, as indicated by one of the participants. The goal is to employ such robot entities as teammates, thus augmenting human capabilities, such as performing activities in areas detrimental to human life, not replacing them.

Any measure of influence can only occur through bidirectional and bilateral communication events. The transmission of influential and informative information is an event that is grounded in Chauncey et al.'s (2016) co-adaptive human-robot interaction framework, Ito's (2020) theory of human-machine metacommunication, and Shannon's (1948) and Weaver's (1949/1964) mathematical theory of communication. The participants agreed that interaction is vital to any dynamic relationship within an organization. Without any form of communication, a necessity in any form of interaction to occur, whether formal or informal, an organization of any size cannot exist, affecting a team's behaviors (Barnard, 1938/1968; Hartley, 1928; Rogers, 2008). The influential dynamics in communication, trust, socio-structural entanglement, and decision-making are integral to an organization. Managers, team leaders, and team members must be able to communicate with their robot counterparts in the same manner as any ordinary human being. There is a significant drawback in which robots, regardless of autonomy level, lack an emotional component that only exists in any intelligent oxygen-dependent lifeform.

Conversations in the development and employment of autonomous mobile robot entities will amplify the evolution of a human-robot team or human-machine partnership where individuals who suffer from some degree of impairment or condition will benefit from the robot's capabilities as an augmentation unit. The acceptance of robots as contributing members to a dynamic society capable of performing life-saving measures, including search and rescue, is greatly needed in areas devastated by natural disasters. Implementing such robot entities is the most significant social change at this level, assisting the most vulnerable individuals who require continuous assistance.

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Appendix A: Initial Questionnaire Form

Age: __ 18-24 __ 25-34 __ 35-44 ___ 45-54 __ 55-64 __ 65+

Gender: __ Male __ Female __ Nonbinary __ Prefer not to say

Education (Circle highest degree complete):

1. Associate Degree (e.g., A.A., A.S.)
2. Bachelor's Degree (e.g., B.A, B.S.)
3. Master's Degree (e.g., M.A., M.S., MEd)
4. Doctorate Degree (e.g., Ph.D., EdD., MD., JD)

Years of Experience using/developing Computing Technologies:

1. 1 to 3 years
2. 3 to 4 years
3. 4 to 6 years
4. 6 to 7 years
5. 7 to 9 years
6. 9 or more years

Years of Experience with the use/development of Artificial Intelligence Applications:

1. 0 to 1 year
2. 1 to 2 years
3. 2 to 4 years
4. 4 to 6 years
5. 6 to 9 years
6. 9 or more years

Instructions

Please answer the following questions as comprehensively as possible. Analysis of your answers will inform the generation of questions in Round 2.

Initial Questionnaire

1. What factors could influence the effectiveness of managing human-robot teams within a human-robot work environment?

2. In what ways might these factors influence the effectiveness of managing human-robot teams within a human-robot work environment?

Appendix B: Responses from Round 1 Questionnaire

Question 1: What factors could influence the effectiveness of managing human-robot teams within a human-robot work environment?

Participant 1	Experience, the amount of work done by each member of the team, the transparency of the expected work/role for each member.
Participant 2	Comprehension, experience, and beliefs could influence effectiveness in the relationship.
Participant 3	1. The degree to which to human members of the team see the robots as beneficial partners. 2. The amount of training necessary to employ the robots effectively.
Participant 4	Some factors could include clear roles and responsibilities, clearly communicated policies and procedures, and routine evaluation of working relationships and the work environment.
Participant 5	Vision and insight to reach beyond physical and mechanical limitations and the desire to embrace or team within a technological/psychological work environment scheme will help to assimilate and advance the implementation of a more autonomous schematic required to welcome a more collaborative human-robotic mindset.
Participant 6	Work environment. Skill set of human-robots Problem solving skills.
Participant 7	Learning, memory, emotional, biases, perhaps physical limitations.
Participant 8	I feel that the baseline code for the AI and ensuring all requirements are looked at and all possible situations must be taken into account. This will allow the developers to have a clearer view of what is to come. Remember computers are still bound by code. How they are developed and what is allowed is on us. There should be no issues if the groundwork is done and things are implemented correctly.
Participant 9	Time will be a major factor in the effectiveness of this work environment.
Participant 10	Barriers to effective communication that leads to poor collaboration and ineffective results or output.
Participant 11	Robots not performing correct procedures during an emergency.
Participant 12	Preconceived beliefs held by the humans regarding AI/ML and RPA.

Question 2: In what ways might these factors influence the effectiveness of managing human-robot teams within a human-robot work environment?

Participant 1	Lack of experience working with such a team could slow progress or productivity with a learning curve and miscommunication of expectations could lead to work being missed.
Participant 2	If humans don't have a full or even partial understanding of the reasoning for the relationship, it will be hard to get to the next step in building the human-robot relationship. If humans don't have experience with working with these AI's, this could influence work experiences going forward, because many people are set in their ways and don't look forward to change. Humans are very funny when it comes to their beliefs or what they think to be their beliefs when it comes to doing something new or if they think the relationship is going in a different direction. It's hard to get individuals to move forward when they are uncertain of the outcome, or even the reason for the outcome.
Participant 3	1. If human members of the team don't see robots as beneficial partners, a person managing a team will need to spend additional time encouraging team members to learn how to use the robots effectively. If the human members of the team fear replacement by the robots, there will be increased resistance to the integration of robots to the team. Both factors will reduce the effectiveness of the team. 2. An extensive amount of training required to effectively employ the robots may lead to reduced enthusiasm to working with the robots.
Participant 4	These factors will help mitigate conflicts, allow for corrections where needed and outline expectations for engagement.
Participant 5	Vision and discernment coupled with scientific and software programming and analytics will pave the way to a more efficacious teaming concept to provide cutting edge industrial breakthroughs to advance our current way of life as we see it today.
Participant 6	Is the environment conductive for working human - robots? What are they programed to do? If they aren't coded properly, how can the error be rectified.
Participant 7	Most people already use some form of AI, but may be unaware and resistant to is usefulness. Could be another form of prejudices, especially for this country.
Participant 8	Not doing the necessary work upfront before the implementation of any AI system can have a negative impact on productivity as well as the quality of the information gathered.
Participant 9	Time would be more static for robots as it would be based on the scheduled programmed into it. How the before and after processes are done could hinder or accelerate the rate of production. For example, if

	the robot is programmed to vacuum floors at a certain time then the humans would be tasked with prepping the area as to promote effective execution of the tasks. If that prep work isn't complete on time, then the delay could cause a bottleneck in the production process.
Participant 10	With the inability of the team members to understand each other; every team member might have different goals and a certain way of thinking which may affect communication between team members and delay results. sometimes it will be harder to predict human intention and understanding intent from other human beings.
Participant 11	Further damage due to a lack of appropriate action taking place.
Participant 12	The humans might be concerned about losing their jobs to robots.

Appendix C: Coded Responses from Round 1 Questionnaire

Question 1: What factors could influence the effectiveness of managing human-robot teams within a human-robot work environment?

NBR	RESPONSES	CODE RESPONSES				
1	Some factors could include: clear roles and responsibilities; clearly communicated policies and procedures; and routine evaluation of working relationships and the work environment.	c	a	b	d	g
2	Vision and insight to reach beyond physical and mechanical limitations and the desire to embrace or team within a technological/psychological work environment scheme will help to assimilate and advance the implementation of a more autonomous schematic required to welcome a more collaborative human-robotic mindset.	c	b	a	g	h
3	Work environment skill set of human-robots problem solving skills	g	a	d	b	h
4	Learning, memory, emotional, biases, perhaps physical limitations.	c	h	d	a	e
5	I feel that the baseline code for the AI and ensuring all requirements are looked at and all possible situations must be taken into account.	c	d	h		
5	This will allow the developers to have a clearer view of what is to come.	c	d	h		
5	Remember computers are still bound by code.	c	d	h		
5	How they are developed and what is allowed is on us.	d	f	c	f	
5	There should be no issues if the groundwork is done and things are implemented correctly	c	d	e	a	g
6	Time will be a major factor in the effectiveness of this work environment.	c	e	a	b	d
7	Barriers to effective communication that leads to poor collaboration and ineffective results or output.	c	a	g		
8	Robots not performing correct procedures during an emergency.	f	e	d	b	h
9	Preconceived beliefs held by the humans regarding AI/ML and RPA.	d	e	a		
10	The degree to which to human members of the team see the robots as beneficial partners.	a	b	d	g	
10	The amount of training necessary to employ the robots effectively.	c	b	a	g	

11	Experience, the amount of work done by each member of the team	b c g e d
11	The transparency of the expected work/role for each member	b c d f e
12	The humans might be concerned about losing their jobs to robots.	b g c e g

Question 2: In what ways might these factors influence the effectiveness of managing human-robot teams within a human-robot work environment?

NBR	RESPONSES	CODE RESPONSES
1	These factors will help mitigate conflicts, allow for corrections where needed and outline expectations for engagement.	d e a g h
2	Vision and discernment coupled with scientific and software programming and analytics will pave the way to a more efficacious teaming concept to provide cutting edge industrial break-throughs to advance our current way of life as we see it today.	c h g d e
3	Is the environment conductive for working human - robots?	c d e a
3	What are they programed to do? If they aren't coded properly, how can the error be rectified.	c h e
4	Most people already use some form of AI, but may be unaware and resistant to is usefulness.	d c b
4	Could be another form of prejudices, especially for this country.	a e c
5	Not doing the necessary work upfront before the implementation of any AI system can have a negative impact on productivity as well as the quality of the information gathered.	c d h
6	Time would be more static for robots as it would be based on the scheduled programmed into it.	c b g
6	How the before and after processes are done could hinder or accelerate the rate of production.	c f b g
6	For example if the robot is programmed to vacuum floors at a certain time then the humans would be tasked with prepping the area as to promote effective execution of the tasks.	f e g c a
6	If that prep work isn't complete on time then the delay could cause a bottleneck in the production process.	c d b

7	With the inability of the team members to understand each other; every team member might have different goals and a certain way of thinking which may affect communication between team members and delay results.	g	b	a	c	f
7	Sometimes it will be harder to predict human intention and understanding intent from other human beings.	a	b	g	d	h
8	Further damage due to a lack of appropriate action taking place.	c	f	d	g	
9	The humans might be concerned about losing their jobs to robots.	a	e	b	g	c
10	If human members of the team don't see robots as beneficial partners, a person managing a team will need to spend additional time encouraging team members to learn how to use the robots effectively.	c	a	b	g	e
10	If the human members of the team fear replacement by the robots, there will be increased resistance to the integration of robots to the team. Both factors will reduce the effectiveness of the team.	d	b	c	a	g
10	An extensive amount of training required to effectively employ the robots may lead to reduced enthusiasm to working with the robots.	b	e	a	g	c
11	Lack of experience working with such a team could slow progress or productivity with a learning curve	b	h	g	d	c
11	Miscommunication of expectations could lead to work being missed.	a	b	c	e	g
12	Preconceived beliefs held by the humans regarding AI/ML and RPA	a	b	c	e	g

Note: NBR refers to the participants' numbers. The numbering of each sentence corresponds to the participants' number. Each theme reflects a letter code, where: a = Interaction, b = Teamwork, c = Management, d = Knowledge, e = Ethical Issues, f = Robot Assistive, g = Partnership, h = Development.

Appendix D: Round 2 Questionnaire Introduction Page

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Welcome to Round 2

Thank you for participating in our survey. Your feedback is important.
Introduction and Background

There are unknown factors that can influence the effectiveness of managing human-robot teams. Various research studies on robotics have referred to the development and use of robot platforms or robotic systems, with simple renditions and uses of mechanical and steam/pneumatic-powered robotic systems development appearing as early as 1023-957 BC (Goodrich & Schultz, 2007; Iavazzo et al., 2014; Yates et al., 2011). Today, the concept of using autonomous robots as collaborative teammates is an emerging dynamic in the management of human-robot teams or hybrid teams (AFOSR, 2018; Hoffman, 2019).

The definition of a robot is an autonomous intelligent entity that is collaborative and socially adaptive, capable of self-learning and self-governing, with the "ability to alter its work environment" (National Science Foundation, 2020, p. 1). A human-robot team consists of one human entity and one robot entity (Chauncey et al., 2016). The teaming ratio may consist of many human entities and one robotic or robot entity; or one human entity and many robot entities; or many human entities and many robot entities (Chauncey et al., 2016; Nikolaidis et al., 2015).

The purpose of Round 2 continues in the evaluation of themes of Interaction: Teamwork, Management, Knowledgeable, Ethical Issues, Robot Assistive, Partnership, and Development. These themes are derived from your responses in Round 1. Please rate the following statements using Strongly Disagree to Strongly agree. There is space at the end of the survey for additional comments.

The average time to complete this survey is 6 minutes. Please let me know if you have any questions or comments.

Most Humbly,

Theodore
Theodore B. Terry
Walden University

Appendix E: Round 3 Questionnaire Form

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Welcome to Round 3

Thank you for participating in our survey. Your feedback is important.

This is the final round of the three round data collection sessions. The Round 3 questionnaire contains the same questions as Round 2, but contains the group's modal response (given with each statement), and your response (given with each statement).

There are unknown factors that can influence the effectiveness of managing human-robot teams. Various research studies on robotics have referred to the development and use of robot platforms or robotic systems, with simple renditions and uses of mechanical and steam/pneumatic-powered robotic systems development appearing as early as 1023-957 BCE (Goodrich & Schultz, 2007; Iavazzo et al., 2014; Yates et al., 2011). Today, the concept of using autonomous robots as collaborative teammates is an emerging dynamic in the management of human-robot teams or hybrid teams (AFOSR, 2018; Hoffman, 2019).

The definition of a robot is an autonomous intelligent entity that is collaborative and socially adaptive, capable of self-learning and self-governing, with the "ability to alter its work environment" (National Science Foundation, 2020, p. 1). A human-robot team consists of one human entity and one robot entity (Chauncey et al., 2016). The teaming ratio may consist of many human entities and one robotic or robot entity; or one human entity and many robot entities; or many human entities and many robot entities (Chauncey et al., 2016; Nikolaidis et al., 2015).

The purpose of Round 3 continues in the evaluation and responses on the themes of Interaction: Teamwork, Management, Knowledgeable, Ethical Issues, Robot Assistive, Partnership, and Development. Please re-rate the following statements using Strongly Disagree to Strongly agree. Please complete the survey by ____________, if possible. The average time to complete this survey is 8 minutes. Please let me know if you have any questions or comments.

Most Humbly,

Theodore
Theodore B. Terry
Walden University

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section A: Interaction

A1. Managers should ensure interaction between human and robot team members is not impeded by personal or religious beliefs. Your previous rating: ___

Group Data Analysis							
Mean	6.08	Modal	6	Std Dev	0.900337	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

A2. Managers should ensure the robot team member is capable of assisting its human teammate autonomously. Your previous rating: ___

Group Data Analysis							
Mean	5.83	Modal	6	Std Dev	0.1.267304	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

A3. Managers should ensure human employees are comfortable with interacting with their robot teammates. Your previous rating: ___

Group Data Analysis							
Mean	6.75	Modal	7	Std Dev	0.452267017	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section B: Teamwork

B1. The human-robot team members should adapt to each other's behaviors for effective collaboration. Your previous rating: ___

Group Data Analysis							
Mean	6.00	Modal	7	Std Dev	6.5	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

B2. The human-robot team members should, together, use critical thinking and analytical reasoning in problem-solving. Your previous rating: ___

Group Data Analysis							
Mean	5.42	Modal	6	Std Dev	1.505042	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

B3. The robot teammate should encourage and guide its human teammate. Your previous rating: ___

Group Data Analysis							
Mean	3.83	Modal	2	Std Dev	2.037526724	Interpretation	Neither agree or disagree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

B4. The human teammate should guide the robot teammate. Your previous rating: ___

Group Data Analysis							
Mean	4.58	Modal	4	Std Dev	0.900336637	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

B5. The robot teammate should provide situational awareness, specifically when security threats and threats to human life exist. Your previous rating: __

Group Data Analysis							
Mean	5.50	Modal	7	Std Dev	1.930614598	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

B6. Human teammates should not fear losing their jobs to a robot teammate. Your previous rating: __

Group Data Analysis							
Mean	5.17	Modal	7	Std Dev	2.037527	Interpretation	Somewhat agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section C: Management

C1. Managers should manage human-robot teams in the same manner as any other team or resource. Your previous rating: __

Group Data Analysis							
Mean	4.50	Modal	3	Std Dev	2.0226	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C2. Managers should accept advice from any member of a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	4.50	Modal	4	Std Dev	1.882938	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C3. Managers should encourage interdependence within a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	4.67	Modal	6	Std Dev	1.874874	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C4. A manager should establish and encourage trust within a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	6.75	Modal	6	Std Dev	0.452267017	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C5. A manager should establish and encourage open communication among human-robot team members. Your previous rating: __

Group Data Analysis							
Mean	6.00	Modal	6	Std Dev	0.6742	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C6. A manager should have the ability to motivate, inspire, and influence a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	6.00	Modal	6	Std Dev	0.603023	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C7. A manager should encourage a human-robot team to be agile and adaptable. Your previous rating: __

Group Data Analysis							
Mean	6.33	Modal	6	Std Dev	0.651339	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C8. Managers should empower human-robot teams and not micromanage. Your previous rating: __

Group Data Analysis							
Mean	5.92	Modal	6’’	Std Dev	1.240112	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

C9. A manager’s personal and religious beliefs may influence the human-robot team’s effectiveness. Your previous rating: __

Group Data Analysis							
Mean	5.08	Modal	6	Std Dev	1.1645	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section D: Knowledgeable

D1. Managers should be knowledgeable about and have a favorable attitude towards robots. Your previous rating: __

Group Data Analysis							
Mean	5.67	Modal	6	Std Dev	1.302678	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

D2. Managers should know how to manage human-robot teams. Your previous rating: __

Group Data Analysis							
Mean	6.58	Modal	7	Std Dev	0.514929	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

D3. Managers should be willing to learn how to advance the capabilities of a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	6.75	Modal	7	Std Dev	0.522233	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

D4. Managers should know the roles and responsibilities of a human-robot team. Your previous rating: __

Group Data Analysis							
Mean	6.75	Modal	7	Std Dev	0.452267	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

D5. Managers should know policies and procedures governing the use and deployment of human-robot teams. Your previous rating: __

Group Data Analysis							
Mean	6.58	Modal	7	Std Dev	0.668558	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

D6. Managers should know how to evaluate human-robot teams' performance and working relationships. Your previous rating: __

Group Data Analysis							
Mean	6.58	Modal	7	Std Dev	0.668558	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section E: Ethical Issues

E1. Managers and only human team members should have control over the robot. Your previous rating: __

Group Data Analysis							
Mean	5.42	Modal	6	Std Dev	1.443376	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

E2. Managers should enforce equity and inclusion programs and training requirements within an organization. Your previous rating: __

Group Data Analysis							
Mean	6.42	Modal	7	Std Dev	0.900337	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

E3. Robots should self-report any performance deficiencies or ethical issues. Your previous rating: __

Group Data Analysis							
Mean	5.58	Modal	7	Std Dev	1.240112	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

E4. Robots should report on any team member's unethical behaviors. Your previous rating: __

Group Data Analysis							
Mean	5.50	Modal	6	Std Dev	1.087115	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

E5. Robots should interfere when team members commit acts of unethical behavior towards humanity. Your previous rating: __

Group Data Analysis							
Mean	5.08	Modal	4	Std Dev	1.311372	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section F: Robot Assistive

F1. The robot should be able to assist its human counterpart in task assignments that robot team members are good at. Your previous rating: __

Group Data Analysis							
Mean	5.67	Modal	6	Std Dev	1.154701	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

F2. The robot should remind their human teammates about schedules and procedures. Your previous rating: __

Group Data Analysis							
Mean	5.33	Modal	6	Std Dev	1.230915	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

F3. The robot should assess the health and well-being of its human teammates. Your previous rating: __

Group Data Analysis							
Mean	4.58	Modal	4	Std Dev	1.564279	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

F4. The robot should monitor an organization's operational environment, (e.g., temperature, containments), and report issues to managers. Your previous rating: __

Group Data Analysis							
Mean	5.58	Modal	6	Std Dev	1.083625	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

F5. The robot should communicate emergencies to managers and proper authorities. Your previous rating: __

Group Data Analysis							
Mean	5.25	Modal	6	Std Dev	1.484771	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

F6. The robot should be able to direct its human counterpart in task assignments, especially in dangerous or life-threatening situations. Your previous rating: __

Group Data Analysis							
Mean	4.83	Modal	4	Std Dev	1.642245	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section G: Partnership

G1. Managers should encourage open communication within a human-robot workforce environment. Your previous rating: __

Group Data Analysis							
Mean	6.17	Modal	7	Std Dev	1.114641	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

G2. Robots should learn from managers and other teammates to be effective teammates. Your previous rating: __

Group Data Analysis							
Mean	5.50	Modal	6	Std Dev	1.087115	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

G3. Robots should also learn from other sources, such as peer-reviewed journals and relevant reading material, to be effective teammates. Your previous rating: __

Group Data Analysis							
Mean	5.50	Modal	6	Std Dev	1.167748	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

G4. Robots should be free to identify and understand problems and share solutions and goals accordingly with other team members. Your previous rating: __

Group Data Analysis							
Mean	6.00	Modal	6	Std Dev	1.044466	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

G5. Managers should ensure robots are fully integrated into the human-robot workforce environment. Your previous rating: __

Group Data Analysis							
Mean	5.92	Modal	7	Std Dev	1.240112	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

G6. Managers should create a positive human-robot workforce environment. Your previous rating: __

Group Data Analysis							
Mean	6.33	Modal	7	Std Dev	1.154701	Interpretation	Strongly Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round
Section H: Development

H1. Managers should specify safety protocol requirements to protect team members. Your previous rating: __

Group Data Analysis							
Mean	5.92	Modal	7	Std Dev	1.240112	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H2. Managers should specify requirements for robots to perform a wide variety of work requirements. Your previous rating: __

Group Data Analysis							
Mean	5.92	Modal	7	Std Dev	1.775251	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H3. Managers should have a general understanding of artificial intelligence, including computer vision and machine learning. Your previous rating: __

Group Data Analysis							
Mean	5.25	Modal	6	Std Dev	1.484771	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H4. Managers should require human employees to become familiar with all operational aspects of robotics and AI-based systems as part of a human-robot workforce environment. Your previous rating: __

Group Data Analysis							
Mean	5.17	Modal	4	Std Dev	1.33716	Interpretation	Somewhat Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H5. Managers should require team dynamics training for all employees assigned to human-robot teams, necessary to employ the robots effectively as team members. Your previous rating: __

Group Data Analysis							
Mean	5.75	Modal	6	Std Dev	1.13818	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H6. Managers should encourage and support the implementation of human-robot teams. Your previous rating: __

Group Data Analysis							
Mean	6.08	Modal	6	Std Dev	1.083625	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

H7. Managers should ensure robots are regularly maintained by technical staff. Your previous rating: __

Group Data Analysis							
Mean	6.00	Modal	7	Std Dev	1.279204	Interpretation	Agree

Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Reason for Change:						

Factors Influencing the Effectiveness of Managing Human-Robot Teams - 2nd Round

Section I: Additional Comments

Do you have any additional thoughts that you would like to add?

Thank you for taking the time to complete the questionnaire.
Your participation is well appreciated and essential to this research.
Your feedback and suggestions will help generate questions for the next session.

Appendix F: Responses from Round 2 and Round 3 Questionnaire

Section A: Interaction

QN	Question
A1	Managers should ensure interaction between human and robot team members is not impeded by personal or religious beliefs.
A2	Managers should ensure the robot team member is capable of assisting its human teammate autonomously.
A3	Managers should ensure human employees are comfortable with interacting with their robot teammates.

	Round 2			Round 3		
PNBR	A1	A2	A3	A1	A2	A3
1	7	7	7	6	6	7
2	6	6	6	4	6	7
3	6	6	7	6	6	7
4	6	3	7	7	7	7
5	6	6	6	7	7	7
6	7	7	7	6	6	6
7	7	5	7	6	6	6
8	5	6	7	6	7	7
9	6	4	7	7	5	7
10	4	6	6	6	6	7
11	7	7	7	7	7	7
12	6	7	7	6	3	7
Mean	6.08	5.83	6.75	6.17	6.00	6.83
Mode	6	6	7	6	6	7
Medium	6	6	7	6	6	7
Std Dev	0.90	1.27	0.45	0.83	1.13	0.39
Intpr	6	6	7	7	6	7

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question Nbr
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

Section B: Teamwork

QN	Question
B1	The human-robot team should adapt to each other's behaviors for effective collaboration.
B2	The human-robot team should, together, use critical thinking and analytical reasoning in problem-solving.
B3	The robot teammate should encourage and guide its human teammate.
B4	The human teammate should guide the robot teammate
B5	The robot teammate should provide situational awareness, specifically when security threats and threats to human life exist.
B6	The human teammate should not fear losing their jobs to a robot teammate.

	Round 2						Round 3					
PNBR	B1	B2	B3	B4	B5	B6	B1	B2	B3	B4	B5	B6
1	7	4	1	4	7	4	7	6	1	6	5	5
2	4	6	2	4	2	2	6	4	4	6	6	7
3	6	5	3	4	7	6	5	6	6	6	7	6
4	7	6	5	5	4	6	7	7	7	7	7	7
5	6	2	2	4	2	6	7	4	4	7	7	7
6	7	7	6	6	7	7	4	6	2	6	2	2
7	7	7	3	4	7	7	6	2	5	6	7	3
8	5	6	7	6	7	4	5	5	2	7	7	3
9	7	6	2	4	5	1	7	7	4	4	7	4
10	6	4	3	4	7	7	6	5	3	6	7	6
11	7	7	6	6	6	7	7	7	3	6	6	7
12	3	5	6	4	5	5	7	6	5	5	4	5
Mean	6.00	5.42	3.83	4.58	5.50	5.17	6.17	5.42	3.83	6.00	6.00	5.17
Mode	7	6	2	4	7	7	7	6	4	6	7	7
Medium	6.5	6	3	4	6.5	6	6.5	6	4	6	7	5.5
Std Dev	1.348	1.505	2.04	0.9	1.93	2.04	1.03	1.51	1.75	0.85	1.6	1.8
Intpr	6	6	4	5	6	5	7	6	4	6	6	5

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5

Section C: Management

QN	Question
C1	Managers should manage human-robot teams in the same manner as any other team or resource.
C2	Managers should accept advice from any member of a human-robot team.
C3	Managers should encourage interdependence within a human-robot team.
C4	A manager should establish and encourage trust within a human-robot team.
C5	A manager should establish and encourage open communication among human-robot team members.
C6	A manager should have the ability to motivate, inspire, and influence a human-robot team.
C7	A manager should encourage a human-robot team to be agile and adaptable.
C8	Managers should empower human-robot teams and not micromanage.
C9	A manager's personal and religious beliefs may influence the human-robot team's effectiveness.

Round 2									
PNBR	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	1	1	1	7	7	7	7	7	4
2	3	3	3	6	6	6	6	6	6
3	6	6	6	6	7	5	7	7	6
4	5	5	4	7	7	7	6	7	4
5	3	2	2	4	5	6	6	6	5
6	7	7	6	7	7	6	7	7	7
7	5	4	4	6	6	6	6	3	5
8	3	4	5	6	7	5	5	4	3
9	2	6	6	6	6	6	6	6	6
10	7	7	7	7	7	6	7	6	4
11	6	5	6	6	6	6	6	6	5
12	6	4	6	6	7	6	7	6	6
Mean	4.50	4.50	4.67	6.17	6.50	6.00	6.33	5.92	5.08
Mode	3	4	6	6	7	6	6	6	6
Median	5	4.5	5.5	6	7	6	6	6	5
Std Dev	2.02	1.88	1.87	0.83	0.67	0.60	0.65	1.24	1.16
Intpr	5	5	5	7	7	6	7	6	5

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

QN	Question
C1	Managers should manage human-robot teams in the same manner as any other team or resource.
C2	Managers should accept advice from any member of a human-robot team.
C3	Managers should encourage interdependence within a human-robot team.
C4	A manager should establish and encourage trust within a human-robot team.
C5	A manager should establish and encourage open communication among human-robot team members.
C6	A manager should have the ability to motivate, inspire, and influence a human-robot team.
C7	A manager should encourage a human-robot team to be agile and adaptable.
C8	Managers should empower human-robot teams and not micromanage.
C9	A manager's personal and religious beliefs may influence the human-robot team's effectiveness.

Round 3									
PNBR	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	5	6	6	7	6	6	7	6	7
2	7	7	6	7	7	6	7	6	4
3	5	5	5	7	7	6	5	4	6
4	7	7	7	7	7	6	7	7	5
5	7	7	7	7	7	7	7	7	4
6	3	3	6	6	6	6	6	6	6
7	4	6	5	6	7	6	6	5	6
8	5	6	4	5	5	6	4	6	6
9	5	4	6	6	6	6	6	3	5
10	6	6	7	6	7	5	7	7	6
11	6	5	6	6	6	6	6	6	5
12	6	5	4	7	7	7	6	7	5
Mean	5.50	5.58	5.75	6.42	6.50	6.08	6.17	5.83	5.42
Mode	5	6	6	7	7	6	7	6	6
Median	5.5	6	6	6.5	7	6	6	6	5.5
Std Dev	1.24	1.24	1.06	0.67	0.67	0.51	0.94	1.27	0.90
Intpr	6	6	6	7	7	6	7	6	6

Notes:

7 = Strongly Agree | 4 = Neither Agree or Disagree | 1 = Strongly Disagree
6 = Agree | 3 = Somewhat Disagree | QN = Question NBR
5 = Somewhat Agree | 2 = Disagree | PNBR = Participant NBR

Also see the computed range as shown in Table 5.

Section D: Knowledge

QN	Question
D1	Managers should be knowledgeable about and have a favorable attitude towards robots.
D2	Managers should know how to manage human-robot teams
D3	Managers should be willing to learn how to advance the capabilities of a human-robot team.
D4	Managers should know the roles and responsibilities of a human-robot team.
D5	Managers should know policies and procedures governing the use and deployment of human-robot teams.
D6	Managers should know how to evaluate human-robot teams' performance and working relationships

Round 1						
PNBR	D1	D2	D3	D4	D5	D6
1	6	7	7	7	5	7
2	6	6	6	6	6	6
3	7	7	7	7	7	7
4	5	6	6	7	7	7
5	6	7	6	7	7	6
6	2	7	7	7	7	7
7	6	6	6	6	6	5
8	5	7	7	7	7	7
9	6	6	6	7	7	7
10	7	6	6	6	6	6
11	6	7	7	7	7	7
12	6	7	7	7	7	7
Mean	5.67	6.58	6.50	6.75	6.58	6.58
Mode	6	7	7	7	7	7
Median	6	7	6.5	7	7	7
Std Dev	1.30	0.51	0.52	0.45	0.67	0.67
Intpr	6	7	7	7	7	7

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5

QN	Question
D1	Managers should be knowledgeable about and have a favorable attitude towards robots.
D2	Managers should know how to manage human-robot teams
D3	Managers should be willing to learn how to advance the capabilities of a human-robot team.
D4	Managers should know the roles and responsibilities of a human-robot team.
D5	Managers should know policies and procedures governing the use and deployment of human-robot teams.
D6	Managers should know how to evaluate human-robot teams' performance and working relationships

Round 2						
PNBR	D1	D2	D3	D4	D5	D6
1	6	7	6	7	7	7
2	7	6	6	6	6	6
3	6	7	7	7	7	7
4	5	7	7	7	7	7
5	6	7	7	7	5	7
6	6	6	6	6	6	6
7	6	7	6	7	7	6
8	7	6	7	6	6	6
9	6	6	6	6	6	5
10	7	7	7	7	7	6
11	6	7	7	7	7	7
12	5	6	7	7	7	7
Mean	6.08	6.58	6.58	6.67	6.50	6.42
Mode	6	7	7	7	7	7
Median	6	7	7	7	7	6.5
Std Dev	0.67	0.51	0.51	0.49	0.67	0.67
Intpr	6	7	7	7	7	7

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

Section E: Ethical Issues

QN	Question
E1	Managers and only human team members should have control over the robot.
E2	Managers should enforce equity and inclusion programs and training requirements within an organization
E3	Robots should self-report any performance deficiencies or ethical issues
E4	Robots should report on any team member's unethical behaviors
E5	Robots should interfere when team members commit acts of unethical behavior towards humanity.

	Round 2					Round 3				
PNBR	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5
1	7	7	4	4	4	6	6	5	6	5
2	5	6	5	6	6	3	7	7	7	7
3	7	6	7	6	7	6	7	7	7	6
4	6	7	5	5	5	6	7	6	6	3
5	4	4	4	4	4	7	7	4	4	4
6	6	7	6	6	6	5	6	5	6	6
7	7	7	7	6	6	3	7	7	7	7
8	5	7	7	7	5	7	7	7	7	7
9	6	6	6	6	3	7	7	4	6	6
10	3	7	7	7	7	7	6	7	6	7
11	3	6	5	5	4	5	6	5	5	4
12	6	7	4	4	4	6	7	5	5	5
Mean	5.42	6.42	5.58	5.50	5.08	5.67	6.67	5.75	6.00	5.58
Mode	6	7	7	6	4	6	7	7	6	7
Median	6	7	5.5	6	5	6	7	5.5	6	6
Std Dev	1.44	0.90	1.24	1.09	1.31	1.44	0.49	1.22	0.95	1.38
Intpr	6	7	6	6	5	6	7	6	6	6

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

Section F: Robot Assistive

QN	Question
F1	The robot should be able to assist its human counterpart in task assignments.
F2	The robot should remind their human teammates about schedules and procedures.
F3	The robot should assess the health and well-being of its human teammates.
F4	The robot should monitor an organization's operational environment, (e.g., temperature, containments), and report issues to managers.
F5	Robots should communicate emergencies to managers and proper authorities.
F6	The robot should be able to direct its human counterpart in task assignments, especially in dangerous or life-threatening situations.

	Round 2					
PNBR	F1	F2	F3	F4	F5	F6
1	7	6	1	6	6	1
2	6	6	4	6	6	4
3	7	5	6	7	6	5
4	6	5	4	4	4	4
5	4	4	4	4	4	4
6	6	6	6	6	7	7
7	5	5	5	6	6	6
8	6	7	6	6	6	6
9	6	6	4	6	2	5
10	7	7	7	7	7	7
11	4	3	4	5	5	5
12	4	4	4	4	4	4
Mean	5.67	5.33	4.58	5.58	5.25	4.83
Mode	6	6	4	6	6	4
Median	6	5.5	4	6	6	5
Std Dev	1.15	1.23	1.56	1.08	1.48	1.64
Intpr.	6	6	5	6	5	5

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

QN	Question
F1	The robot should be able to assist its human counterpart in task assignments.
F2	The robot should remind their human teammates about schedules and procedures.
F3	The robot should assess the health and well-being of its human teammates.
F4	The robot should monitor an organization's operational environment, (e.g., temperature, containments), and report issues to managers.
F5	Robots should communicate emergencies to managers and proper authorities.
F6	The robot should be able to direct its human counterpart in task assignments, especially in dangerous or life-threatening situations.

	Round 3					
PNBR	F1	F2	F3	F4	F5	F6
1	6	6	1	6	6	5
2	7	7	7	7	7	7
3	6	6	6	6	6	6
4	6	6	6	6	5	6
5	7	6	7	6	6	7
6	6	6	4	6	4	4
7	6	6	6	6	7	7
8	6	7	4	4	4	4
9	5	5	5	6	6	6
10	7	5	6	7	7	5
11	4	5	4	5	5	5
12	6	3	4	4	4	4
Mean	6.00	5.67	5.00	5.75	5.58	5.50
Mode	6	6	6	6	6	5
Median	6	6	5.5	6	6	5.5
Std Dev	0.85	1.07	1.71	0.97	1.16	1.17
Intpr.	6	6	5	6	6	6

Notes:

7 = Strongly Agree　　4 = Neither Agree or Disagree　　1 = Strongly Disagree
6 = Agree　　3 = Somewhat Disagree　　QN = Question NBR
5 = Somewhat Agree　　2 = Disagree　　PNBR = Participant NBR

Also see the computed range as shown in Table 5.

Section G: Partnership

QN	Question
G1	Managers should encourage open communication within a human-robot workforce environment.
G2	Robots should also learn from managers and other teammates in order to be effective teammates.
G3	Robots should also learn from other sources, such as peer-reviewed journals and relevant reading material, to be effective teammates.
G4	Robots should be free to identify and understand problems and share solutions and goals accordingly with other team members.
G5	Managers should ensure robots are fully integrated into the human-robot workforce environment.
G6	Managers should create a positive human-robot workforce environment.

Round 2						
PNBR	G1	G2	G3	G4	G5	G6
1	7	7	7	6	7	7
2	6	6	6	6	6	6
3	7	5	6	6	6	7
4	7	5	4	7	6	7
5	4	4	4	4	4	4
6	7	7	7	7	7	7
7	6	6	6	6	4	6
8	6	6	6	7	6	7
9	6	6	6	6	7	7
10	7	4	4	7	7	7
11	7	6	6	6	7	7
12	4	4	4	4	4	4
Mean	6.17	5.50	5.50	6.00	5.92	6.33
Mode	7	6	6	6	7	7
Median	6.5	6	6	6	6	7
Std Dev	1.11	1.09	1.17	1.04	1.24	1.15
Intpr	7	6	6	6	6	7

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5.

QN	Question
G1	Managers should encourage open communication within a human-robot workforce environment.
G2	Robots should also learn from managers and other teammates in order to be effective teammates.
G3	Robots should also learn from other sources, such as peer-reviewed journals and relevant reading material, to be effective teammates.
G4	Robots should be free to identify and understand problems and share solutions and goals accordingly with other team members.
G5	Managers should ensure robots are fully integrated into the human-robot workforce environment.
G6	Managers should create a positive human-robot workforce environment.

Round 3						
PNBR	G1	G2	G3	G4	G5	G6
1	6	6	6	6	7	7
2	7	4	4	7	7	7
3	7	6	6	7	6	7
4	7	7	7	7	7	7
5	7	7	7	6	7	7
6	6	6	6	6	6	6
7	6	4	6	7	4	7
8	4	4	4	4	4	4
9	6	6	6	6	4	6
10	7	5	6	6	6	7
11	7	6	6	6	7	7
12	7	5	4	7	6	7
Mean	6.42	5.50	5.67	6.25	5.92	6.58
Mode	7	6	6	6	7	7
Median	7	6	6	6	6	7
Std Dev	0.90	1.09	1.07	0.87	1.24	0.90
Intpr	7	6	6	7	6	7

Notes:

7 = Strongly Agree	4 = Neither Agree or Disagree	1 = Strongly Disagree
6 = Agree	3 = Somewhat Disagree	QN = Question NBR
5 = Somewhat Agree	2 = Disagree	PNBR = Participant NBR

Also see the computed range as shown in Table 5

Section H: Development

QN	Question
H1	Managers should specify safety protocol requirements to protect team members.
H2	Managers should specify requirements for robots to perform a wide variety of work requirements.
H3	Managers should have a general understanding of artificial intelligence, including computer vision and machine learning.
H4	Managers should require human employees to become familiar with all operational aspects of robotics and AI-based systems as part of a human-robot workforce environment.
H5	Managers should require team dynamics training for all employees assigned to human-robot teams, necessary to employ the robots effectively as team members.
H6	Managers should encourage and support the implementation of human-robot teams.
H7	Managers should ensure robots are regularly maintained by technical staff.

Round 2							
PNBR	H1	H2	H3	H4	H5	H6	H7
1	4	4	4	4	4	4	4
2	6	6	6	6	6	6	6
3	7	1	6	3	6	7	7
4	7	6	5	6	6	6	7
5	4	4	4	4	4	6	4
6	7	7	7	7	7	7	7
7	6	6	6	6	6	6	6
8	6	7	6	7	6	7	6
9	7	6	7	5	7	7	7
10	7	7	2	4	6	7	7
11	6	6	6	6	7	6	7
12	4	4	4	4	4	4	4
Mean	5.92	5.33	5.25	5.17	5.75	6.08	6.00
Mode	7	6	6	4	6	6	7
Median	6	6	6	5.5	6	6	6.5
Std Dev	1.24	1.78	1.48	1.34	1.14	1.08	1.28
Intpr	6	6	5	5	6	6	6

Notes:

7 = Strongly Agree
6 = Agree
5 = Somewhat Agree
4 = Neither Agree or Disagree
3 = Somewhat Disagree
2 = Disagree
1 = Strongly Disagree
QN = Question NBR
PNBR = Participant NBR

Also see the computed range as shown in Table 5

QN	Question
H1	Managers should specify safety protocol requirements to protect team members.
H2	Managers should specify requirements for robots to perform a wide variety of work requirements.
H3	Managers should have a general understanding of artificial intelligence, including computer vision and machine learning.
H4	Managers should require human employees to become familiar with all operational aspects of robotics and AI-based systems as part of a human-robot workforce environment.
H5	Managers should require team dynamics training for all employees assigned to human-robot teams, necessary to employ the robots effectively as team members.
H6	Managers should encourage and support the implementation of human-robot teams.
H7	Managers should ensure robots are regularly maintained by technical staff.

PNBR	H1	H2	H3	H4	H5	H6	H7
1	7	6	7	5	7	7	7
2	7	7	2	1	6	7	7
3	6	7	6	7	6	7	6
4	7	1	7	6	7	7	7
5	4	4	4	4	4	4	4
6	6	6	6	6	6	6	6
7	6	6	6	6	6	6	6
8	4	4	4	4	4	4	4
9	6	6	6	6	6	6	6
10	7	2	6	7	6	7	7
11	6	6	6	6	7	6	6
12	7	6	5	5	6	4	7
Mean	6.08	5.08	5.42	5.25	5.92	5.92	6.08
Mode	7	6	6	6	6	7	7
Median	6	6	6	6	6	6	6
Std Dev	1.08	1.93	1.44	1.66	1.00	1.24	1.08
Intpr	6	5	6	5	6	6	6

Notes:

7 = Strongly Agree
6 = Agree
5 = Somewhat Agree
4 = Neither Agree or Disagree
3 = Somewhat Disagree
2 = Disagree
1 = Strongly Disagree
QN = Question NBR
PNBR = Participant NBR

Also see the computed range as shown in Table 5

Appendix G: Results from Round 2 and Round 3

ROUND 2						
THEME	MEAN	MODE	MEDIAN	STDEV	VAR	RESULTS
Interaction	6.22	7.00	6.00	0.99	0.95	Strongly Agree
Teamwork	5.08	7.00	6.00	1.77	3.08	Somewhat Agree
Management	5.52	6.00	6.00	1.50	2.23	Agree
Knowledgeable	6.44	7.00	7.00	0.80	1.54	Strongly Agree
Ethical Issues	5.60	7.00	6.00	1.25	0.95	Agree
Robot Assistive	5.21	6.00	6.00	1.38	0.95	Somewhat Agree
Partnership	5.90	7.00	6.00	1.14	0.95	Agree
Development	5.64	6.00	6.00	1.35	0.95	Agree
Overall	5.66	6	6.00	1.39	1.94	Agree

Notes: The calculations are from the Round 2 data set.

ROUND 3						
THEME	MEAN	MODE	MEDIAN	STDEV	VAR	RESULTS
Interaction	6.33	7.00	6.50	0.89	0.78	Strongly Agree
Teamwork	5.43	7.00	6.00	1.63	2.61	Agree
Management	5.92	6.00	6.00	1.02	1.02	Agree
Knowledgeable	6.47	7.00	7.00	0.60	0.36	Strongly Agree
Ethical Issues	5.93	7.00	6.00	1.18	1.36	Agree
Robot Assistive	5.58	6.00	6.00	1.18	1.38	Agree
Partnership	6.06	7.00	6.00	1.06	1.11	Agree
Development	5.68	6.00	6.00	1.39	1.91	Agree
Overall	5.89	6.00	6.00	1.20	1.45	Agree

Notes: The calculations are from the Round 3 data set.

Appendix H: Response Analyzer Program

```
#**********************************************************************
# Program Name: Response Analyzer
# Author: Theodore B. Terry
# Description: Program uses the Natural Language Toolkit (TLTK) for Python
# to analyze the responses from participants.
#**********************************************************************

# Import Libraries
from nltk.corpus import stopwords
from nltk.corpus import wordnet
from nltk.tokenize import word_tokenize
import pandas as pd
import numpy as np
import xlrd

# Import stopwords
stop_words = stopwords.words(‘english’)
swords = [“,”,”.”,”?”,”!”,”, “, ““““, “. “,”? “,”! “,”;”,”:”,”-”,”_”]
stop_words.extend(swords)

# Create list and dictionary structures
list_of_rows = []
synonyms = []
theme_list = []
theme_dict = {}

# File paths
file_path = ‘/Users/theodore/Documents/survey_data/R1_surveydata.xlsx’
newfile_path = ‘/Users/theodore/Documents/survey_data/R1_newsurveydata.xlsx’

# Load additional stop words to remove unnecessary words:
df = pd.read_excel(file_path, sheet_name = “stopwords”)
for item in df[‘STOPWORDS’]:
   stop_words.append(item.lower())

# Read in participants’ responses from first question
df = pd.read_excel(file_path, sheet_name =“Response1”)
raw_response1 = df.shape
for row in df[‘RESPONSES’]:
   text_tokens = word_tokenize(row)
   tokens_without_sw = [word for word in text_tokens if not word in stopwords.words()]
   for item in tokens_without_sw:
      if item not in stop_words and item.lower() not in stop_words:
         if item in theme_dict:
            theme_dict[item] += 1
         else:
```

```
            theme_dict[item] = 1

# Read in participants' responses from second question
df = pd.read_excel(file_path, sheet_name ='Response2')
raw_response2 = df.shape
for row in df['RESPONSES']:
    text_tokens = word_tokenize(row)
    tokens_without_sw = [word for word in text_tokens if not word in stopwords.words()]
    for item in tokens_without_sw:
        if item not in stop_words and item.lower() not in stop_words:
            if item in theme_dict:
                theme_dict[item] += 1
            else:
                theme_dict[item] = 1

# Get synonyms for keywords from the two questions
kword =
['factors','influence','effectiveness','managing','human','robot','teams','work','environment']
for item in kword:
    for syn in wordnet.synsets(item):
        for l in syn.lemmas():
            synonyms.append(l.name())

# Compare particpants synonyms to keyword synonyms
for item in synonyms:
    if item.lower() in p_synonyms and item in p_synonyms:
        if item in theme_dict:
            theme_dict[item] += 1

# Save results into a new Excel spreadsheet
scrubbed_df = pd.DataFrame.from_dict(theme_dict, orient ='index')
scrubbed_df.to_excel(newfile_path, sheet_name='Scrubbed_List')
print('End of Job')
```