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The Space Debris Environment and Satellite Manufacturing

Walter Tam
Walden University

Walden University

College of Management and Technology

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Walter Tam

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Dr. Tim Truitt, Committee Member, Doctor of Business Administration Faculty

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Chief Academic Officer
Eric Riedel, Ph.D.

Walden University
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Abstract

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MBA, Pepperdine University, 1986

BS, University of Southern California, 1984

Doctoral Study Submitted in Partial Fulfillment

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Abstract

Space debris is a growing threat to operational satellites and satellite manufacturing organizations. Leaders in satellite manufacturing organizations lacking adequate knowledge on the space debris risks could be at a competitive disadvantage. The purpose of this explorative case study was to explore strategies leaders in satellite manufacturing organizations use to mitigate risks through the conceptual lens of stakeholder theory, contingency theory, and general system theory. The research questions addressed strategies to mitigate the debris threat from the perspectives of both ongoing concerns and long-term risk resolution. Data were collected via in-depth interviews with 12 leaders, purposively selected, in satellite manufacturing organizations, and supplemented with documentation from the literature and archival records from NASA. Member checking was used to validate the transcribed data subsequently coded into 6 themes that included: meeting requirements; using analytical techniques; using shielding to protect satellites; implementing material and process innovation; developing satellite services; and generating end of mission requirements. Recommendations include maintaining and developing analytical competencies, funding research and development, and establishing standardization. Using strategies that facilitate risk mitigation and the preservation of the space environment, business leaders could benefit by developing strategic road maps that ensure continued access to space. Implications for social change include contributing to social stability, technology advancement, increased knowledge base, economic growth, higher education, and improved standard of living.

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Dedication

I dedicate this study to my friends and colleagues who inspired me to keep on learning: Dr. Phillip Behruzi, Dr. Steven Collicott, Dr. Hector Gutierrez, Mr. Don Jaekle, Mr. Gary Kawahara, Dr. Dan Kirk, and Mr. Mathias Larsson. Their wisdom, friendship, scholarship, sincerity, humble nature, and dedication to truth gave me the motivation to seek a higher purpose. I am forever grateful for their continued support.

I also dedicate this study to my son, Aaron, and my daughter, Danielle, with a reminder that life is not about limitations but about endless possibilities!

Acknowledgments

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Section 1: Foundation of the Study

Space debris is a growing threat to operational satellites and the $314 billion space economy (Space Foundation, 2014). Satellite manufacturing is a segment of the space industry and an enabler to space activities (Tauri Group, 2014). Operational satellites provide essential services to government and commercial functions that directly or indirectly benefit the daily lives of billions of people (Meek, 2012). There are approximately 1,000 operational spacecraft in orbit supporting businesses and governmental operations worldwide (Durrieu & Nelson, 2013). The rest of the orbiting objects are space debris. Scientists at the National Aeronautics and Space Administration (NASA) estimated that the total mass and the number of debris objects are growing (Liou, 2011). The growing debris population poses an increasing risk to all stakeholders in the space economy, including satellite manufacturers. This study involved conducting a qualitative case study to explore how satellite manufacturers mitigate the problems caused by space debris. This study includes three sections. Section 1 consists of the fundamental premises of the study, including background, problem statement, purpose statement, and a review of the literature. Section 2 consists of the planning details such as research method, participants, data collection, and data analysis. Section 3 consists of a summary of the research findings and recommendations.

Background of the Problem

The Soviet Union launched Sputnik into open space in 1957. Before Sputnik, the space environment was in pristine condition with no pollution from artificial objects (Adilov, Alexander, & Cunningham, 2015). After nearly 6 decades of space activities, the space environment now contains millions of pieces of space debris (NASA Orbital Debris Program Office [ODPO], n.d.). Objects in space can remain in orbit for days, years, decades, or even centuries (Adilov et al., 2015). Compounding the problem is the high speed in which space debris move through space (Abdel-Aziz, 2013). At hypervelocity, even a small object can carry enough kinetic energy to cause catastrophic damage to an operational satellite (Jakhu, 2010; Lewis, Saunders, Swinerd, & Newland, 2011). Satellite services are becoming an integral part of the modern daily fabric (Williamson, 2012), and the combination of growing debris congestion and the high destructive potential of debris objects is a developing threat to businesses that depend on satellites. As leaders in commercial firms develop new business models requiring increasing access to space (Beery, 2012), the protection of business assets in space becomes a considerable challenge. In 2009, a debris satellite collided with operational commercial satellite Iridium 33 (Tan, Zhang, & Dokhanian, 2013). The complete destruction of Iridium 33 caused tens of millions of dollars in damage. The event was a warning call to stakeholders to start taking the space debris problem seriously. Nevertheless, many factors continue to cause the deterioration of the space environment, including legal and policy challenges (Weeden, 2011), regulatory challenges (Crowther, 2011), and humanity’s tendency to overexploit and overuse nature’s common pool resources (CPRs; Weeden & Chow, 2012). For leaders in satellite manufacturing organizations, coping with the increasingly hostile space environment is a difficult but important task.

Problem Statement

Officials at NASA estimated that more than 500,000 debris objects orbiting the Earth could cause catastrophic destruction to operational satellites (NASA ODPO, n.d.), and the number of debris objects will continue to grow (Liou, 2014). Satellites that provide indispensable services such as resource management, data communications, and financial transactions are under increasing threat by the escalating number of space debris (Williamson, 2012). Four confirmed collisions have taken place since 1991 (Durrieu & Nelson, 2013), including the total destruction of an operational commercial satellite in 2009 that confirmed collision threats to operational commercial satellites are real (Tan et al., 2013). The general business problem is that damaged or destroyed satellites reduce the economic value of space-based systems and negatively affect the satellite manufacturing industry. The specific business problem is that some satellite manufacturing business leaders lack strategies to mitigate the damage caused by space debris.

Purpose Statement

The purpose of this qualitative exploratory case study was to explore strategies that satellite manufacturing business leaders use to mitigate damage caused by space debris. Business leaders in satellite manufacturing organizations located in the United States and Europe participated in interviews to share their strategies on mitigating the space debris risk. Research findings could be helpful in building a strategic road map (SRM) to help business leaders in satellite manufacturing firms address the growing debris problem more effectively. The other two sources of data for this study were documentation from literature regarding space debris and archival records from NASA. Business leaders might use the SRM for long-term business decision making, thereby contributing to positive social change.

Nature of the Study

The nature of this qualitative exploratory case study was to investigate the space debris problem through the lens of business economics. The focus was exploring the increasing threat of space debris to business assets in space and identifying risk mitigation approaches.

Research Method

A qualitative method was appropriate for the exploratory study (Yin, 2014). In the study, the objective was not testing theories or hypotheses, which eliminated a quantitative research methodology. The goal of the study was to acquire intrinsic knowledge through interviewing individuals and drawing concepts, ideas, and recommendations from them on how to address the unique business problem associated with space debris (Aberbach & Rockman, 2002; Harvey, 2011; Stephens, 2007). A qualitative approach with a close-up focus to gain a deep and rich understanding of a specific context was a good fit (Thomas & Magilvy, 2011). The plan called for collecting individual insights and developing a holistic view toward current and long-term business problem resolution. The collection and analysis of data were inherently qualitative, and the adaptation of a qualitative methodology was appropriate.

Research Design

The goal of the study was to use a case study research design to collect data. Case study research involves more than one source of data (Yin, 2014). There were three sources of data in the case study research. The primary source was in-depth interviews with business leaders from satellite manufacturing organizations. The core concept was the acquisition of knowledge and insights through the perspective and experiences of a limited number of individuals most familiar with the subject matter (Seidman, 2013; Thomas & Magilvy, 2011). Transcripts of the interviews underwent coding and analysis for emerging themes. The second source of data was documentation from researchers who have sought to address the space debris problem. The third source was archival records from NASA, including data and publications available on the NASA website.

Research Question

The intent of this study was to explore the strategies that satellite manufacturing business leaders use to mitigate the damage caused by space debris. The overarching research question for this study was as follows: What strategies do satellite manufacturing business leaders use to mitigate the damage caused by space debris?

Interview Questions

The design of the interview questions was to explore the business environment in which the business leaders in satellite manufacturing firms must operate in the presence of the space debris problem. The interview questions were as follows:

1. What was your personal experience in dealing with the growing space debris problem?

This initial question served to put the interviewees at ease by encouraging them to speak freely and to become part of the study (Aberbach & Rockman, 2002).

2. Why is space debris a problem for satellite manufacturers?

This question led to exploring the link between the space debris problem and satellite manufacturers.

3. How severe is the space debris problem for satellite manufacturers?

This question led to exploring the severity of the space debris problem as perceived by those familiar with the problem.

4. What strategies are you taking to mitigate the space debris problem?

This question led to exploring the strategies satellite manufacturers are using to mitigate the space debris problem.

5. What more should satellite manufacturers do to mitigate the growing risk of space debris?

This question served to gauge the perception of interviewees on whether they were doing enough and whether they should do more.

6. What is the role of satellite manufacturers in the context of addressing the space debris problem?

This question led to exploring whether the interviewees thought of themselves as stakeholders.

7. How important a role should the satellite manufacturers play in the context of addressing the space debris problem?

This question led to exploring the perception of criticality the business leaders might perceive themselves in addressing the space debris problem.

8. How important is active debris removal (ADR) for satellite manufacturers?

This question led to exploring the perception of potential business opportunities associated with ADR that business leaders might have.

9. What are some other long-term business opportunities associated with space debris for satellite manufacturers?

This question led to exploring the perception of potential business opportunities that business leaders might have.

10. Can you recommend other experts on space debris who might provide additional insights regarding space debris?

This question facilitated the process of snowballing to obtain the names of additional study participants.

Conceptual Framework

Several conceptual frameworks supported the premise of this study. The Kessler syndrome, theorized by Kessler and Cour-Palais (1978), was the scientific theory that forms the contextual basis of a developing business problem. The general systems theory (GST), introduced by von Bertalanffy in the 1930s, is the conceptual framework linking a system, its environment, and the notion of sustainability (Valentinov, 2014). The GST is the conceptual lens through which the business problem of the interruption of space systems underwent exploration and was applicable to the study. Hardin (1968) provided the conceptual framework linking motivational and behavioral aspects of overconsumption in the CPR environment. The overconsumption of the CPR is the conceptual lens through which the behavioral aspect of overconsumption in the space environment underwent exploration. The stakeholder theory, introduced by Freeman (1984), is the conceptual framework supporting stakeholder influence and behavior in sustainability management (Hörisch, Freeman, & Schaltegger, 2014; Rowley, 1997). The stakeholder theory was the conceptual framework through which stakeholder motivation and behavior in response to the space debris problem underwent exploration. The contingency theory, originated by Woodward, Burns, and Stalker in the 1950s, was the conceptual framework in which organizational adjustments to situational factors are critical to organizational management (Hanisch & Wald, 2012). The contingency theory was the conceptual lens through which organizational response to the space debris problem undergoes exploration.

Definition of Terms

This study has technical content. To facilitate clear communication of ideas and concepts, this section includes definitions for various terms within the research study. Each defined term includes precise contextual meanings regarding the space debris problem to increase understanding for persons unfamiliar with the challenges facing the satellite industry.

Active debris removal (*ADR):* Active debris removal is the removal of objects from orbit beyond currently adopted mitigation measures (Liou, 2011).

Catastrophic collision: A catastrophic collision occurs when the impact energy to target mass ratio exceeds 40 J/g. The outcome of a catastrophic collision is the total fragmentation of a target. A noncatastrophic collision only results in minor damage to the target and generates a small number of fragments (Liou, 2011).

Collision cascade: Collision cascade is the surging of fragments from collisions breaking up other intact objects at an increasing rate (Kessler, Johnson, Liou, & Matney, 2010) or the growth of the space debris population at an exponential rate because of debris-on-debris collision (Weeden, 2011). Collision cascade is the snowball effect of collisions generating objects that generate new collisions (Bombardelli & Pelaez, 2011).

Common pool resource (CPR): Common pool resource is a resource environment or domain characterized by an open-access problem, meaning it is difficult to bar others from accessing and benefitting from that resource (Weeden & Chow, 2012). Examples of CPRs include the oceans, air, and space.

Conjunction: Conjunction is an event in which two orbital objects pass within some specified critical distance of each other (Wang, 2010).

Conjunction assessment or conjunction analysis: Conjunction assessment or conjunction analysis is the process of monitoring, analyzing, predicting, and mitigating collision risks between debris objects with operational satellites (Williamson, 2012).

Debris flux: Debris flux is the number of debris impacts per unit area per unit time (Kessler & Cour-Palais, 1978).

Hypervelocity: Hypervelocity refers to the high speed in which objects travel in space orbits. Orbital objects travel at around 10 km/s to 13 km/s at low Earth orbit (LEO; Abdel-Aziz, 2013).

Kessler syndrome: Kessler syndrome is an orbital debris term that included a prediction that fragments from random collisions between objects would become an important source of small debris about the year 2000, and afterward the debris flux will increase exponentially with time, even with a zero net input (Kessler et al., 2010; Kessler & Cour-Palais, 1978).

Organization elites: Organization elites are people in a position of power (Stephens, 2007). They could also be highly skilled professionals who are professionally competent (Harvey, 2011).

Passivation: Passivation is a term describing the depressurization of all storage tanks to avoid explosions at the end of a mission (Percy & Landrum, 2014).

Postmission disposal: Postmission disposal is a set of guidelines that includes as a recommendation removing payload or upper stage from orbit within 25 years after its operational life. The 25-year rule is a commonly adopted postmission disposal (Lim, Kim, & Seong, 2013). Postmission disposal is one of the United Nations space debris mitigation guidelines (United Nations Office for Outer Space Affairs, 2010).

Space debris: Space debris is a blanket term for any human-made artifact in orbit around a planetary body (Gopalaswamy & Kampani, 2014). Examples of space debris include discarded satellites, launch vehicle upper stages, hardware discharged into space during satellite deployment, tools or hardware accidentally left behind by astronauts during space missions, and debris from explosions and destructive tests involving kinetic energy weaponry testing (Chen, 2011). The United Nations Committee on the Peaceful Uses of Outer Space defined space debris as all manmade objects, including fragments and elements thereof, in Earth orbit or reentering the atmosphere that are nonfunctional (United Nations Office for Outer Space Affairs, 2010).

Sustainable development: Sustainable development is development that meets present needs without compromising the ability of future generations to meet their needs (United Nations, as cited in Durrieu & Nelson, 2013).

Twenty-five year rule: The 25-year rule refers to lowering the orbit of a satellite at its end of life to force the satellite orbit to decay naturally within 25 years or raising its orbit to a graveyard region (Liou, 2011). The 25-year rule is part of the United Nations space debris mitigation guidelines.

Assumptions, Limitations, and Delimitations

Assumptions

Assumptions are circumstances out of a researcher's control, but if they disappear, the study would become irrelevant (Simon & Goes, 2013). Two assumptions formed the basis of this study. The first assumption was that the interviewees would understand the risks associated with space debris. To ensure the interviewees understood the risks, only business leaders with extensive space systems knowledge participated in interviews. The second assumption was that the interviewees would answer truthfully and discuss all potential solutions. To provide assurances to the interviewees, each participant's identity remained concealed, and participants were able to withdraw from the study at any time without ramifications.

Limitations

Limitations are potential weaknesses in a study and are out of the researcher's control (Simon & Goes, 2013). One limitation of this case study was the inability to transfer the findings to a global population because the study took place in the United States and Europe. A second limitation was the inability to address the effect of international politics on the business problem. Governments often promote or protect their national interests by restricting business activities, and international politics has been an influencing factor in the space debris problem. A third limitation relates to the scope. Although some business solutions might be technical, this study did not involve exploring the technical validity of a business problem.

Delimitations

Delimitations are those characteristics that limit the scope and define the boundaries of a study (Simon & Goes, 2013). The population of potential study participants included business leaders from the United States and Europe only because of funding and time constraints. The research findings might not be representative of the entire community that includes business leaders from satellite manufacturers in Asia and South America. Another delimitation of the research design was the strict adherence to business-related solutions only. Solutions promoted by governments or militaries were not part of the study. A third delimitation was that the focus of the research was not on technology unless it pertained to the business decision-making process.

Significance of the Study

Contribution to Business Practice

Space-based systems are prevalent in modern society and critical to the global economy. The capabilities they provide are indispensable to the global community (Buckerfield de la Roche, 2013). The space debris problem is a global problem (Chen, 2011) with the potential to affect billions of consumers subscribing to space services (Meek, 2012). The knowledge base on space debris includes politics, behavior and ethics, space economy, and the space environment. There is also knowledge on the economic benefits of space use. However, no researchers have focused on the implications of the space debris problem on satellite manufacturers. The topic addressed was the space debris problem from the perspective of satellite manufacturers and provided business leaders additional information upon which they can make future business decisions. By providing business leaders at satellite manufacturing organizations insights into an SRM for effective space debris risk mitigation, business leaders seeking strategic solutions to update their business models might find the research findings helpful. The research findings could lead to improved business operations that promote lower operational risk, higher profitability, enhanced competitiveness, and organizational sustainability. By promoting the long-term sustainability of the space environment, business leaders at satellite manufacturing organizations could contribute to technology advancement, economic development, and positive social change.

Implications for Social Change

The benefits of space technology are far reaching. The use of the space environment contributes to economic growth, higher standards of living, increased knowledge base, and technology advancement (Williamson, 2012). Social benefits of space activities include employment-associated hardware manufacture, technology research, and technology spin-offs (Abiodun, 2012; Jarritt, Peeters, & Schrogl, 2011; Machay, 2012). Investments into space technology serve as a source for the technology overflow that contributes to the economic development of nations and benefits many terrestrial industries (Venturini, Verbano, & Matsumoto, 2013). Such technology development could lead to new products, processes, applications, materials, or services to benefit societies (Petroni, Verbano, Bigliardi, & Galati, 2013). Earth observation using satellites in space facilitates the monitoring of the planetary health (Lele, 2012). For example, Earth observation satellites capable of oil spill detection could provide early warnings that reduce clean-up costs and prevent further damage to the environment (Jarritt et al., 2011).

New entrepreneurial ventures in space tourism are becoming a source of job creation and economic growth (Beery, 2012; Reddy, Nica, & Wilkes, 2012). Many developing economies are implementing knowledge-based economies through research in space exploration and the development of advanced products and services to promote human welfare (Acevedo, Becerra, Orihuela, & Varela, 2011; Manikowski, 2013). Economically depressed Africa is adopting space technology to meet continent-wide development needs (Abiodun, 2012). The sustainability of the space environment would specifically benefit the African economy by providing application opportunities inherent in space efforts and preventing brain drain from Africa (Abiodun, 2012). Examples of application opportunities include research and development to develop future industries and applications in medical research.

Satellite systems are important research platforms for investigative studies of Earth sciences, including weather and global climate changes. Climate change is a risk multiplier that affects social issues such as poverty, disease, and food and water scarcity (Rosa, Ehrenfreund, Hornect, & Thiele, 2013). In some parts of the world, the changing climate is contributing to increased levels of famine and food price volatility. The demand for increasingly scarce resources is consequently contributing to regional tension that leads to instability and regional and global security concerns (Rosa et al., 2013).

The preceding examples are indications that the preservation of the fragile space environment for continued space systems application is important for improving living standards, increasing prosperity, and promoting consumer welfare. All space missions contribute to the space debris problem and the pollution of the space environment. The continued destruction of the global commons is an increasing threat to the sustainability of the space environment and directly threatens the global economy. The increasing threat coincides with modern society's growing dependency on space systems and the capabilities they provide. Space resources are not renewable (Meek, 2012), which means it is difficult to eliminate debris from a contaminated space environment. The space debris problem might one day erase the economic advantages provided by space systems that modern society has built since the 1960s.

Every individual on planet Earth is a stakeholder in the sustainable use of space CPR (Weeden & Chow, 2012). The collective knowledge and improved understanding of the fragility of the space environment are prerequisites to implementing social change. Space pollution contributes to the continued destruction of the space environment. If left unmitigated, space debris might one day deny humanity the use of space and the many benefits space systems provide. The goal of conducting this case study was to advocate the preservation of the space environment through improved business practices by drawing attention to the increasingly threatening space debris problem. The study could contribute to positive social change by revealing strategies that might preserve the space environment. This will allow future generations continued access to this critical resource. The accessibility of the space environment will continue to provide incentives and opportunities to derive new benefits for humanity.

Review of the Professional and Academic Literature

Opening Narrative

Space debris is a modern phenomenon and a by-product of the space age. Efforts on space debris research gained importance following the publication of the seminal paper by Kessler and Cour-Palais (1978). The urgency of space debris research took on a new dimension after the Iridium 33-Cosmos 2251 collision in 2009. Conducting the literature review involved identifying multiple themes related to issues and concerns associated with space activity sustainability. Within the various themes, the growing debris population was the common contributing factor toward instability in the space environment and a potential business problem. The following subsections include background information on space debris, the link between space debris and terrestrial businesses, the role played by satellite manufacturers within each theme, the conceptual framework associated with each theme, and insights into the factors that contribute to potential business problems.

Sources of Literature

Sources of the space debris literature included books, journal articles, conference papers, government websites, and space agency websites. The initial search for peer-reviewed literature included the EBSCOhost, ScienceDirect, and ProQuest databases, as well as journal websites. However, peer-reviewed articles relevant to the research topic were difficult to find in business databases. To address the dearth of information, online searches included Google Scholar. The extended search yielded many more articles. Key words used to conduct searches in business databases and Google Scholar included *space debris, space activity, space environment*, and *space activity sustainability*.

Government and space organization websites also include information on space debris. The NASA ODPO is a dedicated resource for space debris information. The ODPO staff members maintain a website and publish a quarterly newsletter on space debris. The European Space Agency (ESA) website included similar data on space debris. Other websites, including the U.S. Strategic Command, Union of Concerned Scientists, and United Nations Office for Outer Space Affairs all contain information on specific elements related to space debris. Conference papers are also good sources of data, especially conferences dedicated to the topic of space debris.

Relevant information on satellite manufacturing came from sources other than the space debris literature. Technical information on satellite manufacturing such as power or propulsion subsystems is in abundance in scientific and engineering journals and papers published in professional conferences. Business-related information on satellite manufacturing is available from books, market research publications such as *Euroconsult*, Satellite Industry Association *State of the Satellite Industry Report*, and the Space Foundation *2014 Space Report*. In addition, satellite manufacturers maintain websites with relevant information on their satellite product lines.

The literature search yielded more than 300 articles. One hundred ninety articles were relevant to the study, and citations for 149 articles appear in this study. Of the 149 articles, 128 (85.9%) had publication dates in or after 2011, and the remaining 21 were pre-2011. Of the 21 pre-2011 articles, three were seminal papers relevant to the study. One hundred and thirty-one (87.9%) of the 149 articles were from peer-reviewed journals or government websites, including all three seminal articles. Eighteen articles (12.1%) were not peer-reviewed articles. Of these 18 articles, five were papers published at various space conferences that are nevertheless and relevant to the study. See Appendix A.

Journal publications covering topics related to space debris include *Acta Astronautica, Advances in Space Research, Celestial Mechanics and Dynamical Astronomy, Cosmic Research, Journal of Astronomy and Space Sciences, Journal of Geophysical Research, Journal of the Astronautical Sciences,* and *Space Policy.* The literature review process resulted in the citation of 60 peer-reviewed journals. Appendix

A includes a list of journals cited in this study. Furthermore, several prolific authors are good sources of information, including R. A. Williamson of Space Policy Institute and N. L. Johnson and J.-C. Liou of NASA ODPO. Johnson was the NASA chief scientist for orbital debris until March 2014. Liou is the current NASA chief scientist for orbital debris and the editor of the *NASA Orbital Debris Quarterly News*.

Analysis of the Literature: Themes From the Literature Review

Several themes emerged from the review and analysis of the literature. Themes included space politics, laws, and regulations; space economics and social change; space tourism and employment; use of space and CPR; debris removal and avoidance; debris and orbital dynamics; and the space environment. Additional themes with background information included space industry and structure; military space; competition and cooperation; business strategy and planning; and applicable theories. Appendix B is a literature map with a summary of the various articles associated with a theme or category. In many articles, the authors touched upon several major themes. The allocation of an article under a theme was primarily a judgment call.

Organization of the Literature Review

The focus of the organization of the literature review was on the analysis of major themes in the literature. The review includes the trivariate relationship among each major theme, its connection to the space debris problem, and the role of satellite manufacturers. The review of each theme may include the presentation of background information, exploration of the factors that affect or are affected by the space debris problem, discussion on the roles played by satellite manufacturers, and evaluation of the business problem based on the applicable conceptual framework. The goal of this organizational framework was to explore the multitude of issues and the complexities of the issues to set the tone and establish the background for the study.

The Space Environment and Space Debris

The space environment above Earth was in pristine condition with no orbiting artificial objects prior to the launch of Sputnik in 1957 (Adilov et al., 2015). The orbital insertion of the Russian satellite ushered in the modern space age and started an international race to put assets in space. Since 1957, spacefaring nations have conducted over 5,000 launches to put satellites, spacecraft, and occasionally humans into the space environment (Durrieu & Nelson, 2013). Many of the launch vehicle upper stages that delivered the satellites as well as the satellites themselves remain in space and became space debris upon completion of their intended missions.

During the early years of the space age, governmental entities funded space activities in pursue of their political, military, and scientific objectives (Durrieu & Nelson, 2013). By the end of the Cold War in 1991, engineers and scientists had gained sufficient space systems knowledge to start using the space environment for commercial applications such as telecommunication and Earth observation (Durrieu & Nelson, 2013). The increase in commercial activities coincided with a reduction in government-sponsored space programs, but sustained use of the space environment continued. Satellite technologies now support commercial services such as satellite television, radio applications, mobile and data services, business applications, and the global positioning system (GPS; Adilov et al., 2015). Furthermore, capabilities derived from satellites provide essential support to the U.S. military (Lynn, 2011). After decades of continuous hardware delivery into the space environment, the accumulated space debris is posing collision hazards to operational space assets.

Space debris, commonly referred to as space junk, consists of discarded satellites, spent launch vehicle upper stages, hardware left in space during satellite deployment, debris from fragmentation events, and even objects accidentally left behind by astronauts during space missions (Chen, 2011; Gopalaswamy & Kampani, 2014). Unlike debris on Earth, debris in space orbits the Earth in accordance with the laws of orbital mechanics. Depending upon their orbital location, the orbital lifetime of space debris ranges from a few months at an altitude of 400 km to 25 years at 600 km and some for several centuries at 800 km before gravity pulls them back down to Earth (Gopalaswamy & Kampani, 2014). In the geosynchronous orbit (GEO) environment, the lack of atmospheric drag effectively renders orbital lifetime infinitely long (P. V. Anderson & Schaub, 2013). As government and commercial entities add objects to the space environment at a pace faster than the removal rate, the risk of collision between debris objects and operational satellites will likely increase in the future (Liou, 2011).

The number of debris objects has been increasing since early 1960s. The first significant growth of debris objects took place in June 1961 when the explosion of an artificial object created more than 300 pieces of trackable debris fragments (Barbee, Alfano, Pinon, Gold, & Gaylor, 2012). The number of debris objects grew steadily since then as fragmentation events and continuous launches added more objects to the debris population (Barbee et al., 2012; Durrieu & Nelson, 2013; Liou, 2011). The increasing debris population led to the first collision of an operational satellite and a piece of space debris on July 24, 1996 (Jesus, Ribeiro, Rossi, & Neto, 2012).

Other factors have contributed to the growth of space debris in recent years. In 2007, an antisatellite weaponry test conducted by China instantly added thousands of fragmented objects to the debris population (Barbee et al., 2012; Wang, 2010). The action caused alarm throughout the space community and drew condemnations for the offender. Nevertheless, the space industry continued to support the big sky theory in which two random flying bodies are unlikely to collide because of the vastness of space (Jakhu, 2010; Levin, Pearson, & Carroll, 2012). The assumption became questionable when decommissioned Russian satellite Cosmos 2251 collided with operational American satellite Iridium 33 in 2009. The collision destroyed Iridium 33 and generated debris objects ranging from large pieces to small dust particles (Wang, 2010). Fragments from these two collision events more than doubled the debris population at the time (Liou, 2011). The unforeseen Iridium–Cosmos collision became the wake-up call to the space community on the destructive potential of space debris in the increasingly congested space environment.

Debris object categories are small (<1 cm), medium (1 to 10 cm), or large (>10 cm; Percy & Landrum, 2014). Representatives of several countries and organizations track space objects and maintain catalogues, including the United States, Russia, ESA, and scientific and academic organizations (Weeden, 2011). Technology can track large objects 10 cm or greater in size in LEO and 1 m in GEO using a variety of equipment (Lele, 2012; Liou, 2011; McKnight & Di Pentino, 2013). In the LEO environment, debris objects smaller than the 10-cm detection threshold are too small and too numerous to track with existing equipment (Liou, 2011). NASA scientists have estimated that there are approximately 20,000 to 22,000 large objects in space greater than 10 cm in size, approximately 500,000 medium objects between 1 and 10 cm in size, and over 100 million small particles smaller than 1 cm (NASA ODPO, n.d.). Among the objects in space, approximately 1,000 are operational satellites (Union of Concerned Scientists, 2014; Williamson, 2012). The rest are space debris.

Orbital objects travel at high speed, from 10 km/s up to 13 km/s at LEO (Abdel-Aziz, 2013). At such hypervelocity, even a small object carries sufficient kinetic energy capable of causing catastrophic damage to orbital satellites in a collision. Collisions between orbital objects could create many more pieces of debris, and continuous debris creation would eventually lead to overcrowding (Kessler & Cour-Palais, 1978). The concept of overcrowding in the space environment originated in the 1970s as increasing space activities started generating orbiting debris objects. Kessler and Cour-Palais (1978) identified a long-term debris-generation phenomenon and described the mechanism for space debris propagation. Kessler and Cour-Palais (1978) predicted increasing numbers of orbital debris with a corresponding rise in the probability of collision between objects. The nature of the collision includes debris-to-debris and debris-to-satellite collisions. Each collision produces more orbiting fragments, and each new fragment contributes to an increased probability of further collisions. This effect, named collision cascade, serves as the conceptual framework for debris growth and the foundation of a developing and long-term business problem. Events in the ensuing decades such as confirmation of increasing collisions (Kessler et al., 2010), increasing frequency of space debris avoidance maneuvers for the International Space Station (ISS; NASA ODPO, 2015a), increasing numbers of conjunction warnings to satellite operators (Gopalaswamy & Kampani, 2014), and computer simulations conducted by NASA scientists (Liou, 2011) have all confirmed the theoretical prediction of collision cascade. Members of the space community call the phenomenon of a runaway collision cascade of debris fragmentation the Kessler syndrome (Liou, 2011).

Within the debris population, large debris objects such as decommissioned satellites or expended rocket bodies pose the highest debris-generation risk (Phipps, 2014). These objects have large surface areas that increase the probability of in-space collision. Satellite construction is an assembly of thousands of pieces of components. Upon collision, pieces fly apart and create a debris cloud that consists of hundreds of pieces of additional debris (Kessler et al., 2010). As the debris population increases, uncontrolled debris-on-debris collisions will likely exacerbate the space debris problem and become a long-term threat to all operational satellites (Liou, 2011).

The Kessler syndrome could already be in effect. Kessler and Cour-Palais (1978) predicted that small debris generation from debris-to-debris collisions would start around the year 2000. The Iridium 33–Cosmos 2251 collision in 2009 became the confirmation event of the predicted orbital collision phenomenon and highlighted the seriousness of the growing space debris problem with the destruction of a multimillion-dollar operational satellite. The confirmation of the scientific prediction on collision cascade has many implications for businesses that rely on satellites. The rising threat of collisions between satellites and space debris is one such implication that business leaders need to address (Jakhu, 2010). Other business implications include increasing risks and cost of space operations, disruptions to economic activities, potential liabilities for damage or service interruption, consumption of precious fuel for increasing collision avoidance maneuvers, and shortened lifespans for satellites (Baldwin, Weiss, Kolmanovsky, & Erwin, 2012; Jakhu, 2010). These business implications formed the basis of the study.

Space Debris Problem in low Earth orbit, medium Earth orbit, and geosynchronous orbit

There are three regions in the space environment supporting commercial space activities. Low Earth orbit is the region between the altitudes of 200 km and 2,000 km (Liou, 2011). Medium Earth orbit (MEO) is the wide region between the altitudes of 2,000 km and 35,585 km (Liou, 2011). Geosynchronous orbit is a narrow region between the altitudes of 35,586 km and 35,986 km (Liou, 2011). The ranking of congestion in these regions, expressed in the standard unit of spatial density (number of debris per km^3), is highest in LEO, in the middle in GEO, and lowest in MEO (Jasper, Anderson, Schaub, & McKnight, 2014).

Low Earth Orbit. The LEO environment has high commercial value because of its close proximity to Earth. Approximately half of the world's operational satellites (Durrieu & Nelson, 2013; Gopalaswamy & Kampani, 2014) and approximately 76% of all tracked and cataloged objects in Earth orbits are in LEO (Percy & Landrum, 2014). LEO is the most studied region because it has the highest density of debris population (Jasper et al., 2014). Several orbits in LEO, such as sun-synchronous orbits and polar orbits, are especially useful for Earth observation or other commercial applications (Cerf, 2013; Percy & Landrum, 2014). These popular orbits are densely crowded with LEO satellites. Accordingly, there are clusters of debris populations across these most populous parts of LEO (Frost, 2011; Levin et al., 2012; Liou, 2011). Objects in LEO travel at high speed and at various planes or inclinations (Levin et al., 2012). Consequently, objects in LEO might cross orbits with each other, and the risk of catastrophic collisions is higher in LEO as compared to GEO (Chen, 2011; Levin et al., 2012). The 2009 collision of Iridium 33 and Cosmos 2251 was an example of such a cross-orbit collision (Tan et al., 2013).

The LEO environment poses the highest debris collision risk for satellites operating in the region (Liou, 2011). The principle source of space debris in LEO is from the fragmentation of space vehicles. N. L. Johnson (as cited in Barbee et al., 2012) reported a minimum of 190 spacecraft breakups, as well as at least 50 more fragmentations events at a lower level, in LEO. Fragmentation results in debris of various sizes. Table 1 includes a summary of the size, characteristics, collision risk, and hazard levels associated with three size categories of debris in LEO.

The softball-size debris objects represent approximately 96 to 98% of lethal objects in orbit, which indicates an overwhelming majority of hazardous space debris fragments remain undetectable (Levin et al., 2012; Shustov et al., 2013). These objects are the primary threat to satellites but they are difficult to track with existing debris detection technology (Gopalaswamy & Kampani, 2014). While government agencies devote extensive resources to track only 2 to 4% of the lethal objects in space, more than

95% of risk items are not detectable and not accounted for (Shustov et al., 2013). The situation is notable given that the global economy is dependent upon satellite systems, whereas current practice mitigates only 2 to 4% of the overall risk (Levin et al., 2012; Shustov et al., 2013).

Table 1

Lethal Debris Objects in Low Earth Orbit

Size	Characteristics	Numbers	Hazards
Medium (shrapnel or softball size)	Untracked, 1 to 10 cm, 98% of lethal objects	~300,000 medium size objects	Objects in this size range are the primary threat to satellites. There are too many objects. They are too small to track and avoid and too heavy to shield against.
Large (hubcap or beach ball size)	Tracked, >10 cm, <2 kg, 2% of lethal objects	~12,000 large size objects	Objects in this size range are the cause of most conjunctions and avoidance maneuvers for operational satellites.
Large (car or container size)	Tracked, >2 kg, <1% of lethal objects		Objects in this size range are the primary source of new smaller size debris objects. They represent 99% of the collision area and mass.

Medium Earth Orbit. Compared to LEO, the MEO environment is much broader and less densely populated with orbiting objects (Liou, 2011). The satellite constellations in MEO include the GPS and the Russian Global Navigation Satellite Systems (Herzog, Schildknecht, & Ploner, 2012; Hinze, Schildknecht, Vananti, & Krag, 2011). The space debris problem in MEO is not as severe as in LEO and GEO (Jasper et al., 2014; Liou, 2011). Given the limited resources and a lesser degree of severity in the MEO region, the focus on debris problem resolution is in LEO and GEO regions (Bombardelli & Pelaez, 2011; Hildreth & Arnold, 2014).

Geosynchronous Orbit. The geostationary ring is a unique commodity to satellite service providers (P. V. Anderson & Schaub, 2014). Satellites in this region complete one revolution around the Earth each day (N. L. Johnson, 2012). The synchronized revolution enables the satellite to appear fixed at one location in the sky as viewed from the Earth. This unique feature makes the GEO orbital slot a highly valued commodity (N. L. Johnson, 2012; Schaub & Moorer, 2012). The number of satellites in GEO orbit is growing steadily and leading to overcrowding and a rise in the probability of collision in this region (N. L. Johnson, 2012).

After nearly 60 years of continuous launches to GEO to take advantage of its economic values, overcrowding in the GEO region is becoming a problem for satellite operators (P. V. Anderson & Schaub, 2014). In February 2014, GEO had approximately 1,145 large objects 0.8 to 1.0 m in effective diameter, and 760 of these objects were uncontrolled debris (P. V. Anderson & Schaub, 2014). The situation will likely deteriorate, as the projected launch rate to GEO will likely increase (P. V. Anderson & Schaub, 2014).

The GEO region is host to many high-value operational assets such as communication and science satellites (Schaub & Moorer, 2012). It is also home to some very large pieces of debris objects including decommissioned satellites, launch vehicle upper stages, spacecraft apogee kick motors, and other mission-related debris (N. L. Johnson, 2012). Similar to LEO, there is localized debris congestion in specific regions of GEO (P. V. Anderson & Schaub, 2014; McKnight & Di Pentino, 2013). Debris in GEO could be the result of two known fragmentation events, as well as perhaps another 10 more (Barbee et al., 2012). In addition to explosion events, collisions, shedding of multilayered insulation, and other debris growth mechanisms continue to increase the space debris population in GEO and the risk associated with operating space systems in this region (P. V. Anderson & Schaub, 2014). Furthermore, GEO satellites retire to a graveyard disposal orbit at some 50 km to 300 km above GEO (N. L. Johnson, 2012; McKnight & Di Pentino, 2013). Debris in this graveyard orbit represents a potential but not fully understood collision hazard to operational GEO satellites (McKnight & Di Pentino, 2013). Unlike LEO, objects in GEO all move in the same direction and at lower speed. Consequently, collisions in GEO are less likely and less destructive than in LEO (Chen, 2011). Nevertheless, overcrowding in the GEO region is becoming a serious concern for satellite owners and operators (P. V. Anderson & Schaub, 2014). Given the long distance, routine tracking of debris objects includes only objects greater than 1 m in size (P. V. Anderson & Schaub, 2014). This limitation might become problematic as the space debris population in GEO continues to grow.

Projection of the space debris environment in LEO, MEO, and GEO. The projection for trackable debris population in the future is continuous growth assuming regular satellite launches and no mitigation measures (Liou, 2013). In the MEO and GEO regions, there will only be a few accidental collisions with debris objects great than 10 cm in size in the next 200 years (Liou, 2011). However, the debris population in the LEO environment has already surpassed the threshold such that, even without future launches, debris-to-debris collisions will continue the growth of the debris population (Liou, 2011).

The exponential growth of the debris population in LEO will likely increase the frequency of debris-to-debris collisions in the near future (Kessler et al., 2010).

The projection of increasing collisions in the future could be an important piece of information for satellite manufacturers. Business leaders from satellite manufacturing organizations could develop strategies that proactively address the space debris problem in the form of new products and services. An example might be developing a spacecraft capable of conducting ADR that could address future market demands. Hamel and Prahalad (2005) advocated a business approach with strategic intent. Developing a strategic solution with the express purpose of mitigating damage caused by space debris meets such a strategic conceptual framework.

Satellite Manufacturing and Space Debris

At the inception of the space age, government-sponsored programs dominated space activities (C. Anderson, 2013). However, space missions are no longer the exclusive domain of governments (Stubbe, 2011). By the end of the Cold War in 1991, commercial firms had gained sufficient space systems knowledge to start manufacturing satellites for commercial applications (Durrieu & Nelson, 2013). As commercial firms acquire more and better satellite manufacturing knowhow, many governments started outsourcing satellite manufacturing to commercial firms. In the United States, even human spaceflight is becoming more reliant on the private sector (Logsdon, 2011). In 2014, commercial satellite manufacturing firms fabricated most of the satellites in the United States, Europe, and Japan (Villain, 2014). Major satellite manufacturing firms in the United States include Ball Aerospace, Boeing, Lockheed Martin, Orbital Sciences, and SSL (Villain, 2014). In Europe, major satellite manufacturers include Airbus, OHB, Surrey, and Thales Alenia Space (Villain, 2014). In Japan, MELCO and NEC are the two commercial satellite manufacturing firms (Villain, 2014). In contrast, NASA manufactures few satellites in house and maintains its focus on mission design, management, and the acquisition of scientific knowledge to optimize value to its key stakeholders (Sutherland, Cameron, & Crawley, 2012).

Satellite manufacturing is a difficult and challenging endeavor. A typical GEO commercial satellite could cost several hundred million dollars to manufacture (Abiodun, 2012) and hundreds of millions more to launch into orbit (Coopersmith, 2011). In 2013, satellite manufacturing accounted for $15.7 billion in revenue (Tauri Group, 2014). Operational satellites are direct contributors to the $314 billion space economy (Space Foundation, 2014). However, the space debris problem has the potential of reducing the economic value of space activities (Adilov et al., 2015), including satellite manufacturing. There are no satellite-servicing facilities in orbit to repair damaged satellites. Satellite manufacturers need to design and manufacture their satellites to operate in an increasingly harsh environment without interim services for the entire duration of the space missions. The growing space debris population would likely compound the challenge of the long-term reliability and survivability for satellite manufacturers as the operational lifetime of the satellites continues to grow (McKnight & Di Pentino, 2013).

Satellite manufacturers have a direct link to space debris generation. Satellite construction is an assembly of thousands of pieces of components. In a collision, pieces fly apart and create a debris cloud consisting of many pieces of satellite hardware (Kessler et al., 2010). In an era of growing concern over sustainability, satellite manufacturers are stakeholders in a unique position to contribute potential solutions to the space sustainability problem. Satellite manufacturers could incorporate sustainability principles in satellite development (Durrieu & Nelson, 2013). Strategies to mitigate further damage to the space environment might include elements associated with satellite design, construction, and operation (Barbee et al., 2012; D'Amico, Ardaens, & De Florio, 2013; Francesconi et al., 2013). Satellite manufacturers' potential contributions toward mitigating the risk of space debris align with the conceptual framework of stakeholder theory. Satellite manufacturers are key stakeholders with the expertise that could contribute to the advancement of best practices (Williamson, 2012). As key stakeholders, satellite manufacturers need to ensure the continued validity and vitality of the business environment (Williamson, 2012). In particular, their potential contribution in designing and building spacecraft with ADR technology could provide valuable services toward stabilizing the space environment (Liou, 2011).

The stakeholder theory was an important conceptual framework in support of the study. Freeman introduced the stakeholder theory in 1984 (Rowley, 1997). The theoretical focus was on organizational behavior and stakeholder influences. In the study, the problems generated by space debris could influence multiple stakeholders, including satellite manufacturing organizations. Satellite operators might incur financial losses from losing operational assets in space. Governments around the world might experience interruptions in governmental functions, including financial, military, and public services

(L. Johnson, 2013; Lynn, 2011). Workers in business organizations might be unable to perform many of their basic operations because of the loss of satellite services (L. Johnson, 2013). Similarly, millions of consumers might experience service interruption from the loss of satellite services (L. Johnson, 2013; Lele, 2012). The conceptual framework of the stakeholder theory is an important tool in addressing the needs of multiple stakeholders. In the case of the space debris problem, the application of the stakeholder conceptual framework could ensure equitable treatment of stakeholders when evaluating organizational performance and value creation (Bridoux & Stoelhorst, 2014).

Space Politics, Laws, and Regulations

Space politics, policies, and regulations are important elements in the study of space debris that dictate the focus and direction of the space industry (Smith, 2011). Multitudes of policies and regulatory deficiencies exacerbate the space debris problem. First, nations participate in space activities with varying interests (Su & Lixin, 2014). There is disagreement among nations on a common code of conduct (Su & Lixin, 2014). Conflicts among parties are inevitable, and developing consensus among all sides for an agreed upon way of conducting space activities is an ongoing challenge (Brachet, 2012). Second, increasing space activities are taking place in the absence of coordinated regulations and standards on an international scale (Weeden, 2011; Williamson, 2012). The lack of a global regulatory framework and the resulting lack of cooperation among space-faring nations is a contributing factor in the continued deterioration of the space environment (Stubbe, 2011). Third, adherence to the space debris regulatory guidelines is voluntary. The absence of enforcement and relaxed compliance prolong the problem without resolution (Adilov et al., 2015; Stubbe, 2011). Fourth, although there is a rising risk of debris-related damage, a comprehensive mechanism for conflict resolution and dispute settlement is not available (Bin, 2012; Tronchetti, 2013).

Furthermore, international politics and national self-interests are preventing the implementation of promising solutions capable of repairing the damaged space environment. For instance, NASA scientists are advocating ADR as a viable mechanism to stabilize the space environment (Liou, 2011). Active debris removal of large debris objects removes debris objects proactively, reduces the risk of collisions that damage operational satellites, and reduces the frequency of debris-on-debris collisions that generate more debris objects (Liou, 2011). However, political barriers to ADR implementation exist, such as a lack of agreement to remove debris objects owned by other launching states (Weeden, 2011). Geopolitics between political adversaries also plays a key role. Countries such as the United States and Russia rely on space for national security (Hilborne, 2013), and potential distrust could develop based on the potential dual use of ADR technology with military objectives (Weeden, 2011). The examples are indications that although ADR has many potential benefits, it would not be possible to implement ADR based on its technical merit alone. In the absence of an international agreement on the legal, geopolitical, and regulatory frameworks, a technically feasible solution might not be a politically feasible solution (Weeden, 2011).

The lack of international agreement is a source of sustainability concerns. Space is a global CPR. Individual states and private organizations have incentives to overuse common resources (Adilov et al., 2015). Overexploitation, overconsumption, and irresponsible use of CPR can and often do result in the tragedy of the commons (Hardin, 1968; Mason, Stupl, Marshall, & Levit, 2011). In response to the growing sustainability concerns, Weeden and Chow (2012) advocated the application of Ostrom's principles for CPR governance as a conceptual framework for sustainability discussions.

Legal, geopolitical, and regulatory issues often affect satellite manufacturers. An example is the Metop weather satellites contract awarded by ESA in October 2014 (de Selding, 2014). Managers in ESA mandated that each new Metop satellite must carry 600 kg of additional fuel to carry out a controlled atmospheric reentry upon completion of its intended mission (de Selding, 2014). At a launch cost of $20,000 per kg (Coopersmith, 2011), the 600 kg of fuel alone represents $12,000,000 in added launch costs to the mission. Other complications might include added mission complexity that leads to more complex spacecraft design.

Satellites historically remained in the space environment and became part of the space debris population after the missions were complete. The decommissioned satellites would not return to Earth until natural forces could pull them back into Earth's atmosphere (Abdel-Aziz, 2013). The process of orbital decay might take years, decades, or centuries (Adilov et al., 2015). The intent of the new ESA policy is to remove the satellites from the space environment in recognition of the growing space debris problem (de Selding, 2014). The immediate consequences are that satellite manufacturers must start designing larger satellites to carry additional fuel for the final reentry maneuver, and the cost of launching heavier satellites will likely increase. The example is an indication that business leaders in satellite manufacturing firms need to adjust to the new marketplace demands by developing contingencies that accommodate market-driven changes (Eriksson & McConnell, 2011; Shustov et al., 2013). The business-level adjustment aligns with the conceptual framework of contingency theory in which organizational leaders must react to market-driven changes effectively to ensure continued value creation.

Space Economics

Space-based systems are prevalent and critical to the global economy. The space economy accounts for $314.17 billion in economic activities globally (Space Foundation, 2014). Space products and services have become an integral part of modern society that benefits the daily life of billions of people. There is increasing support from the public for more space activities (Whitman Cobb, 2011). With the proliferation of space technologies permeating modern daily activities, space economics is becoming a key global economic factor (Dholakia-Lehenbauer, Elliott, & Cordell, 2012).

The importance of space programs also extends to industrial job creation (de Montluc, 2012; Machay, 2012). At a regional or national level, there are economic and social benefits from engaging in space activities by emerging economies in Africa, India, Latin America, Poland, and Venezuela (Abiodun, 2012; Acevedo et al., 2011; Lele & Yepes, 2013; Manikowski, 2013). The benefits include technological advancement and economic growth, with key areas of interest covering communications, remote sensing, weather monitoring, and natural resources management (Stroikos, 2013). Furthermore, technology spinoffs from space-related research can and often do benefit other industries and generate additional social benefits (Jarritt et al., 2011; Petroni et al., 2013). The benefits of space activities include more than value creation. Potential cost savings generated by Earth observation during natural disasters (Jarritt et al., 2011) and increased workforce efficiency from using satellite data are additional positive attributes provided by space systems.

The conceptual framework of GST is applicable to an evaluation of the effect of space debris on the space economy. A system consists of many supporting subsystems. The success of a system depends on the proper functioning of each subsystem and the precise interaction between the subsystems (von Bertalanffy, 1972). The focus of GST, formulated by von Bertalanffy in the 1930s, was exploring both the whole and the components of a system (von Bertalanffy, 1972). The principles of GST lie in the understanding of an organized whole, the knowledge of its parts, and the relationship or interaction between them (Drack & Schwarz, 2010; von Bertalanffy, 1972). The conceptual framework of GST is useful for studying the space debris problem. With the space economy as the theoretical equivalent of a system and satellite manufacturing and space debris as components of the system, it may be possible to apply the principles of GST and study system interactions. By acquiring knowledge about the components of the space economy, findings from this study may contribute to the understanding of the overall economic system. The considerations for potential disruptions to businesses and commerce because of the proliferation of the space debris problem and the contribution from satellite manufacturers to address the space debris problems served as the critical link to the GST conceptual framework.

Satellite manufacturers play a critical contributing role in the space economy by designing and producing the products that enable space systems services. Without their contribution in the design, manufacture, and launch of satellites, the space economy, and to some extent the modern economy, would not exist (Space Foundation, 2014). Expectations are that satellite manufacturers will launch 1,150 satellites from 2014 through 2023, with projected revenue of $248 billion (Villain, 2014). The long-term projection underlines the importance of the space-based infrastructure in the global economy and highlights the important role of satellite manufacturers as enablers of space activities (Space Foundation, 2014; Villain, 2014). However, the space-based economy is increasingly at risk from the deteriorating space environment (Buckerfield de la Roche, 2013), and satellite manufacturers are facing some difficult choices. A business-as-usual approach no longer guarantees the preservation of the space environment for future business applications (Liou, 2011; Percy & Landrum, 2014). A lack of strategic vision could bring forth fragmentation in the space industry that may endanger the entire space economy (de Montluc, 2012). As important stakeholders, leaders from satellite manufacturing organizations need to develop strategies to ensure value creation (Harrison & Wicks, 2013), including addressing the problems associated with space debris. In addition, it is important for business leaders to take a proactive role in resolving the space debris problem where political systems may fail (de Montluc, 2012). The critical need for strategy development fits within the conceptual framework of stakeholder theory in which key stakeholders must work to ensure firm performance and value creation in both the short term and the long term.

Employment and Tourism

The United States has a strong and vibrant space industry. The significance of the space industry includes producing high-quality products, promoting national competitiveness, and attracting and employing talent (Goehlich & Bebenroth, 2011). There are nearly 500,000 highly skilled workers employed by the U.S. space economy (Machay, 2012). In addition, every $1 billion in NASA funding results in 24,000 job openings while providing room for an additional 40,000 jobs in space economy for the long term (Machay, 2012). Satellite manufacturing and launch vehicle fabrication are critical components of the space industry that account for $45 billion of economic activity each year in the United States (Villain, 2014). Furthermore, commercial satellites delivered into orbit have the capacity to generate billions of dollars more in economic activities throughout their lifetime (Space Foundation, 2014).

The development of a new space tourism industry is a logical next step following the maturation of space technology. The emerging industry has promise in promoting economic growth (Beery, 2012; Collins & Autino, 2010) and creating opportunities for employment (Collins & Autino, 2010; Reddy et al., 2012). The growth projection for the new space tourism industry is as high as 26% per year, with revenue projection at $650 million per year (Reddy et al., 2012). Nevertheless, risk is a determining factor in whether to undertake space travel (Reddy et al., 2012; Turner, 2012). The growing hazard in the space environment could only intensify the perception of high risk in space tourism and space travel. Safety, the regulation of commercial spaceflight, and the high risk of accidental collisions are all important considerations in commercial spaceflight

(Crowther, 2011; Stubbe, 2011). The anticipated delay in the development of space tourism because of the fatal crash of Virgin Galactic Space Plane 2 on October 31, 2014, indicates the importance of safety and the need for a continuous focus on safety (Gannon, 2014).

The underlying implication in the employment and tourism theme is that the space debris problem has the potential of hindering economic development and undermining the vitality of the space economy in countries, in regions, or on a global basis (Adilov et al., 2015; Beery, 2012; L. Johnson, 2013; Machay, 2012; Villain, 2014). In a worst-case scenario, the cascading space debris generated could one day render the space environment unsustainable for space activities (McKnight & Di Pentino, 2013; Williamson, 2012). Many economic segments depend on satellite services, including retail, financial, air travel, rail, manufacturing, fishing, television, satellite radio, and cell phone (L. Johnson, 2013). Without a fleet of operational satellites to support services, regional and global economies will likely suffer setbacks (L. Johnson, 2013; Lele, 2012; Williamson, 2012). A key to understanding the space debris problem is recognizing that the potential threat is not limited to satellites in space. At the terrestrial level, the space debris problem could introduce shocks to an intricate global economic system by disrupting satellite-based services, threatening economic stability, hindering economic growth, and affecting employment level on a global scale (Lele, 2012; Williamson, 2012). Another aspect of the debris problem is timing. Catastrophic collisions could happen tomorrow, in a year, or within a decade (Kessler et al., 2010). The unpredictable nature of the space debris problem also makes solving it a challenge.

Contingency planning is an important aspect of crisis management (Eriksson & McConnell, 2011). Within the context of satellite manufacturing and the rising space debris threat, contingency planning might include addressing workforce reduction because of the deterioration of the space environment and the subsequent reduced demand for satellites. Conversely, the contingency plan might address a new demand for a new type of satellite that removes space debris. Exploring contingency planning within the conceptual lens of contingency theory is one way to explore the space debris problem. Donaldson (as cited in Hanisch & Wald, 2012) described contingency theory as a trivariate relationship (p. 6) in which a contingency (*C*) controls the influence of a variable (*V*) on the effectiveness (*E*) of an organization. Within the context of the study, the three elements are the increasing risk of space debris (the variable), the level of firm response (the contingency), and the resulting business performance (the effectiveness). The contingency theory conceptual framework could be a useful tool to explore the adequacy of the organizational responses to a business problem. In this study, the focus of exploring the business problem was satellite manufacturers' adaptability to the increasing threat of space debris.

Commercial Activities in the Space Common Pool Resource

Satellite systems fulfill increasing commercial demands. Commercial services such as global voice, data, and video communications, meteorological data, GPS, and resource management depend heavily on the 24-hour continuous service provided by satellites (Manikowski & Weiss, 2012). Commercial satellite services also provide supplementary but critical security services in support of U.S. military and homeland security functions (Lynn, 2011). The commercialization of space is providing employment opportunities and promoting wealth creation, but there are negative side effects. To remain competitive, commercial firms must choose the lowest price technology that generates the most debris (Adilov et al., 2015). The process of profit maximization is creating sustainability problems by excess launching of space hardware and the pollution and degradation of the space environment (Adilov et al., 2015). Lynn (2011) characterized the space environmental conditions as congested, contested, and competitive, and these factors continue to describe the space environment.

Space is a global CPR. The space CPR is in danger of overconsumption because incentives exist for its overuse (Adilov et al., 2015). The concept of overconsumption in the space CPR is critical to understanding space environment sustainability. Hardin (1968) introduced the concept of the tragedy of the commons in which each consumer of the CPR tries to maximize individual gain, thus leading to overconsumption in the CPR. Competing CPR consumption could be rivalrous (Araral, 2014, p. 11), as in the case of space CPR overconsumption by satellite owners (Mason et al., 2011). Overconsumption in the CPR often leads to environmental damage and sustainability concerns (Hardin, 1968). In the case of space CPR, increasing space activities have resulted in a growing space debris population, increasing hazards to operational satellites, and a long-term space activity sustainability concern (Weeden & Chow, 2012). The conceptual framework of overconsumption in the CPR is critical to understanding the collective behaviors of individuals, businesses, and nations that lead to the space debris problem. The conceptual framework is also the key to understanding a potential solution through the lens of Ostrom's principles on sustainable development in the CPR (Weeden & Chow, 2012). It is important for business leaders to understand the behavioral aspects of overconsumption in CPR because it will be necessary for all competing business interests to work together to address the space CPR overconsumption problem adequately.

Space activity sustainability is becoming a critical issue for firms relying on space systems for commercial activities. In a CPR environment, unrestricted consumption is not sustainable (Weeden & Chow, 2012). The same applies to the use of space. To ensure the sustainability of the space environment, it is necessary to introduce constraints. However, the current governance of space activities is fragmented and ineffective (Percy & Landrum, 2014). National and commercial self-interests prevent space-faring parties to coordinate space activities optimally. Without a system to coordinate space use, overexploitation might eventually deplete a common resource to the detriment of all space-faring parties (Frost, 2011).

The criticality of sustainability in the space environment is similar to the governance of other CPRs such as oceans and air. Developing sustained space use benefits the society by delivering value, controlling risk, and enhancing affordability in space operations (Cameron, Seher, & Crawley, 2011; Su, 2013). The current generation must understand the degree to which it is necessary to regulate and protect the space environment to preserve its use by future generations (Durrieu & Nelson, 2013).

The rate of space debris creation could eventually render the space environment unsustainable for space activities (Liou, 2011; McKnight & Di Pentino, 2013). Maintaining the sustainability of the space environment is an important agenda

(Williamson, 2012). Using Ostrom's principles of sustainable governance in the space commons could be a starting point to developing a feasible framework with potential solutions (Weeden & Chow, 2012). Ostrom's principles include clearly defined boundaries, collective-choice agreements, monitoring behavior, graduated penalties, and conflict resolution mechanisms (Weeden & Chow, 2012). However, Meek (2012) contended that Ostrom focused on small terrestrial commons and the focus might not be suitable for the space CPR in all areas of CPR governance. These conflicting views are indications that the applicability of Ostrom's principles will require further exploration because of the uniqueness of the space environment.

Satellite manufacturers need to examine their strategies in mitigating the threat by space debris and generating solutions toward long-term sustainability in the space environment (Williamson, 2012). Such strategies might include improved satellite design that consists of fewer and more sturdier components, contingency for debris avoidance, smaller cross-sectional areas to reduce collision risk, or autonomous debris avoidance techniques (Barbee et al., 2012; D'Amico et al., 2013). Developing forward-looking strategies aligns with the conceptual frameworks of stakeholder theory and contingency theory.

Nature of the Space Debris Problem

A large number of factors, when combined, create the space debris problem for operational satellites. First, space debris movements are uncontrollable (Abdel-Aziz, 2013). Factors affecting the trajectory of orbital objects include perturbations caused by the nonspherical Earth, gravitational forces from the Sun and the Moon, solar radiation pressure, Earth radiation pressure or albedo forces, atmospheric drag, Newtonian forces, and the Earth's shadow (Hanada, 2013; Hubaux & Lemaître, 2013; Sampaio, Wnuk, Vilhena de Moraes, & da Silva Fernandes, 2014; Stoll, Schulze, D'Souza, & Oxfort, 2011). The multitude of factors made precise tracking and prediction of space debris movements challenging.

The second factor is the limited capability to track the number and the movement of space debris (Gopalaswamy & Kampani, 2014). Technicians at the U.S. Strategic Command Space Surveillance Network (SSN) conduct surveillance of space objects and maintain a catalog of objects in space. The U.S. SSN equipment has detection capabilities for objects greater than 10 cm in size in LEO (Liou, 2011) but is unable to track more than 100 million medium and small objects that are less than 10 cm in size. These undetectable threats, especially the medium-size objects, travel at hypervelocity and carry high kinetic energy capable of destroying satellites (Hoots & Sorge, 2012; Lewis et al., 2011). Although shielding might protect satellites from small debris (<1 cm) bombardments (Abdel-Aziz, 2013), there is no adequate measure to shield operational satellites from collisions with medium to large debris objects (Percy & Landrum, 2014).

A third factor is the growing density of the space debris population. Scientists at NASA determined that the increase in spatial density of space debris at below 1,000-km altitude was approximately 115.4% from January 2007 to January 2014 (NASA ODPO, 2014). The increasing space debris population translates to a growing risk to operational satellites. Given the growing reliance on satellites, it is impractical to ignore the doubling of the collision risk in 7 years. Additionally, NASA scientists have predicted that the space debris population will continue to grow in LEO even under the best case scenario of no future launches (Liou, 2011). The no-future-launches scenario is unrealistic given modern societies' growing dependence on services provided by satellites (Villain, 2014). It is likely that the growing debris population and the resulting overcrowding in the space environment will become increasingly problematic for all satellites operations.

A fourth factor is space debris propagation. Space debris is self-propagating. Collisions between objects at hypervelocity will generate debris clouds consisting of many more pieces of additional debris (Kessler et al., 2010). Space debris propagation will likely be the most serious threat to operational assets in space (Liou, 2011). As an example, the 2009 Iridium 33–Cosmos 2251 collision generated more than 1,600 pieces of trackable debris (Wang, 2010). Approximately 20% of the fragments could remain in orbit for more than 30 years (Wang, 2010). Orbits of about 70% of the cataloged fragments will decay, and these fragments will pass through the orbit of the ISS between 2020 and 2030 (Wang, 2010). The process of orbit decay poses a long-term hazard to the ISS and its occupants. In addition, two debris clouds could spread to form shells around the Earth, and the Iridium fragment shell will likely pose a threat to all satellites that pass through that altitude (Wang, 2010, p. 99). The Iridium–Cosmos collision resulted in a 25 to 30% increase in collision risk to other objects in space (Wang, 2010, p. 102). In the future, there could be a worst-case scenario in which additional debris-on-debris collisions result in a runaway effect of collision cascade that renders the space environment unusable (Liou, 2011).

A fifth factor relates to business economics. Space debris has the potential to damage operational space assets and reduce the expected value of space systems. The increasing risk to high-value assets, combined with high volatility typical of the satellite insurance market (Manikowski & Weiss, 2012), have implications to higher insurance premiums (P. V. Anderson & Schaub, 2014) that lead to higher operating cost. The higher cost might reduce the competitiveness of the services provided by the satellite system, thus reducing their overall value in the marketplace.

Space debris poses the greatest threat to the safe operations of satellites (Gopalaswamy & Kampani, 2014). The threat extends to the global economy, in which satellite technology is a deeply embedded, critical, and fragile component of the global economic infrastructure (Horsham, Schmidt, & Gilland, 2011; Percy & Landrum, 2014). To ensure economic stability and business growth on a global scale, it would be necessary to address the space debris problem in a meaningful way. Solutions to the space debris problem could come from technical, policy, organizational, and regulatory sources (Jakhu, 2010). The implementation of space debris remediation measures needs to start immediately to protect the space environment for future use (P. V. Anderson & Schaub, 2013). Satellite manufacturers could contribute to future economic stability by developing contingency plans that address and mitigate the space debris problem. Taking a business-as-usual or wait-and-see approach could lead to a situation of too little, too late (Eriksson & McConnell, 2011). Adopting a strategy with strategic intent to address the space debris problem could facilitate organizational focus, leverage resources, and secure market leadership positioning (Hamel & Prahalad, 2005).

Space Situational Awareness and Collision Avoidance

Stakeholders of space systems need up-to-date knowledge on the whereabouts of their satellites and other satellites, as well as the positions and threat levels of space debris near their assets. Within the context of space systems operations, space situational awareness (SSA) is the acquisition of critical knowledge to enhance the understanding and awareness of orbital objects and the space environment (Williamson, 2012). Personnel at the U.S. SSN are responsible for monitoring space debris, publishing the orbits at http://www.space-track.org, and providing free updates and advance warnings for all close approaches to enhance SSA for satellite operators. The U.S. SSN has the organizational responsibility for cataloging and tracking space objects since 1957. As of January 2014, technicians at SSN had cataloged over 39,000 artificial objects (U.S. Strategic Command, 2015). Many objects in the catalog had returned to the Earth's atmosphere. However, technicians at SSN continue to track more than 16,000 objects orbiting Earth (U.S. Strategic Command, 2015). Of these 16,000 tracked objects, only 5% are functional payloads or satellites. The rest are debris objects (U.S. Strategic Command, 2015).

The U.S. SSN is crucial to space operations and long-term space systems sustainability (Weeden & Chow, 2012). However, there are many limitations to the SSN and its debris-monitoring capabilities. First, the resource requirements for SSA are extensive, and the cost to conduct space surveillance is high (Milani, Farnocchia, Dimare, Rossi, & Bernardi, 2012). Second, the design of much of the equipment used in space debris detection took place in the 1950s and 1960s, and the aging equipment has severe limitations on both the quality and the quantity of the data (Gopalaswamy & Kampani, 2014). Third, the detection size threshold is 10 cm, and millions of objects smaller than 10 cm are not trackable by current SSN equipment (Liou, 2011). Fourth, conjunction assessment using SSN data requires considerable cost (Lewis et al., 2011). As the debris population increases, the number of conjunction assessments, avoidance maneuvers, and associated costs will likely increase. Fifth, increasing numbers of both satellites and space debris population would further stress the conjunction assessment process (N. L. Johnson, 2012).

Debris objects are capable of damaging or destroying operational satellites and reducing their expected economic value. Satellite operators take advantage of the SSN database to maintain SSA and protect their high-value assets (Jesus et al., 2012; Pimnoo, 2011). When the probability of a conjunction event is high, SSN issues a collision awareness notification to alert a satellite operator of an approaching collision hazard. In response, the satellite operator will conduct a conjunction assessment to determine risk. A conjunction assessment involves a series of steps (Baldwin et al., 2012; Pimnoo, 2011; Stoll et al., 2011):

1. review notification,
2. search for collision risk,
3. determine debris location and shape,
4. refine orbit prediction by radar tracking,
5. determine distance between objects,
6. construct a virtual map,

7. search for optimal passage with minimum fuel consumption and minimum risk,
8. conduct risk assessment,
9. conduct simulation when applicable, and
10. conduct avoidance maneuver when necessary.

Relying on SSA methodology and debris avoidance maneuvers to protect satellites involves many inadequacies, including consuming precious fuel, reducing operational lifetime of the space assets, interrupting normal satellite operations, increasing operational cost, and reducing the value of the satellite (Anderson & Schaub, 2013; Jakhu, 2010; Stoll et al., 2011). During conjunction events, satellite operators face the prospect of immediate short-term risk as well as the reduction of the overall lifespan of the satellite (Gopalaswamy & Kampani, 2014). Neither is good for business. There are no standard processes for collision risk monitoring and collision avoidance maneuvers, although avoidance maneuvers are similar in nature to orbit raising and lowering operations (Stoll et al., 2011). Furthermore, orbit determination is imprecise and difficult (Sampaio et al., 2014; Stoll et al., 2011), yet a precise knowledge of space objects is necessary to make accurate predictions (Abdel-Aziz, 2013). In the case of the Iridium 33–Cosmos 2251 collision in 2009, the collision probability of the two objects was not even in the top 150 most probable predicted conjunctions for that particular day (Jakhu, 2010). Finally, debris objects between 1 and 10 cm are too big to shield against but too small to track using existing equipment (Slann, 2014), yet these debris objects account for up to 98% of lethal hazards (Shustov et al., 2013). Nevertheless, the use of avoidance maneuvers would increase in the future because of the increase of the debris population (Stoll et al., 2011). This prediction included an assumption that satellite manufacturers and satellite operators would continue with current industry practice and settle with existing inadequacies, which need not be so if the industry stakeholders chart a strategic course to repair the space environment and mitigate the damage caused by space debris.

There are two critical deficiencies in SSA in addressing the space debris problems. Debris avoidance maneuvers and SSA are applicable to satellites with built-in maneuvering capabilities only, such as having a propulsion system. However, small satellites such as SmallSats and CubeSats are growing in popularity (Ehrenfreund et al., 2012; NASA ODPO, 2015b), and these satellites might not have propulsion systems to support avoidance maneuvers (Jasper et al., 2014). These small satellites will have little control over their risk of collision. Additionally, having SSA cannot prevent collision between debris and debris (Mason et al., 2011). In the future, the most likely source of space debris generation will be debris-on-debris collisions (Kessler et al., 2010; Liou, 2011), and enhancing SSA capabilities will not prevent space debris growth and the increased risk in space.

Past and Present Attempts to Address the Space Debris Problem

As early as 1967, stakeholders in the space community already recognized the need to protect the space environment, as evidenced in the ratification of the 1967 Outer Space Treaty (Bin, 2012). Major space-faring nations such as the United States, Japan, France, Russian Federation, and China all have their own versions of space debris mitigation guidelines (N. L. Johnson, 2011). Other milestone events in establishing national and international debris mitigation guidelines included the introduction of a Code of Conduct by Europeans in 2006 and the establishment of a set of collision mitigation guidelines by the Inter-Agency Space Debris Coordination Committee in 2007. On December 22, 2007, delegates in the United Nations General Assembly adopted United Nations Resolution 62/217 that endorsed the space debris mitigation guidelines established by the United Nations Committee on the Peaceful Uses of Outer Space (United Nations Office for Outer Space Affairs, 2010). The seven voluntary guidelines were as follows:

1. limit debris released during normal operations,
2. minimize the potential for breakups during operational phases,
3. limit the probability of accidental collision in orbit,
4. avoid intentional destruction and other harmful activities,
5. minimize potential for post-mission breakups resulting from stored energy,
6. limit the long-term presence of spacecraft and launch vehicle orbital stages in the LEO region after the end of their mission, and
7. limit the long-term interference of spacecraft and launch vehicle orbital stages within the geosynchronous region after the end of their mission.

Guidelines 1 through 5 will lead to curbing debris generation in the short term. The intent of Guidelines 6 and 7 is to address the longer term reduction of debris generation. Passivation of rocket bodies complies with Guideline 2. Collison avoidance, an increasingly important (Jesus et al., 2012) but temporary measure already in use, complies with Guideline 3. The 25-year rule, by which satellites are to complete orbital decay within 25 years of mission termination, is one of the most common postmission disposal applications within Guideline 6 (Lim et al., 2013; Liou, 2013; Percy & Landrum, 2014). However, technology implementations such as passivation of rocket bodies and conservation measures such as the 25-year rule are insufficient to stop the growth of the space debris population (Liou, 2013; McKnight & Di Pentino, 2013; Percy & Landrum, 2014). In addition, compliance to the guidelines is voluntary (Adilov et al., 2015; Stubbe, 2011), and voluntary compliance is ineffective because of economic, technical, and operational constraints (Adilov et al., 2015; P. V. Anderson & Schaub, 2014). The space debris mitigation guidelines might slow the process of space environment degradation, but the degree of damage is in such a state that mitigation guidelines alone could not stabilize the space environment (Kessler et al., 2010). Other natural factors might also reduce the effectiveness of the mitigation measures. For example, Lewis et al. (2011) noted a reduced mass density in the thermosphere might lead to reducing drag and increasing lifetime for orbiting objects in LEO. There is a realization that business as usual is no longer practical, and without a mechanism to remove debris from space to reduce collision risk, the space debris problem is likely to persist (Lewis et al., 2011; Liou, 2011; Percy & Landrum, 2014).

The space debris mitigation guidelines affect satellite manufacturers. For example, a spacecraft design that eliminates the release of sensor covers and debris near GEO would comply with Guideline 1 (N. L. Johnson, 2012). A spacecraft design that helps operators comply with the postmission disposal rule fits under the premise of

Guideline 6. There are many existing and potential options to address the space debris problem:

1. take no action (Jasper et al., 2014),
2. perform collision avoidance during close approaches (Abdel-Aziz, 2013; Hoots & Sorge, 2012; Jesus et al., 2012; Pimnoo, 2011),
3. incorporate passivation techniques in spacecraft design to prevent on-orbit break-ups (Percy & Landrum, 2014),
4. incorporate shielding techniques to protect against small debris (Abdel-Aziz, 2013),
5. follow Inter-Agency Space Debris Coordination Committee debris mitigation guidelines (Jasper et al., 2014), and
6. use ADR (Jasper et al., 2014; Liou, 2011).

Satellite manufacturers embed capabilities during spacecraft design or integrate capabilities after production to provide satellite operators with operational options (Percy & Landrum, 2014). Embedding capabilities could be a function of customer demand with which satellite manufacturers must comply. Alternatively, satellite manufacturers could develop capabilities proactively with the strategic intent of developing a new market space (Hamel & Prahalad, 2005). Satellite manufacturers are stakeholders in the sustainable development of the space environment. The stakeholder theory is, therefore, an appropriate conceptual framework through which to explore the behaviors of satellite manufacturers.

The Growing Need for Active Debris Removal

In the space environment, satellite operators use shielding or perform debris avoidance maneuvers to protect satellites from the space debris hazard (Abdel-Aziz, 2013). However, there is no current and effective strategy to mitigate collision risk between debris and debris (Mason et al., 2011). In their seminal paper, Kessler and Cour-Palais (1978) predicted that artificial objects in LEO would randomly collide and cause the debris flux to increase exponentially with time beginning in the year 2000. Kessler et al. (2010) compared the 1978 predictions with observed collision rate and found strong correlations between the 1978 predictions and actual collision events. Kessler et al. concluded that even 100% compliance to space debris mitigation guidelines might be insufficient to control debris growth, and an ADR program to remove large objects in LEO would be necessary to prevent a runaway increase of the debris population. Lim et al. (2013) also noted that the practice of avoiding collisions using monitoring techniques is not a valid long-term solution. It would be more efficient to manage the collision risk proactively than rely on risk predictions (Durrieu & Nelson, 2013).

Despite expert predictions, there is still an ongoing discussion on the topic of ADR. Active debris removal is perhaps the best mechanism for reducing the threat of future collisions and eliminating the source of debris generation (Liou, 2011; Percy & Landrum, 2014). An effective use of ADR is to target large objects for removal because large objects are the main source of new debris (Phipps, 2014). Removing at least five large pieces of debris per year in some popular LEO orbits could reduce the risk of future collisions and stabilize the space environment (Cerf, 2013; Liou, 2011). However, ADR is technically challenging, has a high cost, and is not in a state of readiness (Barbee et al., 2012; Liou, 2011). Multiple ADR methods are still under evaluation, including using drag devices, rockets, nets, harpoons, grapples, tentacles, sails, space-tugs, and laser systems (Barbee et al., 2012; Bombardelli & Pelaez, 2011; Levin et al., 2012; Lim et al., 2013; Schaub & Moorer, 2012; Slann, 2014; Weeden, 2011).

The debate over ADR implementation is not merely over the concept of sustainability in the space environment. The debate extends to the practical business issues of necessity, feasibility, and the return on investment of ADR projects (Jasper et al., 2014). Aspects of the debate include collision projections (Liou, 2011), conservationism (Williamson, 2012), sustainability using CPR methodology (Meek, 2012), legal challenges (Weeden, 2011), regulatory challenges (Crowther, 2011), technology availability (Barbee et al., 2012), and economic factors (Jasper et al., 2014). The return on investment assessment for a business case is difficult given the large pool of stakeholders with varying degrees of risk. The principles of responsible governance of CPR (Adilov et al., 2015; Weeden & Chow, 2012), contingency planning (Eriksson & McConnell, 2011), contingency theory (Hanisch & Wald, 2012), risk management (Hoyt & Liebenberg, 2011; McShane, Nair, & Rustambekov, 2011), stakeholder theory and corporate performance (Brower & Mahajan, 2013), and systems thinking (Seiler & Kowalsky, 2011) continue to frame the ongoing debate.

The importance of ADR is a function of multiple factors, including risk, orbital location, and alternative or complementary solutions (Anderson & Schaub, 2014; Liou, 2011). Active debris removal is important for regions higher than LEO, where there is no natural clean-up mechanism such as atmospheric drag (McKnight & Di Pentino, 2013). Active debris removal is not as critical in MEO because it is less crowded and the risk level is not high (Liou, 2011). In contrast, although the satellite operator community has been working to preserve the GEO space environment, compliance to the Inter-Agency Space Debris Coordination Committee's deorbit guidelines is insufficient for GEO environment remediation (P. V. Anderson & Schaub, 2014). Implementation of ADR is becoming necessary to remediate the GEO space environment (P. V. Anderson & Schaub, 2014).

Low Earth orbit is the region most in need of ADR (Liou, 2011). The Kessler syndrome might be in effect in LEO already (Liou, 2011). Uncontrolled debris cascading could start in the 2030s unless ADR is in place to mitigate the risk (Slann, 2014). Active debris removal, debris mitigation guidelines, and collision avoidance maneuvers are all necessary steps to curb the impending runaway debris growth in LEO (Jasper et al., 2014). The emergence of the small satellite market and human expeditions beyond LEO are two additional reasons for a proactive approach toward preserving the LEO environment (Ehrenfreund et al., 2012).

The decision to implement ADR should incorporate multiple cost considerations such as propulsion capability, downtime, insurance, complying with mitigation guidelines, debris tracking, and debris analysis (Jasper et al., 2014). Other business considerations include the risk of deorbit and causing damages to people and objects on Earth, reputation loss after a mishap in orbit, and the risk to the space environment (Jasper et al., 2014). Timing of ADR implementation is important. The present state of readiness in spacecraft design is only at the preliminary stage (Barbee et al., 2012), but stakeholders recognize that it would be difficult to stabilize the space environment without ADR because of the random collisions between existing orbital debris (Lewis et al., 2011; Liou, 2011). Finally, it will require a collaborative effort to cultivate the international agreement to implement ADR (Weeden, 2011).

Satellite manufacturers are major stakeholders in space environment use. Without a healthy space environment in which to conduct future space activities, the business of satellite manufacturing could eventually decline or become obsolete. The implementation of ADR could ensure the sustainability of the space environment and the continued need for satellites. Satellite manufacturers could also benefit from ADR implementation by building spacecraft with ADR capabilities to meet market demand. These capabilities include maneuverability, rendezvous and docking capability, and the capacity to capture moving or rotating objects in space (Barbee et al., 2012). Consequently, satellite manufacturers might view ADR as a strategic business opportunity with a need to establish the strategic alignment of corporate goals with industry goals (Blatstein, 2012). Satellite manufacturers are important stakeholders in ADR implementation. Accordingly, it would be appropriate to explore the role of satellite manufacturers through the conceptual framework of the stakeholder theory.

Transition and Summary

The modern world has entered the new information age. Modern society is increasingly dependent upon satellites and the information they provide for a wide range of services. Satellite-enabled services are part of the modern economic infrastructure and an integral part of the modern way of life. An interruption of a single satellite service could cause inconveniences to the modern lifestyle. The disruption or termination of many satellite-based services will likely cause a shock to modern society and the global economy. The increasing space debris population has a potential to cause such a shock.

The population of artificial debris objects in space will continue to grow because of continuing launches, spacecraft reaching the end of their useful lives, and explosions and fragmentation of decommissioned satellites and launch vehicle bodies. The forecast for space use is a continuous increase in launches and space activities and, therefore, the continuous introduction of hardware into the space environment. The growing space debris population and increasing space activities are incompatible paths heading toward a collision course with great potential for disastrous consequences for thousands of businesses in the global economy.

Satellite manufacturers are key enablers and major stakeholders in the business of space activities. They are in a position to embed existing technology or develop new technology to mitigate the risks posed by space debris. This study involved exploring the strategies satellite manufacturing business leaders use to mitigate the damage caused by space debris. The research findings could help business leaders in satellite manufacturing firms build a SRM that addresses the growing space debris problem.

This concludes Section 1. Section 2 includes a description of the role of the researcher, the identification of participants, a discussion of the research methodology, a description of the data collection and data analysis methods, and a discussion of the reliability and validity of the study. Section 3 includes a restatement of the purpose of the study, the research questions, and a summary of research findings.

Section 2: The Project

Qualitative studies that include interviews for data collection have four key elements: the interviewer; the interviewee; the interview process; and the descriptions, observations, narratives, and explanations produced (Qu & Dumay, 2011). This section includes an outline of the specifics of the project related to the first three elements. This includes the purpose of the study, the research method, the research design, and the role of the researcher as the research instrument. Additional details include the description of the study participants, participant selection criteria, participant eligibility requirements, and strategies to gained access to the study participants. Other details include data acquisition, data collection instrument, data collection method, data organization, data analysis, and data reliability and validity.

Purpose Statement

The purpose of this qualitative, exploratory case study was to explore strategies that satellite manufacturing business leaders use to mitigate the damage caused by space debris. Leaders in satellite manufacturing organizations located in the United States and Europe participated in interviews to share their strategies on mitigating the debris risk. Leaders in other space organizations could use the research findings to build an SRM to help address the growing debris problem more effectively. The other two sources of data were documentation from the literature regarding this issue and archival records from NASA. Business leaders might use the SRM for long-term business decision making, thereby contributing to positive social change.

Role of the Researcher

The following subsections include the research design, planning, and data collection process. The subsections also include other specifics of the process planning such as relationships with the topic and participants, ethical considerations, and the rationale for the research protocol.

Role of the Researcher

In a qualitative case study that involves interviews, the researcher is the research instrument and is an integral part of the research process (Yin, 2014). In this study, my role as the researcher was to design the case study, collect case study evidence, analyze case study evidence, and report the case study results (Yin, 2014). The primary data for this case study were interview transcripts from interviewing leaders in satellite manufacturing organizations. In that capacity, my role included planning the interviews; designing the interview questions; selecting the interviewees; conducting the interviews; transcribing the interviews; analyzing the data to collect facts and gain insight into the opinions, attitudes, experiences, values, or predictions of the interviewees; and reporting the analysis results (Aberbach & Rockman, 2002; Harvey, 2011; Rowley, 2012; Seidman, 2013).

Relationship With the Topic or Participants

I have worked in the space industry for a component supplier since 1988. However, I have never worked in a capacity that relates to the business strategy associated with space debris. Through professional association, I have access to midlevel managers and senior level executives in satellite manufacturing firms within the United

States and Europe. I relied on this association to recruit study participants. Several study participants were business associates. Others were individuals recommended through the process of snowballing (Rowley, 2012; Seidman, 2013; Suri, 2011). I did not know the study participants from the snowballing process.

The Researcher's Role Relating to Ethics and the *Belmont Report*

The authors of the *Belmont Report* (1979) identified three principles in ethical research conduct with human participants: respect for persons, beneficence, and justice. These principles were part of the study design and followed explicitly. The study design was to maximize benefits and minimize economic or other risks. Before an interview, it was important to communicate the purpose of the study to ensure the participants understood the risks and potential benefits of participating in the research. During the interviews, it was important to avoid influencing participants with personal bias that could alter the participants' responses. Institutional Review Board (IRB) permission was received prior to the start of the interviews. This study does not contain the identity of the participants to protect their privacy. The chairperson granted permission to conduct one interview using a survey format because of a special circumstance. Furthermore, the study did not include vulnerable populations such as prisoners and children. I described to each study participant the confidential nature of the study and received each person's consent prior to the start of each interview.

Rationale for Interview Protocol

The study included a semistructured interview protocol. Several reasons formed the basis of this decision. First and most important was that the study participants had varying degrees of schedule availability. The flexibilities inherent in semistructured interviews were necessary to modify interview type, style, pace, and question order to induce better responses (Qu & Dumay, 2011; Stephens, 2007). The inherent flexibility was essential because the study participants were all busy people. In a few cases, interview duration and time needed adjusting because of availability. Second, study participants might be more receptive to an interview than other data gathering approaches such as surveys (Rowley, 2012). A third reason was the need to gain deep insights from study participants, and a semistructured interview was the correct method to acquire such insights from study participants who had firsthand management experience (Doz, 2011; Stephens, 2007). The fourth reason was that semistructured interviews enabled the study participants to introduce issues they perceived as important (Stephens, 2007). Given the time constraints, the semistructured interview format was the best method to acquire quality data from study participants.

Participants

The participants in the study were leaders in satellite manufacturing organizations. The approach was to recognize the participants as a source of knowledge and to facilitate a process of knowledge transfer by obtaining a rich description of the participants' attitudes, experiences, insights, and values (Harvey, 2011; Qu & Dumay, 2011; Stephens, 2007). The plan was to engage a minimum of 12 participants to attain data saturation (Guest, Bunce, & Johnson, 2006). Data saturation is the point in which collecting further data provides no additional meaningful data (Suri, 2011). Data saturation occurred before the conclusion of all 12 interviews. Nevertheless, the interviews continued with 12 participants as planned.

The 12 study participants were from 10 different organizations. They represented 11 different satellite manufacturing sites in three different countries. The study participants from the United States worked in satellite manufacturing sites in California, Colorado, Maryland, and Virginia. The study participants from Europe worked in satellite manufacturing sites in France and England. The study participants played different roles within their organizations, including engineering, analysis, research, and management. Four of the study participants had PhDs.

Eligibility Criteria

The purpose of the study was to explore strategies used by managers in satellite manufacturing organizations. By definition, a key eligibility criterion was that the study participants were working in a management capacity at a satellite manufacturing organization. Managers in key positions have the knowledge and the insight to understand situations that might facilitate the decision making process (Harvey, 2011; Rowley, 2012; Stephens, 2007). To take advantage of their management insight, the participants in the study needed multiple years of management experience and firsthand experience (Doz, 2011) in satellite manufacturing. It was also important to include people with different roles, experience, and backgrounds to capture potentially different viewpoints in the study (Rowley, 2012). Given the stringent eligibility criteria and the small number of satellite manufacturing organizations, there was a purposeful selection of study participants. An estimate of potential participants was approximately 10 to 15 managers in each satellite manufacturing organization. The study population was approximately 100 to 150 potential participants.

Strategies for Gaining Access to Participants

Satellite manufacturers locate their facilities near manufacturing hubs. In the United States, commercial satellite manufacturing locations are near the Los Angeles, San Jose, Phoenix, Denver, and the Washington, DC areas. In Europe, satellite manufacturing facilities are in the United Kingdom, France, Germany, and Italy. The diverse geographic locations make gaining access to participants a logistical challenge and underline the importance of good planning.

I started with several business associates located in the United States and Europe whose names and contact information were available. Contact was by telephoning or by e-mail. In most cases, telephoning proved difficult, probably because the study participants were busy people. E-mailing an introduction and the request for an interview was a more successful method to establish first contact. Both the telephone introduction and the e-mail introduction consisted of a self-introduction and a description of the study. When a potential participant was receptive, then planning for interviews commenced. The process of snowballing also led to additional participants for the study (Rowley, 2012). The same procedure of telephoning, e-mailing, and self-introduction applied to first contact with study participants found through snowballing. Key factors in gaining access were willingness and availability (Rowley, 2012). Several potential participants did not respond to request for interviews. However, the process of contacting potential participants continued until 12 participants committed to an interview.

The study started with face-to-face interviews in the local area. When potential participants were in other cities and other countries, it became apparent that coordinating face-to-face interviews with busy people was difficult. I then sought and received permission from my chairperson to conduct phone interviews to accommodate the study participants' busy schedule. In two instances, study participants were unable to participate in interviews until weeks after the initial contact. In another instance, one participant was ready for an interview almost immediately, but I was not prepared to do so. It became apparent quickly that schedule flexibility was important in gaining and securing access.

There was no third party solicitation for introductions to potential study participants (Seidman, 2013). During the interviews, I ensured that the potential study participants did not feel inconvenienced or embarrassed (Rowley, 2012). I assured potential participants that they would not be in a position to reveal confidential information (Rowley, 2012). The same process applied to all 11 study participants. For one study participant with special circumstance, e-mail became the communication tool used. At the completion of the data collection phase, nine participants from the United States and three from Europe participated in the interviews.

Strategies for Establishing a Working Relationship With Participants

Researchers need to anticipate and address interactional problems in research interviews. A successful research process depends on the interviewer's ability to build rapport, establish mutual understanding regarding the purpose of the interview, and engage interviewees in acts of self-disclosure (Roulston, 2014). Seidman (2013) suggested that the more rapport the interviewer can establish with the interviewee, the better. To establish good rapport, I was pragmatic with constraints and limitations such as the length and time of the interview (Rowley, 2012). The study participants were all busy people, and accommodating their time and location for the interviews was important. A trusting relationship was necessary to yield high-quality data. Trust building started from the moment of first contact and was a continuous process (Harvey, 2011). To build a trusting relationship, it was necessary to disclose ahead of time the intent and objective of the research (Qu & Dumay, 2011). In addition, adopting the following elements led to a good working relationship (Rowley, 2012):

- identified the course work
- captured the interest of the interviewee
- was clear about the amount of time for the interview
- asked permission to record the interview
- assured the interviewees of confidentiality
- provided details regarding benefits to the interviewees, such as a summary of the research

The structure of the interview questions was important. The interview plan was to ask good questions (Roulston, 2014). The interview questions were clear and understandable within the context of the purpose for the interview. In addition, I was sensitive to the way the interviewees responded to the questions through the unique way they saw the world (Qu & Dumay, 2011).

Other important interview mechanisms included not offering opinions about responses, avoiding nonverbal indications of surprise or shock, and not using cues such as nodding to indicate approval or a correct answer (Qu & Dumay, 2011). In addition, personal reflections were part of the interview process to increase the participants' interest and enthusiasm (Stephens, 2007). It was necessary to project the importance of the research study and present myself as a valid researcher (Seidman, 2013).

Interviewing elite members of an organization had its challenges. In addition to building rapport and gaining trust, having transparency was essential to avoid making the participants feel threatened (Harvey, 2011). It was also important to gain the respect of the elites by showing them that I had done the necessary homework and understood the background of the subject matter (Harvey, 2011). As the interviewer, I gauged the atmosphere of the interview early and adjusted my behavior appropriately to ensure quality data (Harvey, 2011). There was no need to adjust my behavior or style based on the gender, age, or disposition of the interviewee (Harvey, 2011). Through the open-ended questions, the participants were able to articulate their views and provide high-quality information (Harvey, 2011). Time is important to organization elites. Asking for too much time for an interview might lead to refusal, but asking for too little time might lead to limited quality and quantity of data (Harvey, 2011). Harvey (2011) indicated that 45 minutes would be the appropriate amount of time. All the interviews were under 45 minutes. The average was 30 minutes.

There are advantages and disadvantages to using recording devices. Business elite might prefer to speak off the record (Harvey, 2011), and my planning included flexibility between recording and writing notes. I did not wish to use a recording device that might inhibit a study participant from responding openly (Darke, Shanks, & Broadbent, 1998). In all 11 interviews, the use of a recording device was permissible. During each interview, the first question was to ask about the participant's background to put the participant at ease (Aberbach & Rockman, 2002). Finally, I was prepared with knowledge about the company associated with the organization elites to give relevancy and significance to the process (Harvey, 2011).

Research Method

The goal of the study was to acquire intrinsic knowledge through interviewing individuals and drawing from them concepts, ideas, and recommendations on how to address a unique risk (Rowley, 2012), which aligned with a qualitative exploratory case study. Through this knowledge, I identified the key constructs that organizational leaders need to consider when seeking to accommodate the risk of space debris. The study design included asking open-ended questions in a semistructured interview format to collect data. I coded the transcripts of the interviews (Aberbach & Rockman, 2002) and analyzed them for emerging themes (Jalongo, 2013). The focus of the case study methodology was an in-depth understanding of a phenomenon within its context (Darke et al., 1998). The methods of collecting and analyzing case study data were inherently qualitative and exploratory, and the adaptation of a qualitative case study methodology was appropriate for an exploratory study (Yin, 2014).

Using open-ended questionnaires was an original study design consideration. The benefit of conducting research with questionnaires was that it might be easier to obtain responses from a large sample, and research findings might be transferable (Rowley, 2012). Although questionnaires might reach more people, they do not necessarily reach the right people. The careful selection of a few participants with the right knowledge, experience, and insight tends to generate better data that can help resolve a problem (Rowley, 2012).

The Delphi method was an alternate research method considered. The Delphi method is a group problem-solving process when there is incomplete knowledge on a problem or phenomenon (Skulmoski, Hartman, & Krahn, 2007). Skulmoski et al. (2007) contended that some researchers use a modified Delphi technique to collect data from individual experts through a series of iterations and analyses. Organization elites were unlikely to have time to complete multiple rounds of interviews. The logistics of requesting multiple interviews made the Delphi method research impractical. Through the process of elimination and careful selection, a qualitative inquiry with in-depth interviews emerged as the best research approach.

Research Design

The research study had a case study design to collect data. The selection of a case study design was purposeful based on several key factors. First, the space debris problem was a contemporary and emerging phenomenon where research and theory formulation were at the early stage of development. Second, little research existed on the connectivity between space debris and the business of satellite manufacturing, and exploring and understanding the context was important. Third, there was a lack of understanding how and why the experiences of business managers from satellite manufacturing organizations relate to the contexts of actions. Given these factors, a case study of the space debris problem in its natural context was an appropriate strategy (Darke et al., 1998).

The study included three sources of data. The primary source of data was in-depth interviews with leaders from satellite manufacturing organizations. Extracting knowledge using interviews is a way to gather collective wisdom from a specific group of individuals (Aberbach & Rockman, 2002; Jalongo, 2013). The interviews facilitated the acquisition of knowledge and insights through the perspective and experiences of managers most familiar with the subject matter (Doz, 2011; Seidman, 2013). I analyzed the transcripts of the interviews line by line, coded them, and explored them for themes.

The second source of data was documentation from literature in which researchers sought to address the issue. The literature review in Section 1 contains data from the available literature. The third source was archival records from the NASA ODPO. The NASA ODPO web site contains archival records pertaining to debris modeling, debris measurement, debris protection, and debris mitigation. Study participants specified some of the documents such as NASA safety standards. Finally, data from the *Orbital Debris Quarterly News* were relevant and incorporated throughout this study.

The purpose of the study was to explore the strategies business leaders use to mitigate the space debris risk. Conducting semistructured interviews was an effective way to explore the norms and values experienced by participants (Stephens, 2007). Interviews were especially powerful in gaining insights in terms that were meaningful to the participants (Qu & Dumay, 2011; Stephens, 2007). Semistructured interviews enabled the participants to introduce issues they deemed important (Stephens, 2007) by allowing the participants to engage in wide-ranging discussions (Aberbach & Rockman, 2002). In addition, flexibility was necessary in the semistructured interviews to modify interview style, pace, duration, and question order (Qu & Dumay, 2011). Participants were able to reflect further upon the subject because of the flexibility of the semistructured interviews (Rowley, 2012). The additional reflection yielded data not prompted by a set of predetermined questions.

Other designs such as structured interviews can be rigid and inappropriate or impractical with elite participants (Harvey, 2011). In planning for interviewing organization elites, Stephens (2007) did not seriously consider any other interview technique. After conducting the research planning, I also concluded that a semistructured interview design would be the most practical research design.

Data saturation is important in qualitative research (Guest et al., 2006). Data saturation is the point in data collection at which additional data no longer provide new insight (Francis et al., 2010; Seidman, 2013). In the proposal, the plan was to ensure data saturation by interviewing 12 participants (Guest et al., 2006). All the themes had appeared at least twice after the fourth interview, but data collection continued with 12 participants as planned.

Population and Sampling

The target population was leaders in satellite manufacturing organizations. Specifically, the targeted leaders would come from satellite manufacturing organizations such as Airbus, Ball Aerospace, Boeing, Lockheed Martin, NASA, OHB, Orbital ATK, SSL, and Thales Alenia Space (Villain, 2014). An estimate of the population for potential participants was 100 to 150 individuals. Purposeful selection was necessary because the target population must align with the purpose statement. To maintain confidentiality, this study does not include the names of the study participants or their organizations.

Locations where participants resided were geographically diverse. Countries where they resided include the United States, the United Kingdom, and France. Local travel was necessary to conduct face-to-face interviews. I offered to travel and meet study participants from out-of-state and out-of-country. However, the need for schedule flexibility precluded out-of-town travel. Most study participants preferred the phone interview format, probably because of the inherent schedule flexibility. In several cases, the time for the interview had to change to accommodate the study participants' busy schedule. In one case, the study participant requested a 5-minute postponement to clear the office for the interview.

The study involved purposeful sampling instead of drawing random samples or using statistical analysis techniques. The strategy was to design the population to accomplish a specific purpose (Hanson, Balmer, & Giardino, 2011). The sampling technique used to select participants who met a set of predetermined criteria was criterion sampling (Suri, 2011). Criteria for participant selection were that the participants must work for satellite manufacturing organizations, be in a leadership position, and have knowledge and experience on the subjects of satellite manufacture and space debris. The selection criteria supported the goal of engaging participants as stakeholders in the study and stimulating the participants' interest in the study and its outcome (Harvey, 2011; Rowley, 2012). Snowballing was another sampling technique used in the study (Suri, 2011). The purpose of the last interview question (see Appendix C) was to ensure snowballing. This study included six participants from the process of snowballing.

Ethical Research

This subsection includes the ethics compliance processes used in the study. The processes ensured ethical research conducted in strict compliance to Walden University's ethical standards as well as U.S. federal regulations. I started collecting data only after receiving IRB approval.

Informed Consent

Study participants received a copy of the consent form prior to the start of each interview (see Appendix D). I will retain the signed informed consent forms with the study data for 5 years. Prior to each interview, I explained the contents of the consent form to each participant, including background of the research, interview procedures such as duration and types of questions, the voluntary nature of the study, and risks and benefits of being in the study. The consent form included additional information on payments, confidentiality, and contact information of a Walden University representative. In all cases but one, I received a signed consent form prior to the interview. One study participant was traveling and did not have access to a computer and a copier. I received permission from my chairperson to accept verbal consent and received a completed consent form after the participant returned from traveling.

Withdrawal Process

The consent form had a provision regarding the voluntary nature of the study. I ensured each participant understood that participants may withdraw from the interview at any time for any reason. I verbally iterated the voluntary nature of the research process prior to the start of each interview. None of the participants withdrew from the interview process.

Incentives for Participants

Participants did not receive an offer of payment for participating in the study. However, when the interview took place in a restaurant, I paid for any food and beverage purchased. Two face-to-face interviews took place in restaurants, and I paid for both meals.

Ethical Protection of Participants

The interview process posed only minimal risk to study participants. I scheduled the interview to accommodate participants' busy schedules and availability (Rowley, 2012). The interview duration was less than 1 hour to minimize inconveniences to interviewees (Stephens, 2007). The risk of causing minor inconveniences was reasonable. Furthermore, the participants could stop the interview at any time for any reason to minimize harm if the perceived risk of revealing confidential information was high (Rowley, 2012). There was no stoppage for any of the participants. Precautions taken to protect the privacy of research participants include not publishing the names of individuals or the organizations where they worked. To protect the rights of participants, I will maintain the research data in a locked safe for 5 years to ensure data retention. The interview process posed minimal physical, psychological, and social risk. Furthermore, there were no legal or economic risks for participating in the research study.

Finally, study participants received a list of findings so they could benefit from the research. Each study participant will also receive a two-page summary to ensure the benefits of the study outweigh the costs to the participants (E. Newman, Willard, Sinclair, & Kaloupek, 2001). Some of these benefits may include a better understanding of the space debris problem and contribution toward strategies that may mitigate the problems caused by space debris.

Walden University IRB Approval Number

I applied for Walden University IRB approval prior to the start of the interview process. The consent form included the Walden IRB number and the expiration date. The IRB approval number is 06-02-15-0349416. It expires on June 1, 2016.

Data Collection Instrument

The purpose of collecting data in qualitative research was to gather valuable insights from participants and draw from them a body of knowledge (Bluhm, Harman, Lee, & Mitchell, 2011). Interviews are the most popular method of data collection in qualitative research, followed by reviews of archival data (Bluhm et al., 2011). In this study, I collected interview data, archival data, and data from the literature. The focus of the interviews was to gain a deep understanding of the specific phenomenon from a limited number of participants (J. Rowley, 2012; Thomas & Magilvy, 2011).

In this study, I was the primary data collection instrument. I used rigorous methods to sample participants, collect data, conduct analysis, and interpret analysis results (Hanson et al., 2011). The primary data collection method involved collecting data from interviews with 12 participants. The other sources of data were the literature and the

NASA website. I conducted interviews within a semistructured framework by asking study participants a list of open-ended questions. The following overarching research question served as the guide for the open-ended questions: What strategies do satellite manufacturing organization leaders use to mitigate the damage caused by space debris? The study involved 10 interview questions (see Appendix C) to explore the insights and experiences of leaders from satellite manufacturing organizations.

The study participants were organization elites. Organization elites might not like the constraints of closed-ended questions (Aberbach & Rockman, 2002). Using open-ended questions in a semistructured interview framework can open up opportunities for the participants to articulate their responses (Aberbach & Rockman, 2002) and minimize the threats to data validity. In my interviews, the study participants provided answers thoroughly and thoughtfully. They provided their opinions freely, and many of their answers reflected the contents in the literature.

Organization elites often prefer to speak off the record (Harvey, 2011). None of the participants spoke off the record. I received permission to use a recording device on all 11 interviews. I used a survey format to obtain answers to my interview questions from one participant with a special circumstance. Using a recording device was the best way to minimize information loss and threats to reliability. For all the interviews, I started the interview by asking innocuous questions about the participant's background and allowed the participants to open up and discard any inhibitions (Aberbach & Rockman, 2002).

I transcribed the recordings from the interviews and provided a copy of the transcript to each study participant for review and comments. This process of member checking ensured data accuracy (Cho & Trent, 2006). The process was also a component of data analysis by ensuring reliability and validity (J. Rowley, 2012).

I used qualitative analysis software to conduct mechanical processing of interview transcripts and to analyze interview data. I used ATLAS.ti, a commercially available software recommended by Walden professors. The software counted recurring words and phrases. I also coded the key words and identified themes from the coded interview data. In addition, I used features in Word software to conduct a word count and content analysis. Finally, I used Excel software to summarize data analysis results.

The raw data were in two formats. One was the electronic recording of the interview. I converted the electronic recordings to transcripts for further processing. I have transcripts from 11 study participants, and typed responses from the 12th participant. Both the raw data and the processed transcripts will remain in a locked box for 5 years and be available upon request.

Data Collection Technique

The primary research data were in the form of interview recordings transcribed into notes. To maintain consistency and ensure all participants received the same instructions, I prepared a standardized greeting and presented the elements before the interviews or the one survey (see Appendix E). The standard greeting included information on who I am, my school affiliation, and my field of study (Harvey, 2011). I also provided other details such as the possible length of the interview, types of data collected, how I would use the data, and that I was willing to answer questions the participants might have (Harvey, 2011).

To collect primary data from study participants, I compiled a list of open-ended questions to ask the participants (see Appendix C). The responses to the questions generated data through an in-depth understanding from the perspective of industry practitioners based on their insights (Aberbach & Rockman, 2002; Harvey, 2011; J. Rowley, 2012; Stephens, 2007). The nature of the study was similar to deductive research in which the focus of the interview questions was participant experience and practice (J. Rowley, 2012). I did not use closed-ended questions because they impose constraints upon the interviewees, thereby affecting the quality of the data (Harvey, 2011).

An audio recording device recorded the interviews. Using a recording device facilitated a conversational style and minimized information loss (Aberbach & Rockman, 2002). I carried a small portable audio recorder to each interview. The sound quality of each audio recording was excellent. I also took notes to reinforce key points expressed by the study participants.

To address the potential problem of interviewee inhibition when using a recording device (Darke et al., 1998), I included initial personal questions to put the interviewees at ease and encouraged them to speak freely (Aberbach & Rockman, 2002; see Appendix C). An additional technique to put the participants at ease was to transform the interview into a conversation or even a chat (Aberbach & Rockman, 2002; Qu & Dumay, 2011). I tried to use a conversation style as much as possible throughout the interview process.

A semistructured interview protocol was suitable because of its flexibility (Aberbach & Rockman, 2002; Qu & Dumay, 2011; Rowley, 2012; Stephens, 2007). The research participants were organization elites whose time is at a premium. The schedule was flexible based on participant availability. Given the time constraints on some interviews, the number of questions asked was also flexible. Organization elites may expand or elaborate on certain points of the open-ended questions (Aberbach & Rockman, 2002) or introduce new issues they perceive as important (Stephens, 2007), and a semistructured interview protocol had the flexibility to accommodate the extent of probing or question order (Qu & Dumay, 2011; Rowley, 2012). Furthermore, a semistructured interview format enabled participants to provide responses based on their own understanding of events, in accordance with their own values, using their own language, and in terms that were meaningful to them (Qu & Dumay, 2011; Stephens, 2007). Within the context of my research project, the semistructured interview format was effective.

As the research instrument, I was careful about the way I presented myself (Harvey, 2011). The participants were organization elites. In all face-to-face interviews, I dressed appropriately and presented myself professionally. In addition, I adjusted my style, behavior, voice level, and mannerism accordingly to make the interviewees feel as comfortable as possible (Harvey, 2011).

As the interviewer, I needed several important skills to improve the quality of data. A list of such skills follows:

- establish rapport with the interviewees

- find ways to keep the conversation going
- avoid questions that dampen the discussion
- know when to interrupt to keep the discussion on the right track
- keep the focus and pace of the interview
- use a nonjudgmental attitude
- practice patience
- keep participants fully engaged by asking them to reflect upon their own experience
- maintain the flow of the study participants' story
- maintain a positive relationship with the study participants
- avoid interviewer bias (Qu and Dumay, 2011; J. Rowley, 2012)

Maintaining the flow of the interview is important to interview success. Qu and Dumay (2011) suggested considering the following key points:

- do not disrupt the interviewee
- do not rush in to complete the interviewee's sentence
- do not prematurely terminate a narrative
- do not ask questions that the interviewees might not understand and thereby stall the interview
- do not offer opinions about responses
- do not offer nonverbal indications of surprise or shock

- do not use nonverbal cues such as nodding to indicate approval or a correct answer

I followed the above key points. In the first two interviews, I noticed that I had interrupted the study participants. I did not interrupt the participants in subsequent interviews.

The interview questions and the order of the questions were important. The order was such that earlier questions would set the context or be the lead-in for later questions (Rowley, 2012). All questions addressed the purpose of the study, which was to explore what particular groups of people from satellite manufacturing organizations think (Aberbach & Rockman, 2002).

I anticipated that a majority of the interviews would take place in various cities in the United States and Europe where the research participants reside. However, the study participants were busy people with meetings, travels, and other commitments. Schedule limitations precluded the intended face-to-face interviews that required me to travel. The study participants suggested and probably preferred the phone interview format. I accommodated the participants to make them feel comfortable (Stephens, 2007). I conducted three face-to-face interviews that took place in restaurants and at a reception meeting room. The phone interviews involved calling the phone numbers provided by study participants. The study participants were friendly, helpful, accommodating, and considerate.

There were disadvantages to face-to-face interviews. Arranging face-to-face interviews took time given the widely varied geographic locations within the United

States and Europe. The cost of travel to various locations would have been high compared to conducting telephone interviews (Harvey, 2011). The limited number of interviews did not support generalization (Rowley, 2012), as noted in the delimitations under Section 1. Accommodating face-to-face interviews also involved extra efforts for the study participants, such as booking a conference room, driving to a restaurant, or walking to a reception area. In retrospect, the face-to-face interviews might have caused slightly more inconveniences to the busy executives compared to telephone interviews.

There were also positive aspects of a face-to-face interview. Gaining participant trust is more likely in a face-to-face setting (Harvey, 2011). There was no need to develop techniques to provoke conversation because the participants had something to say (Stephens, 2007). Face-to-face interactions enable interviewers to gauge participant sentiments, especially when there might be cultural differences (Harvey, 2011). The ability to observe participants enabled the interviewer to adjust interactions based on visual clues and small nuances (Stephens, 2007). In a face-to-face interview, participants are more likely to give detailed responses compared to a telephone interview (Harvey, 2011). With the right research design, a good list of questions, and properly selected interviewees, a face-to-face interview approach could generate excellent insights and understandings (Rowley, 2012). Face-to-face interactions generated a higher volume of data compared to telephone discussions.

Data collection also involved the member-checking process. I conducted the interviews, interpreted the data, and shared the thematic summary and a copy of the interview transcript with each participant. The member-checking process gained additional data, facilitated data accuracy, improved credibility, and ensured internal validity (Carlson, 2010; Thomas & Magilvy, 2011).

One option within the study was to conduct a preliminary pilot study with at least two participants who met the sampling criteria to ensure the clear formulation and communication of the interview questions. The purpose of conducting a pilot study is to test and refine the research questions (Kim, 2011; Yin, 2014) and to ensure there is no slang or jargon to mislead the interviewees (Rowley, 2012). Other items to look for include no leading questions, no multiple questions in one, and no questions that might invite yes or no answers (Rowley, 2012). However, the goal of the semistructured research design with open-ended interview questions was to promote flexibility during the interview process. A refined list of interview questions from a pilot study might not have contributed to the intended flexibility. After evaluating the advantages and disadvantages, I chose not to conduct the pilot study.

Data Organization Techniques

Data organization facilitated easy access to working files during the study. It was also necessary to organize interview data into a structured format to expedite the analysis effort. In addition, data organization was critical in maintaining a chain of evidence (Darke et al., 1998) to increase the reliability of the study (Yin, 2014).

Data organization techniques included using computerized tools to store, classify, and index data and materials (Darke et al., 1998; Yin, 2014). These materials included journal articles from literature reviews, annotated bibliographies, spreadsheets, cross references, interview notes, correspondence, consent forms, electronic recordings of interviews, and interview transcripts (Darke et al., 1998; Yin, 2014). I stored both raw data and processed data electronically. Sorting and indexing interview-related files occurred by interviewee and by answers to the interview question (Rowley, 2012). I created dedicated directories to store related data files. I developed a master log using Excel. The spreadsheet contained fields such as references, annotated bibliographies, an indication of whether the article was peer reviewed, the year of publication for each article, and important contents from each article. The spreadsheet also had information on the total number of articles (>300), number of articles in the study, and percentages of peer-reviewed articles and articles published before and after 2011. One Excel spreadsheet used throughout the study was suitable to maintain and organize data.

After completing the research, I stored all electronic files in a USB memory stick and placed it in a locked storage compartment. I will retain the data for 5 years. After 5 years, I will delete the data from the USB memory stick permanently.

Data Analysis

The basic elements of data analysis included organizing the data set; becoming acquainted with the data; and classifying, coding, and interpreting the data (Rowley, 2012). Rowley (2012) also noted that data analysis can be difficult and confusing, and some iteration might be necessary. I conducted analysis of the interview data to seek meaning and context. The process of the data analysis involved evaluating large amounts of data, simplifying and reconstructing them into major themes and categories, and turning them into a few key themes to explain a phenomenon by generating a greater understanding of the initial data (Bluhm et al., 2011).

I converted recordings or field notes into verbatim transcripts and provided a copy of the transcript to study participants for review and comments. Returning the transcripts to the study participants for review and comment was a key component of data analysis (Rowley, 2012) to ensure internal validity. To increase the effectiveness of the data analysis, the process involved listening to the recordings, studying the notes or transcripts, reflecting upon the content, and becoming thoroughly familiar with the data (Rowley, 2012). I explored the differences and similarities and searched for key points. Internalizing the data led to formulating themes and finding ways to report findings (Rowley, 2012). I also provided the themes to the study participants for member checking.

Qualitative analysis software facilitated the analysis effort. Researchers use qualitative analysis software to mechanically process interview transcripts and organize interview data. I collected a large amount of data, and reducing data was vital in generating meaning and knowledge (Bluhm et al., 2011). Qualitative analysis software uses descriptive qualitative content analysis techniques to analyze the data set in which the initial phase of the content analysis incorporates word frequency counts (Jalongo, 2013). Coding phrases and words that occur often facilitated the development of major themes. I used ATLAS.ti, a commercially available software recommended by Walden professors. A student license for the software was available to purchase online at http://atlasti.com/product/. The software counted recurring words and phrases and was suitable for the analysis. I also used features in Word to perform word count and content analysis.

Coding was a critical component of the analysis process. The interview data consisted of rich descriptions from organization elites in response to open-ended questions. The rich descriptions were in each participant's own words, and it was necessary to develop a coding system that retained the character of the rich descriptions while facilitating the analysis effort (Aberbach & Rockman, 2002). I summarized the codes by frequency and used the codes to develop themes. See Appendices F and G.

I transcribed all the interview recordings. Transcribing all recordings verbatim was time consuming. However, it was necessary to compile the word count and code summary for data analysis.

Furthermore, I organized other sources of data and conducted an analysis of the database as required pending the interview analysis results. For example, data analysis on interviews pointed to several emerging themes. I reviewed the literature and explored the amount of knowledge and the depth of knowledge in the literature to close the loop in the literature review. During this process, I had the opportunity to examine the literature published after the writing of the proposal for additional or complementary reference material. I noted the themes included in the literature and added themes not mentioned in the literature.

Reliability and Validity

In the context of qualitative research are four components of trustworthiness: credibility or truthfulness, transferability or applicability, dependability or consistency, and confirmability or neutrality (Thomas & Magilvy, 2011). Evidence and validation of these critical elements enable researchers and audiences to have confidence in the research findings and to develop trust in the research results. The following subsections are discussions that relate to the four components.

Dependability

Reliability is the consistency and repeatability of the research procedures used in a case study (Yin, 2014). Developing reliability and thus validity in qualitative research requires rigor (Thomas & Magilvy, 2011). The word rigor signifies being extensive, meticulous, complete, and precise in research methodology and execution (Thomas & Magilvy, 2011). Establishing rigor is a critical aspect of any qualitative research. It indicates establishing confidence or trustworthiness in the findings of a research study (Thomas & Magilvy, 2011).

Reliability relates to the dependability or consistency of a qualitative research study in which another person can examine the work by following the decision trail and come to similar conclusions (Ihantola & Kihn, 2011; Thomas & Magilvy, 2011). Strategies to establish dependability or reliability include the following:

- accurately capture and represent the phenomenon under study, including careful documentation and reporting (Ihantola & Kihn, 2011)
- have peers participate in the data analysis process (Thomas & Magilvy, 2011)
- structure a coding system that maintains the richness of information and at the same time allowing analysis using qualitative techniques (Aberbach & Rockman, 2002)

- provide a thick description of the interviewee population, including demographic and geographic details (Thomas & Magilvy, 2011)

Researchers can ensure dependability and reliability by providing a detailed description of the derivation of research results (Darke et al., 1998). The audit trail is achievable by adhering to the following sequence suggested by Thomas and Magilvy (2011) and Carlson (2010):

1. stating the purpose of the study,
2. describing reasons for the participants' selection process,
3. describing the process and the length of the data collection,
4. explaining the process of data reduction and data analysis,
5. describing the thoughts and processes of data interpretation,
6. presenting the research findings,
7. communicating and explaining the techniques used to determine the credibility of the data, and
8. maintaining audiotapes or videotapes for a predetermined length of time.

In addition, researchers must be aware of threats to procedural reliability during the data collection progress. The following is a list of threats to procedural reliability provided by Ihantola and Kihn (2011):

1. inaccurate and unsystematic interview questions,
2. inaccurate transcripts,
3. failure to tape record or take notes,
4. not having a comprehensive research plan,

5. not having a coherent set of field notes or evidences,
6. relationships developed between researcher and participants,
7. data not collected over a long enough period of time,
8. additional questions not posed to interviewees when needed, and
9. errors made during data classification.

I was mindful of the potential threats to reliability and carefully planned the interviews to establish dependability, maintain dependability, and prevent threats to dependability.

Credibility

Validity in qualitative research is the extent of correlation between an assertion of knowledge and reality (Cho & Trent, 2006). Validity signifies the credibility of the research evidence and the conclusions reached by the researcher (Ihantola & Kihn, 2011). Researchers need to take action to establish and maintain validity and credibility throughout all phases of a study by capturing the facts authentically and presenting them convincingly (Ihantola & Kihn, 2011). In addition, researchers must address threats to validity and credibility by considering alternative interpretations or rival explanations and providing clear reasons for their rejection (Darke et al., 1998; Yin, 2014).

One method of establishing credibility is to ensure transactional validity in the study. The process involves providing a copy of the transcript to each interviewee for review and correction. The iterative process would safeguard validity by allowing the participants the opportunity to revisit the data, correct errors, and minimize misunderstanding. The process enables the researcher to gain a higher level of accuracy (Cho & Trent, 2006; Thomas & Magilvy, 2011). Providing the interview transcripts to the study participants for review and correction is an important way to secure credibility by ensuring internal consistency over a period of time (Seidman, 2013).

Another method of establishing credibility is through triangulation. Triangulation is a method of verifying facts through multiple sources to develop a coherent and objective depiction of reality (Cho & Trent, 2006). Triangulation is possible and perhaps necessary when judging the accuracy of specific data in a study. The methodology involves conducting data analysis as a whole and then individually to explore similarities across all research participants (Thomas & Magilvy, 2011). The data analysis phase involved triangulation. For example, shielding and analyses methods appeared in the literature and in the research data, thereby providing validation to two major themes.

The research design also affected validity and credibility (Ihantola & Kihn, 2011). Organization elites do not like the constraints of closed-ended questions (Aberbach & Rockman, 2002), and using semistructured interviews with open-ended questions was the best way to ensure validity and credibility by enabling the participants to organize their responses according to their values and experiences and within their own framework (Aberbach & Rockman, 2002; Harvey, 2011; Stephens, 2007).

It is possible to embed validity and credibility in a research design. The holistic approach of the study with interconnecting purpose, questions, methods, processes, and participant selection was an example of integrating validity in a research design (Cho & Trent, 2006). The research design had a specific purpose of probing deeply into elite experience and values (Aberbach & Rockman, 2002). The principle of a holistic approach need not end at research design. A holistic approach could extend to data analysis and reporting in which a thick description of research data could enable the readers to experience the study, find credibility, and establish validity (Cho & Trent, 2006).

Interview techniques affect credibility. To ensure internal consistency, it is important for a researcher to keep quiet and not interrupt the interviewees, thus allowing the interviewees to develop their thoughts and responses without external influence (Seidman, 2013). As the primary research instrument, I learned and made certain that my behaviors did not affect the internal validity of the study.

It is also necessary to establish credibility during data analysis. Strengthening the cause-and-effect link by showing the absence of false associations and the dismissal of rival explanations is an example of establishing validity and credibility (Yin, 2014). Finally, it is possible to establish credibility through the proper use of language in a report. Using the participants' words or phrases enable knowledgeable readers to recognize the facts as an accurate reflection of reality or an accurate portrayal of their own experiences (Thomas & Magilvy, 2011).

Transferability

The literature has many examples of considerations for external validity or transferability in qualitative research. Thomas and Magilvy (2011) equated transferability to applicability in other contexts or with other subjects or participants. The study has limited applicability, as the sample was only from the United States and Europe because of funding and time constraints. The United States and Europe have different levels of maturity in space programs than other nations such as Brazil, China, India, and Japan. Research findings from this study might have limited applicability to satellite manufacturing organizations from Asia and South America. This stated delimitation was an integral part of the study.

External validity of a case study is the extent to which the research findings are analytically generalizable to other situations (Yin, 2014). Similarly, Ihantola and Kihn (2011) defined external validity as extending research findings to a wider context. Within the context of the research study, transferability was difficult because of the varying views on risk from organization to organization. Risk posed by space debris is not the same to various groups of stakeholders. In general, satellites in MEO have less risk exposure than satellites in LEO (Liou, 2011). Within LEO, satellites in popular orbits have more collision risk than satellites in less occupied orbits (Cerf, 2013). Furthermore, leaders from organizations with multiple and redundant assets in space might consider the space debris risk different from leaders in organizations with a single satellite in space. Given the potentially different views toward risk exposure, applicability of the research findings in other contexts had limitations. The purpose of a qualitative study is not to generalize but to explore a specific subject deeply (Thomas & Magilvy, 2011). Transferability was not the intent or the goal of the study.

Cho and Trent (2006) used the term transformational validity to describe a process of finding meanings within a social, cultural, or political context. Achieving transformational validity requires a higher level of self-reflection and a deeper understanding of the issues and concerns stimulated by the research effort. Reflecting upon the data during the data analysis phase led to an exploration of the prospects of transformational validity.

One strategy to establish transferability is to provide a rich description of the population. By providing detailed descriptions of the demographic and geographic detail, future readers might find applicability in the research study (Thomas & Magilvy, 2011). The rich description of study participants may enable future scholars to conduct similar studies with the same sample from the United States and Europe and compare results. Another valuable study might include a similar population of managers from different geographic locations such as Asia and South America and involve exploring applicability.

Confirmability

Confirmability happens when credibility, transferability, and dependability are established (Thomas & Magilvy, 2011). In other words, researchers can confirm the reliability, internal validity, and external validity of a study. An important element of confirmability is personal reflection, in which the researcher maintains an elevated level of self-awareness associated with personal bias, thoughts, and insights (Thomas & Magilvy, 2011). The separation of one's personal view is critical throughout the interview process, during which leading instead of following the progress of the interview may result in inserting personal bias and compromising reliability and validity (Thomas & Magilvy, 2011).

Transition and Summary

The purpose of the qualitative case study was to explore strategies satellite manufacturing business leaders use to mitigate the damage caused by space debris. This section includes an outline of the details of the study, including my role as the research instrument, a description of the targeted study participants, a narrative of the research method, and a description of the research design. Also included were the specifics of the targeted participants such as their geographic locations, organizational affiliations, and the requirements for ethical research. Planning details included data collection techniques, data organization techniques, and data analysis techniques. The section ended with a discussion on the process of ensuring validity and reliability.

This concludes Section 2. Section 3 includes details of the study, the study findings, and conclusions. Section 3 also includes the contribution to business practices, implications for social change, and suggested material for future study.

Section 3: Application to Professional Practice and Implications for Change

This section includes the presentation of the findings from an analysis of data gathered from open-ended, semistructured, face-to-face and telephone interviews with leaders in satellite manufacturing organizations. Section 3 includes an overview of the study, presentation of the findings, application to professional practice, implications for social change, and recommendations for action. The section ends with recommendations for further studies, a reflection on my experience, a summary, and the study conclusion.

The purpose of this qualitative exploratory case study was to explore strategies leaders in satellite manufacturing use to mitigate the damage caused by space debris. The design of the case study was to gain knowledge and insights from leaders of satellite manufacturing organizations in the United States and Europe. The results from participant responses to the interview questions led to a rich description of the attitudes, experiences, insights, and values from leaders in satellite manufacturing organizations. ATLAS.ti was suitable for grouping and coding data obtained from interviews and for developing themes from the data.

According to study findings, satellite manufacturers use a range of tools and methods to mitigate the risks associated with space debris. These tools and methods include using analytical techniques to analyze missions, designing satellites to comply with specific customer requirements, and using shielding to protect satellites. Additional tools and methods include implementing material and process innovation to improve satellite construction, developing satellite servicing capabilities, and creating end-of-mission risk mitigation policies and requirements. These elements could be a process, a product, a service, a capability, or a procedure. They are internal responses based on external stimuli. When combined, the range of tools and methods support satellite manufacturers' overall strategy for mitigating space debris risk.

Presentation of the Findings

The main research question for this study was the following: What strategies do satellite manufacturing business leaders use to mitigate the damage caused by space debris? The case study design included data from three sources. Key elements of the study and a summary of findings follow.

Sources of Data

The primary source of data was in-depth interviews with leaders in satellite manufacturing organizations. Using the stakeholder theory, contingency theory, overconsumption of CPR, and GST as guiding conceptual frameworks, I explored the strategies with study participants using a semistructured interview format. The process involved recording the interviews, analyzing the transcripts, coding the data, and developing themes that answered the main research question.

The second source of data was documentation from the literature. The literature review contained some elements noted by research participants, including using shielding to protect satellites (Abdel-Aziz, 2013) and the development of the ADR technology (Liou, 2011). In addition, I added peer-reviewed literature published after the approval of the proposal to support study findings. The third source was documentation from NASA archives. The NASA ODPO website had archival records of debris modeling, measurements, protections, and mitigation, as well as the guiding documents noted by study participants such as NASA Technical Standard 8719.14, NASA Procedural Requirements 8715.6A, and the United Nations *Space Debris Mitigation Guidelines*. The NASA website also had peer-reviewed documents included to support my findings. The literature and the NASA archive did not contain data that supported all of the key findings. However, combining all three data sources yielded a rich description of activities that supported a holistic view of the strategies used by leaders in satellite manufacturing organizations.

Participant Demographics

The targeted population was leaders in satellite manufacturing organizations. I contacted 26 potential participants and received confirmation from 12. The positive response rate was 46%. The 12 study participants had different leadership roles, thereby allowing me to capture potentially different viewpoints from a representative cross-section of the leadership community (Rowley, 2012).

Fourteen individuals declined the interview invitation. Several individuals cited unfamiliarity with the subject as the primary reason. Four people contacted never returned the phone call or the e-mail inquiry. Two people contacted expressed interest but were too busy to follow up on the invitation. The outcome was not surprising because the targeted individuals were organization elites and busy people. Making initial contact and fixing a time for an interview were major challenges. However, once committed, there were no more difficulties in conducting the interviews and obtaining the research data.

Table 2 is a summary of the participant demographics. To maintain confidentiality, I used the letter P to refer to the word participant and numbers to refer to each participant. The average number of years of professional experience of the group was 24 years. Of the 12 participants, eight had more than 20 years of experience in the space industry. All study participants held senior level positions in satellite manufacturing organizations.

Table 2

Participant Demographics

Participant	Position or title	Location	Years of space experience
P1	PhD, group leader	California	24
P2	Vice president	California	32
P3	PhD, group leader	Maryland	13
P4	Site director	California	26
P5	Vice president	Virginia	42
P6	Group leader	Maryland	25
P7	PhD, principle scientist	Colorado	11
P8	Lead engineer	Colorado	29
P9	Program manager	France	19
P10	PhD, head of R&D	United Kingdom	16
P11	Vice president	California	20
P12	Lead engineer	United Kingdom	30

Overview and Thematic Development

Table 3 is a summary of codes from the code development phase of the data analysis. The first item reflects an important sentiment on the absolute necessity to meet customer requirements. The second item reflects the marketplace reality that satellite manufacturers must compete for contracts, and cost is a factor in organizational success in a competitive marketplace. Throughout the data analysis process, the three key elements of meeting requirements, focusing on cost, and developing a competitive advantage surfaced as the foundation in the thematic development.

Table 3

Top 15 Most Frequently Appeared Codes

Codes	*n*	Theme
Satellite manufacturers must meet requirements at mission level or design level	36	1, 6
Satellite manufacturers need to focus on cost	24	1
There is a possible business case in addressing the space debris problem	20	5
One strategy is to improve design or implement innovation	18	4
One strategy is to create an end-of-mission risk mitigation policy	17	6
One strategy is to conduct analysis	14	2
One strategy is to use satellite servicing or ADR	13	5
One strategy is to use shielding	13	3
ASAT testing in 2007 increased awareness of the debris problem	11	
Example of overuse of the Common Pool Resource	11	6
Space environment is getting worse	11	
We need to be proactive to keep things from getting worse	11	5
We need an international solution	10	6
It is necessary to do something proactive to address the growing debris problem	9	5
There is limited debris detection capability	9	

Note. See Appendix F for breakdown by participant.

Word count was an element in the data analysis. In addition to individual words, groups of words used within the same context were similarly important. As key words and word groups emerged, a secondary grouping of words became necessary. The secondary grouping arranged all related key words within the same context to enable a deeper understanding of the knowledge and sentiments of study participants. The secondary grouping of key words supported the thematic development summarized in Table 4.

Table 4

Top 10 Most Frequently Used Words or Word Groups Within the Context of a Specific Theme

Words or word groups	Context	*n*	Theme
Require, requirement	Satellite manufacturers must meet requirements imposed by the customers	95	1,6
Design	Satellite manufacturers must design the satellites to meet requirements	78	1,6
Cost, expensive, afford, and price	Satellite manufacturers must focus on cost and affordability in a highly competitive environment	61	1
End-of-mission, deorbit	End-of-mission deorbit policy is important	56	6
Risk	Satellite manufacturers must address risks associated with the space environment	50	1
Fund, budget, funding, money	Satellite manufacturers have monetary constraints because the customers control the money and dictates what must be done	38	1
Analysis, analyze, assess, assessment	Satellite manufacturers must conduct analyses to assess the risks to satellites	31	2
Improve, innovate, design for	Satellite manufacturers incorporate improved designs to meet requirements	28	4
Satellite servicing, active debris removal	Satellite servicing as a viable future business	23	5
Shielding, protection	Satellite manufacturers incorporating passive protection mechanisms to protect satellites on orbit	22	3

Note. See Appendix G for breakdown by participant.

A third analysis was conducted to determine how many participants had mentioned the same idea, concept, or theme. Table 5 is a list of themes that study participants brought up on their own. The letter Y denotes that the theme was part of the interview discussion. The total column denotes the number of study participants who included the theme in the interview discussion.

Table 5

Summary of Subjects Noted by Study Participants

Code	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Total	Theme
There is a possible business case	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	11	5
Satellite manufacturers must meet requirements	Y	Y	Y		Y	Y	Y	Y	Y	Y		Y	10	1,6
One strategy is to create end of mission requirements	Y	Y	Y	Y		Y		Y	Y	Y	Y	Y	10	6
One strategy is to conduct analysis	Y		Y	Y	Y		Y	Y	Y	Y			8	2
One strategy is to improve design or implement innovation			Y	Y	Y	Y	Y	Y	Y	Y			8	4
One strategy is to use satellite servicing		Y		Y	Y			Y	Y	Y		Y	7	5
Satellite manufacturers need to focus on cost	Y		Y		Y	Y	Y			Y		Y	7	1
One strategy is to use shielding			Y	Y		Y	Y	Y		Y			6	3

The first item in Table 5 indicated that that 11 participants thought there was a potential business case in addressing the space debris problem. The business could be satellite servicing, ADR, or both. One implication was that satellite manufacturers could invest in research and development strategically to develop new technologies in anticipation of future business opportunities. Another implication would be satellite manufacturers could start addressing the space debris risk proactively because of potential opportunities, rather than taking a reactive stance while waiting for potential funding.

An exploration of codes in Tables 3, 4, and 5 confirmed that meeting requirements was the most important item to satellite manufacturers. Codes in all three tables similarly confirmed that focusing on cost was important to organizational success. Conducting analyses was also prominent in all three tables.

Based on findings summarized in Tables 3, 4, and 5, six themes emerged that addressed the research question. The six themes could relate to a product, a process, a service, a capability, or a procedure. The multiple methods indicated that satellite manufacturers are taking different approaches to address a complex problem.

Theme 1: Meeting Debris Risk Mitigation Requirements Imposed by Customers and Noncustomers

One overarching theme that emerged was that satellite manufacturers strive to meet requirements imposed by paying customers and nonpaying entities such as governmental or regulatory bodies. Theme 1 was the predominant theme during code development (see Table 3) and theme development using word groups (see Table 4) and using participant count (see Table 5). Meeting requirements encompasses meeting design goals, meeting cost targets, mitigating risk, meeting schedule and mass goals, and being competitive. Table 6 is a summary of Theme 1 analyses.

Table 6

Theme 1 Analysis Summary

Code frequency	Word frequency	Participant frequency
36 (Meet requirement)	95 (Meet requirements)	10 (Meet requirement)
24 (Cost constraint)	78 (Design to meet requirements)	7 (Cost constraint)
	61 (Cost constraint)	

Paying customers could impose specific mission assurance requirements such as a reliability factor (e.g., a 0.9999999 probability of success) and mission duration (e.g., 15 years). One requirement noted by P2, P3, P9, P10, and P12 was that a spacecraft must deorbit upon completion of the mission. The deorbit requirement is in the literature (de Selding, 2014). This requirement involves carrying extra fuel for the deorbit operation, as well as developing the deorbit technology to ensure safe reentry and splashdown into the ocean. Both tasks have implications on overall mission cost. Carrying extra fuel results in higher launching cost (Coopersmith, 2011). Developing better deorbit technology results in higher performing propulsion systems and better tracking capabilities as noted by P3. Another requirement is spacecraft reliability over the operational lifetime. Participant 3 noted a specific case in which several satellites had to incorporate more shielding to ensure survivability throughout the duration of the mission.

Nonpaying entities such as space agencies, space governing bodies, and regulatory bodies issue risk mitigation guidelines. One example is the seven voluntary guidelines issued by the United Nations (United Nations Office for Outer Space Affairs, 2010). On NASA-sponsored missions, these guidelines are part of the overall requirement for debris risk mitigation. Compliance to the United Nations debris mitigation guideline is voluntary on commercial missions in many countries, including the United States. In contrast, P9 indicated that the French government had enacted a space law in 2010 mandating end-of-life deorbit operation regardless of the program sponsor. Such a law means all satellites originating from France must deorbit, whether it is a government satellite, institutional satellite (for example, ESA satellites), or commercial satellite. The same law also applies to launch vehicles of French origin. Many study participants noted that satellite manufacturers understand the importance of a sustainable space environment for continuing business activities. They also mentioned the importance of being good citizens and good environmental stewards. They strive to meet the requirements imposed by the guidelines, but there are also other circumstances and factors to consider.

Commercial satellite manufacturers operate in a competitive environment (Adilov et al., 2015). Participant 2 noted that there is overcapacity for satellite manufacturing in the United States, in Europe, and around the world. Satellite manufacturers compete fiercely to win contracts from a limited pool of available programs. Within this competitive environment, satellite manufacturers' key focus is to meet the design and programmatic requirements set forth by paying customers to win and execute contracts. Controlling cost and maintaining near-term competitiveness are important, and the cost of debris risk mitigation is part of the overall cost consideration. Some study participants noted that meeting debris mitigation goals set forth by entities other than the paying customer might conflict with meeting mission requirements specified by the paying customer. They also realized that it is inappropriate to neglect the continued deterioration of the space environment on which future businesses will depend. Leaders in satellite manufacturing organizations must balance all the conflicting goals, needs, and requirements within the overall cost constraint. Their challenge is to meet the near-term competitive goal of winning contracts and simultaneously protecting the long-term space environment in which they conduct business. This competitive environment could limit the strategic options available to leaders in satellite manufacturing organizations.

A new generation of entrepreneurial space ventures announced in 2015 could also bring forth a new wave of competition. Richard Branson and leaders of his company Virgin Group plan to add a 648-satellite constellation, while Elon Musk's Space X plans to deliver 4,025 small satellites to orbit (Werner, 2015). Other commercial ventures planning small satellite operations include Google's Skybox Imaging, XCOR, Blue Origin, and Rocketplane (Fous, 2015). Participant 5 noted that price could be the driver of the small satellite business model, and companies in that new market would face stiff competition. Participant 5 expressed concerns that in such a price-competitive environment, satellite designers might not design their satellites for debris risk mitigation, thereby contributing additional debris and increasing risk in an already crowded space environment.

The stakeholder theory is the appropriate conceptual lens for exploring stakeholder motivation and behavior under the theme of meeting requirements within the constraints of severe competition. Satellite manufacturers are important stakeholders with the expertise that could promote best practice (Williamson, 2012). Leaders in satellite manufacturing organizations need to consider both the near-term contractual and operational requirements and the long-term sustainability needs of organizations to promote effective business practice. Neglecting either the near-term requirements or the long-term needs could have negative consequences for satellite manufacturers as well as other major stakeholders in the space industry. This dual responsibility is an important challenge for leaders in satellite manufacturing organizations.

Theme 2: Conducting Risk Mitigation Analyses

Another theme that emerged was that the debris risk mitigation strategy is an integral part of satellite manufacturers' overall risk mitigation strategy. Leaders of satellite manufacturing organizations need to ensure their satellites could survive in a harsh space environment for the duration of the space missions. Survivability is critical when satellite servicing is not available on orbit. To ensure mission success, satellite manufacturers conduct various types of analyses to assess all risks associated with satellite operations, including the space debris risk. The literature (Abdel-Aziz, 2013; Liou, 2011), the code development process (see Table 3), and the theme development process (see Tables 4 and 5) all supported this theme. Table 7 is a summary of Theme 2 analysis.

Table 7

Theme 2 Analysis Summary

Code frequency	Word frequency	Participant frequency
14	31	8

Participant 7 noted that there are many types of analytical assessments. One type of analysis is to assess the spacecraft structural design associated with impact damage and debris generation. Another type of analysis is to conduct simulations and analyze risk factors associated with a specific orbit for a mission. Other analyses include ground casualty analysis for people and structures during satellite reentry or a debris impact study on satellite structures. Engineers and designers also analyze the amount of fuel needed to carry out the deorbit operation and assess the effectiveness and performance of the propulsion system when executing the deorbit operation.

Participants 1, 3, and 7 noted that there are different risk levels in space. A mission through a crowded region in space has a higher risk level than a mission in a less congested region with a smaller debris population. Business leaders analyze the risk levels of each mission, assess the tolerance to these potential risks, and determine an acceptable course of action to mitigate risk. One course of action noted by P3 was to analyze a satellite design and modify the design as necessary to mitigate risk. In some missions, satellite manufacturers had added more shielding to ensure adequate protection of their satellites. Participant 7 noted another course of action that involves working collaboratively with the satellite buyers or end users to ensure acceptable adaptation of the delivered package. The adaptations cited by P7 included modifying the orbit to reduce risk, modifying the mission to reduce risk, or modifying the satellite to increase protection.

The use of modeling techniques for risk assessment is in the literature (Liou, 2011). The literature also contains data on the varied risk levels at different orbital attitudes (Liou, 2011). Satellite manufacturers in this study were aware of different risk levels associated with different orbits and were making necessary adjustments based on the different risk levels. The adjustments could be to satellite design, in-space operations, or both. The customized adjustments reflect sound business practice, in accord with the 2015 announcement by SpaceX chief executive officer Elon Musk, who indicated that in designing his new-generation satellite constellation, he already took into account the rising debris risk in some popular orbits (Werner, 2015). Elon Musk's selection of a sparsely populated orbit for his new Internet in space is indicative of the analyses conducted on the rising risk in the space environment.

In the current study, I found satellite manufacturers used analytical techniques to evaluate the debris risk. In the future and as the threat level increases, P7 noted that satellite manufacturers might need to add personnel with a specialization in debris risk mitigation tools and techniques. These specialists could help leaders in satellite manufacturing organizations gain a deeper understanding of the increasingly complex issues associated with space debris and provide additional assistance in evaluating and addressing the growing debris threat.

The stakeholder theory was the appropriate conceptual lens for exploring stakeholder motivation and behavior in Theme 2. Satellite manufacturers have an important stake in the continued health of their satellites throughout their missions. Participant 1 noted that a collision event that damages or destroys an operational satellite could reflect poorly on the satellite manufacturer's ability to identify, manage, and mitigate risk. Conducting risk analysis is good business practice and a good strategy to mitigate debris risks.

Theme 3: Designing and Installing Shielding to Protect Satellites

Satellite manufacturers design and install shielding to protect their hardware on orbit. Participants 3, 4, 6, 7, and 8 all noted the use of shielding to protect space assets, including satellites and the ISS. Participant 10 mentioned an emerging field of increasing protection to satellites that is the primary function of shielding. The literature (Abdel-

Aziz, 2013; Percy & Landrum, 2014), the code development process (see Table 3), and the theme development process (see Tables 4 and 5) all supported Theme 3. Table 8 is a summary of Theme 3 analyses.

Table 8

Theme 3 Analysis Summary

Code frequency	Word frequency	Participant frequency
13	22	6

Satellite manufacturers are responsible for designing, analyzing, and installing shielding onto satellites. They could improve upon existing technology by implementing lighter weight and higher performance materials as noted by P7. They could also optimize the shielding location through analyses to achieve optimal protection as noted by P3. However, implementing shielding to protect space assets has a cost. More shielding means more mass. More mass from added shielding also means higher cost to launch assets into space (Coopersmith, 2011). Participant 7 noted that while satellite manufacturers try to build lighter satellites that are less costly to launch, the lower mass construction also makes satellites more vulnerable and susceptible to damage caused by micrometeoroids or space debris, thereby requiring more shielding protection that adds back mass. Leaders in satellite manufacturing organizations need to balance carefully the conflicting goals of minimal mass, optimal performance, lower cost, and risk mitigation in their decision-making process.

The literature review indicated that using shielding to protect space assets has its limitations. Shielding is an effective protection mechanism against objects smaller than 1 cm in size only (Abdel-Aziz, 2013). There is no adequate means of shielding operational assets from bombardment by medium to large debris objects (Percy & Landrum, 2014). The effectiveness of shielding diminishes as the number of debris objects grows or as the size of debris objects becomes bigger. Most important, incorporating shielding into satellite design is a passive way of mitigating the space debris risk. Shielding on satellites does not prevent the growth of debris objects or the continued deterioration of the space environment.

The contingency theory is an appropriate conceptual lens for exploring the organizational adjustments to situational factors in Theme 3. Leaders in satellite manufacturing organizations incorporate shielding to protect satellites against the smallest but most numerous debris objects in space (NASA ODPO, n.d.). To protect against debris objects larger than 1 cm, satellite operators could use collision avoidance maneuvers (Jesus et al., 2012). Using multiple approaches in contingency planning promotes safe satellite operations and reflects effective business practice.

Theme 4: Improving Technology and Implementing Design Innovation to Improve Satellite Construction

Satellite manufacturers are experts in the design and manufacture of space hardware. They are in a position to make a positive contribution toward debris risk mitigation by implementing good design practices. Participant 3 noted one risk mitigation strategy is improving technology to control the spacecraft more effectively. Another risk mitigation strategy is to design satellites with fewer components. Participant 9 stated that the traditional manufacturing method of using screws and nuts to integrate complex subsystems and systems could involve the assembly of dozens or hundreds of pieces of hardware. However, new technology such as additive manufacturing or three-dimensional (3D) printing could produce complex and yet monolithic 1-piece structures. Participant 9 noted that the adaptation of 3D printed structures could reduce the number of pieces in satellite construction significantly, thereby reducing the number of pieces that might break off in an on orbit collision. In addition, using 3D printed components in satellite construction could reduce the cost of assembly and minimize the time to assemble a spacecraft, thereby contributing to a satellite manufacturer's competitiveness. Implementing 3D printed structures could contribute to efficiency gains. The process of incorporating innovation could facilitate effective business practice and contribute to marketplace competitiveness.

As noted in the literature review in Section 1, satellite construction involves assembling thousands of components. Upon collision, many pieces could fly apart and create a debris cloud (Kessler et al., 2010). The finding in this study is a confirmation of the existing literature and a source of potential solution to the problem. In addition to the literature, both the code development process (see Table 3) and the theme development process (see Tables 4 and 5) supported Theme 4. Table 9 is a summary of Theme 4 analyses.

Table 9

Theme 4 Analysis Summary

Code frequency	Word frequency	Participant frequency
18	28	8

The stakeholder theory was an appropriate conceptual lens to view the stakeholder behavior associated with Theme 4. Evaluating and implementing new technology with the potential to reduce cost, minimize lead time, increase competitiveness, and reduce future risks to the space environment is an important part of the leadership responsibility. Adopting innovative solutions could introduce many benefits to satellite manufacturing organizations and other stakeholders.

Theme 5: Developing Satellite Servicing Capabilities

Astronauts first conducted satellite servicing during space walks to assemble the ISS. Another example of satellite servicing was astronauts conducting repairs to the Hubble Space Telescope. However, most satellites are not serviceable in orbit. In this study, leaders in satellite manufacturing organizations described the development of satellite servicing capabilities that could lead to reduced risk in the space environment.

Satellite servicing, in the context of space debris risk mitigation, includes repairing or refueling satellites to extend mission duration or moving decommissioned satellites or debris objects to prevent future collisions. Refueling not only prevents a satellite from becoming a piece of debris, but it also enables additional collision avoidance maneuvers for continued risk mitigation. The removal of decommissioned satellites or debris objects to prevent future collision is, in essence, the ADR described in Section 1. Robotic satellite servicing is still in technology development. Participants 5 and 8 noted that difficult technical challenges are still delaying the implementation of robotic satellite servicing. This sentiment was in accord with the literature (Barbee et al., 2012).

Unlike the passive approach of using shielding to protect individual satellites, satellite servicing is a proactive approach to restore the space environment and mitigate long-term risks. Satellite servicing could slow the rate of increase for debris growth. Many participants identified robotic satellite servicing as a potential business model. See Appendix F. Participant 5 noted that several commercial firms are developing the business case for satellite servicing, with ADR as part of the business portfolio. This might be because satellite repair or refueling restores economic value to aging and damaged satellites, whereas removing a decommissioned satellite or a piece of debris out of orbit might not generate economic value directly.

The technology used for satellite servicing is applicable to ADR. Several participants noted that there was no funding to conduct ADR. Nevertheless, if debris congestion in the space environment continues to grow, then the risk to operational satellites will increase, and the economic value of ADR could increase. In the near future, it might be possible for satellite manufacturers to start satellite servicing and provide mission extension or ADR services. Participant 9 noted that a potential sponsor could be a governing body such as the United Nations whose goal is to save the world and benefit humanity. Participant 5 suggested that a satellite fleet operator with perhaps 50 to 100 satellites in GEO might be a good candidate to fund satellite servicing missions to protect its precious fleet of revenue-generating satellites. Participant 10 stated that satellite manufacturers have already demonstrated the feasibility of ADR to potential customers. It might be just a matter of time before ADR becomes a necessity.

The literature review in Section 1 included an entire subsection to a discussion on ADR. Relevant points in the literature that relate to Theme 5 included an industry-wide under-investment in debris mitigation technologies (Adilov et al., 2015) and the importance of ADR on establishing stability in the space environment. In addition, the code development process (see Table 3) and the theme development process (see Tables 4 and 5) were in support of Theme 5. Eleven out of 12 study participants discussed the potential business case of satellite servicing or ADR, which indicated that it was important to leaders in satellite manufacturing organizations. Table 10 is a summary of Theme 5 analyses.

Table 10

Theme 5 Analysis Summary

Code frequency	Word frequency	Participant frequency
20 (Business case)	23	11 (Business case)
13 (Satellite servicing and active debris removal)		7 (satellite servicing)
20 (Proactive)		

Developing satellite servicing capabilities aligns with the contingency theory conceptual framework. The increasing risk of space debris, the organizational response of developing satellite servicing capabilities, and the potential influence on organizational effectiveness and performance form the trivariate relationship in the contingency theory. The organizational adjustment to incorporate satellite servicing in contingency management is a response that fits well within the contingency theory conceptual framework. The realization that organizational adjustment is necessary to address the space debris problem proactively is an important aspect of contingency management. The research finding is also a confirmation of the literature. The literature included references to the development of capabilities for a robotic rendezvous with active satellites to enable life extension, maneuver, disposal, salvage, and recycling services (Weeden, Chow, Lukaszczyk, & Samson, 2013). Within the discussion of the growing space debris threat, satellite servicing is becoming an increasingly relevant topic. Finally, leaders in a satellite manufacturing organization could develop satellite servicing capabilities strategically, thereby improving the competitive position of the organization when satellite servicing becomes increasingly important for potential customers.

Theme 6: Creating End-of-Mission Mitigation Policy and Requirement

Several study participants expressed the sentiment that the best mitigation plan for the space debris problem is to prevent the creation of space debris. The same sentiment is in the literature (Brachet, 2012). The creation of end-of-mission mitigation policy and procedure to dispose decommissioned satellites safely is an effective way to accomplish this goal. It is also a proactive way of reducing and eliminating the debris problem. In the United States, all new U.S. government satellites, including NASA satellites, have a requirement to deorbit. Participant 3 noted that one U.S. satellite manufacturer intentionally created a debris mitigation policy to deorbit in response to the growing debris threat. Participant 9 stated that the French government has a mandate for all new French satellites to deorbit, and French satellite manufacturers must abide by this law. This is an indication that some satellite manufacturing organizations are beginning to align with the goals of the debris mitigation guidelines.

Not all satellite manufacturers have their own deorbit policy and not all satellite operators adhere to deorbit guidelines. Most satellite manufacturers propose to meet their customers' requirements. As noted in Section 1, compliance to the United Nations debris mitigation guidelines is still voluntary and thereby ineffective (Adilov et al., 2015). Nevertheless, NASA researchers reported that all four commercial satellites in GEO followed the United Nations *Space Debris Mitigation Guidelines* and conducted deorbit operations in 2014 (Liou, 2015). The stakeholder theory is an appropriate conceptual lens to explore this behavior in sustainability management. Stakeholders bear the burden and the responsibility to ensure a sustainable space environment for future operations, and some are beginning to align with their long-term interests.

Having a policy and a set of requirements to follow is important to satellite manufacturers, gives satellite manufacturers a clear definition of rules to follow, and sets expectations for the performance of the satellites they produce. Tables 3, 4, and 5 were in support of this theme. Table 11 is a summary of Theme 6 analyses.

Table 11

Theme 6 Analysis Summary

Code frequency	Word frequency	Participant frequency
17 (End of mission requirement)	56	10
10 (International solution)		

In many other parts of the world, compliance to the United Nations debris mitigation guidelines is unknown. Participants 1, 4, and 12 noted that not all countries are abiding by the same rules. Participant 5 noted uncertainties regarding risk mitigation efforts by China or Russia. There is an underlying concern that not all space faring parties have the same interest or commitment regarding debris risk mitigation. In that context, the overconsumption of CPR is an appropriate conceptual framework to explore the motivation and behavior aspects of noncompliant space industry operators. Participant 2 stated the problem: "Nobody is really coming out to solve the problem. It is a worldwide problem, but who's responsibility is it?" Engaging all satellite manufacturers to follow the same rules could be an important step toward total risk mitigation.

Application to Professional Practice

Satellite manufacturers noted they used a range of tools and methods to mitigate the risks associated with space debris. These tools and methods included the following:

- designing satellites to comply with customer requirements, including risks associated with space debris
- using analysis techniques to assess missions and satellite construction
- designing and installing shielding to protect satellites
- developing and implementing new technology to improve satellite construction
- developing satellite servicing capabilities
- creating end-of-mission mitigation policy and requirements

Using analysis tools and techniques to evaluate a space mission is an efficient method of examining the complex issues and concerns inherent in any space project. The analytical process combines mission parameters with available space debris data and hypervelocity impact characteristics to assess the risk factors specific to a mission. Analytical methods can evaluate operational constraints and provide optimal solutions without committing critical hardware. The process involves examining potential sources of problems, and mission designers can generate optimum solutions before a mission takes place. For example, prior to a potential conjunction event, simulation tools could calculate collision probabilities of various operational adjustments without putting the satellite at risk. Using analytical techniques to evaluate mission parameters is also a relatively inexpensive approach for assessing mission feasibility before committing possibly hundreds of millions of dollars in hardware to execute the mission. The knowledge gained from this study is relevant to improving business practice and is a confirmation that analytical techniques are important. Leaders in satellite manufacturing organizations could improve upon existing capabilities or develop new ways to apply analytical techniques, thereby enhancing the efficiency and competitiveness of the organization.

Meeting customer requirements should be the foundation of any business practice. A successful business excels in meeting all aspects of customer requirements, including designing hardware that delivers optimal performance, offering competitive pricing, meeting delivery schedule, and providing exceptional customer service. In this study, I found that meeting customer requirements is a top priority for a satellite manufacturer (see Appendices F and G). Striving to meet customer requirements is consistent with good business practice. Leaders in satellite manufacturing organizations could reflect upon the study findings and aspire to meet and improve upon existing practice to gain a competitive advantage.

Using shielding to protect satellites is a traditional approach to space hardware protection. Satellite manufacturers could custom design shielding in terms of thickness, location, and coverage depending upon the risk levels of a mission. Shielding is effective for small objects less than 1 cm only. Small debris objects are difficult and too numerous to track, and shielding continues to be an effective protection mechanism. For larger debris objects, satellite operators could perform debris avoidance maneuvers to protect their assets. Most important, shielding provides protection against more than 100 million pieces of small debris objects in space. In effect, shielding offers protection against more than 99% of debris objects. As the debris population continues to increase, using protective shielding could become increasingly important. The application of protective shielding emerged as a relevant practice. Leaders in satellite manufacturing organizations should continue to include shielding as an available option for satellite protection. They could also invest in material research to develop lighter and strong protective shielding, thereby improving the capabilities and competitiveness of their product offering.

Like all technology companies, engineers and scientists in satellite companies develop and implement innovation to gain a competitive edge. In this study, 3D printed hardware is one example of an innovative process that might become the next leap in competitive advancement. 3D printed parts could potentially replace complex assemblies in satellite construction, thereby providing savings on material and labor. In addition, using 3D printed hardware could reduce overall assembly time, with a potential positive effect of reducing assembly cost. The application of this innovation was relevant to professional practice. In the space industry, mass, cost, schedule, and performance are all important parameters. The 3D printed hardware could help leaders of satellite manufacturing organizations reduce satellite mass, reduce satellite construction cost, and minimize program schedule. It has many advantages over the existing satellite assembly process and may help leaders in satellite manufacturing organizations gain a competitive advantage.

Scientists at NASA project the debris population will continue to increase (NASA ODPO, n.d.). Developing satellite servicing capabilities could be an important contingency option for satellite manufacturers. Satellite servicing could be attractive to satellite operators because it extends the revenue-generating capability of on-orbit satellites. The technology for satellite servicing is also applicable to ADR. Removal of debris objects reduces the risk of collision to operational satellites. Active debris removal also reduces the frequency of debris-on-debris collisions that generate more debris objects and degrade the space environment. As the risk of operating satellites continues to increase, the demand for satellite servicing could materialize in the future. Developing satellite servicing capabilities could help leaders in satellite manufacturing organizations position themselves for future work.

Finally, developing and meeting debris mitigation policy and procedures is an important step toward total debris risk mitigation. Participants 6 and 8 stated that the best way to prevent the debris problem is not creating debris in the first place. As the debris risk continues to increase in the space environment, it is the responsibility of the leaders in satellite manufacturing organizations to contribute towards a solution. Adhering to the debris mitigation policy is relevant to good business practice and space environment sustainability. Additionally, adhering to good risk mitigation practice aligns with meeting corporate social responsibility. Both are becoming necessities in the space business environment.

As noted in Section 1, the study design was to provide leaders in satellite manufacturing organizations insights into an SRM for effective space debris risk mitigation. The satellite manufactures used a range of tools and take a holistic approach to address the space debris problem. The holistic approach to environmental sustainability is in the literature (Durrieu & Nelson, 2013). This holistic approach could promote effective business practices through an examination of a problem from different perspectives and find the optimal solution for individual components of the problem. The holistic approach is consistent with the conceptual framework of the GST in which the understanding of both the whole and the components of a system could enhance system performance.

Implications for Social Change

Advocating for the preservation of the space environment through improved business practice by drawing attention to the increasingly threatening space debris problem is important. One goal of this study was to contribute to positive social change by revealing strategies that might preserve the space environment for continued value creation. The preservation of the space environment could be the catalyst for continuing economic growth, improving standards of living, increasing employment, and increasing investments into new jobs and infrastructure. All these improvements could lead to positive social change.

Individuals could use the study findings to help leaders of satellite manufacturing organizations develop an SRM and generate a business plan that meets both short-term and long-term needs of the organizations. Many other individuals could benefit from the general increase in awareness of the space debris issues and concerns. Leaders of business organizations could use the study findings to improve business performance and help organization members understand the fragility of the space business environment. Community leaders could apply the improved business practice to develop successful long-term employment that benefits communities and societies. Institutional leaders could use the study findings to draw attention to the struggles and the limitations of satellite manufacturing organizations. As an example, many study participants have voiced the common limitation of having no funding to advance ADR. Through this study, I might help draw attention to the need for funding to develop ADR technology and contribute to the advocacy toward securing funding from governmental institutions.

An improved space environment is an enabler for stability, continued growth, and prosperity. Space technology is an integral part of global citizens' daily lives. Global citizens use satellite weather forecasts to ensure safe travel; use satellite GPS to navigate both on land and on oceans; use Earth observation satellites to manage crops, forests, energy, and traffic; and use communication satellites for financial transactions, data transmission, and voice and video communications. In short, satellite technology enables global citizens to stay safe, be productive, and be in a position to contribute to the value creation process efficiently and effectively.

Recommendations for Action

The following recommendations for action are in response to the findings in this study. I direct these recommendations to the attention of leaders in satellite manufacturing organizations and propose that actions taken could promote a more efficient, effective, and proactive organization. Organization leaders need to generate action plans, ensure proper execution, measure progress, and disseminate results to internal leaders and external partners.

Recommendation 1: Develop and Maintain Analytical Competency

Satellite manufacturers use a range of analytical tools to evaluate risk. Important organizational needs are as follows:

- having competent analysts to conduct the analyses
- having reliable tools, both software and hardware, to perform the analyses
- having up-to-date data to ensure quality and reliability of the analyses

Leaders in satellite manufacturing organizations should provide frequent training and a supportive environment to develop, maintain, and retain analytical competencies. In addition, leaders should conduct cross training and promote knowledge sharing to disseminate knowledge. Making regular updates to the analysis software and hardware will help to maintain and improve analysis capabilities. Several study participants noted the competitive pressure from the marketplace and the resulting focus on cost. Overemphasis on cost control might lead to a tendency toward reduced expenditures on software and hardware updates. Leaders and managers need to find a balance between the need for cost control and the need to maintain analytical capabilities. Finally, I recommend a disciplined approach to update critical environmental data. The space environment is dynamic and constantly changing. Analysts need current and relevant data for modeling and predictive analyses. Using up-to-date data to support analyses could improve the analytical models and improve the quality and reliability of analysis results (Polk et al., 2015).

Recommendation 2: Fund Research and Development Efforts to Improve Shielding Material and Techniques for Satellite Protection

Space debris could cause hypervelocity impact damage to satellites. Shielding emerged as an important element in the protection of satellites. Incorporating shielding into satellite design is subject to the same considerations as other satellite structures, namely cost, mass, and performance. Leaders in satellite manufacturing organizations should commission research and development efforts to identify optimal materials and improve protection techniques for shielding. The field of material science is continuously undergoing innovation. Developing an advanced material with high strength, low mass, and relatively low cost could lead to an improved competitive advantage for satellite manufacturers.

Recommendation 3: Establish a Satellite Manufacturers Community of Interest for Mutual Benefit

Participant 6 noted an important need for satellite manufacturers to follow the passivation guidelines and requirements as a collective group. Assembling a community of interest is an important concept. As a collective, members of the community could share information, contribute or share resources, provide mutual support in advocacy, and contribute positively to their mutual benefit such as the long-term preservation of the space CPR. One contributor to the overconsumption in the space CPR is the incentive for individual actors to overconsume before others do. As a collective group, satellite manufacturers could act collaboratively to promote best practice for the mutual benefit of the group. Although satellite manufacturers are fierce competitors, they all share a common goal in preserving the space environment for their future business use. I recommend forming a community of interest with a specific long-term goal of mitigating the rising risk in the space environment. Membership to the collective need not be exclusively satellite manufacturers. Other stakeholders such as launch vehicle providers and satellite operators could be part of the collective to derive strength in numbers. Working as a collective group would make its voice for advocacy be strong and relevant.

Recommendation 4: Develop Debris Risk Mitigation Technologies and Capabilities Proactively

Space debris is a developing problem. Although study participants did not all agree on the magnitude and severity of the problem, all agreed that the space environment is deteriorating. More important, many study participants indicated that proactively addressing the space debris problem is a necessary course of action. Liou and Johnson (2006) noted that even with the unlikely scenario of no future launches, mutual collisions will continue to degrade the space environment. Given the knowledge from the literature review and the sentiment from all study participants, satellite manufacturers should develop technologies and capabilities proactively to reduce the space debris threat. Satellite manufacturers could develop the technologies and capabilities independently in anticipation of future business opportunities. However, in response to the theme of a lack of funding, satellite manufacturers should pool their resources together to develop the capability as a collective group. Pooling resources together could reduce the financial burden on each member, while the application of the risk mitigating technology could benefit all members of the group. As the space environment continues to deteriorate, it becomes critically important to start pursuing the technological solution before projected runaway collision cascade becomes a reality.

Recommendation 5: Establish Standardization to Facilitate Satellite Servicing

Satellite servicing is a promising approach to mitigating debris risk. To facilitate satellite servicing, it is necessary to establish standardization among satellite manufacturers. Standardization might include common operational protocol, common hardware, common units of measure, and common software commands regardless of the satellite origin. For example, to facilitate on-orbit fluid transfer, the target and host satellites need to have standardized connectors. Satellite manufacturers should establish a community of interest and develop standardized processes, procedures, hardware, and software to enable satellite servicing on all makes of satellites, regardless of manufacturing origin. Although satellite servicing technology is not available in 2015, many satellites have relatively long mission duration. Some GEO satellites have a mission life of 15 to 20 years on orbit. Installing standardized hardware on satellites could enable satellite servicing when the technology does become available.

Recommendation 6: Take a Holistic Approach to Managing Debris Risk

Satellite manufacturers need to take a holistic approach to managing debris risk. Factors to consider include designing missions to avoid high-risk orbits, designing satellite structures to minimize damage and debris generation from a collision, and incorporating contingency features such as the capability to perform debris-avoidance maneuvers. Additional factors to consider include embedding features to allow future satellite servicing, designing the mission to incorporate deorbit operations, and integrating capabilities to avoid damage to people and structures if the satellite is to reenter the atmosphere. All satellite manufacturers should develop an organizational culture that facilitates a holistic approach to debris risk management. Leaders in satellite manufacturing organizations need to align this culture with organizational goals and objectives to ensure implementation.

Recommendation 7: Take a Long-Term View in Managing Satellite Manufacturing Organizations

Leaders in satellite manufacturing organizations need to make decisions that facilitate constant progress. Schedule and budgetary constraints are organizational realities, and there are relentless pressures on organizational leaders to perform. During their daily struggle to deliver value, it is easy to lose sight of or perhaps even forgo the long-term needs of an organization. Although study participants noted that it is still not too late to do something to reverse the worsening conditions in the space environment, they also voiced concerns that nothing proactive has taken place. Leaders in satellite manufacturing organizations should make a deliberate and determined effort to take a long-term view in their daily decision making and balance both the short-term and long-term needs of the organization. Specifically, part of the long-term need is to reverse the worsening trend in the space environment in a proactive way. It involves taking actions and making organizations and people responsible for continued progress toward sustainability in the space environment.

Recommendation 8: Support the Establishment of an International Governing Body to Find a Regulatory Solution to Manage the Debris Problem

Several study participants voiced the need to find an international solution to the space debris problem. Satellite manufacturers should support establishing an international governing body to develop and enforce end-of-mission requirements. Members of the governing body could facilitate governance, oversight, advocacy, and funding. There has been much work done on this effort, but there is still not a true international governing body empowered and dedicated toward finding a solution for the space debris problem. The space community needs such an international governing body. Satellite manufacturers need to transition from following recommended guidelines to adhering to hard requirements. The current regime of voluntary compliance makes the rules unenforceable, thereby benefiting the violators and punishing the adherents. The unenforceable rules continue to allow some parties to misuse the space environment to the detriment of all members in the space community.

Recommendation 9: Fund Research and Development Efforts to Improve Material and Processes

Similar to Recommendation 2, I recommend continued research and development to improve materials and processes and to develop new products and services. Using 3D printing to improve satellite structures is one example of improving material and processes. Incorporating innovative material and processes could help organizations gain a competitive advantage. Acquiring satellite servicing technology is an example of developing new products and services. Satellite servicing could represent potential business opportunities for satellite manufacturers. Investments into new material, processes, and products could be risky, but they also hold promise for potential rewards. Satellite manufacturers are technology organizations and need to stay at the forefront of technology to remain competitive. Funding research and develop is an important part of organizational adjustment in a competitive environment.

Benefits of the Study

The findings and recommendations from this study could benefit leaders in satellite manufacturing organizations by contributing to an SRM that addresses the space debris problem. In addition, satellite operators could benefit from improved satellite construction, enhanced satellite operation, and a sustainable space environment in which to conduct business. Furthermore, global citizens could benefit from a sustained access to space and the application of space technology that leads to enhanced organizational efficiency, continued economic activities, increased knowledge, and prosperity.

All study participants will receive a two-page summary of this study. The results of this study could be beneficial to a wider audience, including other leaders in satellite manufacturing organizations. In addition, leaders in launch vehicle organizations and satellite operators could also benefit from the study findings and recommendations. For wider distribution, it might be possible to present a condensed version of the study at a space conference, or publish the results in a space journal.

Recommendations for Further Research

The focus in this study was leaders of satellite manufacturing organizations. Other researchers might consider conducting the same or similar studies with leaders of satellite operators or launch vehicle providers. Satellite operators are owners of the satellites. Launch vehicle providers deliver satellites into orbit. The growing space debris problem has the potential to affect the business case for both types of organizations. The suggested future studies, combined with this study, could help provide a holistic view of the space debris problem for much of the space industry.

Geographically, the focus was satellite manufacturers in the United States and Europe. Other researchers might consider conducting the same or similar research on satellite manufacturers in other countries, such as China, India, Japan, and Korea in Asia; Brazil and Argentina in South America; and Russia. These countries have varying degrees of maturity in their respective space industries. They also have different purposes for journeying into space. In the suggested future studies, researchers could collect additional insights and help determine the applicability of this study.

The study included large, well-established satellite manufacturers. Other researchers might consider conducting the same or similar research on entrepreneurial space companies that are beginning to emerge in the marketplace. An exploration of the strategies used by leaders of these entrepreneurial firms could provide additional insight from the perspective of space entrepreneurs.

Finally, the study did not focus on factors associated with research funding. However, study participants voiced their concern over a lack of funding to address the space debris problem. I recommend conducting additional research to explore the reasons behind the lack of funding and the effects this condition might have on businesses and the future state of the space environment.

Reflections

Prior to the start of my study, my goal was to conduct a study based on the theme of sustainability in the space environment. My advisors noted the theme was too broad and worked with me to narrow the scope to design a suitable study. Throughout the formulation of my proposal, I often struggled against scope creep because my passion is on the broader subject of sustainability. Pollution of our rivers and oceans frustrates me and so does the pollution of our space environment. My advisors reminded me constantly that the purpose of this doctoral study was not to save the world. That could come later. Finally, I settled on a specific scope somewhat related to space environment sustainability. More important, I had a subject I could explore, and I was confident that I could complete the study. Nevertheless, I struggled with two problems with the nature of my study since inception.

The first problem was that I had to suppress an urge to reach conclusions without collecting and analyzing data. This was a form of personal bias. The bias was evident in one of the comments from a Walden reviewer after a review of my proposal. I learned that my task was to find out what business leaders do and not to predetermine what they should do with regard to business sustainability. The lesson stayed with me as I progressed through my interviews, my data collection, and my data analysis. In retrospect, I was fortunate that I became aware of the potential bias and used the learned lesson to minimize bias throughout my study (Chan, Fung, & Chien, 2013). To ensure I stayed true to the actual words used by study participants, I coded the key concepts with the words and phrases used by study participants, developed and described the themes using words and phrases from the study participants, and used member checking for validation. It was my way of ensuring validity in this study.

The second problem was that, at the inception of the study, I knew nothing about what satellite manufacturers do. During the literature review, I learned that satellite manufacturers were incorporating shielding and satellite operators were conducting debris avoidance maneuvers. However, the literature had little information about what else satellite manufacturers do. I concluded my proposal not knowing the answers to my research questions and started my data collection with an unsettled feeling toward the unknown. However, not knowing the answers to the questions at the start of the research had its advantages. Every concept the participants expressed was a discovery, and I had no initial bias against their answers. Because I was not expecting preconceived answers, I had the opportunity to focus, listen, and take notes during interviews. It raised my awareness level and allowed me to establish a connection with the study participants.

In the data analysis phase of the study, I focused on what the study participants told me and not on interpreting what they had told me. I used their own words within the context of the intended questions and developed themes based on study participants' own views. Looking back, I found the study participants very open in expressing their views. Several participants told me after the interviews that they were more than happy to answer additional questions. I believe the unobtrusive nature of the questions, along with the semistructured interview format, was the correct design for this kind of interview.

Summary and Study Conclusions

The purpose of this qualitative exploratory case study was to explore strategies satellite manufacturing business leaders use to mitigate the damage caused by space debris. In this study, I identified those strategies, evaluated their applicability to professional practice, described their implications for social change, and offered recommendations for future actions and additional research. Throughout the study, I found myself a captivated participant in one of the most important developments in human history. The story of satellites and space debris is a story of humanity's technological advancement and the potential devastating side effects of modernization. Humanity has advanced technologically to escape the confines of gravity. Global citizens are benefiting from that technological advancement by using satellite systems in space to improve many aspects of daily lives. Along the way, humanity has also managed to pollute the space environment to such an extent that people have created a mechanism with the potential of wiping out all the technological and economic gains accumulated over six decades.

The contents of this study led to two important clues regarding how business leaders should respond to the challenge of a worsening business environment. First, it is import to stop polluting the space environment by not introducing additional debris. Second, it is important to find a way to manage the debris population proactively. Being reactive is no longer an option for space environment sustainability. Satellite manufacturers need to play an important role on both recommended actions. Space systems offer many advantages to societies, and humanity is likely to continue launching satellites because of the value created by satellite systems. A sustainable space environment is critically important to future generations. To protect that future, business leaders need to start respecting the space environment and start acting responsibly on all space missions.

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Appendix A: A Summary of Sources in the Literature

Table A1

Number of Sources by Category

Sources of literature	*n*	%
Peer reviewed journals	118	79.2%
Peer reviewed - NASA	9	6.0%
Peer reviewed - Government	4	2.7%
Total peer reviewed sources	131	87.9%
Not Peer reviewed - Conference	5	3.4%
Not Peer reviewed - Journal	2	1.3%
Not Peer reviewed - web site	2	1.3%
Not Peer reviewed - news articles	3	2.0%
Not Peer reviewed - book	4	2.7%
Not Peer reviewed - reports	2	1.3%
Total nonpeer reviewed sources	18	12.1%
Total number of sources	149	

Table A2

List of Peer Reviewed Articles by Name

No. of peer reviewed journals	Journal name	No. of articles
1	Academy of Management Journal	1
2	Academic of Management Review	1
3	Academic Pediatrics	1
4	Accountability in Research	1
5	Acta Astronautica	8
6	Advances in Aerospace Science and Applications	1
7	Advances in Space Research	5
8	Aerospace America	1
9	American Journal of Business Education	1
10	Applied Mathematical Modeling	1
11	Asian Perspectives	1
12	Business Ethics Quarterly	1
13	Celestial Mechanics and Dynamical Astronomy	1
14	Early Childhood Educational Journal	1
15	Environmental Science and Policy	1
16	Environmental Resource Economics	1
17	Field Methods	1
18	Geoforum	1
19	India Review	1

No. of peer reviewed journals	Journal name	No. of articles
20	Information Systems Journal	1
21	International Journal of Business and Social Science	1
22	International Journal of Space Technology Management and Innovation	1
23	Journal for Specialists in Pediatric Nursing	1
24	Journal of Accounting, Auditing and Finance	1
25	Journal of Astronomy and Space Sciences	1
26	Journal of Business Ethics	1
27	Journal of Geophysical Research	2
28	Journal of Guidance, Control, and Dynamics	1
29	Journal of Information Technology Education: Research	1
30	Journal of International Business Studies	1
31	Journal of Management Studies	1
32	Journal of Optimization Theory and Applications	1
33	Journal of Risk and Insurance	1
34	Journal of the Astronautical Sciences	2
35	Management Research Review	1
36	Mathematical Problems in Engineering	2
37	Organization and Environment	1
38	Organization Development Journal	1
39	Planetary and Space Science	1
40	Policy & Society	1
41	Political Science & Politics	1
42	Procedia Engineering	2
43	Project Management Journal	1
44	Psychology and Health	1
45	Qualitative Research	4
46	Qualitative Research in Accounting and Management	2
47	Qualitative Research Journal	1
48	Qualitative Social Work	1
49	Science	2
50	Science and Global Security	1
51	Solar Systems Research	1
52	Space Policy	37
53	Space Weather	1
54	Strategic Analysis	1
55	Strategic Management Journal	1
56	Systems Research and Behavioral Science	2
57	Tourism Management	1
58	The Qualitative Report	2
59	The Washington Quarterly	1
60	World Academy of Science, Engineering and Technology	1

Table A3

Sources of Literature by Year

Time period	Number	Percent
2011 through 2015	128	85.9%
Prior to 2011	21	14.1%
Total Number of sources	149	

Appendix B: Literature Map

Appendix C: Interview Questions

1. What were your personal experiences in dealing with the space debris problem?
2. Why is space debris a problem for satellite manufacturers?
3. How severe is the space debris problem for satellite manufacturers?
    (a) On a scale of 1 to 10, 10 being the worst, what is the severity of the space debris problem for satellite manufacturers now?
    (b) On the same scale, what might be the severity of the space debris problem for satellite manufacturers 10 years from now?
4. What strategies are you taking to mitigate the space debris problem?
5. Researchers are indicating that space debris population will continue to grow. What more should satellite manufacturers do (that they are not doing already) to mitigate the growing risk of space debris?
6. What is the role of satellite manufacturers in the context of addressing the space debris problem?
    (a) Do you think satellite manufacturers play a major role, a minor role, or a supporting role on the periphery?
7. How important a role should the satellite manufacturers play in the context of addressing the space debris problem?
8. How important is Active Debris Removal or ADR for satellite manufacturers?
9. What are some other long-term business opportunities associated with space debris for satellite manufacturers?

10. Can you recommend other experts on space debris who might provide additional insights regarding space debris?

Appendix D: Informed Consent Form

CONSENT FORM

As a leader in a satellite manufacturing organization, you are invited to take part in a research study of what satellite manufacturers do in today's growing space debris environment. This form is part of a process called "informed consent" to allow you to understand this study before deciding whether to take part. The study is being conducted by a researcher named Walter Tam who is a doctoral student at Walden University.

Background Information:
The purpose of this study is to explore what satellite manufacturers do to mitigate the growing risk of space debris.

Procedures:
If you agree to participate in the study, you will be asked to participate in an interview that might take about 45 minutes to an hour. During the interview, you will be invited to discuss satellite manufacturer actions relating to the growing space debris threat. The interview will be audio recorded to ensure accuracy. If audio recording is not permitted by you, the researcher will take notes during the interview. After the interview, the researcher will transcribe the audio recording, consolidate the notes, analyze and interpret the transcript, and return the transcript for your review, validation, and comments.

Here are some sample questions:

1. What was your personal experience in dealing with the space debris problem?
2. Why is space debris a problem for satellite manufacturers?
3. How severe is the space debris problem for satellite manufacturers?

Voluntary Nature of the Study:
This study is voluntary. I will respect your decision of whether or not you choose to be in the study. If you decide to participate in the study now, you can still change your mind later. You may stop at any time. Please be assured that declining or discontinuing participation in this study will not negatively impact your relationship with me. If the researcher is known to you from a professional association, please note that the researcher's role in this study is separate from your professional association.

Risks and Benefits of Being in the Study:
The risks associated with this study are minimal in that you will be asked to answer some questions related to your thoughts on space debris. Participation in this study might involve some minor inconveniences such as time away from work or family. However, being in this study would not pose risk to your safety or well being. The knowledge gathered in this study might help satellite manufacturers develop strategies to mitigate damage caused by space debris.

Payment:
There will be no payment to participants for this study. The interview might take place in locations such as cafe or restaurents, in which the research will be responsible for payment of food and beverages.

Confidentiality:
Any information you provide will be kept confidential. I will not use your personal information for any purposes outside of this research project. Also, I will not include your name or anything else that could identify you in any report. Data will be kept secure by storing in a locker. Data will be kept for a period of at least 5 years, as required by the university. However, if criminal activities are disclosed, they will be reported to the proper authorities.

Contacts and Questions:
You may ask any questions you have now. Or if you have questions later, you may contact the researcher via walter.tam@waldenu.edu. If you want to talk privately about your rights as a participant, you can call Dr. Leilani Endicott. She is the Walden University representative who can discuss this with you. Her phone number is 612-312-1210 for US based participants, or 001-612-312-1210 for participants outside the US. Walden University's approval number for this study is 06-02-15-0349416 and it expires on June 1, 2016.

The researcher will give you a copy of this form to keep.

Statement of Consent:

I have read the above information and I feel I understand the study well enough to make a decision about my involvement. By signing below, I understand that I am agreeing to the terms described above.

Printed Name of Participant ______________________________

Date of consent ______________________________

Participant's Signature ______________________________

Researcher's Signature ______________________________

Appendix E: Interview Protocols

The following statements provide the structure and procedural protocols for the interview process:

1) I will welcome each participant with a standard opening greeting. The standard greeting includes information on who I am, my school affiliation, and my field of study. I will start with the statement: *"Hello, My name is Walter Tam and I am a Doctoral student at Walden University. Thank you so much for volunteering to participate in this study. My study is on space debris and its effects on satellite manufacturers. I appreciate very much your support in this academic endeavor."*
2) I will ask each participant to review and sign a copy of the Informed Consent Form. An interview might take place across the country or overseas. To avoid misunderstandings that lead to wasting time and money, I will send an electronic copy of the Informed Consent Form prior to scheduling an interview. I will ask the participant if he or she had read the consent form in its entirety and would agree to continue as a participant in this study prior to making travel arrangements. Participant signatures immediately prior to the interview constitute their informed consent to participate as unpaid and uncompensated volunteers in this study.
3) I will ask the participant for permission to begin the audio recording for the interview.
4) If the participant decides not to give permission for an audio recording of the interview, I will say the following: *"Thank you (participant's name), I respect*

your decision. I need to take written notes of your responses. There might be gaps in our discussion as I write down important notes. Please do not feel uncomfortable during short periods of silence."

5) If the participant agrees to the audio recording, I will begin the audio recording.
6) I will inform the participant that the total time for the interview should be approximately 45 to 60 minutes.
7) I will assure the participant that all responses will remain confidential, and the published doctoral study will not include recognizable information to protect the identity of the participant.
8) I will state the purpose of the study.
9) I will explain the interview format, including the nature of a semistructured interview using open-ended questions. I will ask each participant to feel free and add clarifying remarks when appropriate.
10) I will reiterate the option to withdraw from the interview process. I will state the following: *"This interview is voluntary and you may decline to answer any question that makes you feel uncomfortable. Additionally, you may withdraw your consent at any time during this interview. All notes, references, and recorded information previously collected will enter a destruction process after your withdrawal. Your withdrawal does not impose any reprisal or negatively affect your professional standing"*.
11) I will begin asking the interview questions.

12) After the participant answers all questions, I will thank each participant again for his or her willingness to participate in the study.

13) I will advise the participant that I will transcribe the interview, study the content, interpret the data, and share my interpretation with the participant by sending a copy of the transcript through email. I will ask the participant to please review for accuracy, sign the document, and return it to my Walden email address. I will also state that I welcome additional inputs and corrections.

14) I will conclude by thanking each participant for the time spend and for the sharing of knowledge and wisdom. I will ask each participant how I might share my research findings at this time. It is likely that many participants or other stakeholders might lack the time or the inclination to review a complete research article. I will, as a minimum, offer a short summary or a verbal presentation.

Appendix F: Top 20 Most Frequently Appeared Codes Broken Down by Participant

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Frequency
Satellite manufacturers must meet requirements at mission level or design level	3	2	6	0	2	6	3	4	2	3	0	5	36
Satellite manufacturers need to focus on cost	5	0	1	0	3	3	6	0	0	2	0	4	24
There is a possible business case in addressing the space debris problem	1	2	2	1	6	0	1	2	1	1	1	2	20
One strategy is to improve design or implement innovation	0	0	3	1	2	1	2	2	3	4	0	0	18
One strategy is to create an end-of-mission risk mitigation policy	2	1	2	1	0	3	0	1	2	3	1	1	17
One strategy is to conduct analysis	2	0	2	1	1	0	5	1	1	1	0	0	14
One strategy is to use satellite servicing or ADR	0	2	0	2	2	0	0	1	1	3	0	2	13
One strategy is to use shielding	0	0	3	3	0	2	2	2	0	1	0	0	13
ASAT testing in 2007 increased awareness of the debris problem	2	3	0	2	1	0	2	1	0	0	0	0	11
Example of overuse of the Common Pool Resource	2	4	0	2	1	1	0	0	1	0	0	0	11
Space environment is getting worse	1	0	2	0	1	1	2	1	1	1	0	1	11
We need to be proactive to keep things from getting worse	2	0	0	2	1	0	0	1	0	1	4	0	11
We need an international solution	1	3	0	1	1	1	0	1	1	0	0	1	10
It is necessary to do something proactive to address the growing debris problem	1	0	0	1	0	1	0	2	0	1	3	0	9
There is limited debris detection capability	0	1	0	3	3	1	0	1	0	0	0	0	9
There is no money from the government to do debris removal	0	0	2	4	0	1	0	0	0	1	1	0	9
Satellite manufacturers need to focus on being competitive	2	2	0	0	1	0	0	0	0	1	0	2	8
Space environment is getting worse. One contributing factor is collisions.	2	1	1	1	1	0	2	0	0	0	0	0	8
One strategy is to minimize debris creation in the first place, including an end-of-mission risk mitigation policy	1	0	0	0	0	0	0	1	2	2	0	1	7
Satellite servicing is difficult and not part of the traditional satellite design	0	1	1	3	1	1	0	0	0	0	0	0	7

Appendix G: Top 10 Most Frequently Used Words or Word Groups Within the Context of a Specific Theme, Breakdown by Participant

Words and word groups	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Individual total	Group total
Requirements, require	47	5	5	0	2	4	6	4	1	3	2	16	95	95
Design	10	0	17	2	8	17	1	9	5	4	0	5	78	78
Cost	13	0	2	1	1	5	7	5	0	3	0	5	42	61
Expensive	0	0	0	0	0	1	4	1	0	1	0	0	7	
Afford/affordability	0	0	0	0	2	0	0	0	0	0	1	0	3	
Price	0	2	0	0	1	3	0	0	0	0	0	3	9	
End-of-mission	0	1	2	1	1	2	0	1	3	6	0	5	22	56
Deorbit	1	2	0	1	0	0	0	4	4	6	0	16	34	
Risk	5	2	0	2	0	6	23	5	3	2	0	2	50	50
Fund, Funding	0	1	0	3	2	1	0	0	0	0	2	6	15	38
Budget	0	0	0	0	0	0	4	0	0	0	0	1	5	
Money	3	0	2	3	3	0	3	0	4	3	2	0	23	
Analysis, analyze	8	0	1	1	1	0	5	1	1	0	0	0	18	31
Assess, assessment	0	0	2	0	0	0	10	1	0	0	0	0	13	
Good design, Improved design	0	0	6	2	3	6	0	4	2	1	0	1	25	28
Innovation	0	0	0	0	0	0	0	0	1	0	0	0	1	
Improve	0	0	0	0	0	0	0	0	1	1	0	0	2	
Satellite servicing	0	0	2	4	1	0	0	0	0	0	0	0	7	23
ADR	2	1	2	0	6	1	0	0	0	4	0	0	16	
Shielding	0	0	6	2	0	4	2	2	0	0	0	0	16	22
Protection	0	0	0	2	0	0	0	1	0	3	0	0	6	