3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria

Quantitative Risk Analysis for Communication Satellite Payload

*Babadoko, D. M[1], Ikechukwu, A. D[2]
[1]Project Management Technology Department, Federal University of Technology, PMB 65 Minna Niger State, Nigeria
[2]Project Management Technology Department, Federal University of Technology, PMB 65 Minna Niger State, Nigeria

*Corresponding author email: babadokos74@gmail.com, +2348024563101

ABSTRACT
The application of risk management is a critical stage for any spacecraft project to achieve required components and system functionality for a successful mission, a risk management plan is high-level accounts and descriptions of risk concepts for any satellite mission to be successful. This research article investigates the application of criticality analysis and risk priority number analysis for communication satellite payload components by following industry standard and using MIL-STD-1628, MIL-STD-1629A termed as military standard and the ECSS-Q-STD-30-02C termed as European Cooperation for Space Standardization for space product assurance in conducting analysis of risk and determining mitigation techniques and also determined the sample correlation coefficient of criticality of components and risk priority.

Keywords: *Correlation, Payload, Project, Risk, Satellite.*

1 INTRODUCTION

The utilization of space technologies has increased substantially, bringing with it, a share of benefits, ranging from early environment and disaster threat detection and warnings, climatic changes, metrological forecasts, geographical information system (GIS), as well as enhanced communication (Spagnulo, 2013). A satellite system performs these multifaceted functions because of its design which consist of two functional areas, the Bus Systems and the Communication Payload Systems as in figure 1and figure 2 respectively.

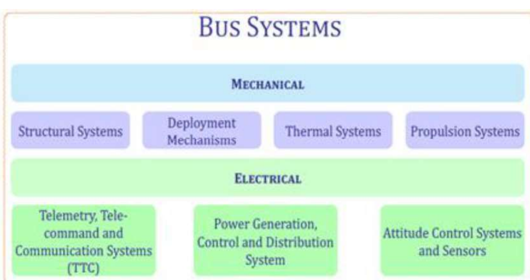


Fig. 1: Components of the functional areas of a satellite system. (Source: (GVF Training & MahdiBagh Computers PVT. Ltd., 2008)

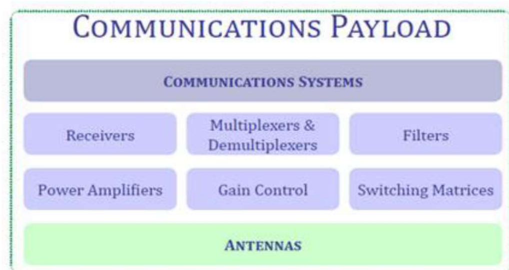


Fig. 2: Components of the functional areas of a satellite system. (Source: (GVF Training & MahdiBagh Computers PVT. Ltd., 2008)

While the Bus system consists of all the elements that support the communication payload, the communication payload provides support for all the functional aspects of the mission for which the satellite is launched (GVF Training & MahdiBagh Computers PVT. Ltd., 2008)

The increased utilization of space technologies necessitated an increased need for space research and explorations. Consequently, satellites are launched into space for either communication or environmental monitoring for disaster. Satellites have different functionalities, determined by their locations in space. Excerpts from existing literature (Braun, 2012; Stanniland & Curtin, 2013) suggest that Low Earth Orbit (LEO) satellites are used for navigation, space missions, and low latency communication, the Medium Earth Orbit (MEO) satellites, while performing the same function as the LEO satellites, are differentiated by the distance from the earth, and the Geostationary (GEO) satellites are commonly used for communication purposes.

Satellite has been recognised as driver for national growth and sustainable development, access to reliable and adequate geospatial information (GI) according to Akinyede and Agbaje (2006). The recognition of this fact, may have prompted the Nigerian government to initiate moves, the NIGCOMSAT-1, a Nigerian Communication Satellite Project (Zhicheng et al., 2006), aimed at addressing the problem of communication, seen as one of the greatest setbacks to the socio-economic development of the country, particularly in the areas of rural telephoning, broadcasting, tele-education, tele-medicine, e-government, e-commerce and real-time monitoring services (Chukwu-Okoronkwo, 2015). Boroffice (2008) noted that the NigComSat-1 project was to provide a platform for capacity-building and the development of satellite technology for the level of transformation in the telecommunication, broadcasting and broadband industry in Africa, as well as prospects increased businesses in rural and remote regions through access to strategic information.

Although the contribution of satellite systems has been substantial, Bargellini and Edelson (1977) noted that satellite communications systems will continue to expand because traffic growth forecasts indicate the need for greater communications capacity. Consequently, the financing of communications satellite has grown from a government organised, privately operated venture, to regulated and competitive part of the economic infrastructure. However, one critical factor confronting the satellite communication industry is the risk of damage, resultant disruption to service and liabilities due to collision as result of derelict satellite (Pelton et al., 2017).

The planning, building, launching, financing, and operating a communication satellite is a routine business for long term investment and its require a high up-front capital expenditure with a start-up period of 2 years, with a large number of high investment risk factors (Pelton et al., 2017). The effect of a satellite failure, in terms of cost and multiplier effect is huge, as noticeable in Zhicheng et al. (2006) containing an account of the failed NIGCOMSAT-1, which was de-orbited due to Electrical Power Subsystems defect in the Solar Array Drive Assembly (SADA), and replaced with NIGCOMSAT-1R.

The risk and cost associated with satellite failures like the NIGCOMSAT-1 is huge and by far outweighs the cost of carrying out a risk assessment of the space project. In the NIGCOMSAT-1 failure cited above, although the satellite was replaced at no cost to the Nigerian government, there were chances of collision with other satellite in the adjacent orbital slot when if it were not de-orbited. Even with the de-orbiting, the resulting space debris posed another risk for other satellites in orbit. To avert all these risk factors, the need for adequate and thorough risk analysis of critical components and risk priority analysis before satellite launch become crucial.

Fales (1984) observes that given the fact that the development and production programme for satellite communications terminals are affected by a variety of risks from both satellite and terminal development, an understanding of the effect and impact of these risks on the terminals becomes a crucial step towards mitigating the overall system risk. Risk analysis of a communication satellite should provide an insight into risk areas with a view to designing a good mitigation strategy, identify areas where management reserve can be committed early to risk reduction activities, and determine the appropriate level of management reserve (Fales, 1984), as shown in table 1.

Inferences from existing studies is that the above, requires the development of a risk management plan to take account of risks by identifying, and conducting analysis, following the root cause of each risk and the consequences of each risk and providing mitigating plans (Gamble, 2015; Gamble & Lightsey, 2014; Gamble & Lightsey, 2015; Gamble & Lightsey, 2016)

TABLE 1: STEPS IN RISK MANAGEMENT PLAN

Main Step	Sub-steps
A.Risk identification	1.Review the mission concept of operation 2.Identify root causes 3.Classify priority of risk 4.Name responsible person 5.Rank likelihood (L) and consequence(C) of root cause 6.Describe rationale for ranking 7.Compute mission risk likelihood and consequence values 8.Plot mission risks on L-C chart
B.Determine mitigation techniques	1.Avoid the risk by eliminating root cause and/or consequence 2.Control the cause or consequence 3.Transfer the risk to a different person or project 4.Assume the risk and continue in development
C. Track progress	Plot the mission risk values on an L-C chart at life-cycle or design milestones to see progress

Table 1: Steps of Risk Management Plan. Source: Gamble (2015)

A risk may be assessed either qualitatively or quantitatively. Risk management process utilizes rating scales for each of the risk factors with impact, likelihood, and time frame (National Research Council (U.S.), 2005). The impact of a risk event can be to cost, schedule and technical performance. Qualitative risk assessment provides relative values of the likelihood of occurrence and potential consequences of each risk, in general qualitative risk assessment method would be adequately for making risk management decision. Quantitative risk assessment which is usually undertaken for high, critical, or unmanageable risks as determined through the qualitative risk assessment is aimed at establishing the amount of contingency to be included in the estimate for the risks undergoing this assessment, such that should the risk(s) occur, there would be sufficient budgeted amount to overcome the extra expenditure (Srinivas, 2019). This is possibly because quantitative methods require more precise analyses and understanding of the risk or allocation of resources for risk reduction (GOES, 2013).

Although Meyer (2015) notes that quantitative risk analysis is less common in risk management of projects due to insufficient data about the project to perform this analysis of risk quantitatively, the practice of quantitative risk methods would be appropriate to the schedule, budget and risk forbearance of communication satellite mission and will result in more informed knowledge and more successful communication satellite missions.

The results from quantitative risk and reliability analysis were an important input into decision making during design process. These results provided ways to compare relative risks and to inform the decision makers. Key programmatic decisions that were influenced by the risk assessment results in the satellite industry include; choice of Crew Launch Vehicle (CLV), choice of propulsion system, choice of lunar mission mode, elimination of unnecessary radiation shield and definition of acceptable risk in a space mission.

However, the approach for this work was to contribute to the risk analysis of communication payload in order to make improvement in the payload system under analysis, which was based on reliability of the payload components by combining both criticality and risk priority number analysis compared to other works which were based on quality, safety, control or depending on the purpose for the FMEA. By including the quantitative risk assessment into the design process effectively blend the performance and risk within time and budget constraint were achieved (Dale, 2005).

2 METHODOLOGY

This research utilized both qualitative and quantitative research approaches. A purposive sampling, a non-probability sampling technique, that focuses on a particular characteristics of a population of interest, thus enabling answers to research questions. Team of engineers from different background in satellite industry participated to come up with the decision on the parameters of the Risk Priority Number (RPN) of each component. Tables related to each of these parameters can be found in the associated standards (ECSS-Q-ST-30-02C, 2009) (European Cooperation for Space Standardization (ECSS), 2009).

Table 2 shows the charting of failure effects severity to the performance of a satellite communication payload. “Severity classification category shall be assigned to each failure mode and component according to the failure effect.

TABLE 2: THE FOUR SEVERITY LEVELS OF FAILURE AS DEVELOPED BY MIL-STD-1628

Category	Effect	Criteria
4	Catastrophic	Failure mode capable of causing complete components, system and mission lost.
3	Critical	Failure mode capable of component damage, system degradation that could reduce the performance of the components or the system.
2	Major	Failure that could cause components damage, system damage that are not critical. It will lead to delay or loss of availability.
1	Minor	Failure that would not cause components damage, system degradation but could lead to unscheduled maintenance.

2.1 FAILURE MODE EFFECT CRITICALITY ANALYSIS (FME(C) A) APPLICATIONS FOR COMMUNICATION SATELLITE PAYLOAD

In line with the FMEA procedures of identifying the failure modes for each components of the system, it was essential to itemize failure modes for each component after decomposing the system into block diagram. The system design, assembly, and installation can provide the information needed for the failure modes for each unit component of the system (Harland & Lorenz, 2007).

The effect on the functional condition of the component under analysis caused by the loss or degradation of output shall be identified so the failure mode effect will be properly categorized" (MIL-STD-1629A, 1980) (Department of Defense United States of America, 1980).

Quantitative risk analysis data shortage gave room for organizations to come up with standards of requirement to meet up their needs, the military standard 1628 term as MIL-STD- 1628. (Liu at el 2013) came up with some ratings on failure occurrence, detection and severity as in table 3, table 4 and table 5 respectively below. These tables are used for computing and analysing the failure mode severity, occurrence and detection for the communication payload components risk analysis.

TABLE.3: SUGGESTED RATINGS FOR THE OCCURRENCE OF A FAILURE MODE

Probability of failure	**Possible failure rates**	**Rank**
Nearly impossible	≤ 1 in 150,000	1
Remote	1 in 150,000	2
Low	1 in 15,000	3
Relatively low	1 in 2000	4
Moderate	1 in 400	5
Moderately high	1 in 80	6
High	1 in 20	7
Repeated failures	1 in 8	8
Very high	1 in 3	9
Extremely high(failure almost inevitable)	≥1 in 2	10

Adapted from (Liu et al., 2013)

TABLE 4: SUGGESTED RATINGS FOR THE SEVERITY OF A FAILURE MODE.

Effect	**Severity of effect**	**Rank**
None	No effect	1
Very minor	Very minor effect on product or system performance	2
Minor	Minor effect on product or system performance	3
Low	Small effect on product performance. The product does not require repair	4
Moderate	Moderate effect on product performance. The product requires repair	5
Significant	Product performance is degraded. Certain functions may not operate	6
Major	Product performance is severely affected but functions. The system may not operate	7
Extreme	Product is inoperable with loss of primary function. The system is inoperable	8
Serious	Failure involves hazardous outcomes and/or noncompliance with government regulations or standards	9
Hazardous	Failure is hazardous, and occurs without warning. It suspends operation of the system and/or involves	10

	noncompliance with government regulations	

Adapted from (Liu et al., 2013)

TABLE 5: SUGGESTED RATINGS FOR THE DETECTION OF A FAILURE MODE

Detection	**likelihood of detection by design control**	**Rank**
Almost certain	Design control will almost certainly detect a potential cause of failure or subsequent failure mode	1
Very high	Very high chance the design control will detect a potential cause of failure or subsequent failure mode	2
High	High chance the design control will detect a potential cause of failure or subsequent failure mode	3
Moderately high	Moderately high chance the design control will detect a potential cause of failure or subsequent failure mode	4
Moderate	Moderate chance the design control will detect a potential cause of failure or subsequent failure mode	5
Low	Low chance the design control will detect a potential cause of failure or subsequent failure mode	6
Very low	Very low chance the design control will detect a potential cause of failure or subsequent failure mode	7
Remote	Remote chance the design control will detect a potential cause of failure or subsequent failure mode	8
Very remote	Very remote chance the design control will detect a potential cause of failure or subsequent failure mode	9
Absolute uncertainty	Design control does not detect a potential cause of failure or subsequent failure mode. Or there is no design control	10

Adapted from (Liu et al., 2013)

2.2 ANALYSIS

1. Criticality Analysis

Critical components are focused on criticality number as a result of multiplying severity number and occurrence number of each failure mode. Criticality number for failure mode usually ranks the potential of components risk of failure which is centered on the component failure mode occurrence and consequence of the failure effect as shown in table 6 below using the MIL-STD-1628 to determine the severity of failure mode of each component.

TABLE 6: PAYLOAD COMPONENTS CRITICALITY NUMBER COMPUTATION

Part Name	**Failure Mode**	**Severity Number**	**Occurrence Number**	**Criticality Number**
Receiver Components				
Input Waveguide Filter	Opening of connections	3	1	3
Input Stage Components				
Low Noise Amplifier	Input signal to down converter	4	1	4

(LNA)	distortion			
	Unstable input signal to down converter	4	1	4
Down Converter				
Oscillator	Disorder in the performance of down converter	2	1	2
PLL	Frequency intermission or disorder of output signal	2	1	2
Mixer	Power loss in output signal of mixer/ increase in the level of unwanted signals	2	1	2
	Low isolation between the openings	2	1	2
High Power Amplifier				
TWTA	High output power	3	1	3
	Output power loss	4	1	4
	Failure of TWTA	4	1	4
	tube or cathode			
CAMP	Failure of transponder	4	1	4
Fixed Amplifier	Interruption of the output signal of down converter	2	1	2
Variable Attenuator	Interruption of the output signal of transmitter	2	1	2

Components with criticality value of four (4) shows tendency of high concern in the system, from this it shows that high power amplifier and low noise amplifier component in the system are critical in the functioning of the satellite communication payload system. To avoid risk of failure of these components is to make provision for redundancy of the active components of the payload as mitigation measures.

2. Risk Priority Number (RPN)

RPN method uses three rankings to come up with an RPN value and these rankings are the probability of the failure-mode occurrence (O), the severity of its failure effect (S) and the probability of the failure being detected (D). These three are measured on a numerical scale and then multiplied with one another to get the RPN value for each component in the system as shown in table 7. Components with a high value of RPN signified that, the component has high risk of failure.

TABLE 7: RISK PRIORITY NUMBER COMPUTATION

Part Name	Failure Mode	O	S	D	RPN
Receiver Components					
Input Waveguide Filter	Opening of connections	3	7	5	105
Input Stage Components					
Low Noise Amplifier (LNA)	Input signal to down converter distortion	5	7	3	105
	Unstable input signal to down converter	4	9	1	36
Down Converter					
Oscillator	Disorder in the performance of down converter	2	9	2	36
PLL	Frequency intermission or disorder of output signal	3	7	2	42
Mixer	Power loss in output signal of mixer/ increase in the level of unwanted signals	2	7	2	28
	Low isolation between the openings	2	7	5	70
High Power Amplifier					
TWTA	High output power	4	10	1	40
	Output power loss	3	10	1	30
	Failure of TWTA tube or cathode	3	10	1	40
CAMP	Failure of transponder	3	7	1	21
Fixed Amplifier	Interruption of output signal of down converter	4	7	28	
Variable Attenuator	Interruption of the output signal	2	5	5	50

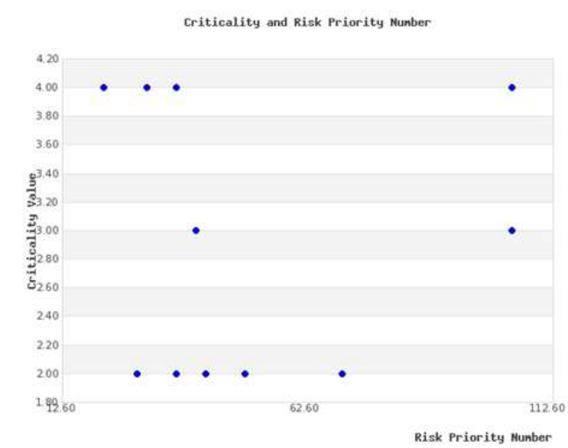
From the RPN analysis it's found that input filter, LNA, mixer has higher value of risk priority and translate to higher chances of risk failure.

3. Correlation Analysis

To establish the association between criticality of component (reliability) and component failure risk priority. Component criticality value is the independent variable while component risk priority number is the

TABLE 8: COMPONENT CRITICALITY AND RISK PRIORITY VALUES

Transponder Components	Components Criticality	Risk Priority Number
Input wave guide filter	3	105
Low Noise Amplifier 1	4	105
Low Noise Amplifier 2	4	36
Oscillator	2	36
Phase Lock Loop (PLL)	2	42
Mixer 1	2	28
Mixer 2	2	70
TWTA 1	3	40
TWTA 2	4	30
TWTA 3	4	30
CAMP	4	21
Fixed Amplifier	2	28
Variable Attenuator	2	50



3 RESULTS AND DISCUSSION

From the analysis of criticality of components using MIL-STD-1628 for the analysis, it shows that Low Noise Amplifier and High Power Amplifier components has critical value (4) four, and it means that at single point failure of these components would result to catastrophic severity effects on the satellite system and this might result to the total loss of signal from the payload and the mission would be at risk of failure.

While the RPN analysis, considering the suggested ratings adopted by Liu et al in their research and the ECSS-Q-STD-30-02C of space product assurance failure modes. The result shows that the input wave guide filter, Low noise amplifier, mixer and variable attenuator has high value of risk priority number 105,105,70, and 50 respectively. Some components with high criticality values like low noise amplifier of input stage component, High Power Amplifier components' has low value for risk priority number. In essence, these components with high RPN value signified high priority of risk

.

Theoretically, it would be that high critical components should have high risk failure priority and the correlation coefficient should be strong. The factors responsible for that not to happen in this study, is that some components with high severity rankings have low detection and occurrence rankings while some components with lower severity rankings with higher value of detection and occurrence rankings and this would definitely have higher value of risk failure priority when these rankings are multiplied out.

The result of the correlation coefficient shows a weak association with a value of r = 0.0488 between critical components and risk of failure, it would be expected that components with high criticality value should have strong association with risk priority of failure.

4 CONCLUSION

Considering single point failure mode of the communication payload components in Table 2, from the four severity level of failure developed by MIL-STD-1628 and components with failure effect of causing complete component, system and mission lost has criticality value of (4) four. Components such as low noise amplifier of the input stage, high power amplifier components are of high criticality values as a result of the criticality analysis of the sample data collected for the study as shown in table 6 and it implies that any failure of these components would bring about mission lost.

To avert or mitigates the effect of single point failure of these active components, a redundancy or back- up components should be incorporated in the design such that at the event of failure of any active components the back-up components would take active position to prevent total system failure.

The risk priority number, is similar to the criticality number, the difference is in computing for the criticality number to determine the critical components only the severity of failure and probability of failure occurrences are considered while in the risk priority number both the probability of failure mode, severity of failure effects and the probability of failure detection are computed.
Table 7 shows that components with high value of risk priority number are of high chances of failure, similar to criticality number. While performing correlation analysis to ascertain the association of criticality number and risk failure priority number, it shows a no correlation.

The study demonstrated that critical components are not necessary the components with high risk failure priority, in as much as components with high critical value are kept in watch likewise components with high risk failure priority number.

.

ACKNOWLEDGEMENTS

All glory is to All Mighty, I sincerely appreciate and grateful to the head and the entire staff of network operation center of NigComSat for their understanding and assistance.

REFERENCE

Akinyede, J., & Agbaje, G. (2006). *Nigeria's Satellite Data Utilisation for Sustainable Development.* Paper presented at the Proceedings of the ISPRS Commission VII Symposium 'Remote Sensing: From Pixels to Processes', XXXVI (7), Enschede, The Netherlands.

Bargellini, P. L., & Edelson, B. I. (1977). Progress and Trends in Commercial Satellite Communications—a Survey. In L. G. Napolitano (Ed.), *Space and Energy* (pp. 259-276): Pergamon.

Boroffice, R. A. (2008). The Nigerian Space Programme: An Update. *African Skies, 12*, 40.

Braun, T. M. (2012). *Satellite Communications Payload and System*. New Jersey: John Wiley & Sons, Inc.

Chronaki, C. E., Berthier, A., Lleo, M. M., Esterle, L., Lenglet, A., Simon, F., . . . Braak, L.

(2007). A Satellite Infrastructure for Health Early Warning in Post-Disaster Health Management. *Stud Health Technol Inform, 129*(Pt 1), 87-91.

Chukwu-Okoronkwo, S. O. (2015). Nigerian Communication Satellite and the Quest for Sustainable National Development. *American Journal of Social Science Research, 1*(1), 1-8.

Dale, F. C., Stephen Grey, Geoffrey Raymond and Phil Walker (2005). *Project Risk Management Guidelines* West Sussex England John Wiley and Sons Ltd.

Department of Defense United States of America. (1980). Mil-Std-1629a - Procedures for Performing a Failure Mode, Effects, and Criticality Analysis. Washington, DC: United States Department of Defense.

Dinas, P. C., Mueller, C., Clark, N., Elgin, T., Nasseri, S. A., Yaffe, E., . . . Asrar, F. (2015). Innovative Methods for the Benefit of Public Health Using Space Technologies for Disaster Response. *Disaster medicine and public health preparedness, 9*(3), 319-328.

ECSS-Q-ST-30-02C. (2009). *Space Product Assurance, Failure Modes and Effects Analysis (Fmea)*

European Cooperation for Space Standardizatio (ECSS). (2009). Space Product Assurance: Failure Modes, Effects (and Criticality) Analysis (Fmea/Fmeca) *ECSS- Q- ST- 30-02C* (pp. 74). The Netherlands: ESA Requirements and Standards Division (European Space Agency for the members of ECSS).

Fales, R. L. (1984). *Risk Analysis and Satellite Communications Terminals.* Paper presented at the MILCOM 1984-IEEE Military Communications Conference.

Gamble, K. B. (2015). *A Software Tool Suite for Small Satellite Risk Management.* (PhD PhD Dissertation), The University of Texas at Austin, Austin Texas.

Gamble, K. B., & Lightsey, E. G. (2014). Cubesat Mission Design Software Tool for Risk Estimating Relationships. *Acta Astronautica, 102*, 226-240. doi:https://doi.org/10.1016/j.actaastro.2014.06.019

Gamble, K. B., & Lightsey, E. G. (2015). *Decision Analysis Applied to Small Satellite Risk Management.* Paper presented at the 53rd AIAA Aerospace Sciences Meeting.

Gamble, K. B., & Lightsey, E. G. (2016). Decision Analysis Tool for Small Satellite Risk Management. *Journal of Spacecraft and Rockets*, 420-432.

Garshnek, V. (1991). Applications of Space Communications Technology to Critical Human Needs: Rescue, Disaster Relief, and Remote Medical Assistance. *Space communications, 8*(3-4), 311-317.

Risk Management Plan (2013).

Goh, D. (2018). Satellite Technology and Disaster Management: Lombok Earthquakes. *SpaceTech Asia*. Retrieved from SpaceTech Asia website: http://www.spacetechasia.com/satellite-technology-and-disaster-management-lombok-earthquakes/

GVF Training, & MahdiBagh Computers PVT. Ltd. (2008). *Satellites and Launch Vehicles*. Paper presented at the ITU Satellite Symposium 2018, Geneva, Switzerland. https://www.itu.int/en/ITU-R/space/workshops/2018-SmallSat/

Harland, D. M., & Lorenz, R. (2007). *Space Systems Failures: Disasters and Rescues of Satellites, Rocket and Space Probes* (1 ed.). Switzerland: Springer Science & Business Media.

Liu, H. C. (2016). *Fmea Using Uncertainty Theories and Mcdm Methods*: Springer Singapore.

Meyer, W. G. (2015). *Quantifying Risk: Measuring the Invisible.* Paper presented at the PMI Global Congress, England Newtown Square.

MIL-STD-1629A. (1980). *Procedures for Performing a Failure Mode, Effects and Criticality Analysis*: Springer.

NASA. (2008). *Agency Risk Management Procedural Requirements*

NASA AMES Research Centre. (March 29, 2008). Missions Operations Risk Management. Retrieved from https://www.nasa.gov/centers/ames/research/technology-onepagers/mission_ops_risk_mngt.html

National Research Council (U.S.). (2005). Risk Identification and AnalysisThe owner's role in project risk management. Washington, DC: National Academies Press.

Pelton, J. N., Madry, S., & Camacho-Lara, S. (2017). *Handbook of Satellite Applications*: Springer Publishing Company, Incorporated.

Pelton, J. N., Madry, S., & Camacho Lara, S. (2013). Satellite Applications Handbook: The Complete Guide to Satellite Communications, Remote Sensing, Navigation, and Meteorology. In J. N. Pelton, S. Madry, & S. Camacho-Lara (Eds.), *Handbook of Satellite Applications* (pp. 3-17). New York, NY: Springer New York.

Spagnulo, M. F., R.;Baldduccini,M.;Nasini,F. (2013). *Space Program Management Methods and Tools*.

Srinivas, K. (2019). Process of Risk Management. In A. Hessami (Ed.), *Perspectives on Risk, Assessment and Management Paradigms*. London: IntechOpen Limited.

Stanniland, A., & Curtin, D. (2013). An Examination of the Governmental Use of Military and Commercial Satellite Communications. In J. N. Pelton, S. Madry, & S. Camacho-Lara (Eds.), *Handbook of Satellite Applications* (pp. 187-219). New York, NY: Springer New York.

Wagstaff, J. (2008). Space Technology: A New Frontier for Public Health: Satellite Technologies Are a Natural Ally in Public Health Emergencies for Tracking the Extent of Disease Outbreaks and Natural Disasters. Jeremy Wagstaff Explains Why They Have Only Become Really Useful over the Past 10 Years. *Bulletin of the World Health Organization, 86*(2), 87-89.

Walter, L. S. (1990). The Uses of Satellite Technology in Disaster Management. *Disasters, 14*(1), 20-35. doi:10.1111/j.1467-7717.1990.tb00969.x

Zhicheng, Z., Min, W., & Qiang, W. (2006, 2 - 6 October 2006). *Nigcomsat-1, the First Export Commercial Communications Satellite of China.* Paper presented at the 57th International Astronautical Congress (IAC2006, Valencia, Spain.