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Risk Mitigation Strategies for Reliability Improvement of University Built Satellite Programs

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Abstract

Risk Mitigation Strategies for Reliability Improvement of University Built Satellite Programs

by

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The University of Texas at Austin, 2010

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University-built satellite programs are prone to failure because these projects are performed by inexperienced student-engineers during the early parts of the satellite-building "learning curve". However, with sufficient attention on risk management, students should be able to identify what risk avoidance actions should be taken, and when. By applying risk mitigation strategies, university built satellite programs will not only contribute students to learn space systems engineering, but also accomplish their scientific missions with higher rates of success.

This thesis study is aimed to provide risk management guidelines that could be adapted to university built satellite programs to increase the risk awareness. Besides indicating the key strategies for risk mitigation, a set of risk management procedures are prepared to help students during the university-built satellite projects.

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Chapter 1: Introduction

Investigating the management and risk analysis of university-class small satellites is an important topic in today's high technology learning environment. Student teams are increasingly becoming involved in satellite building projects. The reasons behind this are many.

First of all, the trend toward miniaturization in electronics has helped to reduce the size and weight of satellites, which can now perform the same functions as their bulkier predecessors but at a decreased cost. The ongoing enhancement of microsatellite capabilities is providing increased access to space at reduced cost because these satellites are smaller and are thus cheaper to produce and to launch (1). A fast-growing small satellite industry has enabled not only industries but also academia to build their own increasingly capable and cost effective satellites.

Moreover as microsatellite technology has become widespread, the partnership between military, commercial and academic groups is providing new opportunities. At the Next-Generation Suborbital Researchers Conference, Commercial Spaceflight Federation chairman Mark Sirangelo announced the creation of a new affiliates program for universities, other research and educational institutions in 2010 (2). As some of the boundaries disappear between civil and military satellites, there are increasing possibilities of joint space projects with university built satellite projects having a "real" mission to achieve, these programs should have appropriate systems engineering and risk management procedures.

1.1. Motivation

Risk permeates every aspect of any satellite project. In any project, there is the potential for unforeseen events to produce negative consequences. Risk management is crucial for space missions which are costly and have little or no possibility of after-launch repairs.

Student satellite projects have learning as their first objective. Hence failure can sometimes be expected. In spite of the fact that students and university-built satellite projects have freedom to fail, which is a luxury for space industry projects, this should not be an excuse to ignore risks which can be mitigated. Students learn from mistakes, but taking unnecessary risks in terms of mission objectives, requirements etc. should not be allowed.

Students can consider risk and its management, if they are taught to do so. Therefore, risk strategies specifically designed for student projects would be very useful in university-built satellite programs. Graduating students who have worked on satellite projects where risk was assessed would be a major asset for the space industry.

1.2. Risk Management

In order to provide a basic understanding of risk management procedures, and their application, terms commonly used throughout this study will be defined here.

Risk is a measure of future uncertainties in achieving program goals and objectives within defined cost, schedule and performance constraints as it is defined in Risk Management Guide for DOD Acquisition (3). The consequences of risks have a very broad range (performance reduction, cost increase, schedule delays, mission failure, and/or spacecraft damage).

Risk management is an organized, systematic risk-informed decision making discipline that proactively identifies, analyzes, plans, tracks, controls, communicates, documents, and manages risk to increase the likelihood of achieving project goals (4). Risk management is a general term used to describe a multi-step process which is commonly applied with a technique called Continuous Risk Management (CRM). In CRM (Figure 1), each step of the paradigm builds on the previous step, leading to improved designs and processes through the feedback of information generated (5).

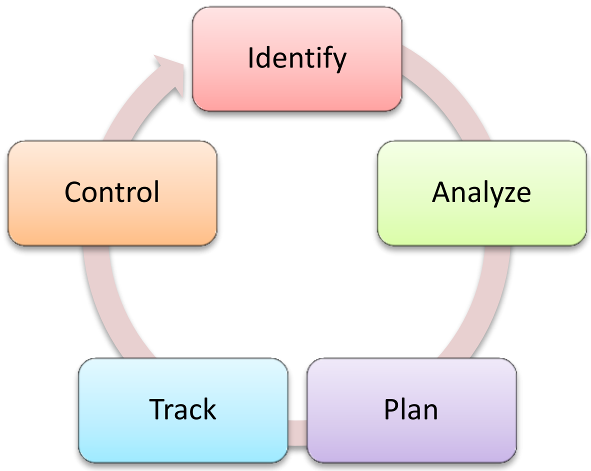

Figure 1: Continuous Risk Management (CRM) (5)

The first step in risk management is to examine each element of the program to identify all individual risks that can affect the project's objectives in terms of cost, schedule and technical performance.

Risk analysis is defined as "the process of quantifying both the likelihood of occurrence and consequences of potential future event" (4). Each identified risk should be studied to be able to isolate the root cause, and determine the effects, support setting risk mitigation priorities.

Risk mitigation planning "is the activity that identifies, evaluates, and selects options to set risk at acceptable levels given program constraints and objectives" (3). For each root cause or risk, a type of mitigation must be determined and the details of the mitigation described.

Risk tracking is “the activity of systematically tracking and evaluating the performance of risk mitigation actions against established metrics throughout the acquisition process. It feeds information back into the other steps of risk identification, analysis, mitigation” (3).

As a result, the ultimate purpose of risk management is to reduce the magnitude of risk by proper mitigating actions in order to achieve the mission objectives; it involves revising the project schedule, budget, scope or quality (6).

1.3. Objectives and Organization of this Thesis

The objective of this thesis is to stimulate risk awareness and to assist students in risk identification and mitigation. In order to achieve this goal, a process guide and an implementation template have been devised that can easily be applied to any university-built satellite program. The body of this thesis is structured as two parts;

Chapter 2 gives an overview of university-built satellite reliability and sub-system level failure analysis with comparison to industry-built satellites. A database for university-built small satellites created by Swartwout (7) has been used to derive results. The subsystem characteristics, launch trends, and failure types are analyzed and compared with the corresponding trends for industry-built satellites.

In Chapter 3 risk management is studied in depth. The risk factors specific to university-built satellites are defined, their causes and remedies are investigated. After an overview of currently available industrial risk management standards, suggestions on how risk management could be implemented for university projects are presented. In addition, commonly used risk management methods and tools are defined and compared while their probable application and benefits are discussed. The following Risk management templates - instructions for their use, and examples are provided in Appendices.

- APPENDIX A. Risk Management Checklist)
- A Risk Register (APPENDIX B. Risk Register: An Example)
- Top Ten Risk List (APPENDIX C. Top Ten Risk List)
- Lessons Learned Documentation (APPENDIX D. Lessons Learned Documentation)
- Risk Matrix and Risk Mapping (Section 3.6)

Chapter 4 presents a summary of the thesis, a set of instructions on implementing risk management templates and propose possible future studies. The contributions to student projects are listed. Additionally, procedures for risk management implementation into university-built satellite programs are discussed.

Chapter 2: Space System Subsystem Characteristics and Reliability

Before developing a procedure for risk management for university-class satellites, it is necessary to investigate such risks at the system-level. Collecting information on historical small satellite missions, generating trends from the data and analyzing them, enables one to be able to see what has changed over time. Benchmarking small satellite programs will also highlight the similarities or differences of the university-class satellites with respect to those built by industry.

Furthermore, the analysis of satellite failures will give an understanding of whether student-built satellites are prone to certain types of failures and how these failures can be diminished. By taking subsystem characteristics of satellites into account, the points where risks are concentrated will become clearer.

As a principal factor in system design, reliability plays a key role in determining a system's effectiveness. Reliability can be defined as the probability that a system will not fail for a given period of time under specified operating conditions (8). Reliability is increased in the systems engineering process through actively implementing specific design features to ensure that the system can perform in the predicted physical environments throughout the mission.

Characterization of satellite subsystem failures is the object of this chapter. In order to have a better understanding in these failures, a database of student-built satellite failures is compared with industry-built satellite failure data. This comparison will lead to the development of risk management procedures for university satellite programs.

2.1. Industry Built Satellite Systems

Risk management and systems engineering procedures are common in industry since the development of large, complex, and operational systems are overwhelming and risky. Industry programs are characterized by long duration and large budgets whereas the university programs have short duration and are characterized by much less funding.

Industry satellite projects have highly defined objectives and requirements. Full success is hard to achieve for industry satellite projects whereas university projects can fully accomplish its goals with a project that does not work as planned. Even though a university satellite suffers a failure, the program would often be still considered as successful since the primary mission objective is the education of the students.

Universities use satellite building programs to create the maximum student motivation and knowledge return. Industries use budget and schedule to develop an operationally significant mission. Risk management is necessary for both types programs, but with fundamentally different foci.

2.1.1. Industry-Built Satellite Database and Subsystem Failures

Despite many years of industry experience with satellites, failures still occur. However in today's environment, satellite reliability can be improved if space community manages to take advantage of lessons learned from failures. Importantly, analyzing anomalies may answer the question, "What types of components are the most trouble-prone?"

In order to avoid repetition of mistakes, The Aerospace Corporation began developing the Space Systems Engineering Database (SSED) in 1992 to acquire and manage validated technical information (9) and (10). As of June 2001, The U.S. Air Force Space and Missile Systems Center (SMC) had implemented the "Space Systems Engineering Lessons Learned" system with 16 published lessons from failures and 25 more lessons are targeted in Table 1.

Table 1, reproduced below, provides insight into the failure modes documented by the Aerospace Corporation. Each entry in the table is a 'lesson learned' from one or more failures. The lessons learned are presented in the form of recommended actions stemming from failures. In the table, some failures have resulted from "catastrophic events" and others from "critical events". NASA (8) defines severity of a failure by outlining a catastrophic event as it is one where a failure could cause loss of life or vehicle whereas a critical event is one where failure could cause loss of mission. Other lessons come from various types of performance degradations and/or anomalies.

Table 1. Space Systems Lessons Learned (4)

Systems Engineering

- Carefully evaluate satellite-launcher interface (a catastrophic failure)
- Rigorously trace and verify every requirement (a catastrophic failure)
- Document engineering requirements as clearly as possible (2 catastrophic failures)
- Perform high-fidelity system validation tests for pyrotechnics (catastrophic failures)
- Systematically monitor and control contamination (numerous on-orbit degradations)

Software

- Rigorously manage and test software, including the database (a catastrophic failure)

Guidance, Navigation and Control

- Perform independent mass property, stability control, and structural load analyses on spacecraft and launch vehicles (numerous catastrophic failures)

Structures and Mechanisms

- Vent honeycomb structures to reduce delamination risk (numerous catastrophic failures and in-factory mishaps)
- Avoid excessive handling of solid lubricant, which can destroy it (several on-orbit degradations)

Electrical Power Subsystem

- Design and thoroughly test solar arrays to withstand extreme environments (numerous on-orbit catastrophic failures and degradations)

Propulsion

- Avoid separable flared fittings (numerous on-ground anomalies and one catastrophic failure)

Thermal

- Acknowledge that flexible solar arrays are susceptible to thermally induced vibrations (three catastrophic failures and three degradations)

Manufacturing, Parts, Materials and Processes

- Avoid pure tin plating (four catastrophic failures and several in-factory mishaps)
- Look beyond specifications in qualifying materials by similarity (an on-orbit anomaly and two ground mishaps)
- Watch out for secondary damage following a major repair (two catastrophic failures)

Space Environment and Operations

- Design satellites to withstand space weather, regardless of solar cycles (numerous catastrophic failures)

To help increase the odds of finding mistakes, 1584 Earth-orbiting satellites have been analyzed launched from 1990 to 2008 using SpaceTrak® database by Jean-Francois Castet and Joseph H. Saleh (11). The captured "culprit subsystems", subsystems contribute to the loss of satellite, are provided in Figure 2 in time-fixed results for failures after 30 days, 1-year, 5-years, and 10-years.

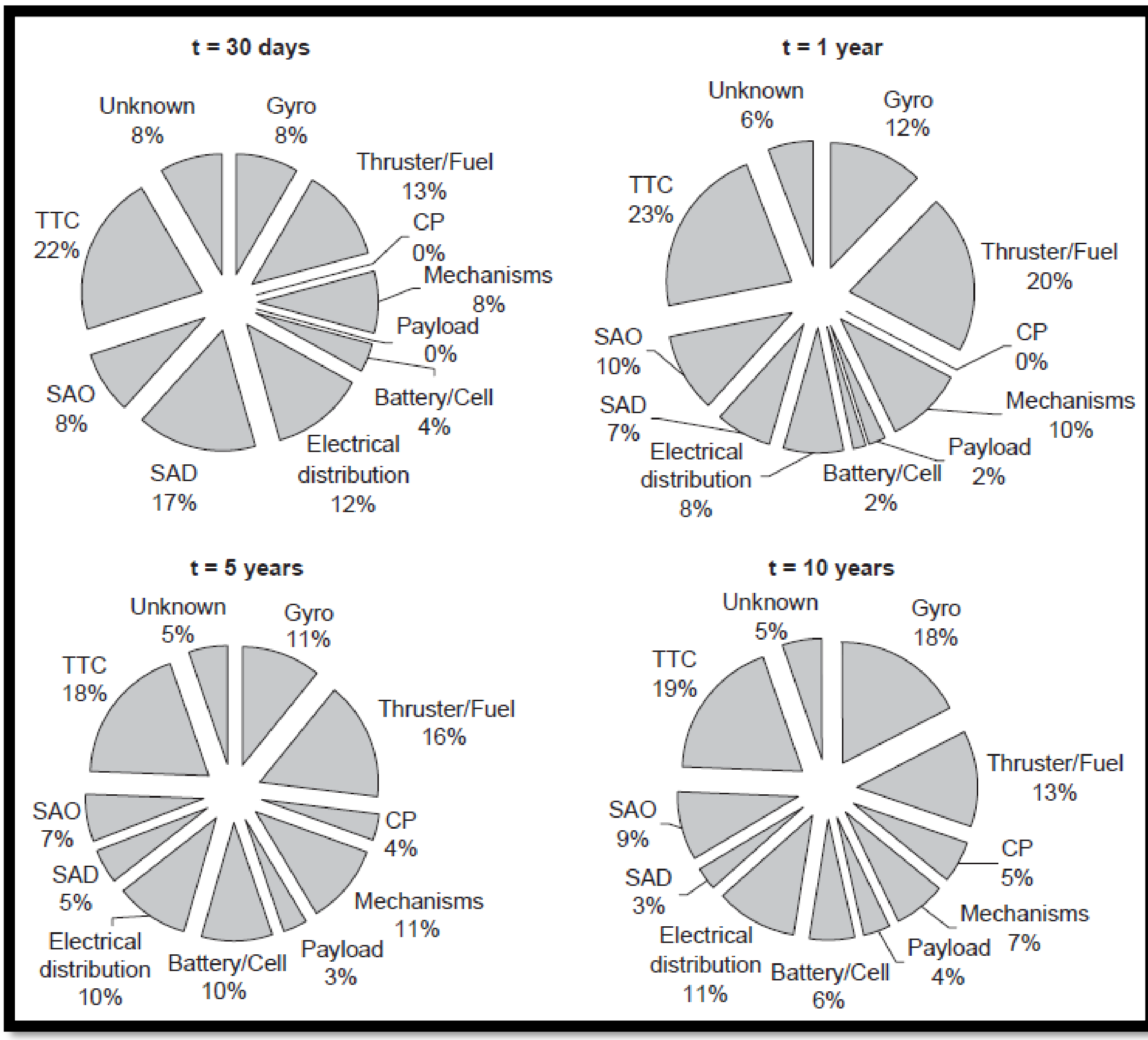

Figure 2. Culprit Subsystems (11)

According to figure, Telemetry, Tracking and Command (TTC) is the lead contributor from 18% up to 23% to satellite failure at any discrete point in time. Similarly, Gyro, Sensor and Reaction wheel (referred simply as Gyro) are the second leading contributor to failure with 18% of satellite failures after 10 years of period. In addition, Thruster/Fuel has a relative contribution hovering around 20% to 16% after 1-year and 5-years of on-orbit operation. Other factors are; solar array deployment (SAD), solar array operating (SAO), control processor (CP), mechanisms/ structures/ thermal (mechanisms), payload instrument/ amplifier/ on-board data/ computer/ transponder (payload) and electrical distribution. The most significant observation is that infant mortality of the satellite is most likely (50%) driven by TTC, Gyro, and followed by Thruster/Fuel subsystems.

Despite the recent interests and publications in Lessons Learned Information System of NASA, most of the space community is still unaware of the knowledge available from their own history.

2.2. University-Built Satellites

Students build satellites as a part of their education. Making mistakes and learning from them are some of the most important parts of a students' education. However, students can learn from mistakes of their peers. They do not need to make the same mistakes as their predecessors.

2.2.1. Benchmarking

The importance of a database focused on university-class satellites failures is that it helps to identify potential error sources before they are encountered on a project and helps student engineers to understand the critical subsystems which tend to fail most. However, most such university-class spacecraft information has not been published. Despite the sparseness of such information, a database has been created by Swartwout (7) on university-class satellites from various online sources, conference proceedings, launch logs and interviews. Swartwout's list of university-class spacecraft launched from 1981 to 2009 with their technical specifications on mass, mission duration, and mission type are presented in Table 2.

According to Swartwout, a satellite can be classified as a "university-class satellite" under certain conditions.

1) It is a functional spacecraft, rather than a payload instrument or component. To fit the definition, the device must operate in space with its own independent means of communications and command. However, self-contained objects that are attached to other vehicles are allowed under this definition (e.g. PCSat-2, Pehuensat-1).
2) Untrained personnel (students) performed a significant fraction of key design decisions, integration & testing activities, and flight operations.
3) The training of these people is as important as (if not more important) the nominal "mission" of the spacecraft itself.

Therefore, this university-class satellite database excludes many student-built satellites such as student labeled $15 million NASA science missions and 3-kg Sputnik re-creations or where the university contributes the primary payload. Moreover, space programs in which spacecraft mission performance is stronger driver than student education are also omitted in Swartwout's table (University of Surrey, University of Toronto, and the Korean Advanced Institute of Science and Technology (12)).

In the table, schools are classified as flagship or independent according to their funding sources; significantly sponsored projects from government (Flagship), self-funded projects (Independent). Furthermore the missions are categorized according to its type, Technology (T), Science (S), Communication (C), and Education (E) and status, Non-Operational (N), Semi-Operational (S), Active (A), Failed (F), and Launch Failure (LF).

Table 2. Swartwout's University-Class Satellite Database (12)

Launch	Mission	Primary School	Nation	Mass (kg)	Mission Duration (months)	Status	Type
1981	Uosat-1	University of Surrey	UK	52	96	N	S
1984	Uosat-2	University of Surrey	UK	60	281	N	C
1985	NUSAT	Weber State, Utah State University	USA	52	20	N	T
1990	WeberSAT	Weber State	USA	16	96	N	C
1991	TUBSAT-A	Technical University of Berlin	Germany	35	210	N	C
1992	KITSAT-1	Korean Advanced Institute of Science and Technology	Korea	49	77	N	T
1993	ARSENE	CNES Amateurs	France	154	4	F	C
	KITSAT-2	Korean Advanced Institute of Science and Technology	Korea	48	96	N	C
1994	TUBSAT-B	Technical University of Berlin	Germany	45	1	F	T
	BremSat	University of Bremen	Germany	63	11	N	S
1995	Techsat 1-A	Technion Institute of Technology	Israel	50	-	LF	C
	UNAMSAT-A	National University of Mexico	Mexico	10	-	LF	C
1996	UNAMSAT-B	National University of Mexico	Mexico	10	0	F	C
1997	Falcon Gold	US Air Force Academy	USA	18	0.5	N	T
	YES	ESA/ESTEC	Europe	187	0.1	N	E
	RS-17	Russian high school students	Russia	3	2	N	E
1998	TUBSAT-N	Technical University of Berlin	Germany	8	46	N	T
	TUBSAT-N1	Technical University of Berlin	Germany	3	20	N	T
	Techsat 1-B	Technion Institute of Technology	Israel	70	51	N	S
	PANSAT	Naval Postgraduate School	USA	70	60	N	C
	SEDSAT	University of Alabama	USA	41	33	F	T
1999	Sunsat	University of Stellenbosch	South Africa	64	23	N	C
	DLR-TUBSAT	Technical University of Berlin	Germany	45	120	N	S
	KITSAT-3	Korean Advanced Institute of Science and Technology	Korea	110	55	N	T
2000	JAWSAT	Weber State, USAFA	USA	191	1	F	T
	Falconsat 1	US Air Force Academy	USA	52	1	F	E
	ASUsat 1	Arizona State University	USA	6	0	F	E
	Opal	Stanford University	USA	23	29	N	T
	JAK	Santa Clara University	USA	0.2	0	F	E
	Louise	Santa Clara University	USA	0.5	0	F	S

Table 2. (continued)

Launch	Mission	Primary School	Nation	Mass (kg)	Mission Duratin (month	Status	Type
	Thelma	Santa Clara University	USA	0.5	0	F	S
	Tsinghua-1	Tsinghua University	China	49	30	N	E
	TiungSAT-1	ATSB	Malaysia	50	39	N	S
	Saudisat 1A	King Abdulaziz City for Science and Technology	Saudi Arabia	10	36	N	C
	Saudisat 1B	King Abdulaziz City for Science and Technology	Saudi Arabia	10	27	N	C
	UNISAT 1	University of Rome	Italy	12	24	N	E
	Munin	Umea University/Lulea University of Technology	Sweden	6	3	N	S
2001	Sapphire	Stanford, USNA, Washington University	USA	20	36	N	E
	PCSat 1	US Naval Academy	USA	12	96	S	C
	Maroc-TUBSAT	Technical University of Berlin	Germany	47	96	A	S
2002	Saudisat 1C	King Abdulaziz City for Science and Technology	Saudi Arabia	10	82	A	C
	UNISAT 2	University of Rome	Italy	17	24	N	E
2003	QuakeSat	Stanford University	USA	3	61	N	S
	CUTE-1	Tokyo Institude of Technology	Japan	1	75	S	E
	XI-IV	University of Tokyo	Japan	1	75	A	E
	CanX-1	University of Toronto	Canada	1	0	F	E
	AAU Cubesat	University of Aalborg	Denmark	1	3	F	E
	DTUsat	Technical University of Denmark	Denmark	1	0	F	E
	STSAT-1	Korean Advanced Institute of Science and Technology	Korea	100	72	A	T
	Mozhayets 4	Mozhaisky Military Academy	Russia	64	72	A	C
2004	Naxing-1	Tsinghua University	China	25	66	A	T
	SaudiSat 2	King Abdulaziz City for Science and Technology	Saudi Arabia	15	63	A	S
	SaudiComsat-1	King Abdulaziz City for Science and Technology	Saudi Arabia	12	63	A	C
	SaudiComsat-2	King Abdulaziz City for Science and Technology	Saudi Arabia	12	63	A	C
	UNISAT 3	University of Rome	Italy	12	63	A	T
	3CS: Sparky	ASU/NMSU/CU Boulder	USA	16	-	LF	E
	3CS: Ralphie	ASU/NMSU/CU Boulder	USA	16	-	LF	E
2005	PCSat 2	US Naval Academy	USA	12	13	N	C

Table 2. (continued)

Launch	Mission	Primary School	Nation	Mass (kg)	Mission Duratin (month	Status	Type
	XI-V	University of Tokyo	Japan	1	47	S	E
	Mozhayets 5	Mozhaisky Military Academy	Russia	64	0	F	E
	UWE-1	University of Wurzburg	Germany	1	1	F	E
	Ncube II	Norwegian Universities	Norway	1	0	F	E
	SSETI Express	European Universities	Europe	62	0	F	C
2006	CUTE-1.7	Tokyo Institute of Technology	Japan	10	1	F	C
	Falconsat 2	US Air Force Academy	USA	20	-	LF	S
	UNISAT 4	University of Rome	Italy	12	-	LF	E
	Ncube	Norwegian Universities	Norway	1	-	LF	E
	KUTESat	University of Kansas	USA	1	-	LF	E
	CP2	Cal Poly San Luis Obispo	USA	1	-	LF	E
	CP1	Cal Poly San Luis Obispo	USA	1	-	LF	E
	ION	University of Illinois	USA	2	-	LF	T
	ICE CUBE1	Cornell University	USA	1	-	LF	T
	ICE CUBE2	Cornell University	USA	1	-	LF	T
	PiCPoT	Politechnico di Torino	Italy	2.5	-	LF	E
	SEEDS	Nihon University	Japan	1	-	LF	E
	SACRED	University of Arizona	USA	1	-	LF	E
	Rincon	University of Arizona	USA	1	-	LF	E
	MEROPE	Montana State University	USA	1	-	LF	S
	HAUSAT-1	Hankuk Aviation University	South Korea	1	-	LF	E
	Baumanets 1	Bauman Moscow State Technical University	Russia	92	-	LF	E
	HITSat	Hokkaido Institude of Technology	Japan	2.7	5	N	C
	RAFT-1	US Naval Academy	USA	1	5	N	C
	MARScom	US Naval Academy	USA	1	5	N	C
	ANDE	US Naval Academy	USA	75	12	N	C
2007	LAPAN-Tubsat	Technical University of Berlin	Germany	56	33	A	C
	PEHUENSAT-1	National University of Comahue	Argentina	6	3	N	C
	Falconsat 3	US Air Force Academy	USA	54	31	A	S
	MidSTAR-1	US Naval Academy	USA	120	31	A	T
	Saudi ComSat-3	King Abdulaziz City for Science and Technology	Saudi Arabia	12	30	A	C
	Saudi ComSat-4	King Abdulaziz City for Science and Technology	Saudi Arabia	12	30	A	C

Table 2. (continued)

Launch	Mission	Primary School	Nation	Mass (kg)	Mission Duration (months	Status	Type
	Saudi ComSat-5	King Abdulaziz City for Science and Technology	Saudi Arabia	12	30	A	C
	Saudi ComSat-6	King Abdulaziz City for Science and Technology	Saudi Arabia	12	30	A	C
	Saudi ComSat-7	King Abdulaziz City for Science and Technology	Saudi Arabia	12	30	A	C
	CP4	Cal Poly San Luis Obispo	USA	1	5	N	E
	CP3	Cal Poly San Luis Obispo	USA	1	5	N	E
	Libertad-1	University of Sergio Arboleda	Columbia	1	1	N	E
	CAPE-1	University of Louisiana	USA	1	5	N	E
	YES2/Floyd	ESA-led partnership	Europe	30	0	N	T
	Yes2/Fotino	ESA-led partnership	Europe	6	0	F	T
2008	Cute 1.7	Tokyo Institude of Technology	Japan	2	17	A	E
	CanX-2	University of Toronto	Canada	2	17	A	T
	AAU Cubesat II	University of Aalborg	Denmark	1	17	A	T
	SEEDS 2	Nihon University	Japan	1	17	A	E
	COMPASS 1	Fachhochschule Aachen	Germany	1	17	S	E
	Delfi-C3	Technical University of Delft	Netherlands	3	17	S	T
2009	SpriteSat	Tohoku University	Japan	50	0	F	S
	PRISM	University of Tokyo	Japan	8	9	A	T
	KKS 1	Tokyo Metropolitan College of Industrial Technology	Japan	3	0	F	T
	STARS 1	Kagawa University	Japan	8	0	F	T
	ANUSAT	Anna University	India	38	6	A	C
	CP6	Cal Poly San Luis Obispo	USA	1	5	A	E
	BEVO-1	University of Texas	USA	5	3	S	T
	AggieSat2	Texas A&M University	USA	3.2	3	S	T
	SumbandilaSat	University of Stellenbosch	South Africa	80	2	A	T
	UGATUSAT	Ufa State Aviation Technical University	Russia	30	2	A	T
	UWE-2	University of Wurzburg	Germany	1	1	A	E
	SwissCube-1	Ecole Polytechnique Federale de Lausanne	Switzerland	1		A	S
	BeeSat	Technical University of Berlin	Germany	1		A	T
	ITU-pSat	Istanbul Technical University	Turkey	1		A	E

From Swartwout's table, we see that there have been 119 university-class satellites built by 61 universities in 24 countries, launched since 1981. Figure 3, below, captures the Table 2 as a whole in terms of numbers and shows the sharp increase in manifested spacecraft numbers. The chart is mainly divided into five-year periods and percentage of satellites in these periods; however year 2000 needs an additional zone itself since it was the break-out year for university-built satellites.

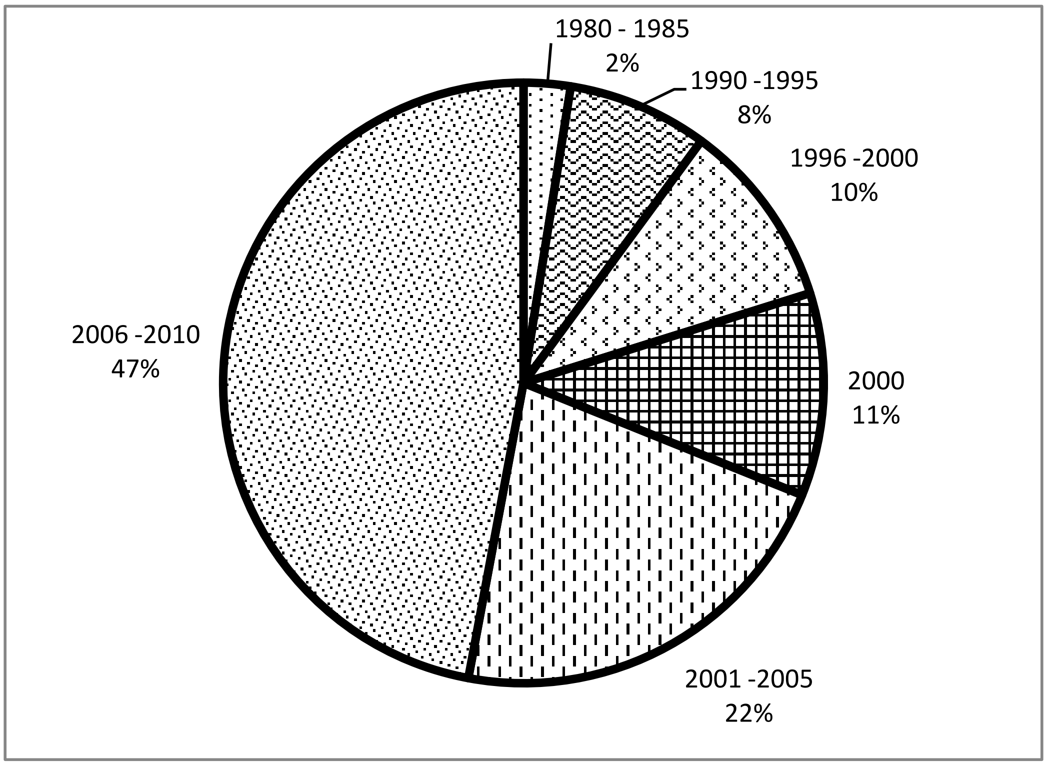

Figure 3. Total number of manifested University-Class Satellites

In reviewing the list of satellites, one thing is obvious that university-class spacecraft are becoming smaller with time. After exponential curve-fitting, the figure proves that the trend is towards building either 1-kg class CubeSat or 15-30 kg class Nanosat as shown in Figure 4.

In Figure 4, the continuous line shows all university-built satellites' change in mass with respect to time. And to be able to obtain a detailed point of view on if a specific type of satellite is becoming lighter and lighter, different mission types Education (E), Science (S), Technology (T), and Communication (C) are also shown with different line styles.

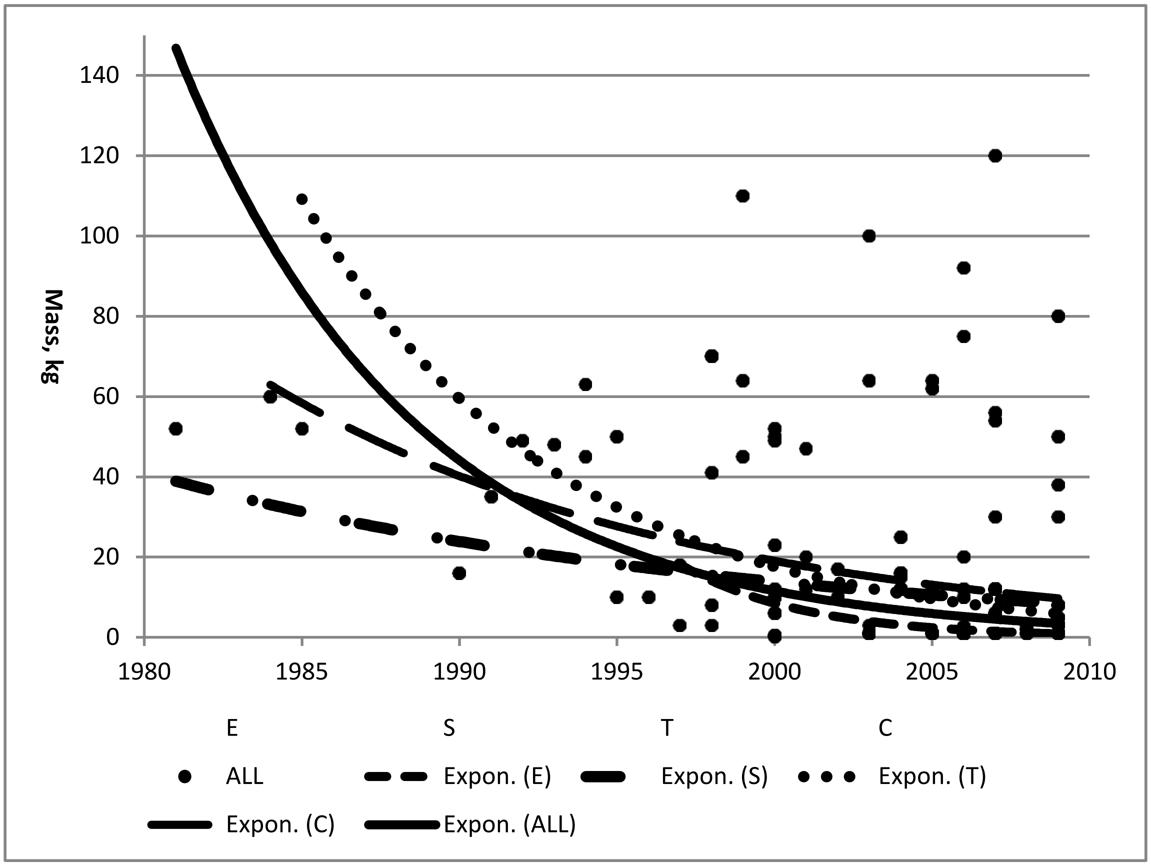

Figure 4. University-Class Satellites' Mass Trends

The Figure 5 shows that while the number of universities that are new to satellite building is increasing, there are universities that sustain their satellite projects and continue in building. Since 'Repeat' missions are an increasing trend (Figure 5), this indicates that schools tend to continue satellite programs students graduate and leave the projects. This turnover in personnel indicates that it is really necessary to apply a system for risk management and to plan to integrate newcomers into an already implemented risk management plan.

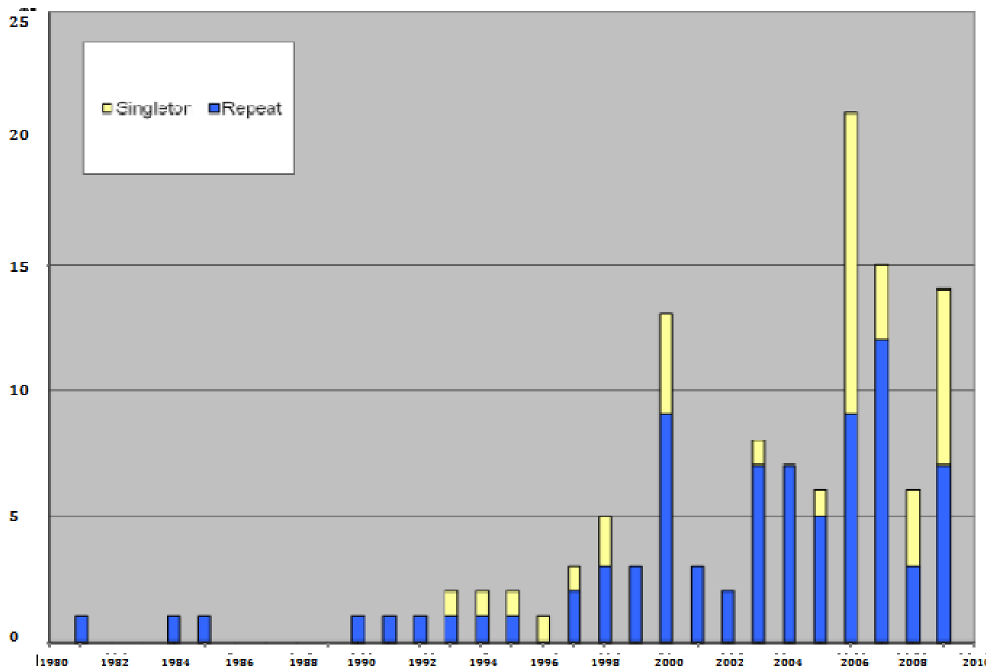

Figure 5: Swartwout's Number of Repeat missions vs. Single Launch (13)

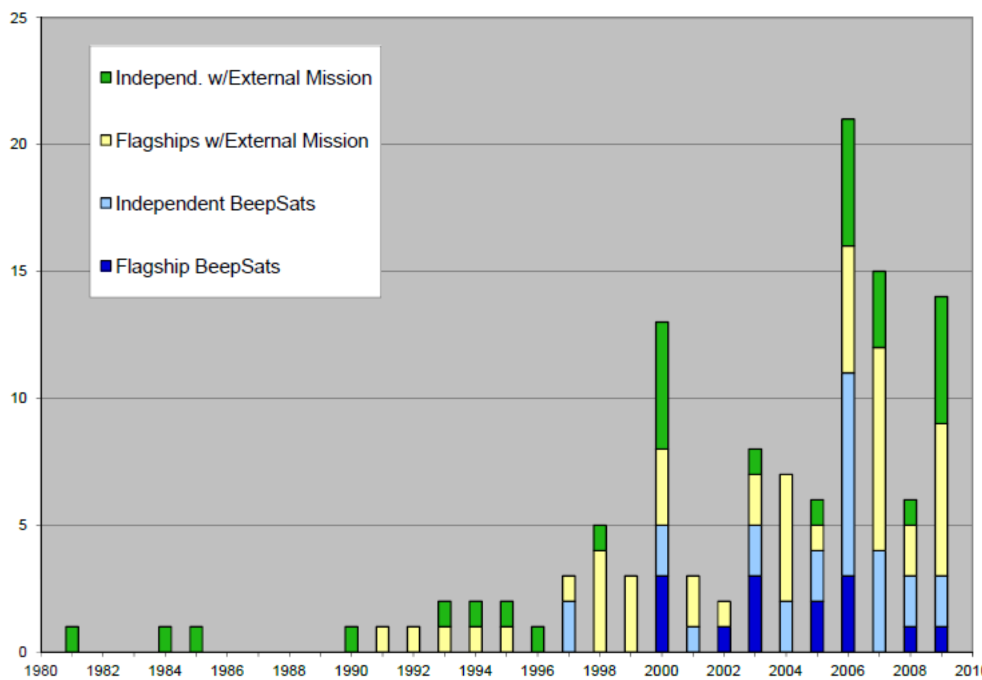

Figure 6. Swartwout's Mission type by year and university classification (13)

Since the flagship universities have significant sponsorship, flagship schools tend to build more satellites, most of which provide 'external' missions (Figure 6). On the other hand, 'Beepsats', generally E-class (i.e. Education) satellites with no payload, are concentrated in, but not exclusive to, the independent schools. And the trend seems to indicate that flagship schools use Beepsats as an "entry-level" mission before building more complex payloads.

As it is seen in Figure 6, Beepsats (and typically, CubeSats) have become the "entry-level" spacecraft for all schools and flagship schools use that as a stepping stone to be able to upgrade to riskier missions. Therefore, despite the fact that some universities have been building and launching sustainable spacecrafts without any problems and without overt system engineering for years, as their missions get complex, they should consider implementing a risk management plan into their projects to assure mission success.

It is obvious that university-class satellites have a higher risk tolerance than commercial satellites. However, as student-built CubeSats begin to have real science and technology requirements, they all need risk mitigation procedures. Besides, performing a real mission could be funded by organizations or companies and the sponsors would like to see the projects include a plan to reduce risks.

2.2.2. Launch Trends

As part of the study of university-built satellite failures, launch failures must also be explored. Figure 7 shows the proportion of small satellites being launched annually in a normalized plot. The statistical data shows the trend of an increasing annual share of small satellites. The increase in the number of nanosatellites is greater than other types.

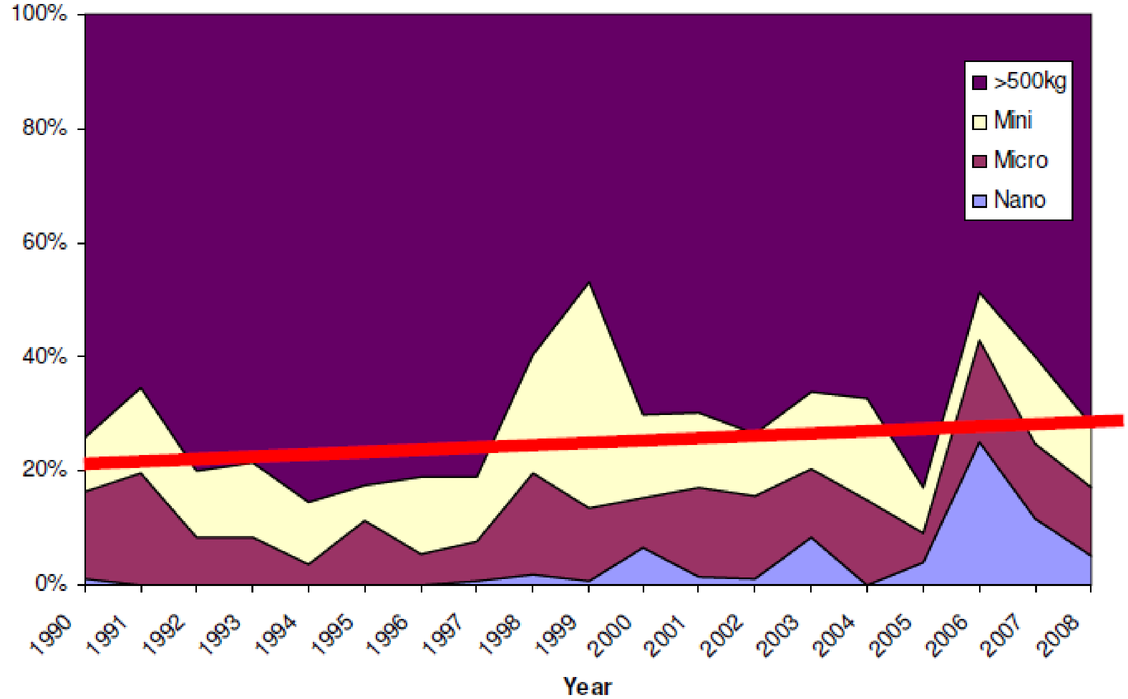

Figure 7. The number of launched satellites according to their mass (14)

Half of the small satellites have been launched as piggy-back payloads (14) and the second mostly selected launch type is ride-share. Swartwout notes that every university-class satellite has flown either as a secondary or part of a large group of secondaries (15).

While sharing a launch increases the possibility of launching a satellite with a low-cost, it also increases the risk of reaching orbit since launch vehicle reliability is a secondary consideration. Even though launch vehicle reliability and flight-safety risk are topics for another study, it should be noted that launch vehicle reliability can be improved with the use of common spacecraft-to-launch vehicle interfaces. These interfaces could be standardized.

2.2.3. University-Built Satellites Subsystem Failures

Governments and industries have been reluctant to share failure data due to security, proprietary and other concerns. On the other hand, students have not usually shared failure data due to lack of time, interest, and/or documentation.

According to Swartwout (13), 22 of the 119 (18.5%) university-class satellites have failed prematurely, before the end of their nominal mission. Table 4 shows the most probable reasons lying behind these failures.

Table 4. Combined University-Class Satellite Subsystem Failure Causes (13), (16)

Satellite	Failure Reason
TUBSAT-B	Killed by the Van Allen Belts due to its orbit altitude of 1250 km
Mozhayets 5	Failed to separate from launch vehicle; a signals problem in launch interface.
UNAMSAT-B	Cold prelaunch thermal conditions led to an inability to contact the spacecraft immediately after launch, leading to thermally-induced battery problems
Arsene	Lost either its transmitters or receivers (or both) unexpectedly and bad wiring is also suspected
SEDsat	Lost either its transmitters or receivers (or both) unexpectedly and bad wiring is also suspected Problems with the connection between batteries and solar arrays
JAWSAT	Lost either its transmitters or receivers (or both) unexpectedly or the main battery failed
Cute-1.7	Lost either its transmitters or receivers (or both) unexpectedly and bad wiring is also suspected
UWE-1	Lost either its transmitters or receivers (or both) unexpectedly and bad wiring is also suspected
ASUSat-1	Solar arrays could not charge the batteries during sunlight after half of a day
FalconSAT-1	Solar arrays could not charge the batteries during sunlight after a few weeks
AAU CubeSat-1	Batteries could not store enough energy to continue operations
SSETI-Express	Batteries could not get sufficient charge due to excess power dissipation arising from a short-circuited transistor
PCSat	Batteries run from a semi-degraded state to degraded state due to instantaneous need for power during a reboot from a reset condition
SpriteSat	Unexpected CPU lockups within days of launch
STARS-1	Unexpected CPU lockups within days of launch
JAK, KKS-1, CanX-1, Louise, Thelma, DTUsat, NCube II, YES2/Fotino	No contact was ever made. Bad communications or bad power is suspected in each case

Some failure sources which might be expected to cause failures are absent from that list. Converted commercial electronics (COTs), batteries or solar arrays were not the established root cause in any failures.

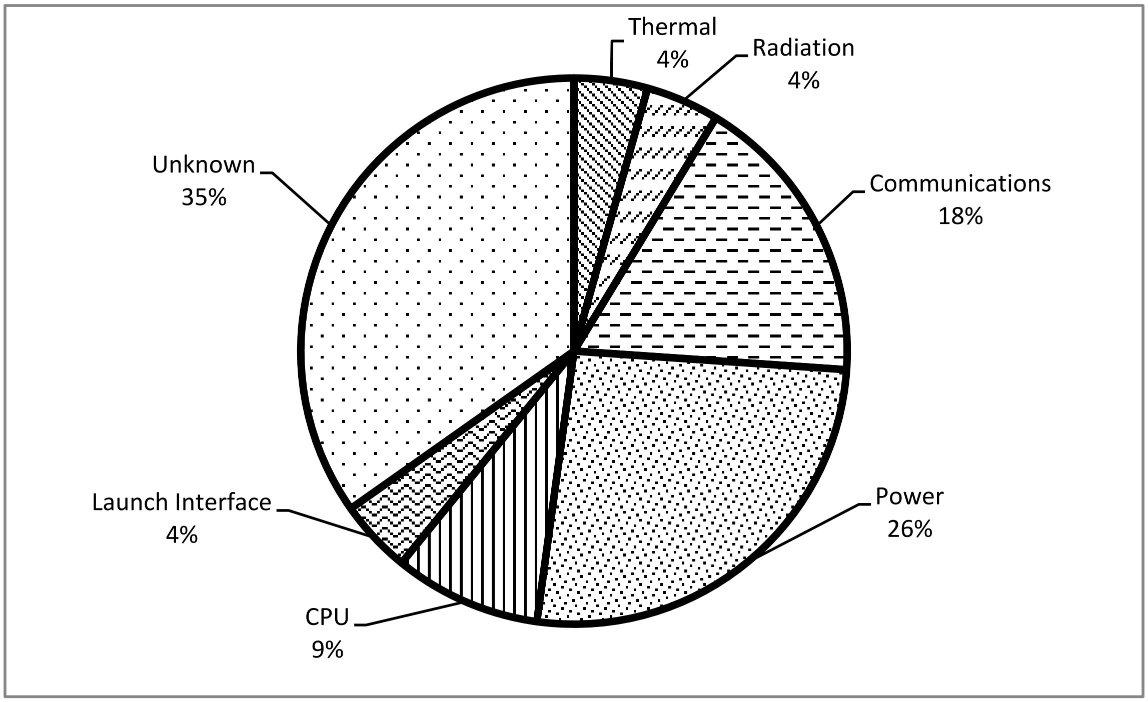

Figure 8. University-Class Satellites Subsystem Failures

Even though exact causes could not be determined for many of the missions, power subsystem including the batteries and the solar arrays appear to be the main failure source (Figure 8). It appears that problems related to structure and thermal (on-orbit) subsystems are the least factors contributing to the system failure for student built satellites.

While the main culprit subsystems can be pointed out as TT&C (Computer, CPU), ATC (Gyro, Sensor, Reaction Wheel) and Propulsion subsystems (Thruster, Fuel) in industry built satellite programs, university-class satellites are more prone to failures from power related errors. The difference can be traced to several sources, one of which is the 'unknown' failure modes that prematurely ended the missions. Since the number of satellites in the industry built satellite databases, their mass categorization and their mission types are not equivalent, making comparisons with the small database of the university-class satellites and deriving results are much more complicated.

Identifying critical spacecraft subsystems and recurrent failure modes has been reviewed in previous studies (15), (13) and the authors suggest the following ways to increase university-class satellite reliability;

- building small spacecrafts with fewer parts,
- using common-interfaces,
- design in large-operational margins,
- design for short-duration of mission times.

Note that the implementation of risk management procedures into university-class spacecraft projects is not suggested. While these studies illuminate the issues by examining error sources, they do not make any recommendations about risk identification and reduction nor on how students should build satellites.

2.3. Analysis of University-Class Satellite Characteristics and Concluding Remarks

This chapter shows that the extrapolation of industry built satellite failure trends to university built satellites is inappropriate. Engineers working for the space industry have the experience and knowledge which students lack. The differences in the failure types between university-built and industry-built satellites are understandable. Moreover, the much larger percentage of university-built satellites that have failed for 'unknown' causes must be explained. Industry-built satellites usually have extensive "health checking and reporting" systems that are not present in university built satellites. Hence, when an industry built satellite fails, we are more likely to know why. In order to decrease the number and percentage of 'unknown' failure causes in university built satellites, system engineering, more specifically, risk management procedures should be applied.

The first area where risk management should be applied to university built satellites is in the conceptual design phase. Risk management procedures should then be continued through all phases of the design-build-test process.

Chapter 3: University-Class Satellites Risk Management

Throughout this study, the aim is to raise awareness of risk management issues and to suggest suitable practical solutions for university-built satellite programs. Thus, templates for a risk register, a risk management checklist, a risk matrix are presented in Appendices to help students in developing risk management implementation plans for their space projects.

Application of risk management increases the probability of success and reduces both the probability of failure and the level of uncertainty associated with achieving the objectives of the project. In this chapter, common characteristics of university-built satellite programs are explored.

3.1. Risk Domain and Risk Sources

Risks are introduced by potential problem situations in a project that have undesirable consequences in terms of cost, schedule and technical performance (17). Risks can occur in four domains (technical, performance, social, and/or acquisition). The Venn diagram in Figure 9 depicts the risk domains.

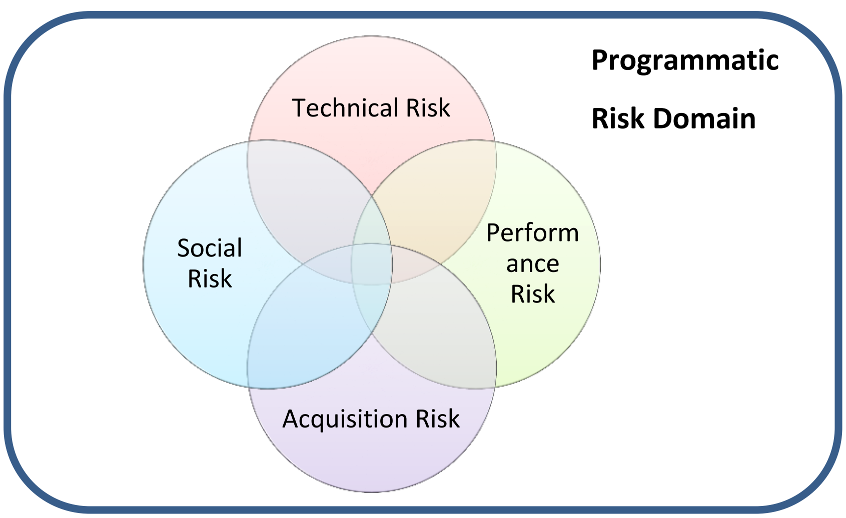

Figure 9. Venn diagram of risks

Table 5 summarizes the examples of key risks in these domains and shows that some specific risks can have drivers rooted from more than one factor and for that reason there are some overlap areas in the Figure 9.

Table 5. Programmatic Risk Domain in University-Built Satellite projects

PROGRAMMATIC RISK DOMAIN			
Technical Risk Factors	Performance Risk Factors	Acquisition Risk Factors	Social Risk Factors
Requirement Changes Direction Experience Competition	Staffing Communication Competition Direction Documentation Experience Performance Coordination Budget	Funding Budget Schedule Training Procurement & Quality	Responsibility Reliability Strategy Motivation Communication

3.1.1. Schedule

Schedule is a major risk area for student-built satellites. Students find it difficult to devote a specific amount of time each week to the project because of other time demands such as classes, studying for exams, and homework. There are also extracurricular and social activities in which students are involved. Therefore, setting a timetable for students to meet and/or work even for one sub-group is not easy. In contrast, engineers working full-time for a company often spend all of their working time on one satellite project.

In addition, many student satellite projects are initiated with no firm deadline to help the team to organize their work. Creating a timetable with margins is necessary for student projects. The schedule needs to be prepared bearing in mind that in some periods, team members will be busier with non-project work than in other periods. A real danger is that in order to finish their project work within the scheduled time, students might skip steps in risk management such as in risk monitoring & control or in documentation. Thus, student time pressures must be considered as a risk that might cause other risks to be ignored. This is a very serious matter that should be discussed early and often with student design teams.

3.1.2. Funding & Budget

Funding is one of the key drivers of university-built satellite projects. However, to be eligible for funding requires that students prepare a strong proposal with detailed information about the resources. Most student groups writing proposals would not think of dedicating budget and time to risk management. Their budget would likely not even address risks. Thus, proposals for student project funding usually would not include resources for risk analysis. However, showing that the team is aware of the risks and will be working to minimize them should enhance chances for funding.

3.1.3. Staffing & Experience

Recruitment of undergraduate and graduate students to work on satellite projects is one of the positive sides for university satellite programs. Students usually volunteer in university-built satellite projects. Even though volunteer students may devote themselves to project, unfortunately, they do not work as if they were paid, and they usually join the team with little or no experience. In an ideal situation, a core group of paid staff could be hired to work fixed number of hours per week for student projects. This would provide continuity and leadership for the project, minimizing several risks. University-built satellite project teams usually consist of small number of people. Student volunteers do a lot of work, but their schedules do not match. Their work schedules are dictated by their academic schedules and communications among team members is often a problem. Keeping the program manager, chief engineer, and systems engineer aware of their work is often a low priority. Checking of the work of new volunteers by experienced teammates is a must. Lack of sufficient meaningful communication is a major risk for student satellite projects.

Another risk is the loss of information that occurs when a student chooses to leave the project. This is most serious when a student leaves without notification. No one is aware the status of his/her work on the project. Students should work with partners on all aspects of the project and partners should communicate with each other and document their work as they go. This would avoid the many problems that can occur if a student worker, with no partner, leaves a project abruptly.

Project duration of student satellite projects is a risk in itself. Recruitment of volunteers could be a problem in the cases when the project launch date is predicted to be beyond the graduation of the student working on the project. In addition, the passing of project information from initial team members to replacements (due to graduation) can create the possibility for knowledge gaps caused by inadequate communication and/or documentation. This risk could be minimized by having the small paid team core staff suggested above.

3.1.4. Motivation

University satellite projects are great motivators. However, students tend to be more affected by negative events than the engineers in industry. Unexpected negative events occur in any project (test failures, equipment burn outs, etc.) and such events can greatly dampen motivation. This risk can be minimized by discussing possible negative outcomes with the team ahead of time and having them analyze the risks and develop ways to minimize the likelihood of the risk occurring. The team should also develop plans for dealing with the risk if the negative event occurs.

3.1.5. Requirements Changes

Some requirement changes are to be expected in any project, but when frequent changes start to take place, it is often a reflection of the fact that the initial requirements were poorly understood. Poorly written requirements are a major risk at any point in a project. Effort spent early in a project developing and refining requirements is a primary way to minimize risks.

3.1.6. Communication

Possibly the most important aspect of risk management is communication. Having fewer team members and so, short communication lines can be one of the social advantages of university-built satellite programs. Communication between project team members is an essential instrument of effective and successful project management. However, for student built satellites, communication can also be a problem, as was discussed earlier. Items that can cause communications problems among student team members are 1) students coming from different major backgrounds, 2) students having different knowledge levels, 3) students having different academic levels (freshmen to doctoral student), and 4) students having different work schedules. The communication management task should not be underestimated, because bad communication generates mistrust and dissatisfaction and always results in bad project relationships (18). To reduce the risk associated with lack of communication, it is necessary to integrate communication management into the risk management procedure.

3.1.7. Coordination

Another issue comes when project team consists of having project sub-groups. Sub-groups are often focused on individual spacecraft subsystems. One sub-group may progress well, while others do not. At some point, the team that is progressing well has to wait for other teams in order to be able to continue their work. This may create a slow-down in the project and can lead to poor inter-team relationships. Coordination between the groups must be arranged through frequent periodic meetings to exchange information.

3.1.8. Reliability

University-built satellite projects have the advantage of being able to take risks at a level higher than would be allowed for industry satellite projects. This is because education and hands-on experience are the main goals for student projects. However, student satellite projects should have reliability as a primary goal. The application of risk management procedures throughout the life of a student satellite project will help to minimize risks.

3.1.9. Documentation

For almost every university-built satellite, the creation of proper documentation is an issue. One way to make documentation easier could be by the use of checklists, fish-bone diagrams, or another online documentation system. Proper documentation helps to solve the problem created by student turn-over. Transferring information from experienced team members to new project volunteers is a primary role for documentation.

3.2. Risk Management Standards

In order to establish a suitable risk management process, available standards on systems engineering, focusing on risk management should be consulted. As every risk management procedure must reflect the specific circumstances of its specific project, a uniform approach can never be adequate. Nevertheless, risk management standards can provide useful support for designing and implementing a comprehensive and consistent risk management system.

Risk management is an iterative process that is applied to engineering projects according to standards in industry. Created in 1969, MIL-STD 882 provided the first definition of the scope of project management and system safety in an engineering project. In 1995, NASA/SP 6105 followed and provided additional guidance on the process of writing system specifications for space missions. These standards were influential in defining the scope of systems engineering in their time. As time passes, improvements in requirements and standards are occurring. More recently government agencies outside of NASA and the Department of Defense have created systems engineering guidance documents. All such documents contain some discussion of risk management. A sampling of these documents is listed below:

- **MIL-STD 882 (1969)** DoD Standard practice for system safety
- **NASA/SP 6105 (1995)** NASA Systems Engineering Handbook
- **ECSS-M-10A (1996)** ESA Space Project Management
- **CAN/CSA Q 850 (1997)** Canadian Risk Management Standard on Guideline for Decision-Makers
- **AZ/NZS 4360 (1999)** The Australian and New Zeeland Standard on Risk Management
- **ECSS-M-03A (2000)** ESA Space Project Risk Management
- **JSA JIS Q 2001 (2001)** Japanese Industrial Standard on Guidelines for development and implementation of risk management system
- **IRM/AIRMIC (2002)** Risk Management Standard from UK Risk Management Organizations
- **NPR 8000.4 (2002)** NASA Risk Management Procedural Requirements
- **ISO 17666 (2003)** Space systems - Risk management
- **ONR 49000 (2004)** Austrian Risk management Standard for organizations and systems
- **NPR 7120.4 (2005)** NASA Program/Project/Risk Management
- **NPR 7120.5D (2007)** NASA Space Flight Program and Project Management Requirements
- **BS 31100 (2008)** British Standard on Code of practice for risk management
- **NASA S3001 (2008)** Guidelines for Risk Management
- **ISO 31000 (2009)** provides principles and generic guidelines on the design, implementation and maintenance of risk management.

The Risk Management approach provides a framework for the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, evaluating, treating and monitoring risk. With the application of Risk Management standards into the space projects, it is hoped that the risk inventory and estimation will be performed for a regular basis for every project. Standards provide vision, guidance, and a generic iterative process of risk management.

3.3. The Risk Management

In order to develop risk management strategies for university class satellite projects, we must examine the processes used in designing and building the satellites. As part of this process, following questions have to be answered.

- What steps are currently present in the design, build, and test process?
- What is the order of the process steps?
- How comprehensive and sophisticated are the process steps?
- How well are the steps in the process implemented?

Figure 10 indicates an orderly way to establish and maintain a risk management process. We first describe ground rules and assumptions, risk categories, methodologies, etc.

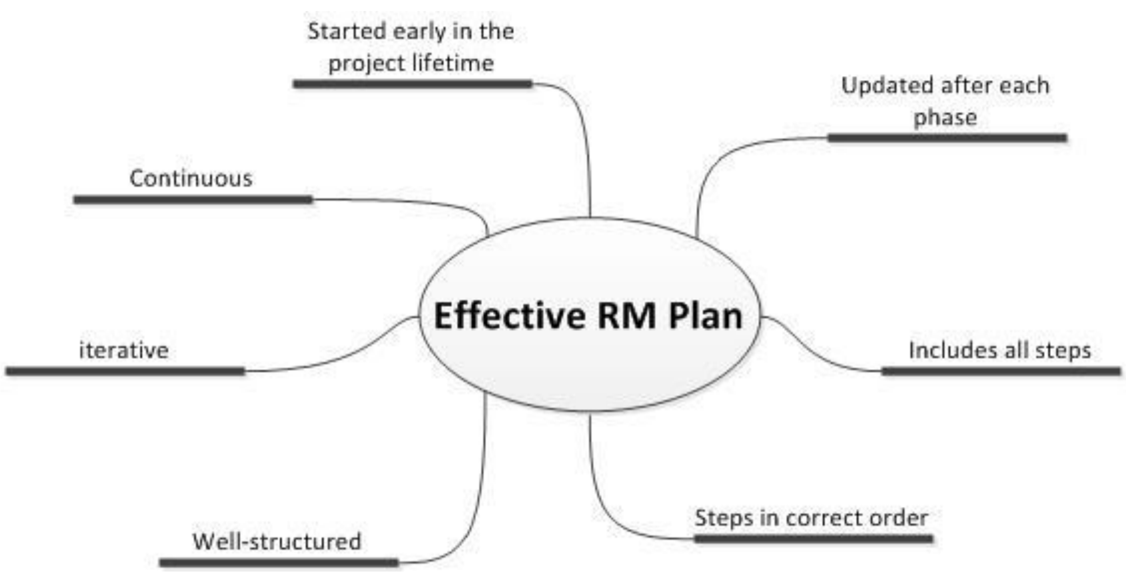

Figure 10. Key Elements for an effective risk management

Risk management activities should be initiated at the beginning of the project since decisions with major impacts are often made at the earliest stages. Risk management should be continuous throughout the project life cycle with iterations being determined by the progress of project phases. Risks appear at every phase of a program's evolution. Thus, it is necessary to update potential risk factors at each stage simultaneously. A well-structured risk analysis should start with risk planning and identification and continuing with assessment, mitigation and control as it is seen in Figure 11.

The commonly used method for handling the risk in university-built satellite programs is bringing outside help from outside professionals. This is always helpful, but is usually a one-time review. Risks are an ongoing problem and students need to learn to recognize and manage risks themselves to ensure project success.

Students must take ownership of the risk process and of individual risks. Each risk should have an "owner" or "monitor" on the team who tracks the staus of the risk and associated mitigation actions.

Openness and inclusiveness in communication can help to prevent risk related crises from developing. Early discussions reduce misunderstanding, disagreement and resentment and ensure smoother implementation of changes. Engaging more team members into the decision cycle can help ensure that decisions take account of a wide range of views and experience. Additionally, this can lead to better decisions about how to handle risks by spotting aspects of a risk that might otherwise have gone unnoticed.

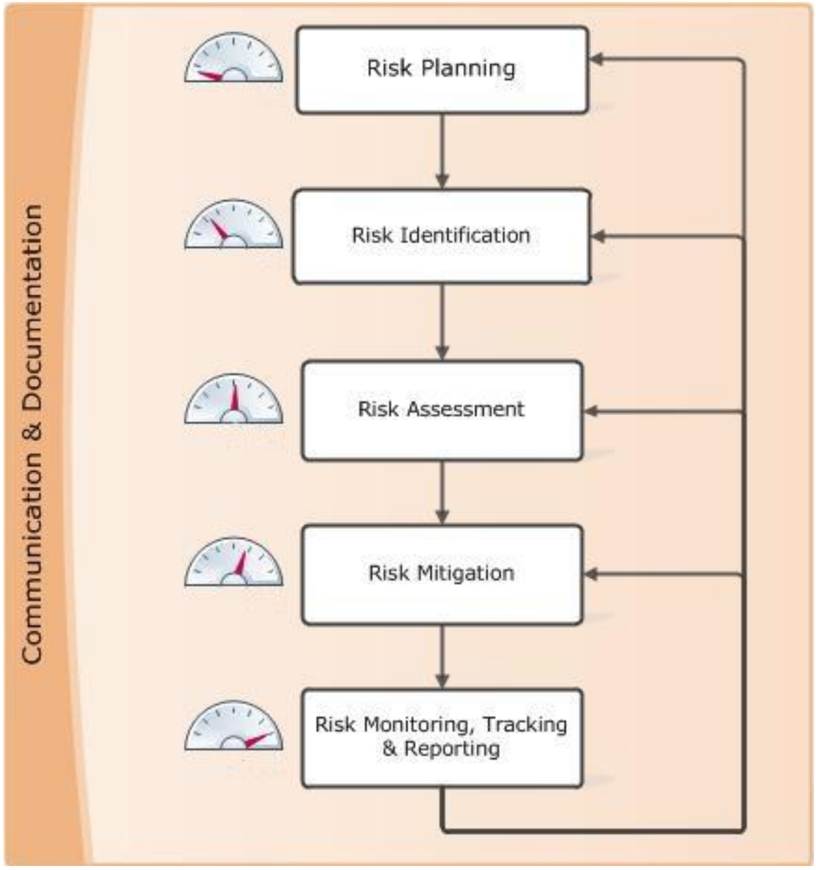

Figure 11. Risk Management Steps

In Appendix A, a Risk Management Checklist is presented. Here we list of actions that should be completed in order to fully satisfy risk management requirements. The items on the checklist are intentionally redundant. They ask students to consider risks from several different angles.

3.4. Risk Planning

Project planning determines how to conduct a project in order to satisfy its objectives. In a project plan, all roles and responsibilities must be clearly defined. At the beginning of the project life cycle, the ability of the advisors to influence the final project outcome is highest and gets gradually lower toward the end of the project. With many unknowns, potential risks and uncertainties, the probability of successfully completing the project is lowest at the beginning of the project life cycle and highest at the end. As the project nears its end, there are fewer opportunities for risks and uncertainties.

The value of project scope changes decreases over time during the project life cycle while the cost of scope changes increase over time. An agreed risk management strategy helps to finalize project scope as early as possible.

3.5. Risk Identification

The initial step in implementing a risk management plan is to proactively address potential risks in order to evaluate the decision options and identify appropriate actions. Additionally, a comprehensive and structured set of assumptions should be defined at this step.

For effective risk management, the focus has to be on risks which may affect the success of the mission or project. It is possible to identify these critical and potential error sources by simply developing a list of risks. The output of the each risk identification can be documented in a '*risk card*', an example of which can be seen in Figure 12. A database of all risk scenarios will take the form of a *Risk Register* (APPENDIX B. Risk Register: An Example) which will be a primary tool for tracking risks and the status of any risk mitigation actions. In the risk register, each listed risk should be characterized by the following information.

Risk ID: A unique order number used to track the risk

Author: Name of team/individual who is filling the risk matrix

Date of Identification: The date when the risk is identified

Risk Owner: Designation of the individual who owns the responsibility for managing the risk

Risk Description: Brief name and description of the risk which can be understood by all members of the project

Risk Classification: Summary of all risk factors contributing to the risk

Impact of Risk: Summary of consequences and impact on project performance

Probability of Risk: Estimation of probability of risk occurrence

Effect of Risk: Evaluation of the risk effect

Criticality of Risk: Calculated by multiplying the risk probability by the effect of the risk

Risk Mitigation Approach: Description of type of strategies that will be used to manage risks

Date of Mitigation: The date when the risk mitigation is to be implemented

Contingency Plan: Description of procedures which have to be initiated if the risk factor actually becomes a problem

Risk Tracking: Estimate of frequency for revisiting the risks or estimate of time within which the risk effect can be corrected

Current Status: Describe the up-to-date status of the risk mitigation actions

Comments (Optional): Additional comments that the individual/group would like to add

Risk Owner	Risk ID	Author	Date of Identification
Risk Owner: *<< Designation of the individual who owns the responsibility for managing the risk>>*	**Risk ID:** *<< Number of sequence >>*	**Author:** *<< Name of team/ individual filling the risk matrix >>*	**Date of Identification:** *<< The date when the risk is identified >>*
	Risk: *<< Brief name and description of the risk which can be understood by all members of the project >>*		
	Risk Classification: *<< Summary of all risk factors contributing to the risk >>*	**Impact of Risk:** *<< Summary of consequences and impact on project performance in every aspect >>*	
	Probability: *<< (1-100%) Estimation of probability of risk occurrence >>*	**Effect:** *<< (1-10) Evaluation of the risk effect based on predefined criteria >>*	**Criticality:** *<< Calculated by multiplying the risk probability by the effect of risk>>*
	Mitigation Approach: *<< Description of type of strategies that will be used to manage risks >>*		**Date of Mitigation:** *<< The date when risk mitigation is to be implemented >>*
	Contingency Plan: *<< Description of procedures which have to be initiated if the risk factor actually becomes a problem >>*		
	Risk Tracking: *<< Estimate of frequency for revisiting the risks or estimate of time within which the risk effect can be corrected>>*		**Current Status:** *<< Describe the up-to-date status of risk mitigation actions >>*
	Comments: *<< (Optional) Additional comments that the individual/group would like to add >>*		

Figure 12. A Risk Card

3.6. Risk Assessment

After a risk has been identified, it must be assessed. This process includes risk evaluation, risk classification and risk prioritization. A major step is to determine the sensitivity of identified risks to mission objectives and requirements.

A structured risk assessment approach should be used to analyze risks. There are three types of risk assessment; qualitative, semi-quantitative and quantitative.

Quantifying what has been identified as a risk root cause should be done within a methodology. Despite the fact that, there is almost always an unknown uncertainty in estimating probability values, risk analysis is designed not to be a guess-work.

The most commonly used quantitative risk assessment option is Monte-Carlo simulation. A Monte-Carlo simulation calculates the probabilistic distribution of overall risk impact. However, Monte-Carlo simulations are time-consuming and require considerable expertise to conduct properly. Therefore, these simulations are recommended for industry projects and/or projects bigger in size, staff and budget.

A second quantitative assessment method, Failure Mode Effects Analysis (FMEA), is also used in analyzing risk factors in industry. However, FMEA usually requires a considerable amount of study of systems prior to implementation and is most effective in addressing technical and/or quality risks. It is not very effective for addressing cost or schedule risks. Quantitative risk assessment techniques are much more complex than the qualitative techniques and usually require much more time and effort to complete.

Qualitative or semi-quantitative methods of risk assessment are generally simpler than quantitative methods and are recommended to be used in university-built satellite programs whenever possible. A common practice for making risk based decisions without conducting quantitative risk analysis is risk ranking using risk matrix.

3.6.1. Risk Matrices

A risk matrix is a tool for risk analysis which presents a matrix of risk events with respect to their corresponding probabilities of occurrence and impact levels. According to the categorization of the probability of occurrence and the impact level, risk matrix could be either qualitative (e.g. ranking level as high, medium and low) or semi-quantitative (e.g. ranking level as 25% and 75%) risk assessment tool.

A 3x3 risk matrix is usually quite adequate for student-built satellite projects. Both the impact and likelihood (probability) assessments are made on the basis of low, medium and high thresholds. However, some projects find assessing risk with a 5x5 matrix would create a better evaluation. The best thing is to focus on the needs and the characteristics of the project and find the most suitable risk matrix measures.

An overall likelihood rating indicates the probability that a potential vulnerability may be exercised within the construct of the associated threat environment. While determining the magnitude of the likelihood of the occurrence Equation 1 can be used. Probability of occurrence and impact measures should be defined by the project manager according to mission needs.

$$R(n) = P(n)x\ C(n)$$

$$\text{where } P(n) = \text{probability of occurrence of scenario } n$$
$$C(n) = \text{consequence of occurrence of scenario } n$$

Equation 1. Risk Rating Calculation

The likelihood that a potential vulnerability could be exercised by a given threat-source can be described as high, medium, or low. Table 6 below describes these three likelihood levels. The matrix indicates how these assessments are segmented into three distinct categories.

Table 6. Risk assessment Levels

	Likelihood	Impact
Low	not likely to occur	minimal (or no) impact on the mission
Medium	possible to occur with less than 25% chance of occurrence	moderate adjustments in mission objectives and goals
High	likely to occur with more than 75% chance	would threaten the mission objectives / may result in mission failure

The risk matrix chart given in Figure 13 is divided into 3 zones according to their assessment measures. In this conventional analysis;

- Risks in the green zone need to be reviewed from time to time.
- Risks in the yellow zone need constant monitoring by systems engineers and team members to prevent any negative outcomes.
- Risks in the red zone need immediate attention of project manager and the application of proactive risk management strategies to reduce the risk outcome.

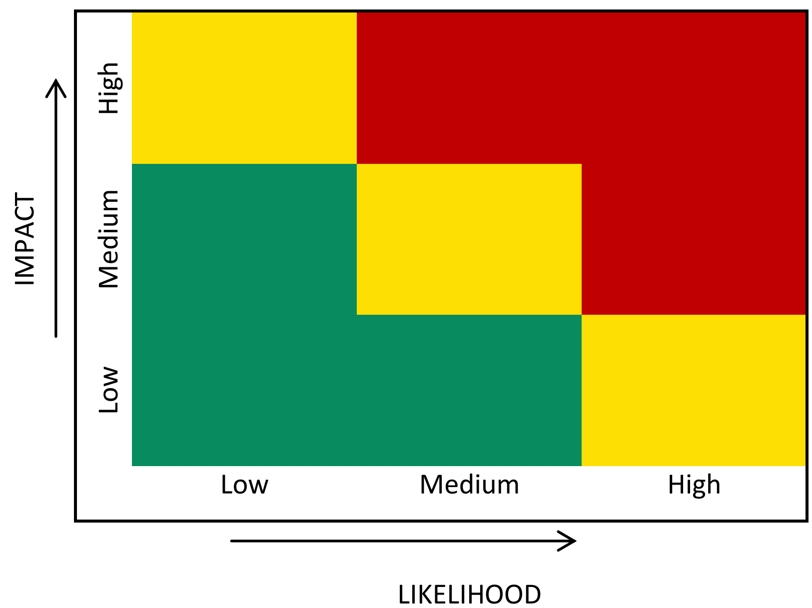

Figure 13. Risk Matrix

A useful way of summarizing risks is to plot them onto the selected risk matrix against relevant criteria which provides an indication of their criticality. "*Risk mapping*" is a simple and useful method for assessing risks by prioritization. It is possible to visualize critical and potential error sources in a risk map. However, it could be hard to read with all of the risks plotted. To eliminate this problem, either a specific set of risks could be plotted at a specific point in project time like a snapshot or numbers can be used instead of risks themselves. Each numbered marker would represent a unique risk in the risk register. Having identified risks assessed on the basis of two criteria; impact and likelihood are recorded in the appropriate quadrant of the map as seen in Figure 14 (19).

The result of the risk analysis can be used to produce a risk profile that gives a rating of significance to each risk and provides a tool for prioritizing risk treatment efforts. This procedure ranks the risks according to their relative importance. This process allows defining correct mechanisms and indicates where the level of resources might be increased, decreased or reapportioned.

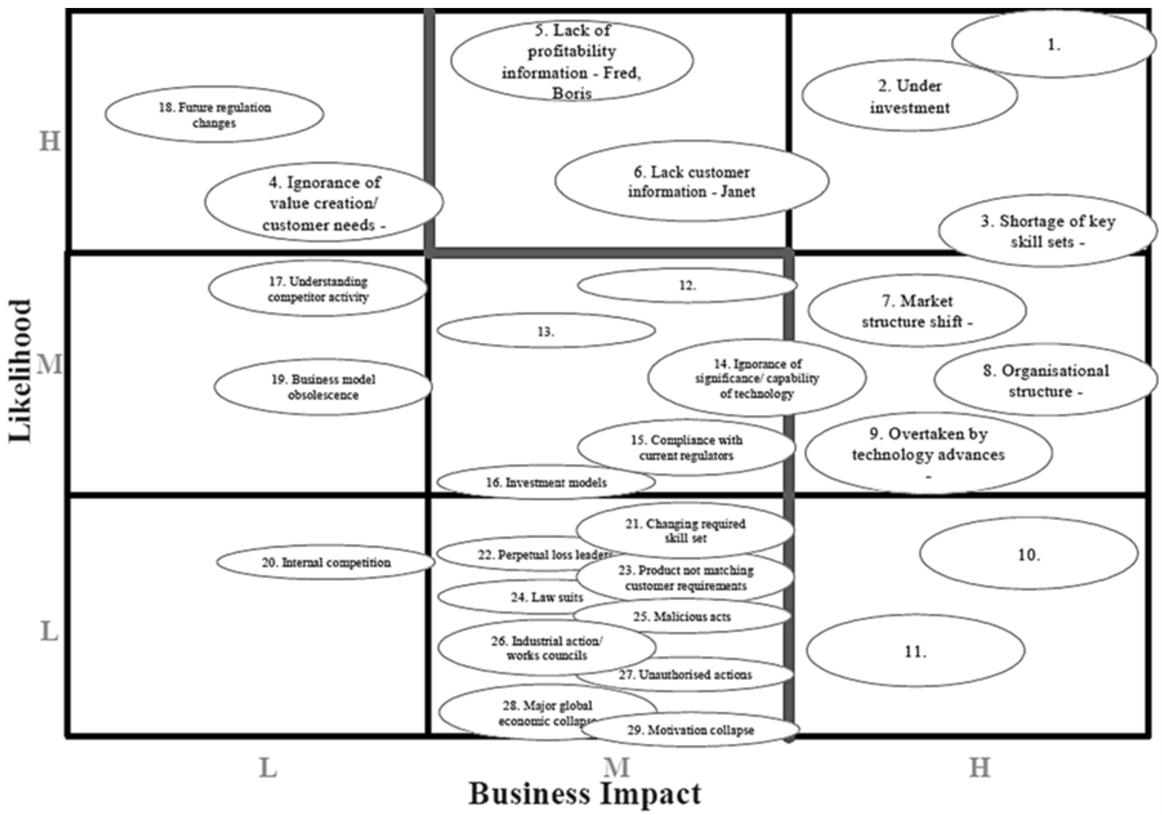

Figure 14. Risk Mapping (19)

As new information becomes available, updating risk assessment is mandatory. The aim is to be continuously looking to the future for developing risk sources that may impact the program. One more advanced approach might be to do qualitative techniques first; then implementing quantitative techniques on just the high risk items.

3.7.Risk Mitigation

The aim in risk mitigation is to control the risk by eliminating the risk itself or lowering its impact. The magnitude of a risk can be reduced by implementing mitigation procedures which aim to remove the initial cause of a problem or interrupt the propagation of a problem to an actual impact.

First, students should decide what, if anything should be done about each individual risk. The best implementation strategy for student projects is mitigating each risk with the most fitting option while having an alternate method available.

Ways To Handle Risks

There are four options in handling any risk: avoid, control, assume, or transfer the risk.

Avoid: This option consist of deciding either not to proceed with the activity that involves an unacceptable risk, or choosing an alternative more acceptable or a less risky course of action that still meets objectives. (e.g. probable fault in connection between the components)

Control: Here, the aim is not to prevent the risk totally, but to contain it to an acceptable level. Strategies aim to reduce the likelihood of occurrence and/or minimize the negative impacts of risk on the program. An example of a risk control strategy is the development of contingency plans. (e.g. insufficient experience in a necessary software)

Assume: Here, the course of action is to accept the potential risk and continue operating Assumption of a risk implies a full understanding of the scale of the risk and why acceptance is justifiable. (e.g. deficiency in COTs verification testing)

Transfer: Transferring a risk may not decrease the level of impact to the project, however relocating risk by using other options can compensate for the consequences. (e.g. personnel/team member shortfall in one subsystem group)

Success Probability of the Risk Mitigation Plan

If the probability distribution terms is defined accordingly, then the structure of a risk event would be as it is in Figure 15. When the risk occurs, risk event will either occur with probability p, or it will not occur with probability 1-p. For the chance that risk will occur, the prevention phase starts. If the risk can be prevented it has the probability $p(1-F_p)$. However, if the prevention itself fails, mitigation is reqired with likelihood of pF_p. The success possibility in the mitigation phase is $pF_p(1-F_m)$. More information could be found in Ref. (20) regarding the cost and schedule impact on the program.

$p = Probability\ that\ the\ risk\ event\ will\ occur$

$F_p = Probability\ that\ prevention\ will\ fail$

$F_m = Probability\ that\ mitigation\ will\ fail$

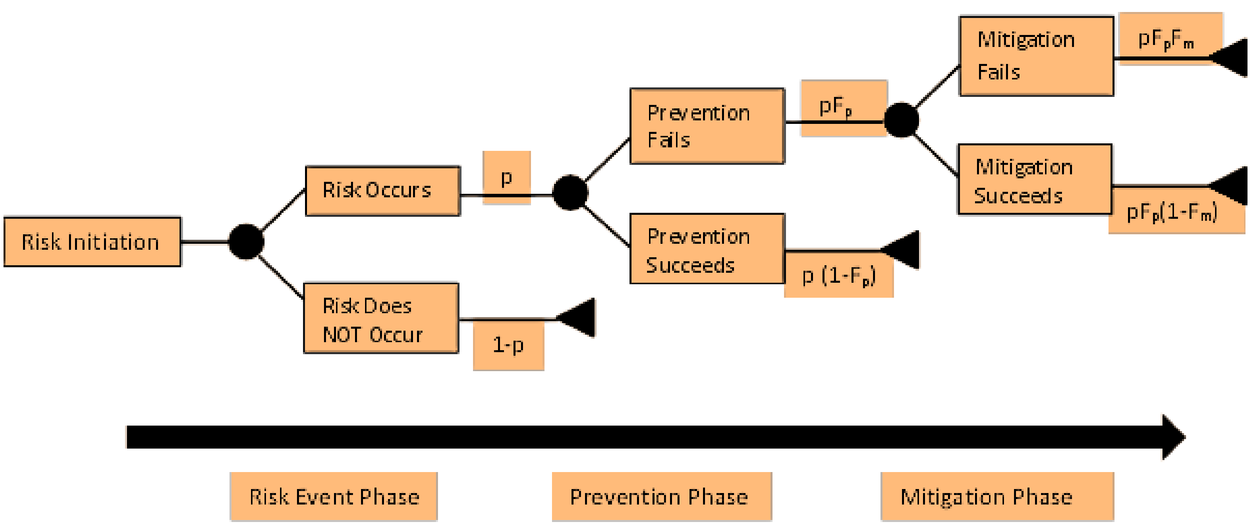

Figure 15. Probability Distribution of a risk event

Student projects generally start and develop with great uncertainty. In cases where there is high uncertainty in risk, the risks might be watched for a little while. As the project progresses, the uncertainty level could decrease without much time spending on evaluating the action. However, if pre-defined threshold is exceeded, then risk mitigation should be activated. The other cases when the risk mitigation should be activated are;

- risk that was assumed to be acceptable is found to be significant,
- risk that was not addressed during the analyses is discovered
- significant changes made to the program needs, objectives or requirements

Each sub-groups' system engineer should be responsible for preparing the avoidance/mitigation plans, which would be submitted to the project manager. Students would likely choose to concentrate initially on a small number of high impact and likelihood risks. Usually, only a small number of risks will be initially identified for each subsystem.

Risk mitigation planning is intended to enable program success. To make this step easier a tree-based evaluation methodology can be used (Figure 16). The mitigation planning should answer fundamental questions in the risk register such as, what should be done, when it should be accomplished, who is responsible, and the funding required to implement the risk mitigation plan. The output of this step should be one of the following:

- Risk Resolved
- Risk Partially Resolved: still create a potential danger, but for which the impact or likelihood is estimated to be reduced to acceptable levels
- Risk Unresolved: no mitigation plans can be devised, or the resources required exceed the anticipated benefits

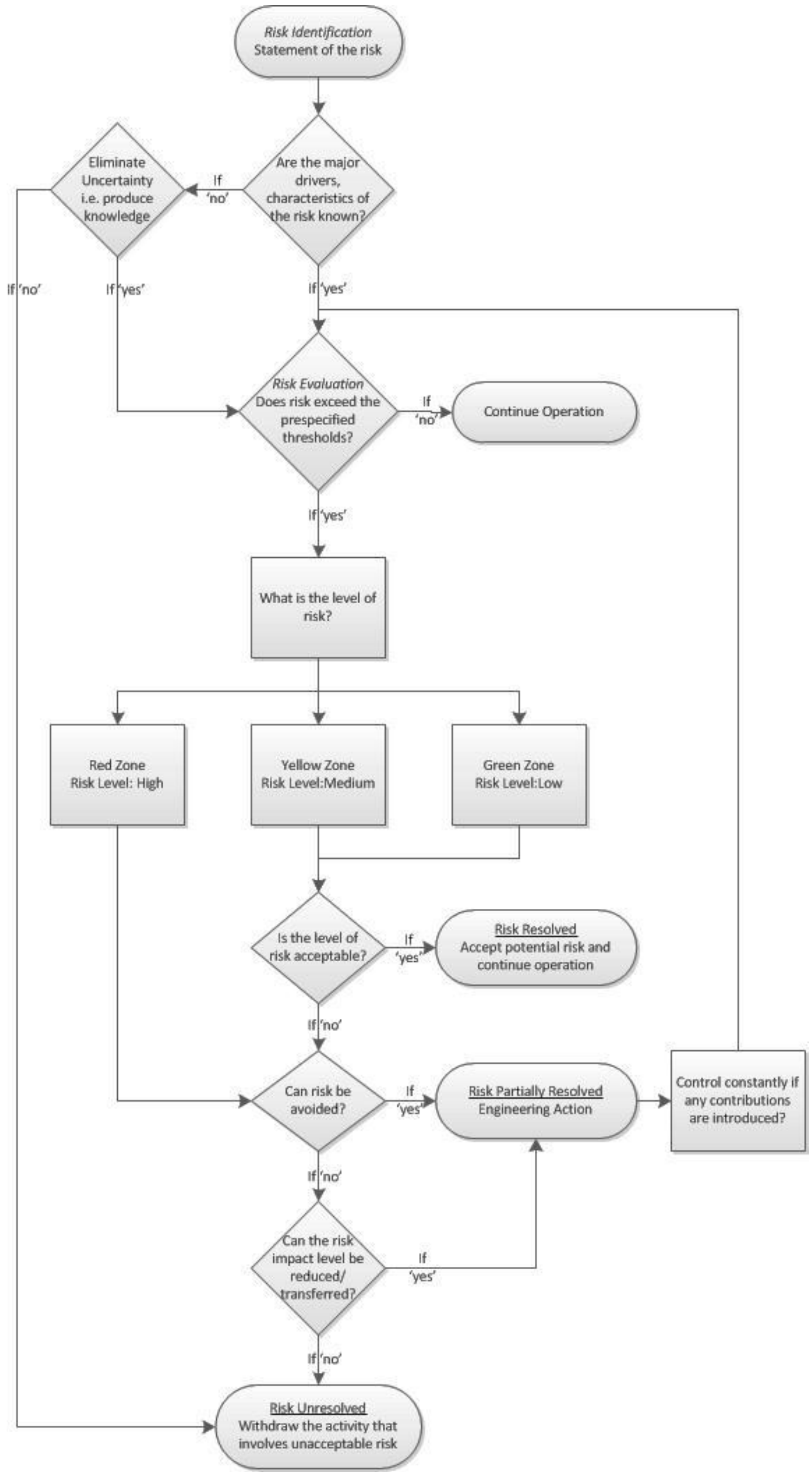

Figure 16. Risk Mitigation Chart

3.8. Risk Monitoring, Tracking and Reporting

Tracking the status of risks and verifying the effectiveness of their risk mitigation plan implementations are very important. Figure 17 provides a risk monitoring, tracking and reporting flowchart.

The actions necessary include;

- tracking identified risks,
- monitoring residual risks,
- identifying new risks,
- executing risk contingency plans, and
- evaluating their effectiveness throughout the project life cycle.

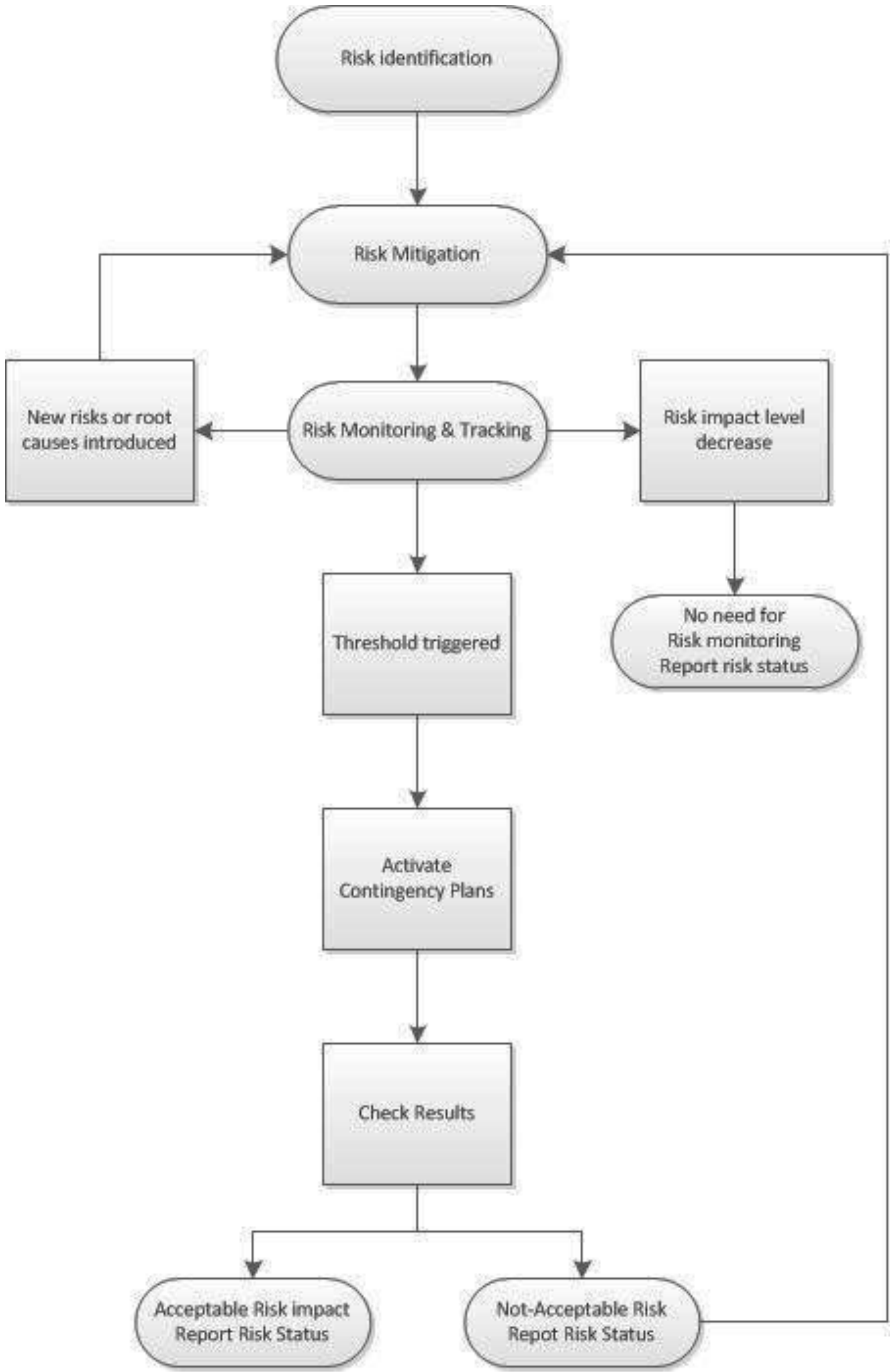

Figure 17. Risk Monitoring, Tracking and Reporting Chart

3.9. Risk Management Tools

In this section, the risk management methods and tools which are proactively used space industry in identifying and assessing risks are described. Project risk management effectiveness can be increased with the application of these methods which are tailored specifically for the project.

3.9.1. Work Breakdown Structure (WBS)

A WBS is a structuring tool for turning raw data into useful information in project management. The Project Management Institute (PMI) defines a WBS as: “A deliverable oriented grouping of project elements that organizes and defines the total work scope of the project. Each descending level represents an increasingly detailed definition of the project work.” (21)

The reason a WBS is a necessary part of risk management is that the WBS presents project work in hierarchical, manageable and definable packages to provide a basis for project planning, communication, reporting and accountability. The WBS refers to the itemization of a project for planning, scheduling, and control purposes while defining the scope of the project. Team members can look at the WBS as the structural support for risk management since work and risk can be systematically broken down into task groups. Thus, WBS permits the implementation of a “divide and conquer” concept for project control. Figure 18 shows an example of a WBS structure for a hypothetical design project. The basic approach for preparing a WBS is as follows: (22)

Level 1 WBS: contains the aim of the project

Level 2 WBS: contains the major subsections of the project

Level 3 WBS: contains definable components of the level 2 subsections

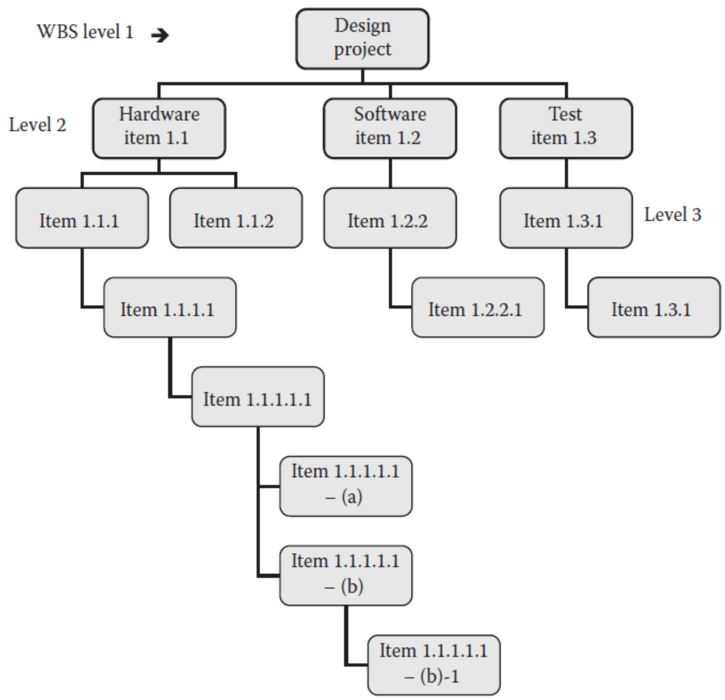

Figure 18. Work Breakdown Structure

In the same way, risk data can be organized and structured by what is called Risk Breakdown Structure (RBS). To provide a standard presentation of project risks, RBS is defined as: "A source-oriented grouping of risks that organizes and defines the total risk exposure of the project. Each descending level represents an increasingly detailed definition of sources of risk to the project." (21) The RBS is therefore a hierarchical structure of potential risk sources.

Despite the fact that, 'universal risk areas', which might apply to any type of project in any sector, are unlikely to include the full scope of possible risks to every project, generic versions of the RBS (Figure 19) might be useful as a starting point.

The main uses and benefits of a specific RBS structure for university-built satellite projects are 1) identification of the risks with a checklist using lower parts of the RBS, 2) mapping identified risks categorized by their source into the RBS, and 3) providing input to tradeoff studies examining alternative development options (21).

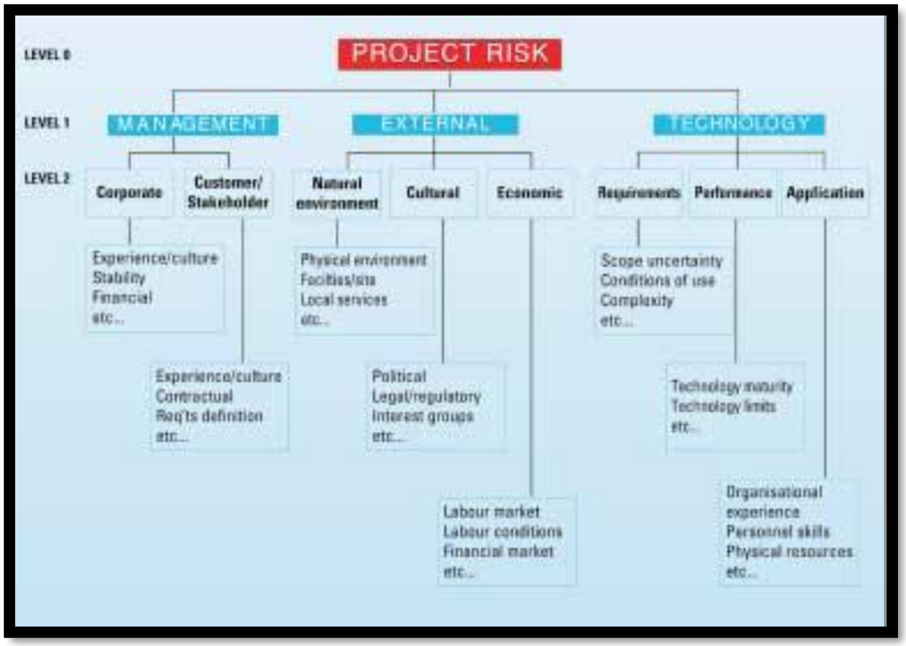

Figure 19. Risk Breakdown Structure (RBS) (21)

3.9.2. Lessons Learned Information System (LLIS)

Recording the lessons learned is one of the ways to improve risk analysis within the project. However, it should be noted that the information should be learned and implemented into the risk management or it would never go beyond being stored data in a database.

Mistakes are an essential part of learning and learning is essential for future project success. The process starts with the planning the project while considering the potential risk sources. During the mission, recognize the mistakes and learn from them. Documentation of these learned lessons and the best practices for the use of next project is the last quadrant as it is summarized in Figure 20. (22)

On the other hand, students should learn whenever a decision is made using knowledge instead of considered common practice. Students should be sensitive to hidden traps and try to interpret the warning signs beforehand. This could help them to identify a developing problem in a known area of risk.

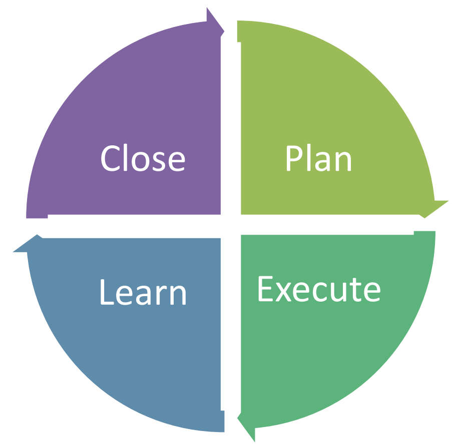

Figure 21. Plan-Execute-Learn-Close quadrants

Experience is an excellent teacher in risk management. However, lessons learned should be documented so that future project managers can learn from the past mistakes of his/her team or from earlier teams. A 'Lessons Learned Template' is provided (APPENDIX D. Lessons Learned Documentation) for students in order to avoid reoccurrence of mistakes. Provided Lessons learned documentation could and should be adopted according to encountered failures, high risk areas, general thoughts and suggestions in a project. Yet, risks will occur and projects may suffer. However, if external documentation becomes a habit in university-built satellite projects, then sharing this information would increase success both in future projects within the university small satellite community.

3.9.3. Fishbone Diagram

In the development phase of the project, systems engineers could solve the problems during the design process, development and test. When utilizing a team approach to problem solving, there are often many opinions as to problem's root cause. One way to capture these different ideas and stimulate the team's brainstorming on root causes is the Ishikawa diagram, also known as a fishbone diagram or a cause-and-effect diagram (Figure 22. Fishbone Diagram). The fishbone diagram will help to visually display the many potential causes for a specific problem. When the root cause of the risk is targeted, risks can be managed more easily.

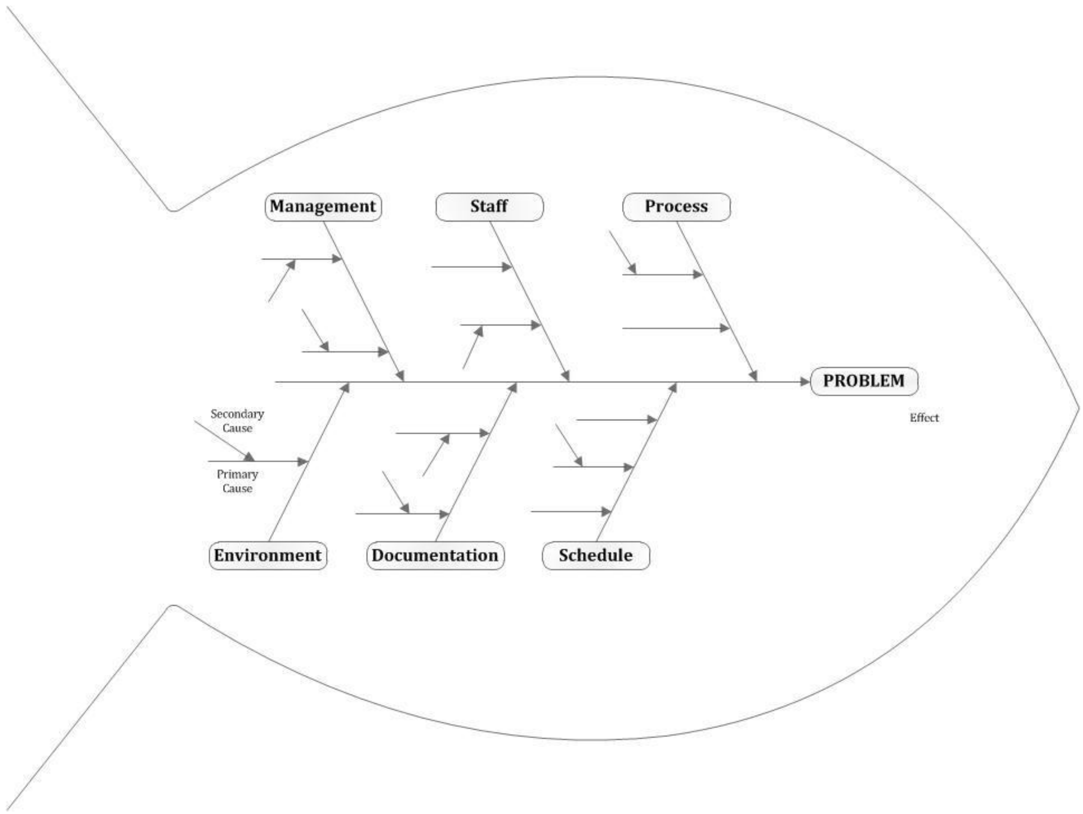

Figure 22. Fishbone Diagram

3.9.4. Fault Tree Analysis (FTA)

A fault tree analysis (FTA) is a top-down symbolic logic model which includes creating a fault tree with symbols, logic gates, to represent events and consequences and describe the logical relationship between events.

FTA (Figure 23) provides team members an objective basis for analysis and justification for changes and additions generated in the failure domain. FTA shows the cause-and-effect relationships between a single failure and the relevant contributing causes from top to bottom of the tree.

As a design tool, FTA is used to compare top event probability. As a diagnostic tool FTA is used to investigate scenarios that may have led to the top event failure (23).

A fault tree is similar to an event tree in that it starts with an event, but instead following the consequences, it traces the causes. The other main difference is that event trees are generated both in the success and failure domains. Fault trees are usually very detailed and use probabilistic information, which makes them difficult for a university-because of these complexities.

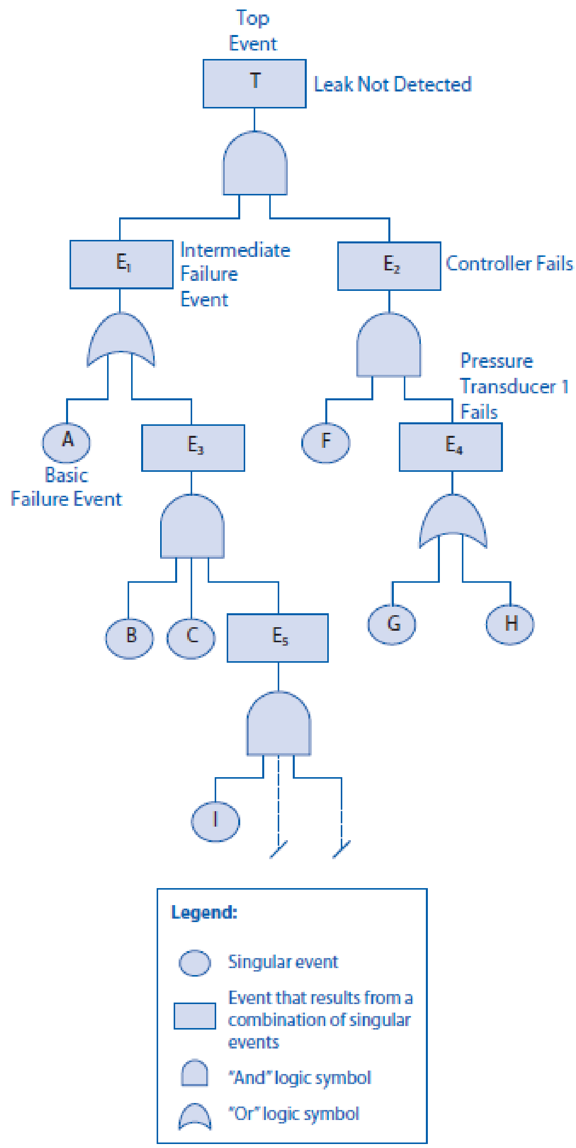

Figure 23. Fault Tree Analysis Example (24)

3.9.5. Failure Modes and Effects Analysis (FMEA)

FMEA is an early warning process that identifies the types of failures, the causes, and effects, prioritizes them according to their rankings, and develops mitigating strategies that can be employed to control the effects of the failures.

Failure Modes and Effects Analysis (FMEA) is much like a checklist, only more complex. The technique includes selecting a method to rank project failure modes, identifying all failure modes, analyzing failure modes and their mission effect, determining those failure modes that might benefit from corrective action, e.g., Alternative designs, Redundancy, Increased reliability, and lastly determining which, if any, corrective actions will be implemented. The FMEA works perfectly in solving problems at each risk management step, but this makes FMEA a time-consuming assessment method.

3.9.6. Probabilistic Risk Assessment (PRA)

PRA is a scenario-based risk assessment technique that quantifies the likelihoods of various possible undesired scenarios and their consequences, as well as the uncertainties in the likelihoods and consequences (24).

PRA is a comprehensive discipline that uses tools like FMEA and FTA to analyze every possible failure mode both qualitatively and quantitatively at great detail. PRA uses a much more complex failure mode identification to evaluate risks quantitatively. PRA uses a comprehensive methodology to evaluate risks and PRA can express the evaluation results more accurate. However it requires considerable amount of time and staff with insight, which makes PRA is a better option for larger projects. Because of its inherent complexity and dependence on staff insight and experience, the PRA is not a good match for university-built satellite projects.

3.9.7. Analysis of Options

Besides all of these risk assessment methodologies, the other options such as using simple and widespread programs such as Microsoft Excel to track risk, using Microsoft Project as a server application, creating logic diagrams and fault trees in Microsoft Visio minimizes the amount of time spent on learning how to do risk management using these software packages.

Checklists are a useful form of safety analysis despite their simplicity. As an example, an airplane is a safety-critical system. As one level of safety analysis, a pilot completes a pre-flight checklist before flight to ensure that the plane is working properly. Checklist is a simple, fast and easy form of safety analysis which also can be performed by students for each satellite subsystem. Therefore a risk management checklist (Appendix A) is provided for students covering each risk management step and main risk factors. The checklist provided is broad and general, covering pre-defined areas of risk. Once working on a project, students should create their own checklists.

Another simple but effective technique for monitoring risk is a top risks list (Appendix C) of the major risk items. A top risks list is an easy method for students to communicate regularly about critical risks, their consequences, and the current mitigation strategy. This is an excellent way to keep risks visible to the team and management so that they are not forgotten. .

Risk management takes time and effort away from other activities, so it is important for the team to implement only that level of risk management necessary for project success.

Considering the lack of experience of students, the optimized option will be combination of two or more of the easy to implement methods, each of which requires very little learning curve and is widely available at universities. Therefore, creating a checklist for risk identification, including a top risk list while having a risk register for tracking and a risk matrix for risk analysis, should be sufficient for a whole risk management procedure for team member use. A combination of these methods for university-built satellite projects should give students a procedure that can be generalized for small satellites but then be made to be applicable to a specific mission.

3.10. Risk Management Implementation for University-Class Satellite Projects

Staff should be encouraged to manage risks systematically and this should lead to the development of a risk management culture in departments rather than a stand-alone risk management “function”. Risk management can be integrated into the culture of the department with the implementation of key rules such as;

- Risk management is the concern of everyone in the team, therefore all students should be aware of the failure modes throughout the project
- Risk management is part of normal day activities and should be done simultaneously, thus consider training and recruiting new members constantly
- Risk management is logical and systematic and ideally should become second nature of the department so retain a core group of graduate students to become the mentor of the new personnel

As a summary, there are several factors that affect the success or the failure of a project with limited resources. The factors that enhance project success include the following:

- Well-defined scope
- Proactive risk management
- Simple and straightforward risk management which will not overwhelm students
- Create a database of failures that can serve as a reference to help identify risk

- Complete set of requirements
- Realistic time, cost, and requirements
- Distinct task descriptions and objectives
- Definition of time for the implementation of each task
- Identification of resources and responsibility for each assignment
- Communication among project team members
- Consistent documentation within the group
- External reporting, documentation for public use
- Share information on lessons learned, probabilities of failure
- Cooperation of project teams
- Coordination of project efforts
- Successful interpretation of the risk management cycle frequency

Chapter 4: Conclusion

4.1. Summary

As universities become more and more involved in satellite projects and new opportunities in terms of funding and cooperation of academia with industry arise, formal risk management is becoming increasingly important. The data indicate that for university built satellites, there have been a large number of “unknown” failures.

As the first step to identify these “unknown” causes, prevent failures and increase the success rate of the university satellite projects, a proper, modern and updated risk management procedure should be developed. In this context, this study defines simple but effective risk management processes, which can be applied to the active satellite projects of the universities.

In the beginning of the study, satellite failures, satellite failure characteristics and their trends are addressed and compared with industry related satellites in Chapter 2 with details. The comparison reveals that even though the industries do not show great interest in documenting their failures, we know much more about their problems and solutions. Besides, the difference between the working engineers in the industry and the student engineers in the university causes risk management standards and procedures, developed mainly for industries, hard to implement into the student projects.

After that, the main risk sources unique to university-built satellite projects (e.g. risk factors related to schedule, funding & budget and staffing & experience) are presented in Section 3.1 in a problem and remedy form. However, it is obvious that the addressed risk factors are not sufficient enough to identify all of the risks in a real life university built satellite project phases (e.g. design and testing phases).

In order to choose necessary risk management tools and methodologies for students, common risk management tools are discussed and compared in Section 3.9. It has been observed that the methods which are easy to learn and less time consuming could bring success to student projects. A simple, rapid and effective risk management procedure is developed.

Therefore, risk management templates, presented in Appendices, are able to identify the university built satellite project risks, evaluate and reduce their effects and enables students to control the risks throughout the project.

As a result, this study accomplishes three goals;

- It acquaints students with risk management and its implementation on university satellite projects.
- It outlines the roles and responsibilities of project manager, (i.e. graduate student(s)), and staff (i.e. team members) in establishing and maintaining a robust approach to managing risk and provides a number of specific guidelines that should be followed.
- It describes a number of techniques that can be employed to develop a structured and systematic approach for identifying and mitigating risk.

4.2. Student Guide for Risk Management Templates

This study presents a discussion of risk identification, risk assessment, risk mitigation, and risk monitoring, tracking and reporting. Tools are presented below specifically for student teams.

4.2.1. Risk Management Checklist

A checklist of actions that should be completed in order to fully satisfy risk management requirements is created (

APPENDIX A. Risk Management Checklist). This list of yes/no questions helps students in identifying the risk items. The presented checklist mainly covers the programmatic risk domains and the implementation of risk management procedure, but, if needed, satellite related risk factors could definitely be implemented into the list. In order to ensure good standards of risk governance this checklist should be filled. Some example questions are given below.

- Is a risk management framework identified and adopted with modifications as appropriate?
- Does the project include resources and funding for risk management activities?
- Are all the team members sufficiently involved in risk management?
- Do risk management activities raise awareness of risks within the team?
- Are the steps in the chosen risk management process well defined?
- Are the risk factors clearly identified and validated?
- Is risk identification being performed continuously throughout the project life cycle?
- Is a Risk Owner assigned to each risk?
- Are risks categorized according to a risk matrix and risk criticality data analysis?

- Have risks been ranked and prioritized?
- Are mitigating efforts adequate to control risk level at an acceptable level?
- Does the Risk Monitoring Process allow the Risk Owner to update information from the Risk Register?
- Is the Top Risk List reviewed and updated? (weekly, monthly, quarterly)
- How often does the team meet for risk management?
- Is there a communications strategy for risk management?
- Is everyone aware for the need giving feedback on risks?

4.2.2. Risk Register

A risk register (APPENDIX B. Risk Register: An Example) is a primary tool in risk management since it starts from the risk identification phase to the risk monitoring step. It enables students to cycle risk management steps directly. The efficiency of the risk register could be enhanced by students as they become familiar with the risk management and modify the presented risk register.

The risk register is basically a database of all risk scenarios (see Section 3.5) which answers fundamental questions such as, what should be done, when it should be accomplished, and who is responsible. The risk register contains the overall system of risks and the status of risk mitigation actions and includes details of the further actions that are planned.

When a risk first identified, the author should give a description of the risk and fill his/her name in the risk register with a sequence number and the date to track the risk. Then, project manager should evaluate the description and assign the proper risk owner and the priority number. From that point, risk owner should be responsible for that risk and its consequences. To improve categorization, the source of the risk should also be identified in risk classification column. The probability, impact and criticality of the identified risks should be quantified during the risk assessment step (see Section 3.6). Next, appropriate risk mitigation action should be determined, and the team should plan for actions if/when the risk factor becomes a problem. The frequency for revisiting the risk helps students to track and monitor the development. The overall instructions on how to fill risk register are given in Figure 24.

Risk ID	A unique order number used to identificate the risk for tracking	
Risk Priority #		
Author	Risk recording team or individual who is filling the risk card to register a potential risk	
Date of Identification	The date when the risk is identified	
Risk Owner	Designated individual who owns the responsibility for managing and monitoring the risk	
Risk Description	Description of the risk which can be understood by all members of the project	
Risk Classification	Summary of all risk factors contributing to the risk and their root causes	
Risk Consequences	Summary of possible outcomes, consequences and its impact on project	
Probability of Occurance	Estimation of probability of risk occurrence	
	High:	Risk is most likely to happen
	Medium:	Risk has possiblity to happen
	Low:	Risk is unlikely to happen
Impact of Occurance	Evaluation of the risk effect	
	High:	Risk has critical impact potential on project
	Medium:	Risk has some impact potential on project
	Low:	Risk has relatively little, if any impact on project
Criticality of Risk	Calculated by multiplying the risk probability by the effect of the risk and mapped on risk chart	
	Green:	LL (Low Probability, Low Impact), LM (Low Probability, Medium Impact), ML (Medium Probability, Low Impact)
	Yellow:	LH (Low Probability, High Impact), MM (Medium Probability, Medium Impact), HL (High Probability, Low Impact)
	Red:	MH (Medium Probability, High Impact), HM (High Probability Medium Impact), HH (High Probability, High Impact)
Risk Mitigation Approach	Description of type of strategies that will be used to manage risks	
Date of Mitigation	The date when the risk mitigation is to be implemented	
Contingency Plan	Description of procedures which have to be initiated if the risk factor actually becomes a problem	
Risk Tracking Frequency	Estimate of frequency for revisiting the risks or estimate of time within which the risk effect can be correcte	
Current Status	Describe the up-to-date status of the risk mitigation actions including what has been done	
Comments (Optional)	Additional comments that the individual/group would like to add	

Figure 24. Risk Register Instructions

4.2.3. Top Ten Risk List

The Top Risk List (APPENDIX C. Top Ten Risk List) is a simple tool that gives a quick snapshot of the highest risks logged in the risk register. The list consists of the 10 highest priority risks ranked from 1 to 10 in descending order. This is a one-page chart sorted by their risk rating, and includes the risk ID number which enables students to go back and investigate the risk details from the risk register. The report provides the risk trend which is observed and evaluated according to the last likelihood and consequence estimates. It also shows planned risk mitigation treatments and simple risk description.

Top ten risk list could assist students in risk tracking and monitoring. The team might track more risks than the ones in the list, but the risk mapping typically includes the top ten ranked risks for management review with ease. The act of updating and reviewing the top risk list each week raises awareness of risks and contributes to timely resolution of them.

4.2.4. Lessons Learned Documentation

Recording the lessons learned is one of the ways to improve risk analysis within the project. Students could benefit from lessons learned documentation before and during the project by learning from past mistakes.

In APPENDIX D. Lessons Learned Documentation a 'Lessons Learned Template' is provided for students in order to avoid reoccurrence of mistakes. Programs that are similar at a large number of schools (e.g. CubeSat) have unique ability to reduce risks by this way. The teams might have thoughts on their own failures or suggestions for other schools. If Lessons Learned documentation could be implemented wide-spread, students are less likely to make the same mistakes. Provided Lessons learned documentation includes examples in risk factors unique to university built satellite projects and general risk management steps. However, this document could be modified by adding, removing or redefining sections to meet the team's particular suggestions according to encountered failures, and satellite related risk domains.

4.2.5. Risk Matrix and Risk Mapping

A Risk matrix is a tool for risk assessment which presents risks with respect to their probabilities of occurrence and their corresponding impact levels. Risk matrices (Figure 25) with 3x3 risk assessment levels are presented in Section 3.6 for student-built satellite projects. Both the impact (consequence) and likelihood (probability) assessments are made on the basis of low, medium and high thresholds.

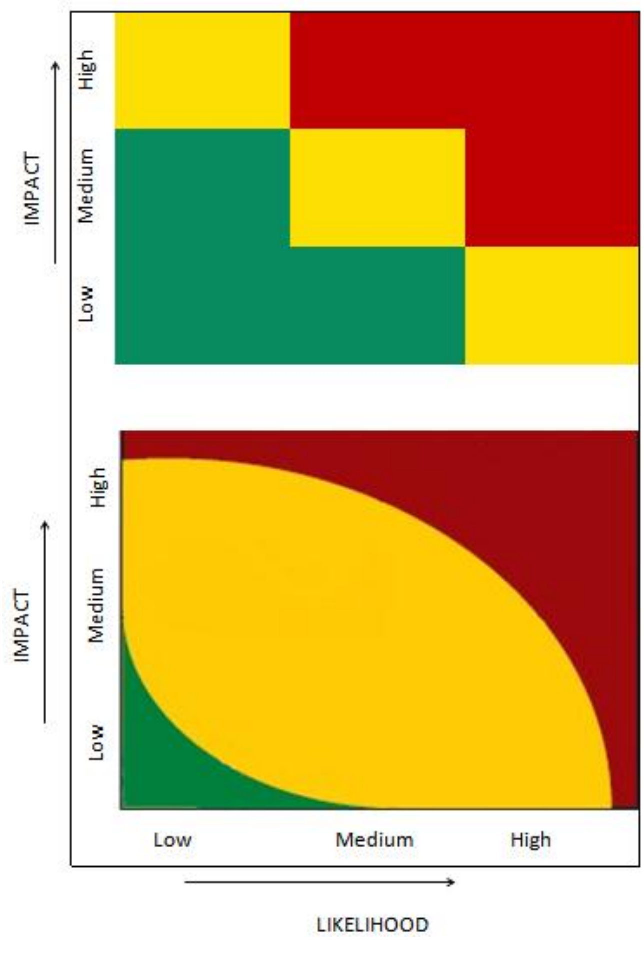

Figure 25. Risk Matrices

The use of a well-designed structure is necessary to ensure a comprehensive risk assessment process. By considering the impact and likelihood of each risk, the key risks that need to be analyzed in more detail could be mapped.

Risk mapping is a simple and useful method for assessing risks by prioritization. However, it could be hard to read with all of the risks plotted. To eliminate this problem, most serious risks could be plotted (see Section 4.2.3).

4.2.6. Fish-bone Diagram

When a team of people identify risks, there are often many opinions as to problem's root cause. One way to capture these different ideas and stimulate the team's brainstorming on root causes is the fishbone diagram in Figure 26. The fishbone diagram will help to visually display the many potential causes for a specific problem. (See Section 3.10 for details)

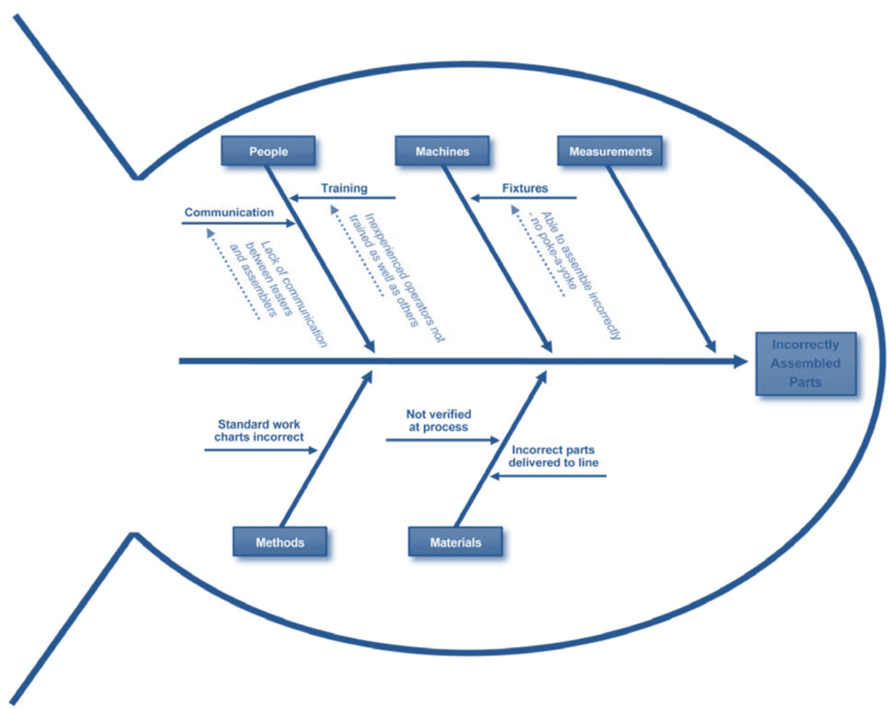

Figure 26. Fishbone Diagram (25)

4.2.7. Risk Breakdown Structure

It is important to incorporate risk management at the conceptual stage of projects as well as throughout the life of a specific project. RBS structure helps students to identify risks for university-built satellite projects (See Section 3.9.1 for details).

4.2.8. Other

Microsoft project and Microsoft Excel could be used in risk management implementation both in risk planning and tracking. Microsoft Visio could assist students to create event trees and logic diagrams.

4.3. Recommendations for Further Study

This study presents a basic level approach to risk management. However, as the students become more familiar with the risk management procedures and risk itself; more advanced tools might be applied to university-built small satellite projects.

During the study the most important aspects of the risk management are tried to be addressed to create a sufficient, simple and user friendly guide for students who are involved with satellite projects. Since the stepwise one-to-one application of risk management process is not investigated in details, the future effort on this subject could probably define case specific risk management methods and/or tool applications in each step.

In addition to that, the customization of the risk management process for different university-built satellite projects may reveal other important aspects of the subject. It should be mentioned that, the implementation of the suggested processes to an actively running project may create the best experience for identifying and managing the risks, which will expand the knowledge for further studies.

APPENDIX A. Risk Management Checklist

RISK MANAGEMENT CHECKLIST

		Status?	Comments?
		Y / N / NA	

Risk Management

1	Is a risk management framework identified and adopted with modifications as appropriate?		
2	Does the project include resources and funding for risk management activities?		
3	Are all the team members sufficiently involved in risk management?		
4	Does the project manager or advisor have sufficient involvement in risk management?		
5	Are the systems engineers' roles clearly defined with the risk manager and with their subsystem teams?		
6	Is risk explicitly considered as an integral part of reports and as a key factor in key decisions?		
7	Do risk management activities raise awareness of risks within the team?		
8	Have any risk standards been tailored for project risk management purposes?		
9	Have steps been taken to build a culture where everyone is a 'risk manager'?		
10	Are the required staff and/or skills available for the project in the required time frame?		

Risk Planning

11	Are the steps in the chosen risk management process well defined?		
12	Are the activities, roles, responsibilities, and deliverables determined for each step?		
13	Are the project/mission objectives defined?		
14	Has the risk management approach been established?		
15	Are the risk factors clearly identified and validated?		
16	Are the critical dates determined in the schedule for implementing risk management?		
17	Does the schedule make allowances to handle requirements changes that are likely to occur?		

Risk Identification

18	Is risk identification being performed continuously throughout the project life cycle?		
19	Are the tools or methods defined that will be used for risk identification purposes?		
20	Are the assumptions and constraints identified for risk management?		
21	Is a Risk Owner assigned to each risk?		

Risk Assessment

22	Is a risk analysis method chosen (e.g. qualitative, semi-quantitative, quantitative) for each risk?		
23	Are risks categorized according to a risk matrix and risk criticality data analysis?		
24	Have risks been ranked and prioritized?		
25	Have review dates been set for risk assessment?		

Risk Mitigation

26	Are the risk handling approaches identified and documented for the project?		
27	Are the high probability and/or serious consequences risks being mitigated first?		
28	Are mitigating efforts adequate to control risk level at an acceptable level?		
29	Are contingency plans created or ready to be executed for any risk exceeding defined trigger values?		

Risk Monitoring & Control

30	Are the tools or methods that will be used to monitor and track risks determined?		
31	Does the risk monitoring process involve continuous tracking of the risk levels and mitigation?		
32	Does the Risk Monitoring Process allow the Risk Owner to update information from the Risk Register?		
33	Are changes to the Risk Register evaluated to determine if additional actions are needed?		
34	Is the Top Risk List reviewed and updated? (weekly, monthly, quarterly)		

Risk Documentation & Communication

35	Has sufficient consideration been given to reporting on risk management?		
36	Is information about risk management shared within the group and externally?		
37	Do the team members provide feedback through mechanisms identified in the risk management plan?		
38	How often does the team meet for risk management?		
39	Is there a communications strategy for risk management?		
40	Is everyone aware for the need giving feedback on risks?		
		# of Y's:	
TOTAL		0	

APPENDIX B. Risk Register: An Example

RISK REGISTER

Risk ID	Risk Priority #	Current Status	Risk Owner	Risk Description	Risk Classification	Probability	Impact	Criticality	Risk Mitigation Approach	Mitigation Date	Risk Track Freq	Risk Consequences	Author	Identification Date	Contingency Plan	Comments
1	3	Open	All systems engineers	Activities take longer because they are more complicated than estimated	Schedule	High	Low	HL	Mitigate		2 weeks	Missing the launch date and/or availability	Jane Doe			
2	-	Closed	Project Manager	Personnel shortfalls	Staff	Medium	Low	ML	Transfer		1 month	More work for other team members	John Doe	Phase B	Team Building	Training undergraduate students shold be implemented into the project schedule
3	-	Closed	Project Manager	Lack of knowledge in Thermal Analysis Software	Experience	Low	High	LH	Mitigate		2 weeks	Non-Converging Heat-radiation results for the satellite	Jane Doe	Phase C	Training students for improving their ability to use necessary software	
4	-	Closed	Testing group	Faulty Connections between the components (e.g. solar cells - battery)	Technology	High	Medium	H M	Avoid		1 week	Failure in power subsystem	John Doe	Phase C	Individual output check of the components	
5	-	Closed	Propulsion & power Group systems engineers	Verification experiments needed for new COTs systems	Funding	Low	Medium	LM	Accept		3 weeks	New sensors/systems are needed, budget shortfall	Jane Doe	Phase D	Use space-verified parts/systems and structures	

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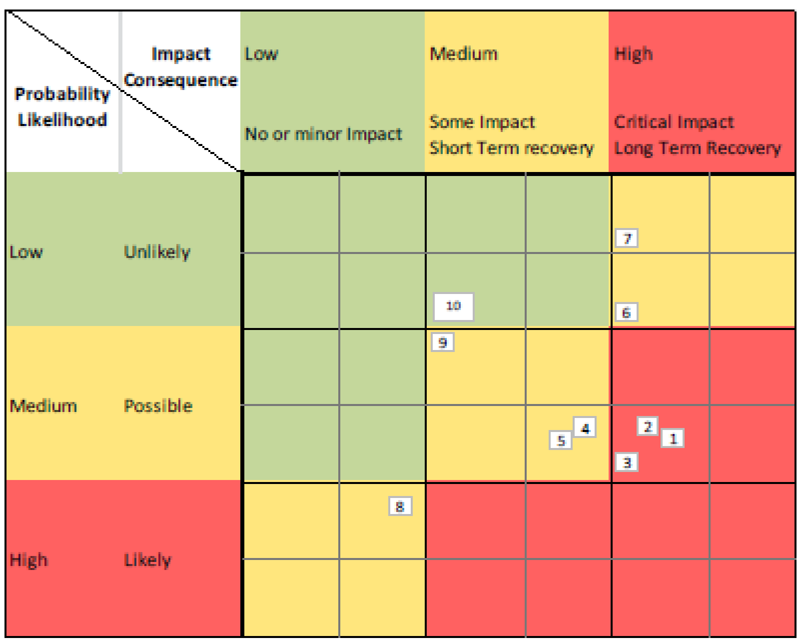
APPENDIX C. Top Ten Risk List

TOP 10 RISK LIST

Risk Priority #	Criticality	Risk Trend	Risk Description	Risk Mitigation Approach	Risk ID
1		⇨	Project requirments changes from previous semester	Avoid	24
2		⇨	Miscalculation of total costs	Mitigate	12
3		⇩	Hardware delivery delays	Mitigate	8
4		⇧	Required technical expertise lacking	Transfer	34
5		⇨	Sensor data formats undefined	Mitigate	19
6		⇨	User interface uncertainty	Avoid	42
7		⇨	COTs inadequate performance	Transfer	35
8		⇩	Tight schedule	Accept	21
9		⇩	GPS failed	Accept	53
10		⇨	Circuit problems	Accept	7



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APPENDIX D. Lessons Learned Documentation

POST-PROJECT
LESSONS LEARNED DOCUMENTATION

Risk Management Phases and Risk Factors	What worked well? <<Describe the strategies and/or processes that worked and led to success so that a novice would understand. Add rows as needed for each section.>>	What did not work well? <<Describe the strategies and/or processes that need potential improvement so that a novice would understand. Add rows as needed for each section.>>	Recommendation <<Provide a recommendation for each lesson learned that did and/or didn't work well. Add numbers as needed for each section.>>
Risk Management	Implementation of Risk Management		The risk management approach is settled into the project. Be sure that risk management becomes customary.
Risk Planning	Setting mission goals and requirements		When the project boundaries defined strictly, then the team members take the project more seriously.
Risk Identification	Using checklist for identfying risks	Lack of specific questions to clarify misunderstanding	Checklist should be updated according to project needs and/or the current phase.
Risk Assessment	Quantitative Risk Assessment		No need for qualitative risk assessment for university-built satellite projects.
Risk Mitigation	Top 10 Risk List	Failure to keep list up to date	Top 10 risk list is essential so make sure that it is updated and checked by project manager.
Risk Monitoring & Tracking	Risk Register	Failure to calculate probabilities of failures and their impacts when possible	Be sure that every team member know how to fill risk register
Risk Reporting & Documentation	Adoption of online documentation system	Tracking of current information	Documentation should be in a central location with access control from systems engineers.
Communication		Issue Escalation	Have a solid communication plan that outlines the escalation process, team members responsibilities and required response time.
Funding/Budget/ Cost	Meeting sponsor needs and requirements		Design re-use should be done carefully.
Schedule		Falling behind schedule	Each subsystem can be built by staged relese approach, it would take more budget but every release can fly.
Staff/Recruitment /Experience		Inadequate project team skill set	Application-based training or academic classes could be one option.
Social Risk Factors	Direction		Advisors and project manager help students to maintain a proper focus into their work.

Name of School:
Name of Project:

Bibliography

1. West, J., "Space Security 2009," Project Ploughshares, Ontario, Canada, 2009.

2. Gedmark, J., "CSF Announces New Research and Education Affiliates Program, Initial Participating Universities," Commercial Space Flight Federation, [http://www.commercialspaceflight.org/?p=1108], February 18, 2010.

3. "Risk Management Guide for DoD Acquisition," Department of Defense, 2006.

4. NASA Procedural Requirements, "NASA Systems Engineering Processes and Requirements w/Change 1," [http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1A], November 19, 2009.

5. *Systems Engineering Handbook,* NASA/SP-2007-6105 Rev1, Washington, D.C. NASA, 2007.

6. Verlag, C. H., "Handbook of Space Technology," Wilfried Ley., A John Wiley and Sons, Ltd., 2009.

7. Swartwout, M. A., "The role of Universities in Small Satellite Research," Space Systems Development Laboratory, Stanford University, California, 1997.

8. *Systems Engineering Handbook.* s.l. : NASA, 2007.

9. Tosney, W. and Chiu, R., "A Space Systems Pedigree Database Program," 1992.

10. Tosney, W. and West, B., "Space System Test Database Design Concept," 1993.

11. Jean-Francois Castet, Joseph H. Saleh., "Satellite and satellite subsystems reliability: Statistical data analysis," *Elsevier*, 2009.

12. Swartwout, M. A., “Student-Built Gossamer Spacecraft*,” AIAA Proceedings*, California, 2009.

13. Swartwout, M. A., “The Promise of Innovation from University Space Systems:Are we meeting it?,” *AIAA 23rd Annual Conference on Small Satellites*, 2009.

14. Webb G., Curiel A. S., “Is it really hard to get your hardware into space?,” *AIAA 23rd Annual Conference on Small Satellites*, 2009.

15. Swartwout, M. A., “Twenty (plus) Years of University-Class Spacecraft,” *AIAA 20th Annual Conference on Small Satellites*, 2006.

16. Deems, E., “Risk Management of Student-Run Small Satellite Programs,” Massachusetts Institute of Technology, 2007.

17. Preyssl C., Atkins R. and Deak T., “Risk Management at ESA,” *ESA Bulletin*, 1999.

18. Ley W., Wittmann K. and Hallmann W., Handbook of Space Technology, 2009.

19. “Risk management in higher education”, *HEFCE: Higher Education Funding Council for England*, 2005.

20. Latta, Carolyn J., “REAL Cost-Risk: The Risk Management Imperative,” *AIAA*, San Jose, California, 2006.

21. Hillson, D., “Structuring A Breakdown,” 2003.

22. Badiru, A. B. “STEP Project Management Guide for Science,Technology, and Engineering Projects,” *CRC Press*, 2009.

23. Guerra, L., “Risk Module: Risk Management, Fault Trees and Failure Mode Effects Analysis,” Department of Aerospace Engineering , The University of Texas at Austin, 2008.

24. NASA Systems Engineering Handbook. Washington, D.C. : s.n., 2007.

25. Noria Corporation, “Problem-solving techniques for a high-performance team” [http://www.reliableplant.com/Read/14690/high-performance-team], Accessed: July 23, 2010.

26. Cheng P. G., et al, “Space Systems Engineering Lessons Learned System,” The Aerospace Coorporation, *AIAA*, 2002.

27. Michael G., “A Risk Management What We Have Learned,” Hampton, Virginia, 2001.

28. Hsu J. C., Raghunathan S., and Curran R. “A Proposed Systems Engineering Diagnostic Method,” *AIAA,* Orlando, Florida, 2009.

29. Schroeter, J. “Risk Management in ESA’s Scientific Directorate: A Case Study,” *ESA Bulletin*, 2001.

Vita

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