2022-12-01

Evaluation And Implementation Of Lean Engineering Principles For Improving A University Rocket Team

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EVALUATION AND IMPLEMENTATION OF LEAN ENGINEERING PRINCIPLES FOR IMPROVING A UNIVERSITY ROCKET TEAM

by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Aerospace and Mechanical Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

December 2022

Acknowledgements

First, I would like to thank the person who made this possible, his guidance, support, patience, and professionalism of faculty members and mentor, Dr. Amelia Greig. Thank you for trusting me, finding a thesis topic, and knowing the restrictions I have as an international student to work or do research in aerospace. Also, thank you for allowing me to work for you during summer 2021; that research project allowed me to be the leader of UTEP's Rocket Team, a position that gave me leadership, experience, and networking. It will always be helpful in my professional life. Thank you for the countless hours of support and weekly progress meetings and for always treating me humanely; this world needs more leaders like you. I would also like to thank Dr. Angel Flores-Abad, my thesis supervisor, for your time dedicated to this thesis; your support and advice were extremely helpful in completing this thesis; without your help, it would not have been possible, thank you so much for taking the time and effort to collaborate with me to finish this paper! I also want to thank my committee members Dr. Miguel Cedeno for the support and advice through this journey working as a leader of the rocket team, and the Eng. Byrce Chanes for their valuable advice and support during the competition acting as our flyer of record. I also want to thank Dr. Lin for being my graduate advisor these years and facilitating the official list of students who applied for graduation. Furthermore, to my family members, my mom Gloria Monroy, my dad Ruben Garcia, my siblings Ruben, and Edith, and my future wife Maria Salette Ontiveros, thank you all for the support throughout this journey and for always trusting me since the first day of my master’s Degree, I am sure that without your help, this would not have been possible. Thank you, everyone!

Abstract

In the present day, lean is a tool applied to manufacturing industries trying to reduce waste and non-value-added work to every process during the supply chain. While implementing lean thinking in the industry has been highly effective, it is less common for academic purposes. However, it can also improve performance if the concept is correctly applied. The purpose of this thesis is to show and analyze the application of Lean Engineering thinking and its six principles to the Sun City Summit Rocket Team from the University of Texas at El Paso which competed in the Intercollegiate Rocket Engineering Competition (IREC) Spaceport America Cup 2022, the world largest rocketry competition that gathers students across the world to design, build and launch a rocket. The project Initium was the first rocket designed and built by Sun City Summit rocket team, integrated with mechanical, aerospace, and electrical students, targeting an apogee of 10,000 ft, using a propulsion system powered by a Commercial-Off-The-Shelf Aerotech M2500T solid propellant motor.

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Chapter 1 - Introduction

1.1 Lean Engineering general concepts and a brief history

The concept of lean engineering has been implemented around the world. It started thanks to the philosophy and concepts of the automotive industry, specifically by Toyota with the Toyota Production System (TPS), a philosophy created by its founder Sakichi Toyoda, his son, Kiichiro Toyoda, and chief engineer Taiichi Ohno. It was created to organize the manufacturing and logistics of the company, including the interaction with customers and suppliers. [1]

Nowadays, this philosophy is known as lean engineering, with companies competing through production cost, time, and waste. The lean approach has been central and crucial, and it targets improving operational performance and getting customer satisfaction. In the present day, it has been applied not only to the automotive industry but also to other industries, such as new product development, IT operations, insurance companies, public administration, banking, and hospitals, among others. According to Gershenfeld [2], competitive leaders from the economy consider lean engineering as one of the central successes of establishing high-quality products and continuous production flow.

In 2008, a network of management consultancies surveyed how many of the respondents use lean in their companies; 57 percent responded affirmatively, while 20 percent considered using lean. [1] Another study, referring to the IW/MPI Census of Manufacturers, showed that 70% of manufacturers in the USA had implemented lean engineering in some parts of their processes. [2] Both studies show the importance of the lean approach during the last decades to all kinds of companies, trying to serve customers with the exact products or services targeting a higher quality, lower price, and less time wasted in the supply chain.

The first key element to apply lean thinking in management practice is respect for the people, trust, and delegation. Where the leader and the workers are a team, and the issues do not rely on the employees but on the processes. The second key aspect of lean is to eliminate waste in the process. Eventually, the concept is trying to make the perfect system; rework, production of items or services with no relevance, unnecessary production steps, and employees' movements with no sense, are some examples of waste that does not add anything to a perfect system. Third, continuous improvement. This is done using practical knowledge applied with different lean tools, as explained later in this thesis. The entire process relies on how the process is laid out and organized. People working near and together to transfer knowledge and lean practices, applying poka yokes to eliminate human error, and wasting using 5s are examples of continuous improvement. The fourth key element is to obtain perfection through the standardization of tasks. If the process is not standardized, it is not possible to obtain Flow, letting people the possibility to guess what to do and how to do it; every part of the process should be precisely described and measured in detail. Good documentation practices, Corrective and Preventive Actions (CAPA), and Production Part Approval Process (PPAP) are some tools that can be implemented to standardize the processes. Moreover, fifth, lean engineering creates Flow and harmony. The production process should be organized in this way, every step of the process follows the next stage.

These five essential elements of lean engineering described above are embedded in the Japanese culture. The concept relies on how modern Japan was created, inspired by Confucian thinking during the Edo Period (1600-1868), a time of relative peace in Japan with four basic categories: Samurais, Peasants, Artisans, and Merchants, considered a hierarchy of moral virtue. [2]

The town had around 5,000 samurai residents. The samurai community chose their leaders, selecting their higher warriors. These samurai codes influenced Japanese society, their administration, leadership, and behavior. Another reason is how Japan closed its ideals during that time to foreign ideals. This led to its current way of thinking about Japanese culture.

During the Meiji period between 1868-1912, it reflected the idea of protecting the country through the development and the government. It wanted to keep the central values of the Japanese culture the same. Then, the wars such as the surrender to the US in 1945 or the Korean war led to many changes in the country. However, the Japanese model and culture prevailed.

After the mentioned wars and the start of Japan's industrialization, Shintoism, Buddhism, and Confucianism, three religions were created. The thinking and practices of Japanese leaders regarding these religious ideas describe lean by Toyota founder Kiichiro Toyoda. These religions influenced him, and the Toyota Production System is a Confucian-influenced system. [3]

As mentioned, the five key elements of lean engineering are influenced by Japanese culture, history, and religion. Also, as we know, Japanese behavior is described by its principal codes and values, such as discipline, rituals that ensure quality and tidying up, and behavior that was taken from religious influence.

The codes pass on into what we know today as lean engineering. The first critical long-term orientation is linked to several Asian religions.

The second element is to reduce waste and serve society, which are trademarks of a Zen community and Confucianism. Third, continuous improvement through practical knowledge is similarly connected to religious values, where Confucian learning stresses the practical value of knowledge. Fourth, the Japanese state promoted perfection through standardization early by giving guidance and quality between the wars and religious rituals for personal development. The fifth concept consists of creating Flow and harmony, a very salient Confucian value to order the way societies should be organized in four castes mentioned before, Samurais, Peasants, Artisans, and Merchants. [2] The history of lean engineering tells us that it is embedded in the Japanese culture and religious context.

Value, waste, and the process of creating value without waste are the three fundamental concepts of lean thinking. To create value without waste is captured into six lean principles that are fully described in the next chapter: first, value, which defines the final value for the deliverable to the customer. Second, map the value stream, which eliminates waste by mapping the program's plan. Third, flow, adds steps and processes without stopping or idle time, unplanned rework, or backflow. Fourth, to pull the value implementing as the Just-in-Time (JIT) delivery of materials or service to the next step. Fifth, perfection, pursues perfection in all processes by implementing continuous improvement tools. Furthermore, the sixth, Respect for People, confirms how lean is embedded in Japanese history; the goal of the last principle is to recognize the people as the most valuable resource and to blame the system, not the workers. [4]

1.2 Sun City Summit Rocket team and Spaceport America Cup

The summer of 2021 was spent trying to gather helpful information to start a rocket team at the university. Two objectives were defined for the project, to get data to start a successful rocket team and to apply the six lean engineering principles to the entire process.

After a successful summer research, the Sun City Summit Rocket team was founded in August 2021 to compete in the 2022 Spaceport America Cup. The Intercollegiate Rocket

Competition (IREC) gathers students worldwide to design, build and launch a rocket that reaches 10,000 ft or 30,000 ft altitudes, depending on the selected category. [5]

Sun City Summit Rocket Team is a student-led rocketry team affiliated with the Aerospace and Mechanical Engineering Department at The University of Texas at El Paso. The union of the university's new program helped the students gain experience in designing, constructing, and flying high-powered rockets. Since it was the team's inaugural year, the name "Initium" was chosen for our launch vehicle; it means "from the beginning" to mark the university's first-year endeavor in an intercollegiate rocketry competition. [5]

Sun City Summit 2021-2022 was comprised of 34 students made up of five sub-teams:

- Avionics: Responsible for all electronic systems that conduct flight data acquisition, send telemetry, establish communication with the ground station and perform launch operations.
- Payload: Design an experiment to compete in the SDL Payload Challenge that can successfully provide data of scientific merit during a flight that enables meaningful learning opportunities.
- Propulsion: Provide Initium with safe, efficient, and reliable propulsion during flight to reach the target apogee using a solid–propellent motor.
- Structural Aerodynamics: Design and manufacture structural components, ensuring integrity during flight, and characterization of flight dynamics through testing and simulations.
- Recovery System: Safely land Initium by utilizing a dual-deployment recovery system. [5]

The design and implementation of the project and more information about the competition are described in the next chapter, along with a long explanation of the six lean engineering principles.

Chapter 2 - Literature Review

2.1 Six Lean Principles

To understand how the entire process can be improved using the six lean principles, it is necessary first to know why the value and waste are critical information. Value means what the customer says and is willing to pay for. This means that the client states the requirements while the contractor makes it and delivers it on time, always trying to satisfy the customer. This basic concept of any interaction between seller and buyer, being more challenging when talking about a complex system, can be applied. [4]

The value must be clear, unambiguous, and understandable for everyone involved in the process. If the value is not defined precisely, it will suffer delays, added costs, or even the complete closure of the system. To understand lean engineering, it is essential to know the meaning; reduce the waste, which needs to be embedded through the entire process, where it is defined as anything that does not add any value to the end product from the client's perspective. [6] The ability to identify waste and eliminate it in the process is a critical lean engineering skill. All work activities are classified into three distinct categories, value-added activities, required non-value-added activities, and non-value activities, defined as:

- Value-added activities (VA), creates value and it is any operation that contributes to the form, fit, or function of the final customer-required product [7] and must satisfy three conditions [4]:
    - Transform information or material.
    - The customer understands the details of the activity and must be willing to pay for it.

- It is done right the first time.

- Necessary non-value-added activities (RNVA) do not meet the VA definition but cannot be eliminated because they are required by law, contract, company, or other similar reasons; they are necessary for streamlining the production process to reach the value of the final product. [4]
- Non-value-added activities (NVA) that consume resources and create no value are pure waste and must be removed when detected [4], waste in any operation that the customer is unwilling to pay. [7]

Taiichi Ohno is considered the father of the Toyota Production System and has his definition of waste "The needless, repetitious movement that must be eliminated immediately. For example, waiting for or stacking subassemblies." [4] He classified it into seven categories, which are defined in table number 1.

Table 1. Seven types of wastes with examples. [4]

Seven Wastes Engineering	Engineering Program Examples
Overproduction of Information	• Producing more than needed by the following process. • Creating documents that were not requested. • Redundant tasks, unneeded tasks.

	• Over-dissemination sends information to too many people (e.g., excessive e-mail distribution). • Sending a volume when a single number was requested. • Work on an incorrect release (information churning). • Lack of reuse of expertise, reinventing the wheel.
Waiting	• Waiting for information or decisions. • Information or decisions waiting for people to act. • Large queues throughout the review cycle. • Long approval sequences. • Unnecessary serial effort.
Unnecessary Movement of Information	• Hand-offs. • Excessive information distribution. • Disjointed facilities, politically motivated geographical distribution

	of work (e.g., "made in 50 states"), lack of colocation.
Over-Processing of Information	• Refinements beyond what is needed. • Point design used too early, causing massive iterations. • Uncontrolled iterations (too many tasks iterated, excessive complexity). • Lack of standardization. • Data conversions. • 2-D drawings (3D should be used consistently). • Use of excessively complex software "monuments" for no apparent reason (e.g., use of complex software when a spreadsheet would be acceptable).
Inventory of Information	• Keeping more information than needed. • Excessive time intervals between reviews.

	• Poor configuration management and complicated retrieval. • Poor 5 S's (sorting, straightening, systematic cleaning, standardizing, and sustaining) in office or databases.
Unnecessary Movement of People	• Unnecessary movement during task execution. • People have to move to gain or access information. • Manual intervention to compensate for the lack of process.
Rework, Defects	• The killer "re's": Rework, Rewrite, Redo, Re-program, Retest. • Unstable requirements. • Uncoordinated complex task taking so much time to execute that it is obsolete when finished and must be redone. • Incomplete, ambiguous, or inaccurate information. • Inspection to catch defects.

With the definitions of lean engineering thinking, the concept of lean has been interpreted in many different ways by authors and experts. Rachna Shah and Peter Ward suggested having philosophical and practical lean orientations in their research. They proposed three levels of lean thinking: philosophy, principles, and tools and techniques, as shown in Figure 1. [8]

The top-level shows the philosophy of the concept, the core of lean engineering, to eliminate waste and improve customer value. The second level constitutes the six lean principles; value, map the value stream, Flow, pull, perfection, and respect for people. The third and last level shows the operational level, a collection of lean tools and techniques to successfully apply lean. [8]

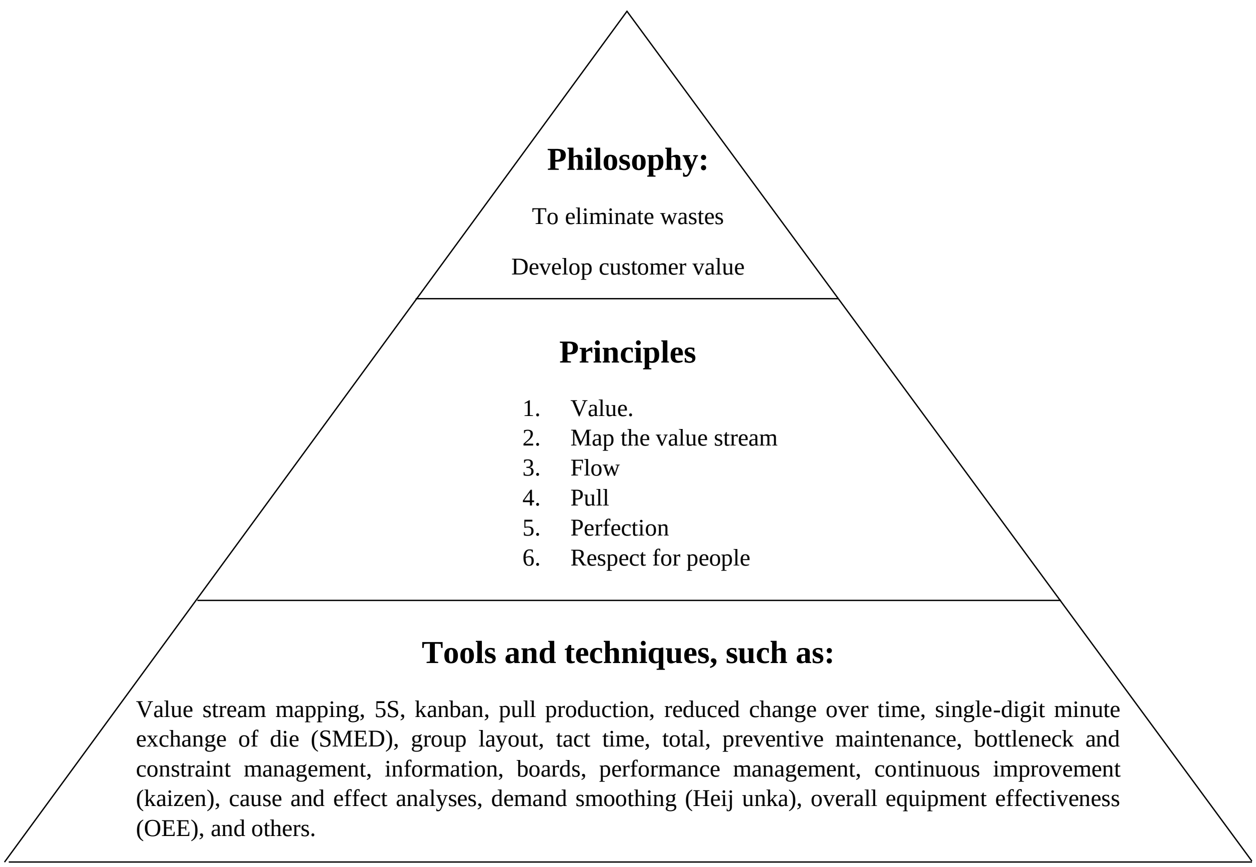


Figure 1. Three levels of lean. [8]

2.1.1 Principle. Value

Capture the value defined by the customer, which could be internal or external; internal clients receive the output of a task and external pays for the system. In both cases, the one who puts the money defines what is going to be the value of the final product. [4]

The value should be defined with precision and clarity for everyone involved in the process. From the beginning to the end of the supply chain, the entire process and all activities may be focused on the same value and need to be classified into one of the two first categories of activities; value-added activities or necessary non-value-added activities. It is critical to revisit, update or revise the value as often as needed. The customer value expectations can change, and the original value proposition could become obsolete. For example, the rules, documents, and forms used to determine the value of the IREC Spaceport America Cup 2022 were published in October 2021; however, these files changed over the year. Effective communication with the customer and a clear value definition will always be critical. Constant change and instability must be avoided, or the project costs and the schedule will lengthen [4].

To determine the value and start working with the following principle, time becomes one of the most crucial factors, delivering the value when the customer requires it. This needs to be defined by the customer as well, and it is part of the plan management before start producing the final product. Taking Spaceport America as an example, the organization panel uploads a calendar file with the activities, submissions, and deliverables dates. This shows what the customer wants and when it is required; if a deliverable is submitted later than the assigned date, the score of that submission is 0. Taking the industry as an example, delivering the product after the agreed date could lead to a cancelation of the agreement with the customer.

The process to capture the value with precision and clarity should answer critical questions, such as, what is the timeline? When and how is going to be the delivery of the final product? What is the price? Moreover, all the vital requirements that the product must be met. Seeing the lean engineering principles as steps, they must be applied. The second principle will be correct and successful if the value is defined correctly.

2.1.2 Principle 2. Value Stream

The following principle to apply lean engineering successfully to a system is capturing the value defined. Now that the project has a value defined and scheduled, it is necessary to draw the entire plan. Also known as Value Stream Mapping (VSM), it consists of eliminating waste, drawing the customer's value, and linking the tasks and decision nodes, all end-to-end, to get customer value. The main goal of the VSM is to identify and organize all types of waste and reduce them. It contains value-added and non-value-added activities, starting with the raw material and ending with the consumer.

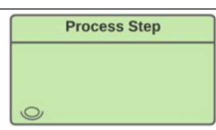
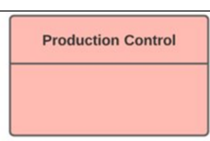
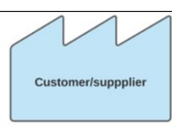
A key concept in manufacturing is that material is being transformed and moved. While in the engineering domain, the information is transformed and moved, the term information flow refers to the packets of information which flow from one task to another, such as design, analysis, test, review, decision, or integration. Using VSM and lean engineering tools, the material can be transformed and moved as an engineering domain, which is one of the goals of the value stream and the subsequent principles. [4]

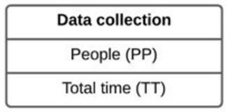
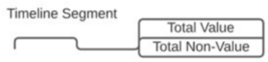
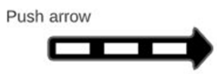
Applying the lean engineering definition of trying to get better results by eliminating the waste, mapping an incorrect series of events would only create more waste instead of eliminating it. The value stream should be a representation of the actual process, resources, and schedule instead of supposed events. In addition, it provides steps of each process and the timing to complete them. [9]

The term planning includes two phases. Number one the enterprise preparation, where the companies prepare resources that will serve all programs, such as people, processes, and tools. Furthermore, number two is program planning; once the resources are prepared to contribute value to the plan, this second phase refers to the planning effort for the program, in this case, the value stream mapping.

To map the value stream, the collected data and information will flow through a drawing; for the purpose of this study, the mapping is based on the simplified application by Sean M. Gahagan [10], who gathered all details in a simple manner. The VSM iconography consists of small boxes, arrows, data boxes, and figures, which are described in three categories: material flow, information flow, and general icons.

Table 2. Value Stream Map icons. [10]

Type	Icon	Description
Information flow		The process step icon describes an activity or sub-activity in the map.
		The production control determines the entity or people in charge of the program.
		The customer/supplier describes the state of the people involved in the process.

		The data collection icon records the essential attributes of the process (process cycle time, resource quantity, changeover time.)
		The timeline segment determines if the time (seconds, minutes, hours.) is creating value.
		The push arrow is used to push the process to the next step.
Material flow		The inventory icon shows places on the map where products sit and wait for the following process.
		It is used to determine the place where the material is being sent.
		The truck shipment icon shows the arrival of raw materials on the map.
General icons		The kaizen icon shows a potential improvement area that needs special attention.
	Other icons	To complete value stream maps.

2.1.3 Principle 3. Flow

The concept of lean engineering is always focused on waste minimization that can occur in the entire process, using the VSM as a baseline. To flow the work planned is the next step to apply lean engineering to the system. It adds value-added steps and processes without idle time, unplanned work, or backflow [4].

This third principle's correct design and plan are critical; developing schedules, budgets, and other requirements are part of this step. To optimize Flow, the maximum tasks need to be addressed up to the near capacity of the company. Many tools can be used to flow the work, such as digital calendars, cloud storage, and software.

Flow management can be a more challenging task to apply if the system is extensive. These projects have complicated supply chains and resources and are subject to significant changes; however, lean execution can take years to be perfect; for instance, it took decades to perfect the Toyota system, and their employees still claim that the process is far from perfect.

2.1.4 Principle 4. Pull

The objective of this fourth principle is to implement the pull as the Just-in-Time (JIT), aiming to deliver the parts and materials to the needing station or the external customer. Following the behavior of Toyota's founder, this principle is embedded in the Japanese Culture, too, with the strong codes of discipline, rituals to ensure quality, and tidying up, where delivering the object or information is an agreement between the lean manager and the customer stakeholder that needs to be done in time. [1] The system's value needs to be delivered according to the schedule imposed by the customer, not before or after.

The pull principle has two main goals: first, all the activities in the program must be justified, it can be a specific need, a request, or even necessary non-value-added activities, and it should be stated by the internal or external stakeholders and coordinated with them. Second, the activity should be completed when the stakeholder needs it, and it is easy to think of an early completion as an innovative idea; however, this will only lead to a destabilization of the system that includes shelf-life obsolescence, overproduction, poor 5 S's implementation, and even scrap if the initial value changes. [4]

An uncontrolled pull tends to create chaos in the system. Implementing this principle must consider the availability of resources, limiting the inventory, and work in process is always better than delivering more than needed. The lean manager must think about the best organization of the supply chain; having all the resources available in the exact location will allow the system to finish a specific activity without waste. [4]

2.1.5 Principle 5. Perfection

It is the most important principle that will take more time to accomplish. The global competition is enormous, and the winner is those who know how to achieve customer satisfaction with continuous improvements in all processes and products.

Then, an important question pops up, who determines if the processes and products achieve perfection? The most common question may be the customer. However, there are experienced specialist judges and certifications to look for perfection in coordination with system engineers and program managers.

The community of Practice on Lean in Program Management [4] proposes two features of lean to prioritize processes improvements: one, to make all the imperfections visible to all; when an issue is noticed early, the potential solutions tend to be easier and cheaper, in the other hand, problems that are not noticed early tend to grow and can create chaos to the entire system. Making the imperfections visible to everyone motivates them to apply continuous improvement in real-time, and it subsequently tries to achieve a perfect system. Second, prioritizing to eliminate the biggest impediments to flow, several companies have an entire department focused on continuous improvement, finding issues in the workflow, such as bottlenecks or unnecessary work. This will conduct to make better decisions on corrective actions.

Different tools can be applied to a lean enterprise, focusing on continuous improvement, 5 S's, making a visual factory, implementing poka-yokes to manufacturing to avoid people's mistakes, and problem-solving tools to find root causes and solutions. Furthermore, other tools to continuously evaluate the performance to achieve perfection.

2.1.6 Principle 6. Respect for people

In the previous chapter, the Toyota Production System stated (now known as lean engineering) that it was influenced by religion. Confucian thinking is essential for this last principle with how they saw the work. First, it should be made for the company and to benefit society. If it does not achieve this requirement, it is not considered work for Confucianism; hence it is a waste. Second, the emphasis on serving the customers in lean is a way of serving society. This last principle summarizes lean engineering; a system focused on the customer, serving, and people. [1]

A lean enterprise may be an organization that recognizes people as the most valuable resource of the entire system. [4] In a regular company, when issues arise, the bosses blame their employees for doing a specific activity wrong; on the other hand, in lean engineering, the system must be blamed, not the people. The concept tries to find a root cause and an effective plan to solve the issue. If the issue persists, it has yet to achieve perfection, and continuous improvement must be implemented.

Lean thinking requires an environment of mutual respect and trust and open and honest communication between all the people, from employee to employee, to employees to customers or stakeholders.

2.2 Evidence of the six principles applied to university projects

The previous chapter showed the success of lean engineering applied in the industry with many benefits; since Toyota created its production system, companies are now able to improve quality and customer satisfaction. However, the academic environment could be quite different and challenging to apply this thinking. This chapter starts with the evidence of lean engineering applied to academia and shows how implementing lean thinking can lead to successful university projects.

Data taken from the American Society for Engineering Education showed approximately 2 million engineers in the US in 2018 and 70,000 recent graduates during the same year; the reality is that industry sometimes can be dissatisfied with the engineering knowledge that the academia taught. In this case, the root cause indicates outdated courses and teaching methods; the academic environment is different from industry, but lessons learned from industry can help to ensure that the graduates receive the required knowledge and capabilities, and the education should be accommodated to the changes in the entire industry to understand customer needs with tools and techniques, such as lean engineering and its six principles. [11]

Lean is a client-driven philosophy, and the application is based on the six principles described before; value, map the value stream, Flow, pull, perfection, and respect for people.

The value in an educational environment is set on the course design. It needs to include more value-adding activities, and the content needs to be better organized and always try to reduce waste in teaching and lessons. The concept of lean, in this case, should be viewed as an iterative process. The improvement of the lessons, the course content, changes in the way students learn, and the role of the instructor will take some time to be considered a lean environment. The way faculty address these changes can significantly impact what students learn, focusing on the student's expectations of what they need to learn and perform. [11]

By eliminating waste, instructors will get many hours to address other vital lessons or projects. Some examples of waste in an educational setting could be an excessive review of prerequisite course materials, unnecessary introduction, and waiting for unprepared students to catch up. [11] The lean thinking should be applied to other courses of the Degree, and it would be irrelevant to implement the concept in one course and not in the others; for instance, those courses that have a prerequisite of a class required to register must be linked to the consequent course the same way lean principles work, flow the work for one course to the next one will reduce the waste in learning the same content again.

Implementing lean engineering tools in an educational setting can help identify course activities and enhance student knowledge and new skills. These activities may be value-adding ones. The quality function deployment (QFD) is a matrix created by selecting a set of specifications that will be ranked on a scale from one to five by how well they are related to customer satisfaction and needs (in this case, the students). The table below shows an example of the quality function deployment for course design applied to the University of Windsor in Ontario, Canada. [11]

Table 3. QFD for course design. [11]

Students' graduate attributes (knowledge and skills) \ Course activities	Lectures	Class applications	Written assignments	Problem-based projects	CAD applications	Additive manufacturing	Progress tests	Class presentations	Feedback	Course design ranking* *(Likert scale 1-5)		
										Improved design	Initial design	Areas of improvement
Integration of knowledge	▶	●	⌗	●	●	●	●	●	●	5	3	
Problem-solving skills		●		●			⌗	▶	●	4	3	x
Communication skills		⌗	●	●	●	⌗	⌗	●	●	5	2	
Teamwork		⌗		●	⌗	⌗		●		4	2	x
Creativity		⌗	⌗	●				⌗		4	3	x

● Strong relationship; ⌗ Moderate relationship; ▶ Weak relationship.

2.3 Initium design and implementation

Initium was the first rocket designed, built, assembled, and launched by the Sun City Summit, the University of Texas at El Paso rocket team. It compromised of 34 students that make up five sub-teams, avionics, payload, propulsion, structural aerodynamics, and recovery system. The team structure is shown in the following figure. [5]

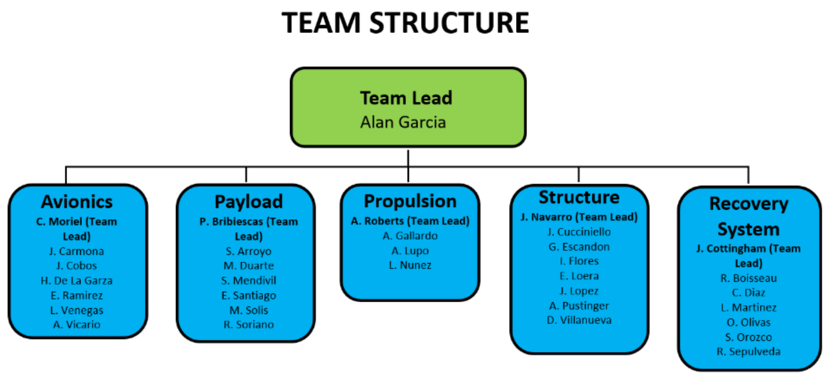


Figure 2. Team organizational chart. [5]

The development of Initium began with satisfying top-level requirements of the IREC SAC 2022, taken from the official rules document and the IREC Design, Test, and Evaluation Guide. These main requirements were to:

- Utilize a COTS motor certified by TRA or NAR.
- Reach an apogee of 10,000 ft AGL.
- Maintain an ascent stability between 1.5 to 6 calibers.
- Achieve a rail exit velocity of at least 100 ft/s.
- Achieve a minimum 5:1 thrust-to-mass ratio.
- Design a payload of no less than 8.8 lbs. that conducts a scientific experiment or technology demonstration with a 3U CubeSat form factor.
- Safely recover and prevent excessive damage to the vehicle upon landing.

To fulfill these requirements, initial prototypes were made using a software called OpenRocket. This simulator allows users to design the rocket and its components, giving results before and after the flight considering the environment. [5]

The team leader, alongside sub-team leaders, proposed preliminary designs and first-order estimations. After meetings with all the team, counselors, and faculty members, initium was divided into five main sub-systems: propulsion, recovery, payload, and avionics. Figure 3 shows the cross-section of initium. [5]

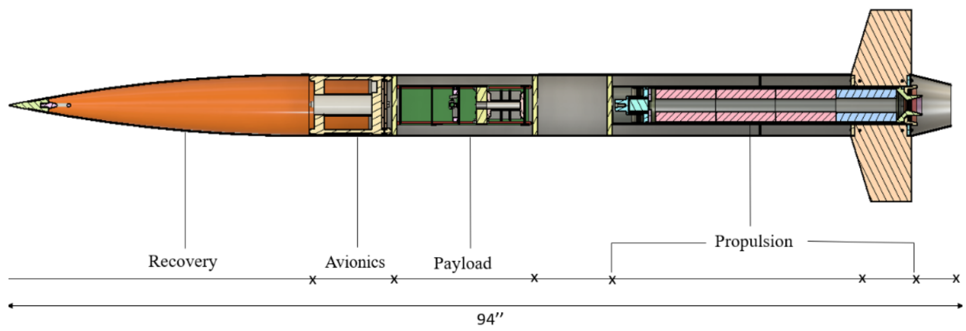


Figure 3. Initium architecture by sub-systems. [5]

The following figure shows the mission concept of operations (CONOPS) that describes the requirements and general phases of initium, which are:

1. First, the ignition system will be activated to launch the rocket the SAC staff.
2. The burn out of the propulsion system until it reaches the requirement of 10,000 ft apogee.
3. During the initial deployment, the rocket is separated, the drogue parachute is released, and stabilize the attitude to reduce the descent rate.
4. The main parachute is deployed at 800 ft.
5. The mission is finished, and the rocket is ready to be recovered with a Global Positioning System.

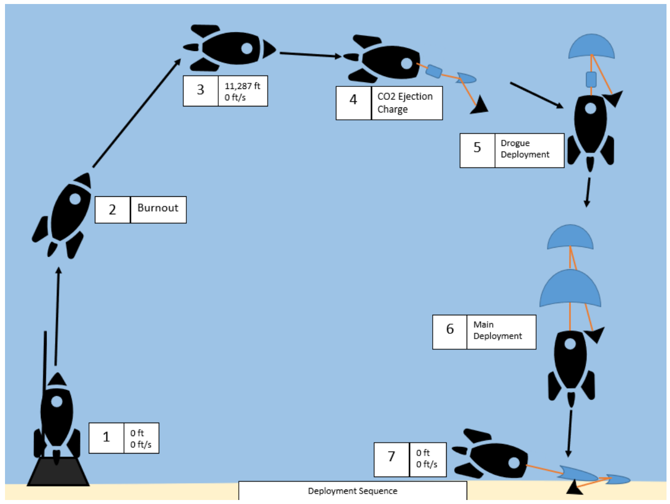


Figure 4. Initium CONOPS. [5]

The rocket design and implementation are divided into sub-systems.

2.3.1 Propulsion

Initium was launched using an Aerotech M2500T single-stage M class solid rocket motor with a total impulse of 9,671 Ns, with a burn time of 3.9 s, and the thrust curve can be found in the following picture. In the calculations to achieve the required ΔV and ideal launch thrust needed to satisfy the 10k ft COTS category, the sub-team made requirements to select the best motor options from a certified M class motors list. After considering three different motor options, the Aerotech 2500T was selected since it has the characteristics needed to achieve the ΔV required to reach 10,000 ft. [5]

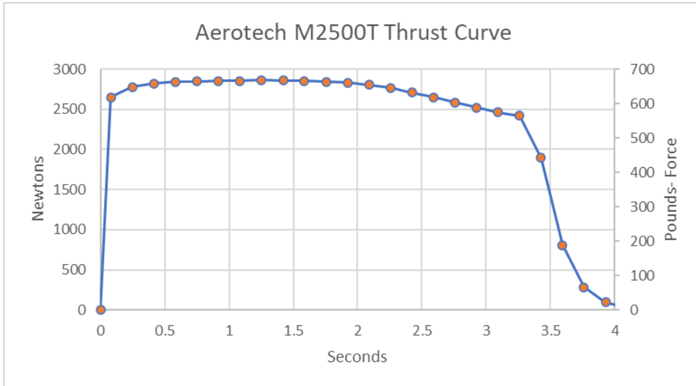


Figure 5. Aerotech M2500T thrust curve. [5]

2.3.2 Structure

Initium is constructed of G12 fiberglass COTS components, an airframe or main body tube of 60 in, lengthwise with an outer diameter of 6.17 in, and an internal diameter of 6 in, and a nose cone with a 5:1 tangent-ogive shape those measures 27 inches in length with the same inner and outer diameters of the main body. The airframe's primary influence is adequate space for the 3.86 in motor mount to properly fit the Aerotech M2500T and the 3U CubeSat form factor 3.9 in x 3.9 in x 13.4. And a nose cone. [5]

The fins were constructed using a 1/8-inch thick G10 fiberglass, the structure sub-team manufactured the fiberglass sheets with a delta shape chosen due to the aerodynamic properties, and they measured a root chord of 6 in., tip chord of 4 in., and a span of 6.5 in. Secured with M5 screws attached to the centering rings and epoxied to the airframe, four fins were assembled to the main body.

2.3.4 Payload

The team decided to participate in the Space Dynamics Laboratory (SDL) payload challenge to create experiments that accomplish a relevant function and provide valuable opportunities. The primary mission for the initium CubeSat is to deposit a special ink that cures in space and becomes conductive, trying to demonstrate a 1-D printing mechanism and simulate repairing an electric circuit. [5]

The valuable learning opportunity of this experiment is to show repairing hardware in microgravity at the apogee. The experiment can be replicated at zero gravity for outer space purposes. The following picture shows the payload experiment.

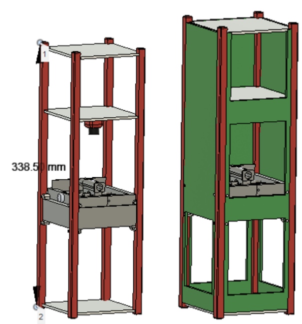


Figure 6. Initial payload experimental bay. [5]

2.3.5 Avionics instrumentation and control

The team designed a bay to communicate, navigate, display, and manage electronic systems, including controlling the CO2 deployment system for the recovery system. The avionics bay was created with additive manufacturing 3D-printing and used PLA for the filament with an 80% infill.

The avionics bay included a Global Position System (GPS), an altimeter, an IMU, a microcontroller, and other electronic components such as the battery, cables, and connectors. The TeleMega flight computer includes all the required sensors to obtain the data; it has an altimeter, 70cm ham-band transceiver, barometric pressure sensor, 9-axis accelerometer, GPS receiver, and supports dual deployment, which requires a nominal of 12V. [5]

The arming system was derived from two main functions, both of which were independent of each other; each system control is entirely independent of other systems, and all signals and commands were sent and decoded by the transmission RF link.

The ground station consisted of two high-gain receiving antennas connected to an independent modem (TeleBT) via serial COM USB to a computer. The laptops analyzed live satellite data and recorded all sensor data. The following figure shows the avionics bay assembly.

Figure 7. Initium avionics bay assemble. [5]

2.3.6 Recovery system

The recovery system is built with one drogue parachute, one main parachute, a tender descender, and two eagle CO_2 ejection redundancy systems. The IMU triggered the first deployment that sent the signal at the apogee to activate the e-match system; once the combustion was generated with the black powder, it caused the CO_2 cartridge to pressurize the rocket internally and ejected the nose cone and deployed the drogue parachute. [5]

The rocket descended vertically until 800 ft when the IMU activated the second e-match. The system deployed the main parachute until the rocket hit the ground about 15.5 ft/sec. The following figure shows the recovery system diagram with the redundancy system.

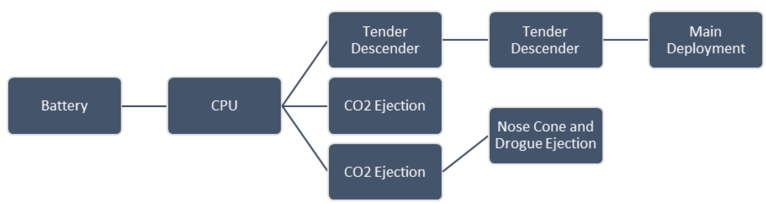


Figure 8. Initial recovery system redundancy diagram.

2.4 Lean Engineering tools and techniques with potential application to the system

A selection of tools and techniques will be essential for a tremendous lean implementation; a tool is used to improve quality in constructing a building; they have a clear role and defined application; on the other hand, a technique is viewed as a collection of tools. Examples of lean tools are cause and effect diagrams, Pareto analysis, control charts, flow chart, and others, while benchmarking, failure mode and effect analysis (FMEA), or design of experiments (DOE) are examples of techniques. [12]

A lean enterprise approaches continuous improvement, and practical tools and techniques implementation may lead to satisfactory results, such as they help to initiate the process, people using them feel involved, create lean culture, enhance teamwork through problem-solving, they facilitate a quality culture. However, three key factors should be considered carefully when selecting tools and techniques:

1. Rigour in purpose: There should be a reason for its application.
2. Rigour in training: All the members involved need to be trained to a level of competence to apply it effectively.
3. Rigour in application: The last key factor is to show success determined by the results of its application. Has it solved the issue or improved the overall process?

The concept of tools and techniques were implemented since the creation of lean thinking; the original Toyota production system (TPS) implemented eight tools and approaches that are listed below:

- Total Productive Maintenance (TPM).
- 5S's.
- Just in Time (JIT).
- Single Minute Exchange of Dies (SMED).
- Judoka.
- Production Work Cells.
- Kanban.

- Poka Yoke.

Some of these tools and others have been researched to apply in the Sun City Summit rocket team to pursue perfection and continuous improvement. The potential tools and techniques are listed below, and there were three requirements to be considered as potential implementation: one, university availability of resources; second, every member of the team can understand and apply the tool or technique, three, it is relevant to improve the quality of the team and adds value to the system. [13]

5S's

Represented by a set of Japanese words beginning with "s" five S is a tool for improving the housekeeping of a process [13]:

- Seiri (Sort): The purpose of this process is to separate what is essential from what is not, leaving only value components in the system.
- Seiton (Set in place): To leave all the components in an orderly manner and marked space.
- Seiso (Shine): To keep all the workstations involved in the process clean and tidy.
- Seiketso (Standardize): The purpose of this process is to clean all the equipment and tools used in the process according to standards.
- Sasuke (Sustain): Discipline is the last step; the purpose is to follow the last procedures.

Kaizen

It means continuous improvement in Japanese, with the philosophy of being better gradually daily, doing little things better to achieve a long-term objective. Companies worldwide have adopted kaizen as an activity to improve the process where all the members can participate and sometimes receive an award for detecting a potential solution; the philosophy of this activity is to finish the day improving somewhere in the company or process.

To improve the quality, the lean manager should trust the members and see them as a key to finding root causes and solutions to the system; this will reduce costs and time. [13]

Ishikawa or Cause and Effect

Created by Ishikawa and known by this name, the Cause and Effect Diagram is a graphical representation of potential causes to assist in brainstorming and identifying the potential root causes and sub-causes of a problem with a graphically displayed representation as a bone structure of the skeletal fish.

There are different variants in the application of a diagram. The most common and used in the Sun City Summit team is the 6M Diagram and Cause and Effect Diagram. The bone structure typically consists of a classification of six processes to find the correct root cause; the processes are:

- Machine – The machines or technology involved in the process.
- Manpower – People involved in the process.
- Material – Material used in the process.
- Method – The method applied in the process.
- Measurement – The measurement of the general process.
- Mother Nature – Environment where the process or material is implemented.

After all the potential causes are considered, one or more are selected as root causes; the next picture shows an example of an Ishikawa diagram. [13]

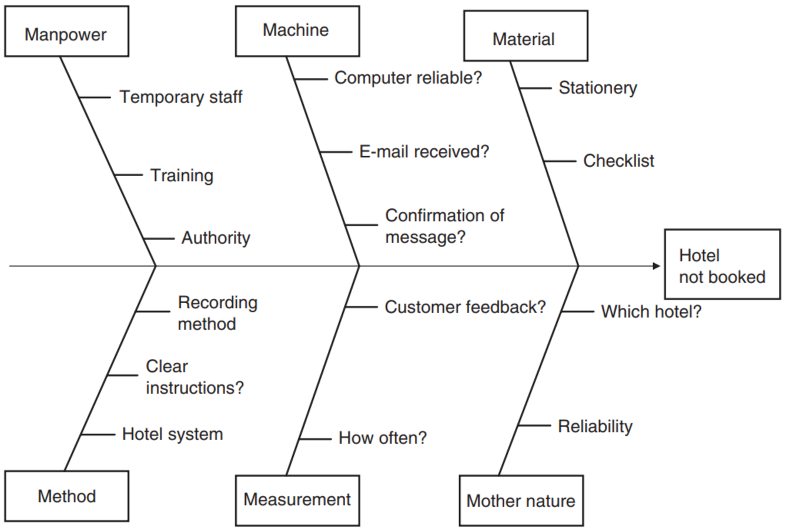


Figure 9. Cause and Effect Diagram example. [13]

5 Why's

It is a highly effective tool to find a problem's root causes by asking six questions [13]: Why, What, Where, When, Who, and How. There are four basic steps applied to implement the 5 Why's technique correctly to the system:

- Problem selection.
- Implementation of the five questions starting with why.
- The answer does not need to be defended or blamed the others.
- Find the root cause.

Key Performance Indicators (KPI)

It aims to monitor the system's performance, finding good results or poor performance and potential improvement areas. It measures different types of performance, for example, customer satisfaction, overall score, cycle, total cost, budgets, financial results, and others.

Low performance is a waste feature; the system's quality can improve by identifying poor performance and implementing corrective actions. The methodology can vary from industry to industry; however, software applications are mainly used to show the results; they are easy to update later and show the data plotted for every member involved in the process. [14]

Chapter 3 - Methods

The methods implemented to apply lean engineering use the five principles, value, map the value stream, Flow, pull, perfection, and respect for people.

To define the value, it is crucial to consider some data from the competition; the IREC Spaceport America 2022 has six different categories available, which can be seen in the following table.

Table 4: IREC Spaceport America 2022 categories. [15]

Option	**Category**
1	10k – COTS – All Propulsion Types
2	10k – SRAD – Solid Motors
3	10k – SRAD – Hybrid/Liquid
4	30k – COTS – All Propulsion Types
5	30k – SRAD – Solid Motors
6	30k – SRAD – Hybrid/Liquid

A trade study was made based on research on previous teams competing in the cup. The intention is to determine the best option for the Sun City Summit rocket team. All of the students had yet to experience competition or designing a rocket. Being an inexperienced group, on a scale from 1 to 5, being five the maximum grade, the following criteria (weight) were considered:

Table 5: Trade study criteria.

Criteria	**Weight**
Safety	5
Timeline	4
The failure rate of inexperience teams	4
Cost	3
Chance of winning	3

With a weight of 5, safety was considered the most essential criterion to determine the category; being a new team with no ready facilities to manage propellant and other hazardous materials, the team manager and faculty responsible wanted to fly with any incidents or accidents during the first year of competitions.

Having six different categories, four of them are designing the propulsion system while the rest are focused on selecting a Commercial off-the-shelf (COTS) motor. The COTS motors are safer, considering that they need to be certified to use them by the National Association of Rocketry (NAR) or the Tripoli Rocketry Association (TRA), and they are specially made for this type of competition.

The other safety criterion considered was comparing the solid motors against hybrid and liquid motors. Solid motors have the advantage of being simple and storable. However, they can be ignited at any time if not stored correctly. Hybrid and liquid motors are more difficult to make, but they have issues with storage and transportation (cryogenic fuels require storage at shallow temperatures). These engines have the advantage of shutting down, a helpful safety feature.

These two reasons showed that a COTS motor is safer since they are certified by an accredited association and built by specialists in rocketry. Hybrid/liquid motors are safer than solid motors. Selecting one of the 30k ft categories will require more propellant or fuel, which leads to higher risks. The first criteria grades are shown in the next table.

Table 6: Safety criteria grades.

Option	**Grade**
Option 1	5
Option 2	3
Option 3	4
Option 4	3
Option 5	2
Option 6	3

The second criterion selected is the timeline, defined as the total time available to complete the project against the customer requirements (Spaceport America official schedule); the following picture shows the integrated master schedule of the 2022 competition.

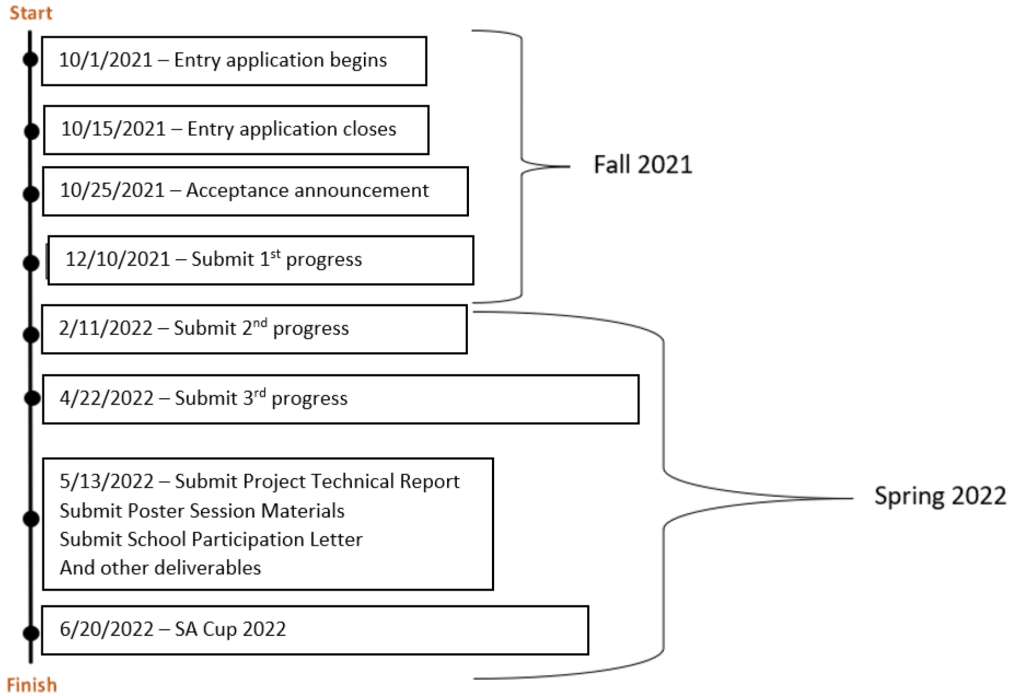


Figure 10. IREC Spaceport America 2022 integrated master schedule 2022. [16]

Since the timeline to submit the deliverables is the same for all categories, the score that each option received is based on the difficulty of each category. SRAD and 30k ft options are more challenging and require more research and time. Being a new team with no previous experience, facilities, materials, and tools, the options requiring less time will receive higher scores, which can be found in the following table.

Table 7: Timeline criteria grades.

Option	**Grade**
Option 1	5
Option 2	4
Option 3	2
Option 4	4
Option 5	3
Option 6	1

At the beginning of the project, the team needed to learn information about the budget available for the mission. There was money available to cover the total mission; the cost is relevant to select the best option; however, criteria such as safety, timeline, and inexperienced teams are critical. The cost criteria weighs 3, according to the department of mechanical engineering of UTEP. For this reason, the weight is low to determine the cost criteria; the higher grades are given to the cheaper options.

To compete in a COTS category, a propulsion system goes from 400 US dollars to 1,600 for the propellant, plus other components such as a motor mount or motor rings. The price to compete in the 30k category can be double or triple the 10k ft. For these reasons, the grades assigned for the cost are shown in table 8.

Table 8: Cost criteria grades.

Option	**Grade**
Option 1	5
Option 2	4
Option 3	3
Option 4	4
Option 5	3
Option 6	2

Having a new team and students with no previous experience in rocketry projects, it was known that winning an award was extremely hard. Applying lean engineering to this state, with the correct continuous improvement tools, to pursue perfection will take some time. The chance of winning weights 3, along with the cost, has the lowest value; the lead of the team and the mechanical engineering faculty considered fly safety the most crucial factor for the first year of competition.

Previously known, it will take some time to apply lean engineering to this state with the correct continuous improvement tools and pursue perfection.

Picture number 11 shows the overall winners by category of the five previous years; on the other hand, picture number 12 shows the overall winners by target apogee, with 80% of them targeting a 30k ft apogee.

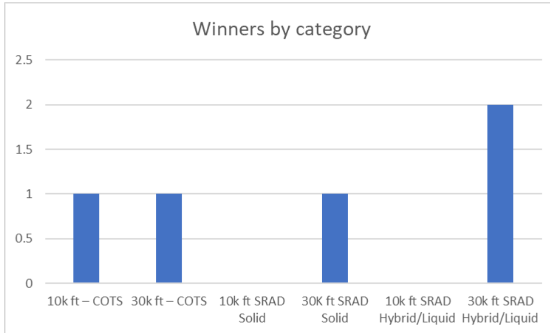


Figure 11. Five previous overall winners by category.

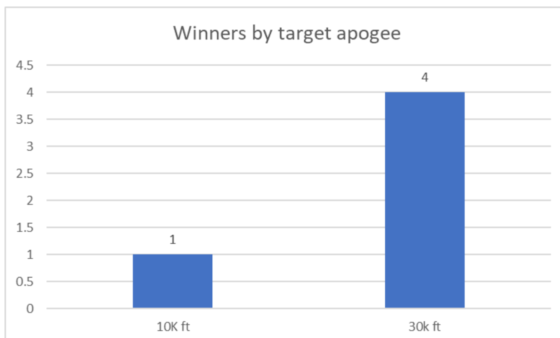


Figure 12. Five previous overall winners by target apogee.

Those teams that selected SRAD categories targeting 30k ft apogee have more chances to win; however, those teams competing for the award had years of previous experience. Based on this research, the grades for a chance of winning criteria are shown in table 9.

Table 9: Chance of winning criteria grades.

Option	**Grade**
Option 1	2
Option 2	3
Option 3	4
Option 4	3

Option 5	4
Option 6	5

Data on the overall scoring of the SAC 2018 and SAC 2019 competitions was taken, shown in table 10. Fifty-six teams in total competed for the first time during those two years. The last criterion considered is the failure rate of inexperience teams. Teams that chose a 30k ft category had a failure rate to fly from 66.67% to the 100% of the two new teams that selected option six and could not pass the flight safety review. On the other hand, 34 teams selected the COTS 10k ft category as their first option, and 20 launched their vehicle, with a failure rate of 41.18%.

Table 10: Failure rate for new teams.

Option	**Successful flight**	**Failure flight**	**Total**	**Failure rate**
Option 1	20	14	34	41.18%
Option 2	3	6	9	66.67%
Option 3	1	4	5	80.00%
Option 4	1	2	3	66.67%
Option 5	1	2	3	66.67%
Option 6	0	2	2	100.00%

Clearly, those categories where teams can use a commercial off-the-shelf propulsion system are the best option. The grades for the failure rate of inexperience teams are shown below.

Table 11: failure rate of inexperience teams.

Option	Grade
Option 1	5
Option 2	3
Option 3	2
Option 4	3
Option 5	2
Option 6	1

Option 1 was the best option for the Sun City Summit rocket team, with a general score of 4.52. In 4 of the five criteria, it received the maximum grade available, but the chance of winning that received is 2; however, the weight is three and did not affect the final score of option 1. The next option could be weather option 2 (SRAD 10k ft) or option 3(COTS 30k ft); however, with a final score of 3.36, option number 1 is the correct option. Taking these six criteria into account, the result of the trade study is shown below.

Table 12: Trade study to select the best category to compete for Sun City Summit.

Criteria	Weight	Weight %	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Safety	5	26.31578947	5 (1.32)	3 (0.79)	4 (1.05)	3 (0.79)	2 (0.53)	3 (0.79)
Timeline	4	21.05263158	5 (1.05)	4 (0.84)	2 (0.42)	4 (0.84)	3 (0.63)	1 (0.21)
Failure of inexperience teams	4	21.05263158	5 (1.05)	3 (0.63)	2 (0.42)	3 (0.63)	2 (0.42)	1 (0.21)
Cost	3	15.78947368	5 (0.79)	4 (0.63)	3 (0.47)	4 (0.63)	3 (0.47)	2 (0.32)
Chance of winning	3	15.78947368	2 (0.32)	3 (0.47)	4 (0.63)	3 (0.47)	4 (0.63)	5 (0.79)
Average raw score	N/A	N/A	4.4	3.4	3	3.4	2.8	2.4
Grand total	19	100	4.52	3.36	3	3.36	2.68	2.31

3.1 Value implementation

To determine the value, it is necessary to review the customer and stakeholder requirements. The IREC Spaceport America Cup uploaded the official documents and forms with all the information about the competition. Table 13 shows the available documents, including standards, guidelines, schedules, and required forms. [15]

Table 13: Documents and forms available for SAC 2022. [15]

Document	**Purpose**
IREC Rules & Requirements Document	This document defines the rules and requirements governing participation in the IREC.
IREC Design, Test, & Evaluation Guide	This document defines the minimum design, test, and evaluation criteria the event organizers expect IREC teams to meet before launching at the SA Cup.
SA Cup Integrated Master Schedule Document	This document primarily defines the schedule for participants in the Spaceport America Cup: Intercollegiate. Rocket Engineering Competition must submit required deliverables to the event organizers to be considered. "timely" in scoring.
SAC Range Standard Operating Procedures	This document promotes flight safety at the SA Cup by defining the overarching "run-rules" governing rocket launch related activities (aka "the launch") occurring on NMSA property (aka "the Spaceport") during the cup – to include

	all IREC launches, as well as all non-competing demonstration launches
IREC Project Technical Report Template	Template with all the information which needs to be filled with the overview of the projects for the judging panel and other competition officials.
IREC Extended Abstract Template	Each team shall submit an Extended Abstract on a particular aspect of their work for competition officials and the judging panel to consider including in a Podium Session held during the conference day at the Spaceport America Cup.

After a lengthy review of the official documents and forms provided by IREC, the team had a stakeholder and an external customer. These two entities will define the value, including the mission's objectives, dates, outputs, and more.

During the first year of competition, the department of Mechanical Engineering of the University of Texas at El Paso functioned as the stakeholder since it achieved the three different requirements to be considered a stakeholder. [4] First, it is the program's sponsor; second, the department will be affected or derive gain from the benefits that the program delivers, and it influences the program execution.

The external customer to determine the value is the Spaceport America judging panel and other competition officials. They are the people that determine what to deliver, how, and when.

They provided the flight safety review cards to launch the rocket at the competition and gave the final scores.

Starting with the value, the lean engineering principles applications for the Sun City Summit rocket team to compete in the SAC 2022 need to be implemented using the stakeholder that will pay for the system and the external customer requirements and expectations.

The value depends directly on the category selected, 10k ft using a COTS motor. The following information shows the top-level requirements of the category [1]:

- 10,000 ft AGL apogee must be realized using a Commercial-Off-The-Shelf (COTS) solid propulsion motor.
- The motor must be selected from the Spaceport America Cup approved list.
- Demonstrate Safe Stability by reaching a 100 ft/s (30.5 m/s) exit rail velocity.
- Motor class M (between 5,120.01 and 10,240.00 N·s of impulse).
- Achieve a 10:1 Thrust to Liftoff Weight Ratio.
- Minimum payload weight of 8.8 pounds.
- 3U CubeSat version 30x10x10cm for the payload bay.
- Implement redundancy recovery system measures as per Spaceport America Cup guidelines.
- Deploy the main and drogue parachutes at specified altitudes to safely land the rocket.
- Recover the system using a Global Positioning System (GPS).
- Design and assemble all electronic circuits to maintain communication between sub-teams and rocket-ground station.

- Design an avionics bay for data gathering to turn in the flight performance to Spaceport America.
- Stability margin no less than 1.5 Cal before apogee.

Along with the top-level requirements of the system, the value is determined by the deliverables and submissions to Spaceport America competition officials, which can be found in the following table.

Table 14: Deliverables and submissions for SAC 2022 [15].

Deliverable	**Description**
Team Entry form	Each team shall inform ESRA of their desire to compete in the IREC by registering as a new team on the Spaceport America Cup HeroX website and submitting an entry form with the general overall of the team.
1st Progress Update	This progress update will record the progression in the project's technical characteristics during development. Total completeness is required.
2nd Progress Update	This progress update will record the progression in the project's technical characteristics during development. Total completeness is required.

3rd Progress Update	This progress update will record the progression in the project's technical characteristics during development. Total completeness is required.
Project Technical Report	Overviews of the project for the judging panel and other competition officials.
Podium Session Extended Abstract	Each team shall submit an Extended Abstract on a particular aspect of their work for competition officials and the judging panel to consider including in a Podium Session held during the SA Cup Conference.
Podium Session Presentation	At the same time, they submit their Extended Abstract; teams shall also submit a digital PDF copy of any slides, they wish to use in their presentation to the HeroX website.
School Participation Letter	Each team shall have the academic institution(s) in which its members are enrolled provide a signed letter to ESRA acknowledging the team's participation in the IREC at the Spaceport America Cup.

Poster Session Materials	Each team shall bring to the Spaceport America Cup a poster display that overviews their project for industry representatives, the public, other students, and members of the judging panel.
GoPro Video Challenge Submission Form	Each team shall submit two videos, a team video which is a 2-5 min video that may or may not is used in the live stream. And an introduction video no longer than 30 seconds.

The scoring has a scale from 0 to 1,000 plus 150 bonus points; this is a vital feature to define the value. Lean engineering is focused on pursuing perfection and exceeding customer expectations. The plan of the subsequent principles needs to be designed to get the maximum points available and those 150 bonus points to fulfill Spaceport America Cup needs; the scoring tables are shown below. [15]

Table 15: Scoring table for SAC 2022 [15].

Scoring	**Points**
Entry form	15
1st progress update	15

2nd progress update	15
3rd progress update	15
Project technical report	200
Design implementation	240
Flight performance	500
Total	1000

Table 16: Bonus points for SAC 2022 [15].

Bonus	**Points**
CubeSat based payloads	50
Efficient launch preparations	100

The schedule is critical to define the value and deliver what Spaceport America Cup and the mechanical engineering department as a stakeholder when they require it. The schedule determines the best time to design, build, and assemble the rocket and submit the deliverables. The schedule for the SAC 2022 can be found in the following tables. [16]

Table 17: IREC deliverables schedule and other important pre-event dates. [16]

Date	**Action(s)**

10/1/2021	The entry application window begins
10/15/2021	The entry application window closes
10/25/2021	Acceptance Announcement
12/10/2021	Submit 1st progress update
	$200 Entry Deposit fee
2/11/2022	Submit 2nd progress update
4/22/2022	$500 Rocket Fee
	Payment deadline for the $50 individual Rocketeer
	Submit 3rd progress update
5/13/2022	Submit Project Technical Report
	Submit Poster Session Materials
	Submit School Participation Letter
	Submit Spaceport America Cup Waiver and Release of Liability Form

Table 18: SAC 2022 event schedule overview. [16]

Date	**Event(s)**
6/20/2022	Rocketeer Check-in

	Event Staff, Judge, and Volunteer Coordination Kick-off Meeting
6/21/2022	Conference Day Podium and Poster Sessions
	Group Photo
6/22/2022	Launch Preparations and Design Implementation Evaluation
	Early Launch Opportunity for Solid Motors Only
	On-site Camping Begins
6/23/2022	Launch Day
6/24/2022	Launch Day 2
6/25/2022	Final Launch Day
	Site Cleanup
	Awards Ceremony

3.2 Map Value Stream implementation

The following picture shows the map value stream proposed to deliver the customer their needs on time. The VSM is designed in a do it once do it proper format; the map is not considering iterations or other issues that can show up later. For example, lean engineering thinking tries to get the perfect process without waste on shipping issues.

The map value stream was explained to the entire team, and it had to be printed and placed in the lab to make a visual factory, a lean engineering tool, at the creation of the map. The lean manager needed the dates to create the rocket team in the university and how many members would be part of it. For this reason, this could lead to delays to begin with the first step of the VSM, and it is shown as a potential improvement area (Kaizen Burst) on the map. Fortunately, it was created in August 2021, and this implementation could start on time by September 6th of the same year.

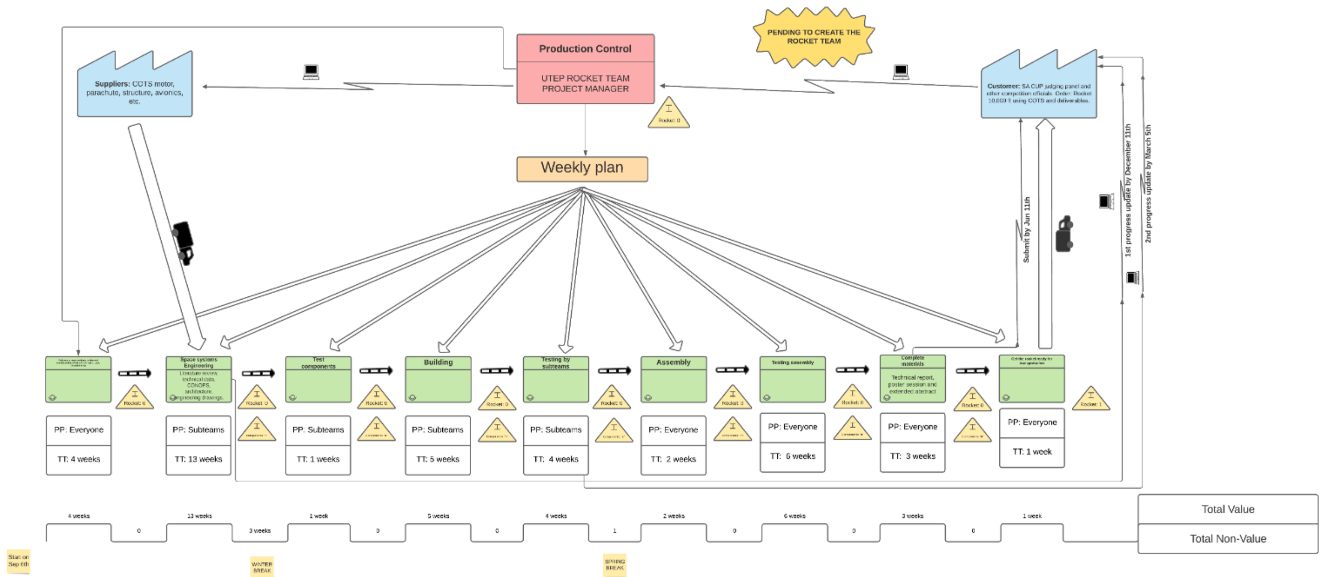


Figure 13: Map Value Stream for Sun City Summit Rocket team to compete in the SAC 2022.

3.3 Flow implementation

Using the previous VSM as a baseline to flow the process, this principle added value-added activities to the process. The first activity was to create sub-teams to optimize Flow; research was made to create these teams according to the resources in the university. Five sub-team were created to fulfill the value requirements: avionics, payload, propulsion, structure, recovery system, and business with the following descriptions.

- Avionics: Responsible for all electronic systems that conduct flight data acquisition, send telemetry, establish communication with the ground station and perform launch operations.
- Payload: Design an experiment to compete in the SDL Payload Challenge that can successfully provide scientific merit data during the flight, enabling meaningful learning opportunities.

- Propulsion: Provide Initium with safe, efficient, and reliable propulsion during flight to reach the target apogee using a solid–propellant motor.
- Structural Aerodynamics: Design and manufacture structural components, ensuring integrity during flight, and characterization of flight dynamics through testing and simulations.
- Recovery System: Safely land Initium by utilizing a dual-deployment recovery system. The design and implementation of the project and more information about the competition are described in the next chapter, along with a long explanation of the six lean engineering principles.

It is shown in the following picture organizational chart with the ideal number of members and degrees.

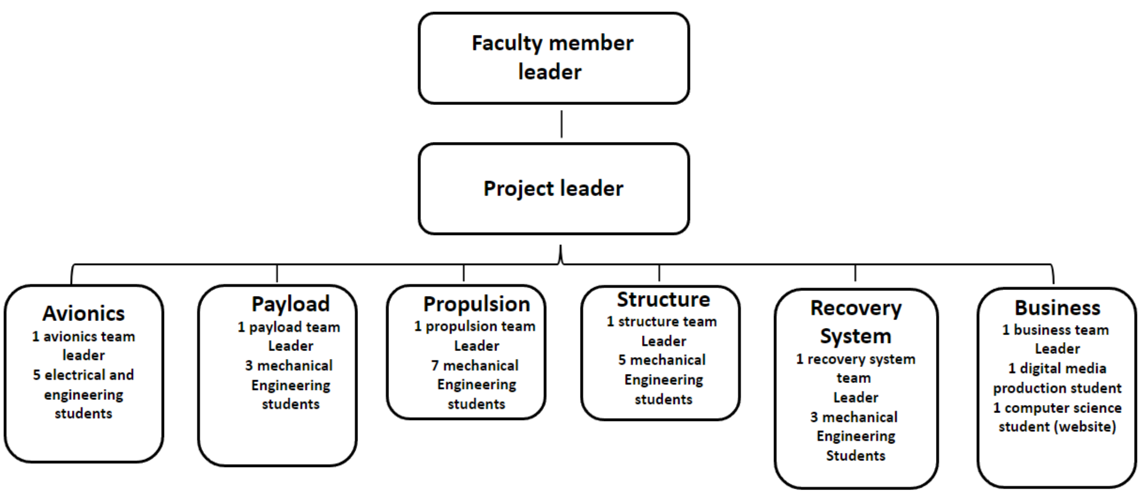


Figure 14: Ideal organizational chart before the actual team creation.

To add more value activities, two weekly meetings were added to the plan, one general meeting and another one with the officers and team lead only. Then, it a calendar was created with all the meetings, the activities of each meeting, and the process (noted in the VSM), and all the students were added to the calendar.

To create continuity, assigning value-added activities to one of the meetings throughout the year of competition was critical. All the information is shown in the following table.

Table 19: Flow Implementation to Sun City Summit for SAC 2022.

Process	**Meeting number**	**Date**	**Activities**
Introduction	1	9/10/2021	Introduction session, welcome to new members, IREC SA CUP overall description.
	2	9/17/2021	Lean engineering session, overall concept, principles, and LE implementation to UTEP rocket team in the SA CUP.
	3	9/24/2021	IREC SA CUP rules, schedule, deliverables, forms, scoring and example of videos of SA CUP, technical reports, and poster sessions.
	4	10/1/2021	Brainstorming, read one or more successful technical reports (available at the IREC website)

Space Systems Engineering	5	10/8/2021	Share literature review, and document everything according to LE practices.
	6	10/15/2021	
	7	10/22/2021	Brainstorming session.
	8	10/29/2021	Share literature review, document everything according to LE practices
	9	11/5/2021	Brainstorming sessions and selecting options.
	10	11/12/2021	Run a trade study for each of the sub-systems and the assembly.
	11	11/19/2021	CONOPS, architecture, engineering drawings, and CAD, in general, are all design considerations. Order the components, motor, and parachute.
	12	12/3/2021	
	13	12/10/2021	Week focused on the 1st progress update.
Test Components	14	1/14/2022	Week to test everything that each sub-team received, each

			component needs to have the performance required.
Building	15	1/21/2022	To build the sub-systems bay, activities are done by sub-teams.
	16	1/28/2022	
	17	2/4/2022	
	18	2/11/2022	
	19	2/18/2022	
Testing by Sub Teams	20	2/25/2022	Week to test the sub-systems completed, avionics, payload, propulsion, structures, and recovery system.
	21	3/4/2022	Focus week on the 2nd progress update
	22	3/11/2022	Weeks to test the sub-systems completed, avionics, payload, propulsion, structures, and recovery system.
	23	3/18/2022	
Assembly	24	4/1/2022	To assemble the rocket.
	25	4/8/2022	
Testing Assembly	26	4/15/2022	To test the rocket and make changes if needed.
	27	4/22/2022	
	28	4/29/2022	
	29	5/6/2022	

	30	5/13/2022	
	31	5/20/2022	
Complete Materials	32	5/27/2022	To complete deliverables.
	33	6/3/2022	
	34	6/10/2022	
Get the rocket ready	35	6/17/2022	To leave everything prepared for the IREC 2022 CUP.

3.4 Pull implementation

To pull the work, the workspace needed to be appropriate. Team members and hardware were placed in a lab room to reduce the time required moving resources, such as people, rocket components, and other items. This lean engineering setup is ideal for minimizing the waste of time of the stakeholder. The department of mechanical engineering of UTEP provided the team with a rocket team lab with access to the members when they needed it. The lab was next to the department machine shop, providing many advantages while the team was working with the components. This was also important for the tools implemented in the following principle.

The goal of a pull-based system is to prove that the SAC judging panel, which is other competition officials, and the mechanical engineering department of UTEP need the correct quantity that helps to reduce waste such as overproduction. The following table shows the pull implementation, which shows the input of the process, the process, and the output of each process (stated in the VSM).

Table 20: Sun City Summit pull system for SAC 2022.

Pull System		
Input	**Process**	**Output**
	Introduction	Deep understanding of what is the SA Cup and all the rules.
		LE general knowledge and how it is applied to the project.
Deep understanding of what is the SA Cup and all the rules.	Space Systems Engineering	Sub-systems components selection.
		CONOPS.
		Rocket architecture.
LE general knowledge and how it is applied to the project.		Engineering drawings.
		CAD.
		Order and receive components/hardware.
Sub-systems components selection.	Test Components	Components working according to specifications.
CONOPS.		
Rocket architecture.		
Engineering drawings.		
CAD.		
Order and receive components/hardware.		
Components working according to specifications.	Building	Rocket sub-systems are built and ready to be tested.

Rocket sub-systems are built and ready to be tested.	Testing by Sub Teams	Rocket sub-systems are built, tested, and ready to be assembled.
Rocket sub-systems are built, tested, and ready to be assembled.	Assembly	Rocket adequately assembled and ready to be tested.
Rocket adequately assembled and ready to be tested.	Testing Assembly	Rocket adequately tested and ready to be sent to the customer.
		Everything is ready to document all the work according to customer specifications.
Everything is ready to document all the work according to customer specifications.	Complete Materials	Deliverables.
Deliverables.	Get the rocket ready.	Rocket.

3.5 Perfection implementation

To pursue perfection, some tools were implemented to create a lean engineering culture. Every rocket team member should strive towards perfection while delivering customer needs. The five tools implemented in the team are 5 S's, visual rocket team lab, good documentation practices (GDP), key performance indicators (KPI), and kaizen.

The table below shows the 5 S's implementation.

Table 21. 5S's implementation to the rocket team.

Activity	**Action**
Sort	Eliminated the objects not needed in the lab room after each meeting.
Set in order	Labeled each component in the lab room and organized the components in their own labeled bureau.
Shine	Maintained the lab room cleaned and inspected after each meeting
Standardize	Delimitated the area by sub-teams with masking tape.
Sustain	The previous four actions were implemented in the lab room for the entire year.

A visual rocket team was implemented in the lab room; it was assigned a section of the lab to store all the project components by sub-teams; a team logo was created and printed to the lab along with sub-team logos to delimitate the areas to work by sub-teams. The official team calendar, the value stream map, rules, forms, and other essential documents were printed and placed in the lab room to be visible and of easy access to all the members. The following picture shows the official Sun City Summit logo for SAC 2022 and the other logos used in the lab room.

Figure 15: Sun City Summit logo and sub-team logos.

Good documentation practices were implemented the entire year to transfer the knowledge to future generations properly and have all the data available in the same place. It was created a Microsoft Teams group with all the members to properly document all the data, meetings, official announcements, and other important information. Templates were created for all the general and sub-team meetings, presentations, preliminary design reviews, and project reports to have the same documentation style and information in each file. Sub-team channels were created using the MS Teams tool to create an additional sub-channel; all the sub-team information is documented in their channel using the available templates.

The team implemented key performance indicators to measure the performance of four essential features: safety, number of attendees to the meetings, scoring of SAC 2022, and total cost of the mission.

This lean engineering tool allowed the team to measure some critical results and deliver results to stakeholders and future team members. The data shown in the graphs will be easy to evaluate and make changes to allow the team to achieve future goals.

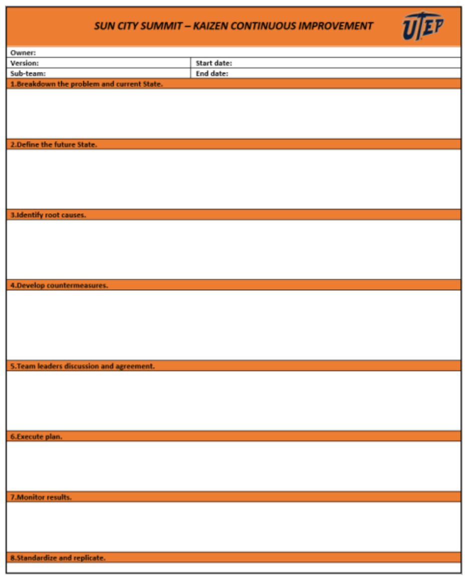
Figure 16. KPI implementation to the Sun City Summit.

The last engineering tool implemented by the team was kaizen. Continuing improvement will lead the rocket team to get better overall results and win the SAC. The goal of implementing lean engineering in the system is to do better year after year. A correct kaizen implementation will help to achieve this goal. As part of the following principle, people are the most crucial resource. All the members can suggest improvements to the system and will be the team lead responsible for deciding whether to approve the implementation or not.

The rocket team kaizen implementation steps are the following, and the template is shown in the following figure:

1. Break down the problem and current state.
2. Define the future state.

3. Identify root causes using the five why's or Ishikawa diagram.
4. Develop countermeasures.
5. Team and sub-team leader discussion and agreement.
6. Execute plan.
7. Monitor Results.
8. Standardize and replicate.


SUN CITY SUMMIT – KAIZEN CONTINUOUS IMPROVEMENT

Owner:	
Version:	Start date:
Sub-team:	End date:

1.Breakdown the problem and current State.

2.Define the future State.

3.Identify root causes.

4.Develop countermeasures.

5.Team leaders discussion and agreement.

6.Execute plan.

7.Monitor results.

8.Standardize and replicate.

Figure 17. Sun City Summit kaizen template.

3.6 Respect for people implementation

The last principle was implemented during the entire process from the first day to the last day of SAC 2022. During all the year, every team member was treated according to UTEP policies.

When an issue arose, the system was blamed and not the student. The team's most influential members were recognized with diplomas, such as the sub-team leaders and some other students that exceeded expectations. Some of these students will be part of the team that will compete in SAC 2023, and they were awarded becoming sub-team leaders, team lead, or other vital activities that will give them leadership skills. The graduate students were awarded a stole of the team, an action done to recognize their service to the team and to congratulate them on their graduation.

The following pictures show one of the diplomas given to a recognized student and the stoles given to Spring and Summer 2022 graduate students.

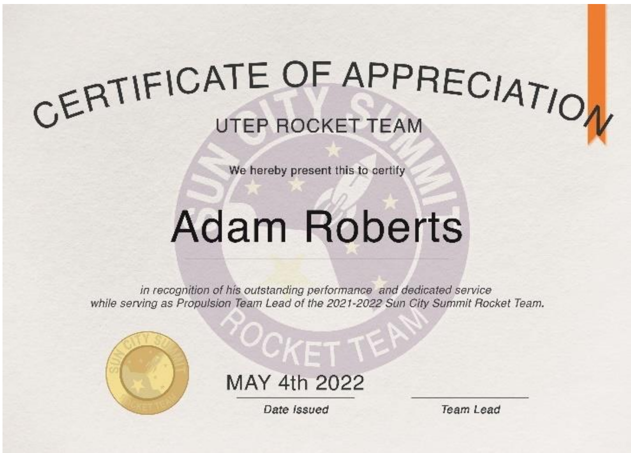


Figure 18. Certificate of appreciation given to recognized students.

Figure 19. Graduation stoles awarded to Sun City Summit graduate students.

Chapter 4 - Results

The results include implementing lean engineering principles during the entire year step by step and a summary of the scores obtained at the Spaceport America Cup 2022. In the next chapter, conclusions and lessons learned are documented.

The team participated in the cup with a successful launch phase of the CONOPS 1 to 5 achieved. The actual apogee of the mission was 11,421 ft, within 98.9% accuracy against the predicted apogee of 11,296 ft simulated in OpenRocket. Drogue was visually on the descent; the deployment worked according to specification triggered by the IMUevent, for the main deployment charge was recorded in the computer. However, the main parachute was not deployed and was not visually seen. As initium ascended into clouds visually, it was lost, and the directional antenna was pointed to the general direction assumed. The communication was lost after apogee; however, the computer was able to keep some valuable telemetry data of the flight, as is seen in the next figure.

	Course degree	Course Angle	Speed	Accelaration	Height	Pressure PSI
0	0	0.25	200	375	0	12.1
1	0.05	0.3	630	421	560	12
2	0.1	0.35	880	985	1080	11.8
3	0.15	0.4	998	155	2542	11.6
4	0.2	0.45	560	-85	3520	11.4
5	0.25	0.5	520	-53	3326	11.2
6	0.3	0.55	570	-52	4110	11
7	0.35	0.65	850	-48	4983	10.8
8	0.4	0.7	602	-53	5723	10.4
9	0.45	0.75	663	-49	6543	10.2
10	0.5	0.8	543	-37	6983	10
11	0.55	0.84	485	-25	7523	9.8
12	0.6	0.95	415	-30	8000	9.2
13	0.65	0.87	473	-23	8572	9
14	0.7	0.9	325	-20	8993	8.8
15	0.75	0.93	410	-19	9324	8.6
16	0.8	0.94	236	-15	9714	8.4
17	0.85	0.95	253	-12	10012	8.2
18	0.9	0.96	113	-11	10217	8.1
19	0.95	0.98	165	-10	10514	8
20	1	0.98	143	-11	10826	7.9
21	1.05	1	67	-13	10956	7.6
22	1.1	1.01	123	-9	11089	7.4
23	1.15	1.04	47	-10	11178	7.1
24			15	-7	11324	6.3
25			12	-6	11421	6.4

Figure 20. Telemetry captured by initium, boost in green, burnout in yellow, and coast in red.

Initium could not be recovered, and a failure of the main parachute, as well as losing communication with the rocket to receive the global position data, caused the loss of the component. The team spent hours in the desert of New Mexico trying to find the rocket with no success. There are three potential causes of the primary deployment failure:

- Both charges did not go off; the tender descender failed to release the main.
- Charges went off, and the main failed to release from the parachute bag.
- Main bridle lines twisted, not allowing the main to fill with air and deploy.

From the overall scoring, half of the points were given to flight performance since the team could not be recovered the actual hardware to transfer the data for SAC 2022 judges. The score of this section was 0, and for this reason, Sun City Summit ended up at place 93. The summary of these events was only to show evidence of the team participation; however, the actual results of this thesis are focused on the lean implementation, shown below.

First, the category selected of 10k COTS all propulsion types was correct with implementing systems engineering using a trade study. According to the research, the flight failure rate of inexperience teams was higher for those who selected SRAD or 30k ft categories. Initium was launched with success; however, it could not be recovered.

The timeline was affected by different factors; first, the covid-19 shipping delays, vendors needed more components for all the teams on time. Second, being this the first year of competition, there was no a previous experience with third parties; some of the suppliers failed to deliver the components on time, or they even did not send the items. This caused a delay in the overall mission forcing the team to find better suppliers.

The first engineering principle of value was implemented correctly. All the deliverables were submitted on time according to the schedule sent by the customer. It was stated that the SAC judging panel and other officials were the customers and that the mechanical engineering department was the stakeholder. This assumption was correct; however, the first mistake detected applying lean thinking is that the team focused the work on the customer and the stakeholder. It was placed in second place. The Sun City Summit had clear ideas of the needed components and how to build the rocket, but the department needed more convincing. This led to delays in approvals to purchase components; the miscommunication between the team and the department forced the team to start working with the components until March, when it was supposed to happen during the second week of January.

The Value Stream Map and the subsequent steps were affected by the previous reasons; however, the assumptions and the processes were correct; continuous improvement needs to be applied to the correct execution of the VSM being the ideal case to have all the components before the semester of Spring starts and to begin building the sub-systems at the end of January.

The team's structure was modified later; the business team was removed from the ideal organizational chart because of university resources. The team had two business students in charge of this sub-team; however, they left the team after one month. The team leader tried to find more students but ended up with him and other students in charge of business activities, such as social media, website, future sponsors, and some of the deliverables. This needs to be modified according to the initial plan since it led to wasting time using people in charge of other activities. The value may be better with student experts in marketing, graphic design, and content creation.

Since the Flow of the work was affected by the previous reasons, the system's pull was also implemented with failures, and the output of the processes was incomplete when the following process needed to start. Also, it took much work to purchase and receive all the components simultaneously per the reasons stated at the beginning of this chapter. Some sub-teams received their parts in March, while others in May. This led to delays in the final assembly; some sub-teams were ready to start the next process; however, this was not possible until the completion of other sub-team activities.

Chapter 5 - Conclusions

After the implementation of lean engineering to the team, the conclusions and lessons learned are documented in this chapter; first, I would like to mention that applying lean engineering to any system will always be worth it to keep it in the process can be discussed later. However, the knowledge and skills given by lean thinking will remain in the student's life even for daily activities unrelated to work.

We can divide the overall lean principles into two branches, the opinions and results from the stakeholder and the customer. Overall, the application of lean engineering gave good results to the team and led to competing successfully during the first year. The department of Mechanical Engineering of UTEP was pleased with the results because the stakeholders and the team achieved the goal, and participation in SAC 2023 is necessary for the department. On the other hand, the team can deliver better results and should improve many things for next year's competition. The team ended up in an overall wrong position since the rocket could not be recovered and the data delivered to judges. Some of the changes that I recommend implementing to improve the system are listed next.

First, the team must implement meetings with the stakeholder. If next year the department sponsors the competition again, weekly meetings are recommended with staff in charge of the budget available to the team; different topics can be seen during the meetings, such as timeline, approval of the design, costs, placing orders, shipping status, and additional information. Although the stakeholder is interested in good results, the team is responsible for delivering value to the customer on time. It must follow up the process with the stakeholder periodically.

Second, the team must have better communication with the customer (the Spaceport America judges and other competition officials); the customer made changes without previous notifications during the year, and some of the rules and top-level requirements needed to be clarified. The team should have asked on time and assumed different things that the team lead and sub-team officers considered obvious. This led to adjustments in the design at the competition that could be led to failure. If the system could not be adjusted after the judge's comments, the team would not have been able to launch the rocket.

Third, applying lean engineering with a rotative team is complicated; the team lead should have trained and been involved in lean thinking; otherwise, there will not be commitment to continuous improvement and implementing lean techniques and tools. I recommend creating a sub-team or some people in charge of lean engineering implementation in the team, always presented in the meetings and involved in the process as the other members. They can implement the tools better, giving proper training to members and transferring the knowledge to future generations. There are lean certifications where students can get lean management to build a team with a continuous improvement system.

Fourth, the best way to implement lean thinking is to apply it in the university or, at least, to the department. If the culture is adequately implemented, the students will have knowledge of lean engineering, its techniques and tools, and the results that can be obtained to improve every process by eliminating waste.

Finally, I would like to emphasize that reaching perfection can take many years. The competition is extensive, and more than 150 teams were admitted to Spaceport America Cup 2022; only those who know how to achieve judge satisfaction will win an award in the future by prioritizing continuous improvement and not giving up during the journey to be perfect. That will be the answer to be one of the best teams in rocketry competitions.

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Curriculum Vita

Alan Garcia Monroy graduated in 2017 from the Autonomous University of Ciudad Juarez with a Bachelor of Science in Aerospace Engineering and a Master of Science in Mechanical Engineering focusing on the aerospace field graduating in 2022. Mr. Garcia took an internship at the Delphi Technical Center as a Customer Quality Engineer in 2016. Then took employment in Continental Automotive as Process Engineer in 2017. Later, he worked for three years at Johnson & Johnson at the Biosense Webster Franchise as a Quality Engineer from 2018 to 2021. It was until 2021 that Mr. Garcia enrolled in the master's Degree at The University of Texas at El Paso. He started working here as Graduate Teaching Assistant and working as Graduate Research Assistant in the 2021 summer at The Center for Exploration and Technology Research part of the university. After that summer, Mr. Garcia started working as Graduate Teaching Assistant again, being the team lead of the UTEP Rocket Team and bringing 40 students to compete in the 2022 SA Cup. Mr. Garcia is currently working as master's assistant professor teaching advanced mechanical coursed at the University of Texas at El Paso.

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