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Application of Project Management Strategies and Tools for an Efficient and Successful Competition-based Engineering Senior Capstone Design Project

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Application of Project Management Strategies and Tools for an Efficient and Successful Competition-
based Engineering Senior Capstone Design Project

Benton Duane Morris

Thesis submitted
to the Benjamin M. Statler College of Engineering and Mineral Resources
at West Virginia University

in partial fulfillment of the requirements for a degree of

Master's of Science in
Aerospace Engineering

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Morgantown, West Virginia

2021

Keywords: AVTC, Project Management, Team, Communications, Schedule, Risk, Change, Requirements,
Safety

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Abstract

Application of Project Management Strategies and Tools for an Efficient and Successful Competition-based Engineering Senior Capstone Design Project

Benton Morris

The industry-level engineering workforce for a project in modern times requires a clear plan and management process to execute the goals of the consumer and the producer. The engineers of tomorrow need the ability to be competitive and successful upon entry into the industry, where there have already been established management tactics for the execution of the company's goals. The mentality within the industry is adaptable to senior collegiate-level competition-based capstone projects. Therefore the West Virginia University EcoCAR Mobility Challenge team has adapted, altered, or adjusted industry-level practices in order to have an overall functioning and effective team that follows a project management plan evaluating industry. The main intention of the EcoCAR Mobility Challenge is to convert a stock vehicle into a hybrid electric vehicle over four years following the Vehicle Development Process (VDP). The team started with fresh new members and team management at the start of the competition, and over the course of the competition, the team was able to adapt, alter and adjust industry-level management tactics and practices into the overall successful team. In Year 1 of the competition the team placed seventh and through the practice of using the tools from industry finished in third place in Year 3 of the competition. By executing a project management plan, teams at the university level can mitigate risk, develop proper schedules, team structures, communicate efficiently, and be successful. The skills adapted and used from industry for a competitive and efficient competition-based senior-level capstone not only will make the project itself successful as it would in industry, but knowledge of these tools prepares the students for the demanding rigorous career within a project-based or product-based industry of choice. The methods of management and tactics adopted by the team cover traditional and agile management, along with understanding management tactics in terms of communication, team structure and organization, scheduling, risk management, requirements management and change management. The tactics of management covered in this document can be adapted and applied to any engineering competition project with the desire to produce a successful product and manage and operate an efficient team for continued sustainability for future endeavors.

Dedication

This thesis is dedicated to my family and friends. I want to thank my parents for supporting me on this journey. I know it has been a long time in the making and returning to school to pursue a master's degree was not the preferred change in lifestyle at the beginning, but we can finally see the light at the end of the tunnel and the conclusion of this chapter of my life. It is through your support that this thesis has been possible. And finally, to my friends and loved ones, I'd like to thank you, the ones who have continued to support me and been the driving force to ensure I finish grad school, this thesis, and maintain optimism about my future career in engineering. I could not have done this without the love and support of my friends and loved ones.

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1.0 Introduction

The Advanced Vehicle Technology Competition (AVTC) series has been around for more than thirty years, since 1988. The United States Department of Energy (US DOE) has sponsored this competition in partnership with North American auto industry leaders throughout the years. The AVTC series is managed by Argonne National Laboratory (ANL). The AVTC series is a competition for both graduate and undergraduate students, and includes students from a variety of fields, ranging from multiple disciplines of engineering to business-focused disciplines such as project management and communications. The competition series has given students the opportunities to simulate the development of advanced propulsion systems and alternative fuel technologies while being provided in-depth training from industry-level automotive engineers to help educate the next generation of automotive engineers [1]. AVTC's do not only challenge students through engineering knowledge gained from the classes their universities have provided but also with hands-on applications to real-life problems that include a variety of engineering and technical problems, teamwork development, management, communication, and technical reporting at an industry level.

Throughout the years of the AVTCs, there have been numerous competitions involving more than 20,000 students from 93 different educational institutions in North America. Of those 93 institutions, West Virginia University (WVU) has been one of the most actively involved participants throughout the AVTCs life span. WVU has participated in nine of the twelve competitions since 1988. From this experience, WVU has been indoctrinating new management styles throughout the years to continue pursuing an effective and vital program to undergraduate and graduate student development for industry readiness. As a result of years of experience, the WVU team involved with the AVTC program has developed methods that not only benefit the operation and management of the current competition but are also applicable and

beneficial to other university-level senior capstone competition programs. The practices of the AVTC team at WVU are not set in stone but are instead agile and fluid. The team is ever-changing with industry standards and methods to merge and adapt the academic and industry knowledge into the team setting for students to learn and benefit.

The current four-year competition in the AVTC series is the EcoCAR Mobility Challenge (EMC). Eleven different universities are working on converting the 2019 Chevrolet Blazer RS into a Hybrid Electric Vehicle (HEV). The headline sponsors for this competition are General Motors, the United States Department of Energy, Mathworks, and ANL. The main objective of the EMC is to design a functional HEV sports utility vehicle (SUV), that must operate at a Level 2 automation and vehicle connectivity as described by the Society of Automotive Engineers (SAE) to improve energy efficiency. Factors of emission, performance, safety, and consumer appeal as well as project management and communications are all included in the EMC's evaluation process.

As a result of the goals of the competition, WVU has intertwined the competition into a multi-disciplinary engineering senior-level capstone project with the ability of lower-tier academic university students to join for a challenging hands-on design project. The EMC team is comprised of two different colleges from the university, including the Benjamin M. Statler College of Engineering and Mineral Resources as well as the Reed College of Media. In past AVTCs at WVU the Chambers of Business and Economics had students involved with the competition for project management. Therefore, the students involved with the project come from various departments, majors, and cultures, and it is critical to have effective industry-level methods and tactics of management adapted into the academic stage in order for the overall success of the program.

The competition is structured in such a way that it is organic for teams to learn and adapt to different industry-level methods of design, communication, and management. From this style of competition, WVU

has adapted industry-level project management tactics through the years and hybridized these methods for a senior-level capstone project. The methods of management used in industry are not only applicable to the AVTC program and the EMC team but can be developed and used for any competition senior-level capstone project that desires to have a more successful outcome for a project. A student competition project needs to fulfill two main goals. The competition must maintain a fun and healthy work environment that results in a viable product upon reaching the end of the project's lifecycle, and the competition must also challenge students in the technical setting to prepare them for modern industry practices.

2.0 Project Management

Manufactured projects are not new to the 21st century. There are monuments still from the earliest civilizations of incredible achievement in today's world that still evoke admiration at the industry level. Current projects with more technical sophistication are not always grander in the scale of early works, which could be due to poor project management. Advances in technology, competition between organizations, and the tremendous respect for the value and costs of employment of the working man have led to the demand for new project management tactics and techniques. [2]

Projects at the industry level can be classified generally into four different types. The first classification involves civil engineering, construction, mining, and quarrying. The second classification type is manufacturing products which include research and development, automotive, ship, equipment, or any other product. The third type is management projects related to systems reorganization. And the last type is a purely scientific research product with high-risk, high investments, and an unpredictable outcome [2]. Based on the four categories outlined within the industry, senior-level competition projects such as AVTC's EMC fall under the type two classification as competition teams are producing a finished product for a specific customer or goal. Teams may have the ability for internal product design methods and learning.

The role of a Project Manager (PM) is key to the critical achievement of the project's objectives. The PM is responsible for what the team produces in the project outcome. It is up to the PM to take an overarching view of the product and development by the team to plan, coordinate, and complete the project's desired outcome. Having the responsibility for planning, coordinating, and completing the project, it is not possible for the PM to perform every role within a project but should possess the knowledge to manage the team related to the technical difficulty, understanding, and experience of the project. The

management of communication performed by the PM is critical to the communication between sponsors, team members, and stakeholders within a project. The stakeholders for the WVU EMC team are:

- ANL
- GM Mentor
- MathWorks Mentor
- Dean of Statler college
- Dean of the Reed college
- Assistant Dean of administration
- Assistant Dean a finance
- Assistant Dean of academics
- Department chair of mechanical and aerospace engineering
- Department chair of computer and electrical engineering and computer science
- Office of enrollment and outreach staff
- Coordinator of corporate relations and career assistance

The communication is not limited to providing direction or identifying the vision of success for the project but also using skills of interpersonal communication and the ability to effectively manage and communicate with people to balance competing goals of individuals involved with the project. Research reveals that their bosses designate the top 2% of project managers and team members distinguished the PM by demonstrating superior leadership and communication skills while maintaining a positive attitude [3].

The factors that make a successful and beneficial PM towards a project are typically transferred and relatable to the standards set forth by competition-level projects. ANL states that the EMC PM “shall

provide management and planning of overall project development, the project schedule and work plan, monitor and control all project-level activities, serve as an essential communication figure between competition organizers and the team, and leading coordination for recruiting and sustainability activities, knowledge transfer, and stakeholder management.” [4][5]

2.1 Project Management Structure

To establish an overall efficient and effective senior-level capstone project, one of the first steps is to define the team's management structure. The management system has to be organized in such a manner that supports the unique demands of the project. For the EMC team, this demand is the multidisciplinary project covering mechanical, aerospace, computer engineering, and computer science student programs that work in three designated lab spaces, dyno, two potential work classrooms, and the ability to work remotely through modern technology systems. The team's management structure must be operated and organized to support the demands of three technical swimlanes. The three swimlanes are:

- Propulsion System Integration
- Propulsion Controls and Modeling
- Connected Automated Vehicles

The first step in defining a team's project management tactic is analyzing existing or former competition-level project management tactics. The EMC program does this by performing a closeout report survey of the prior competition at the start of the EMC program by the PM. Inside the industry performing a closeout report is typical at the end of a project's life cycle. The closeout report naturally leads into and supports an organization's transition planning from one project to another project within the company or organization.

2.1.1 Closeout Report

A closeout report process involves solidifying project records, verifying and documenting project results, analyzing where the project was successful and effective, and archiving project information for future use. Once the initial process has begun, an outcomes assessment meeting is typically scheduled within the industry upon the PM or PM office's discretion for the project's lifecycle closure. The meeting should develop and commence with the focus of primary project success, problems, and issues that will benefit the ability of lessons learned and recommendations for future improvement processes. All parties of a project (team members, management, leadership, or stakeholders) should all be present during this meeting to have a clear understanding and acceptance of the project's overall outcome [6].

The WVU EMC Closeout Report Survey of EcoCAR 3 competition from the AVTC series pulled areas of importance based on industry practices. The closeout report covered information storage and archiving, human resources, team structure and organization, risk analysis and risk management, financial management, the process of knowledge transfer from the previous competition, and the method in which technical specifications were established and selected. In Appendix A the Year 1 closeout report survey can be seen.

In addition, it can be helpful for a team to perform a smaller closeout report for each pre competition deliverable or report once judge feedback has been provided. By performing closeout report for pre competition deliverable the team can gain insight and what corrections need to be made and what was successful persuading the judges in your favor. This process best works for pre competition deliverables that teams know will occur every year of a competition. For example, the WVU EMC team will always have an execution plan each year for project management as well as an impact report. Is important to note that judges may vary per year with a competition, but the main ideology of the deliverer does remains

the same therefore the benefits of a closeout report can support improvement and overall team score and knowledge transfer for a new team lead.

2.2 Project Management Plan

Once the closeout report is completed, the PM must propose a Project Management Plan (PMP) to the team leadership that covers how the execution of the project will be performed and the handling of other management systems within the team. Organizations have developed various processes in which the approach on how the structuring of the master project plan is to be orchestrated and optimized for the best performance for a single project. In the Figure 1 below, the development of the PMP and standard variables of a plan can be understood best in a visual flowchart representation [7]

Figure 1 Generic project management plan [7]

The PMP gathers information from past projects, guidelines, and other areas in the organization with information relatable to the project. The process includes the foundation of all the work formed in completing the project objective and the process development of management and control for several areas within the project [7]. Not all industry-level general inputs from a project plan are incorporated into a student competition-level project. For the WVU EMC team the inputs stem from a team vision statement, archived work, and the closeout report executed at the start of the new competition. Inside the architecture of the EMC, the PMP is supported by each year's execution plan. The execution plan ends up being a process the PM uses to effectively and efficiently plan, organize, implement, and control all project activities for each year of the competition. The execution plan is developed to be a working tool just as the industry practice of a project management plan that assists the project manager and the leaders to maintain consistency while conducting work throughout the project's lifecycle. The execution plan is one of the first deliverables per year that is submitted for the EMC competition. In practice, some organizations within the industry require the submission of a PMP before activities can begin. Since not all student competition are the same and the largest difference is in budget and procurement management these portion of planning and control will not be discussed along with the detailed analysis of the scope of the EMC project since the scope can not be apply to other competition based projects.

Traditional and agile management practices related to a competition team need to be analyzed and determined before further explaining the EMC team's execution plan for the project management methods and adaptations of industry-level tactics for the competition team. The project management body of knowledge is a guide that does not state the best form of project management but highlights 47 different subsets of management processes [3]. Two forms of management relate closely to engineering industry practices and senior-level capstone competition project teams. The first is managed through a traditional waterfall method, and the second is agile. [7][8]

2.2.1 Quality Triangle

Traditional PMs work is deterministic in which the manager attempts to determine as many aspects of the project as possible. In order to do so, the PM divides work into tasks and allocates a number of resources and time necessary for the completion of each task. In this practice, PMs carefully control the unknowns and develop contingency plans for what may arrive. The traditional management system that allows the PM to easily take aspects of the project and break up the project into smaller pieces has worked in the industry for centuries. All of the pieces that have been broken up can be related to three project categories of scope, budget, and schedule [7]. These three categories are just as relevant in a competition project. The scope of a project is all the aspects or chunks that can be compiled together to deliver what the team desires as the final product for the customer. The budget is simply the cost of resources, whether people, facilities, or things of the project. And the schedule is the time it takes to complete tasks that incumbrance to the final length of the project. For industry and competition teams, these three categories are the project's key constraints, but how they are constrained varies between industry and competition. The three categories generate what is defined as the quality triangle, and its lines link the triangle's three categories, and as one aspect is changed, the others must adjust. If a project requires more time, the PM must work to increase the budget or remove work from the scope of the project in order to maintain the quality triangle. Figure 2 is a visual representation of how the quality triangle adjusts for industry applications.

Figure 2: Industry quality triangle

However, for a senior-level capstone competition project such as the EMC, the categories of the quality triangle may be locked or semi-locked. With a student competition project, the deadline for deliverables and final competition rarely have input from the team and lack the flexibility of changing time and submission dates. The budget for a competition team is typically set before the start of the competition; it does not have the flexibility within the university for an increased budget; however, the ability to gain team sponsors is a possibility. As a result, the scope of the project is the only thing that is fully adjustable. Therefore, the project's scope is the only aspect that is completely unlocked and left to the team to decide on how large the scope and what criteria are within the scope for the team. Figure 3 highlights the quality triangle for the typical senior-level capstone competition team or the EMC team at WVU.

Figure 3:Competition level quality triangle

2.2.2 Waterfall Management

A traditional engineering approach to the project management plan in terms of management is the waterfall method. The waterfall method works within the three constraints of a project and is used within the industry for engineering projects. The central concept behind the waterfall approach is to spend a large portion of time at the beginning of the project to develop and understand all aspects of the project life cycle. The management method breaks down the project into sequential phases. Each phase leads to the next and so forth. Each phase has control processes established that allow each phase to transition organically. The phases start with planning, followed by designing, Integrating, testing, and deployment of the final product [9]. The concept of project shifting between phases is not unforeseen within a competition project. The EMC it's broken down into four years, with each year focusing around a different phase. Year 1 is planning and design, followed by Year 2 integration, Year 3 testing, and Year 4 refinement. Figure 4 visually represents the initial outline of the VDP and phase changes for the life cycle of the project.

Figure 4:EMC VDP schedule [10]

A downside of this management tactic is the ability to accept changes over the lifecycle of the project. As change requests come in, the PM and the team leadership must rebalance the three constraints and readjust the project; accordingly, as a result, planning of activities can be off on how much time is needed for the execution of design or integration, and the management tactic creates a dynamic in which changes for the better of the project are typically challenged. From this, when a customer develops a new idea or inputs a new requirement for the scope, the team must adapt and go through a complicated change process that must be applied to the project for the overall success [8]. Concerning competition teams is not uncommon for the customer or competition organizers to adjust new aspects to be incorporated into the project or readjust the rules of competition throughout the academic year. New sponsors may enter

the competition within the EMC requiring teams to use their product, and yearly and non-yearly specific rules (NYSR) frequently have revisions due to unforeseen design or safety regulations.

2.2.3 Agile Management

The second management method that relates to competitive project teams is agile management. Agile management helps answer the challenge of uncertainty, complexity, and ambiguity in the work environment of a project. As there are delays and changes from competition organizers within a competition, the necessary knowledge to fulfill the requirements or produce the product is not readily available. The agile working method is the preferred choice for teams that deal with uncertainty, complexity, and ambiguity in the work environment [11]. The methods within agile management are designed in a way to be simple and easy to learn for team members; however, the difficulty stems from how different it is from most people's traditional thinking of work. [8] In 2001 managers within the industry met to develop what is now known as the agile management practice, which comes down to the agile manifesto. The agile manifesto has a shortlist of four values. The four values include :

- Individuals and interactions over process and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

The four values each have aspects that are competitive and complimentary of one another. The method is not establishing that one portion of a value is better than the other for each value. However, the process of managers spending more time planning and not enough time responding to change must change for a project to be successful [9]. In turn, leads or managers hand over part of the responsibility to the team members of a project and take on the role of being more supportive throughout the project lifecycle.

Managers will not only perform the practice of instructing or inspecting but will lean heavily towards establishing ground rules and general conditions for operations for the team.

The agile management approach draws on three roles typically within the responsible infrastructure work process: the product owner, the agile master, and an implementation team. The product owner represents the customer and the success of the project. The agile master is in charge of making agile working teams that adhere to the principles of agile through their work while resolving roadblocks the team faces in order to allow them to concentrate on the main objectives. The implementation team is the sub-team that is working on delivering the product eventually to the product owner. The work cycle for agile working is broken down into two-to-four-week cycles that are referred to in the industry as sprints. Sprints enable the team to focus on the scope of the current sprint and not the overall scope of the project. In addition, it allows sub teams working in parallel to adjust and synchronize the sub team's work for a desired milestone achievement. For the PMs, this allows the product owner to adjust the requirements or the prioritization within each sprint cycle. As a result, this enables the constant ability to adapt and adjust to changing conditions through the project's lifecycle

At the start of every sprint cycle, a planning meeting is established to allow the team to pull stories from the product backlog and determine how the stories will be broken up into tasks and how the implementation team will resolve the task. A story is a short and distinct sentence describing a problem from the customer's point of view for the team to resolve [11]. The tracking of tasks based on the breakdown of stories within a sprint cycle is executed by a visual system implemented by the team. Through this process, the project's progression can be reported to management by the compounding and execution of successful sprint cycles that'll eventually lead to the end of the project lifecycle. Multiple stories combine together to form Epics. In practice multiple Epics can be combined to form the milestone

the team is attempting to reach. To better understand below in Figure 5 is an example of how each process of the agile management system works.

Figure 5: Agile Management visual term chart

2.2.3 WVU EMC Management Method

With two adequate management practices, both traditional and agile, the team must select the management tactic before executing the project management plan. In Year 1 of the competition, the EMC organizers encouraged PMs to explore the option of agile management into the competition series based on the teams being broken down into different types of technical swimlanes covering both physical and software-based product development. Therefore, the WVU EMC team adapted agile management tactics for the overarching project plan however realized that a student competition level elements of agile management are not practical based on student maturity and experience, faculty experience, and mentor experience. As a result, the team has attempted to hybridize methods from agile management and the traditional waterfall for management practice. It is not uncommon for a large organization that employs various technical areas of focus covering different projects to adapt and develop management methods unique to the company [3]. The team incorporates features of the phase changes from the waterfall management method along with overall project reporting tactics and planning. However, at the sub-team level, sub-teams have been encouraged to use agile practice to booster small sub-team working groups more responsibility, ownership, and understanding of the competition requirements and the product

development. The practice has allowed sub-team members to determine with the support of team leads and leadership the duration of task completion, the definition of stories within a sprint cycle, and the availability of time of each individual to contribute during each sprint cycle. Adopting this practice has helped mitigate the limitations of setting specific hours of operations within the established course curriculum at the university registration level. In addition, this helps mitigate one environmental factor that student competition teams had to deal with over industry. The environmental factor this affects the most is the ever-changing schedule of team members on a student competition team. Team members' schedules can change due to unexpected homework issues, to different team members deciding how much time they require to study for an exam or multiple members of a group having multiple exams in one week, so their work is limited, resulting in the desire to produce more work after the exam week. The flexibility of agile allows the team to support each other to help support team culture and ease the scheduling strain of available time and space in the garage, lab, or classroom. In addition, this approach strongly supported lab space limitations during the COVID-19 pandemic. Another benefit is that graduate leads supporting the undergraduate sub-team can provide more direct support to sub-teams at a given time. Below is an example of a potential work week for the PSI team in Figure 6. In the example, the sub-teams meeting outside of scheduled class time may not be present during class time but are still maintaining and choosing how much time is required to complete the task and stories within the set sprint cycle.

2021

CALENDAR YEAR

MARCH

CALENDAR MONTH

MONDAY

FIRST DAY OF WEEK

Monday	Tuesday	Wednesday	Thursday	Friday
08	09	10	11	12
EcoCAR Class Time (2pm - 5pm) PSI CAD group (7pm - 9pm)	Formula Garage time (3pm - 6pm) PSI Trunk Team (7pm -10pm)	EcoCAR Class Time (2pm - 5pm) PSI Fuel Tank Team (7pm - 9pm)	Formula Garage time (3pm - 6pm)	PSI Low Voltage Team (8am - noon)

Figure 6:Example of a working agile sub-team schedule

The PM performs the process of creating an execution plan that incorporates the aspect of a project management plan highlighting team standards for controlling, monitoring, and managing practices. In Appendix B, the Year 3 project management plan for the WVU EMC team can be seen.

Since not all industry-level management tactics are 100% adaptable for a senior-level competition capstone project, different universities have various procurement, budgets, and institutional structures. The remaining chapters will focus on areas of a project management plan that will help support the success of a senior-level competition project for an engineering curriculum that is adaptable not only from industry but also for the general application of engineering competition projects. Those chapters include team structure and operations, communication strategies, scheduling aspects and tactics, and the management of change and design.

Chapter 3 will cover the team structure and operations of industry practices adapted by the WVU EMC team. Strategies for both traditional and modern communication based on industry practices and the proper application to an engineering competition project will be covered in chapter four of communication strategies. The development effects and input of risk assessment into the overall benefit and scheduling of industry-level technical projects adapted to the EMC team will cover chapter 5 scheduling effects and tactics. Companies releasing a safe and reliable product always have

developmental changes based on customer requirements or roadblocks during a product's lifecycle. The industry's ability to properly handle changes and requirements using change and requirement management tactics that can be adjusted for any engineering senior-level competition project will be discussed in chapter 6 management of change and design. Chapter 7 shall analyze the overall execution and ability of the WVU EMC team to successfully adapt various industry-level project management methods and tools in order for a competitive successful senior level engineering competition program that allows students engineering student to be ready for industry practices.

3.0 Team Structure and Operations

A team in the industry is essential to the success of a project. The diverse abilities and methods of problem-solving are the core strengths of having a team [6]. There are six fundamental team factors when developing and leading a team. Three of those factors focus on the core construction of team size, composition, and governance. The remaining three factors focus on team identity, interactions, and mindset [12]. Organizations that rely on a structure that fails to account for teamwork that expands across various areas tend to foster conflict, miscommunication, and poor coordination, resulting in the failure of project goals, ambitions, and overall performance [13]

3.1 Team Construction

3.1.1 Team Size

For team size, there is no golden ratio on how large a team can be. However, as a team size increases, there are two areas of concern within the industry. The first is that informal groups can develop within a team or project, which can cause a breakdown. Second, with a size increase of a team, the internal dynamics can become cumbersome if it is not well constructed and organized [12]. Bigger is not always better. This process in the industry is referenced as process loss. As the size increases, it becomes more and more difficult to coordinate actions, communicate effectively, and adjust to change [14]. PMs have the responsibility of determining the ultimate size of a team in order to counter the law of diminishing returns on a team due to the decrease in productivity that will follow an increase of team members. The WVU EMC team has a history of being a sizeable senior-level capstone project. The last competition team varied between forty to sixty members, including undergraduate, graduate, and faculty members. The past competition team finished in 2nd place in year four of the competition with numbers between 40 and 60 members for the year. Through Years 1 through 3 of the four-year competition, the EMC team has averaged around 88 members throughout the years. With this increase, the PM was able to see a

difference in performance. The size of the team is always greater in the Fall semester over the Spring semester based on how the team is built. Understanding when your team will be at the larger size when comparing the Fall and Spring semesters of the academic year; it is best to try to progress the team as much as possible in the semester with the larger team. In addition, it is critical for team sustainability to maintain a returning member amongst any sub teams if the size of returning team members allows for it. The size of the team does not fluctuate when it comes to the number of faculty or graduate students involved however does fluctuate based on the number of undergraduate students enrolled in an EMC class or volunteering with the team each semester. The team has four faculty advisors, along with 7 graduate students at any given time. However, the structure and realization of increased growth teams were still able to be structured into positive working environments; this was done through the fundamentals of team development.

In addition to potential issues and too large of a team too small of a team can play a factor as well. And in industry if a project requires more team members the company will simply pull employees from another project or hire new additional employees based on experience and skill. Unfortunately, with a student competition team that is not a possibility and too small of a team can lead to issues of increased stress on team members resulting and potential danger on team sustainability due to the lack of students returning to the team the following semester. Figure 7 visually represents the two sides of the coin when determining the size of your team to consider.

Figure 7: Factors of team size

3.1.2 Team Composition

Team composition refers to what type of team members should comprise the project. Factors of experience, skill, and salary can all play roles in developing a team within the industry. Of the three factors, two stand out more than the others, which holds true at the competition student level. These two factors are skill and experience. Typically, organizations will group team members with complementary skills and experience from one another. Effective and high-performance teams have these two critical elements of diverse skills and experience for each sub-team member in order to achieve synergy. The WVU EMC team is orchestrated at the university level, allowing students to join the program to gain class credit for a senior-level capstone, and undergraduate technical electives. In addition, the team always encourages and allows for volunteers. By having multiple courses that pull from different skills and experience levels of students from multiple departments aids in the support of sustainability of the student competition project. The course at WVU related to the EMC project are the following:

- CpE 480 (Senior Capstone for Electrical and Computer Engineering and Computer Science)

- CpE 481 (Senior Capstone for Electrical and Computer Engineering and Computer Science)
- MAE 471 (Senior capstone for Mechanical Engineering)
- MAE 472 (Senior Technical Elective Course)
- MAE 371 (Junior Technical Elective Course)
- MAE 271 (Sophomore Technical Elective Course)
- MAE 495 (Independent Study)

As a result of this, the team is unable to hand-select the best students with skills or experience; however, the EMC team does have the opportunity to provide and require a pre-registration presentation meeting that covers the demand and expectations of every team member on the EMC project. Followed by observing the presentation from the meeting, all students desiring to join the team must sign a Memorandum of Understanding (MOU). The team's MOU can be seen in Figure 8 and Figure 9, which highlights all team members' expectations and behavior. The MOU is not a legally binding document but a formal process for team leaders to understand students' commitment and develop new sub-teams for upcoming years for the team's sustainability. In addition, it benefits team members to better understand the demand the project will have thought out the semester. The practice of the MOU has done well for the WVU EMC team and no negative outcomes have resulted in this requirement.

WVU EcoCAR Team Member Memorandum of Understanding (MOU)

I, _____, a student at West Virginia University, want to join the West Virginia University (WVU) EcoCAR Mobility Challenge Advance Vehicle Technology Competition (AVTC) team. I want to join the team and benefit from the knowledge gained and ability to use this class towards graduation requirements.

1. I understand that I am joining a team that represents WVU as a competitor in a student design competition while earning class credit. The course attached to this team does not function as a normal lecture course, rather the course is laboratory and garage work focused.

A general rule for a lecture course is that the number of hours spent weekly working on the course material is equal to or double the amount of credit hours being received.

2. Class attendance is mandatory, which includes:
 - a. Normal scheduled class times
 - b. Shop Nights
 - c. Communication/Outreach Events

We are aware that there may be circumstances that arise that cause you to miss and these will be handle on an individual basis.

Grading is primarily based on effort in the project and contribution to hands-on vehicle development and written deliverables. If you want the highest possible grade you will have to work well with other members of the team and exhibit a deep understanding of the work you complete as well as how your effort ties into the overall vehicle development goals. Much of the work is hands on as we have a vehicle that we are building, but a major aspect of the project is creating continuity throughout the years of the competition, so you will be expected to write a significant amount of documentation. Your final grade will be a combination of peer evaluation, GRA evaluation, faculty evaluation, and completion of required activities such as outreach events and shop nights. Students registering for MAE 471 are expected to return for MAE 472.

3. Attitude
 - a. We are Mountaineers who are not only receiving class credit but represent the university in a program which has a rich history on campus and in AVTCs. I will do my part to continue the overall team success by working outside of normal class hours.

Please note the majority of one's grade comes from the effort put into the program, in and out of class time

- b. Many of the software programs that we use in our labs you may have no experience with, however if asked; you as a member of the WVU team will be willing to put effort into learning the program and helping the overall team succeed.

Willingness to learn: Many of the programs that we use in our lab you may have no experience with such as Siemens NX, Mathworks Simulink, Vector CANoe, Mentor Graphics VeSys and others. Students will be expected to learn and design in these programs.

I, _____, will have a willingness to learn

Figure 8:Part 1 of MOU

4. I am aware that students will not only be expected to work on the vehicle directly, but will also contribute to written deliverables (reports and presentations).
5. Competition deliverable due dates are hard deadlines as the semester progresses and I will do my part to manage my workload in order to fulfill my responsibilities and commitments to the WVU EcoCAR team.

I, _____, read the entire document and agree to these requirements.

Additional notes:

- Availability outside of scheduled class time: The scheduled class time for EcoCAR is a way for this course to open up time in your class schedule to work on EcoCAR assignments, but working only during this time is not sufficient effort. The scope of the work required by the competition is vast and the timeline that we must follow is very demanding, the only way we as a team can successfully complete all of vehicle development milestones is to put in the time and effort outside of class time. As a rule of thumb, I would expect every student to log double the amount of time scheduled for the class, at the very least, to be successful.
- Time Management Skills: As a senior in engineering you should have pretty good time management skills. You will have to balance your other course work with EcoCAR assignments. The deadlines for deliverables for the competition have very hard deadlines and your work on these deliverables will be required regardless of any homework assignments or exams that you may have in other classes.
- Technical writing ability: Much of the work that we do involves technical writing. As a team, we spend a considerable amount of time writing and revising our documentation. As a senior in engineering, you have completed a multitude of lab reports and project reports so this should not be the first time you have had to demonstrate your writing ability. Students are expected to be able to write about their work professionally.
- Willingness to learn: Many of the programs that we use in our lab you may have no experience with such as Siemens NX, Mathworks Simulink, Vector CANoe, Mentor Graphics VeSys and others. Students will be expected to learn and design in these programs. Additionally, there will be principles of automotive engineering that you are not familiar with that you must learn. Students should join this class with the mindset that you will takeaway skills that you can apply in your career.
- Team mentality: EcoCAR is a team not just a class. You will be required to work with other team members from different backgrounds and skillsets. You are expected to have communication skills to work effectively with each other in a positive and healthy way.

Figure 9 Part 2 of MOU

3.1.3 Team Governance

The governance of a team is how the overall project management will be executed throughout the project's lifecycle. A team's control on the management of the project can vary within the industry from more traditional manager lead teams that have little control over their own team operations to more self-managed teams that have more control over their daily operations. In manager lead teams, individual team members are told what to do and how to execute the task, while self-managed teams are provided objectives. However, the ability and method to execute and achieve the objective is left up to the individual team members [12]. These two methods of understanding a team's competencies can provide the necessary ability to solve problems, communicate, make decisions, and manage conflict throughout the project span between the team [13]. ANL organizers for the AVTC's have organized the EMC in such a manner that the competition is governed in good faith with agreements with universities that six graduate positions will be filled including project management, engineering management, propulsion system integration lead, connected and automated vehicles lead, propulsion controls and modeling lead, and communications manager. In addition to the student-mandated positions set by the competition organizers, each team has a minimum of two faculty advisors and two industry-level mentors (one from General Motors and another from MathWorks). Outside of these concreted positions, teams have the flexibility to decide how they will govern the team overall. Therefore, the WVU EMC team, based on initial fall workshop training, team history, and the current leadership, takes a hybridized approach of merging the best qualities of both manager lead and self-managed teams. The process is executed using aspects of traditional management and project execution with new applications of agile management for individual sub-teams that are easy for new members to understand and adapt in order to have transparent management practices and fun within the project. As a result, the leads have established clear roles and responsibilities for the teams to allow them to have the flexibility of agile practices while incorporating the terminology into the reporting of traditional systems to faculty advisors and mentors. The process

results in students learning more than one management tactic and prepares team members for industry while increasing team member exchange, collaboration, and brings the attitude of competition to an academic competition team. This is not always a possibility within the industry but is a perk that senior-level capstones can adapt within a program.

3.2 Team culture

3.2.1 Team Identity

Once the factors of constructing a team are performed, the factors that focus on team identity, interactions, and mindset become more highlighted. A team's identity is critical to the effectiveness of team communication and commitment. The team's identity is both important to the members of the team project and the outside observers who will respect the project and the team. [12] Establishing a team identity helps maintain the sustainability of the project year after year by making membership of the team more attractive internally and externally [6]. The WVU EMC team does this with the aid of the communication manager (CM), the team's history, experience, and the individual team members throughout each year of the competition. The CM produces social media content for team branding and identification on the online platforms while promoting the achievements of individuals' progress made by sub-teams on the vehicle and the team's overall experience preparing for the final competition at the end of each year. The content the CM releases over the course of a competition year should be able to easily represent the progression of the competition team and its identity of the team for the year. Figure 10 is an example of a typical Facebook post followed by Figure 11 for Twitter and Figure 12 of the team's Instagram account page.

Figure 10: Facebook Social Media Post Example

Figure 11: Twitter Social Media Post Example

Figure 12: Instagram Social Media Post Example

From industry tools, the WVU EMC team manages all social media accounts and scheduled material releases using the industry-standard tool Hootsuite. The tool also allows the CM to easily track and report the number of views, interactions, and other aspects of social media essential to understanding the impact the team's posts have to report to stakeholders and evaluate the team's branding. Figure 13, Figure 14 and Figure 15 shows an example of the WVU EMC accounts Hootsuite page and the data tracked to help evaluate the impact.

Figure 13: WVU Hootsuite

Figure 14: Hootsuite tracking data example 1

Figure 15:Hootsuite tracking data example 2

In addition, to encourage new team members to follow the team's social media accounts and interact with postings, it is best to use a two-pronged approach. First, having a 1st day of the semester post that has all team members interact with for a grade in the project clarifies if any students do not have social media. The second is to have a scheduled set of social media campaigns that engage a different swimlane throughout the semester. The practice encourages students to interact with the accounts to help support the identity of the team and helps with creating fun content for both internal and external stakeholders.

In addition, the CM works on developing a branding image that will portray the projects or the team's identity for the life cycle of the competition. As a result, the team and competition organizers provide swag (t-shirts, koozies, polos, hats, etc..) to internal members each year, allowing them to promote the team externally across the campus, establishing a difference amongst other senior-level capstone projects. Swag that does not require individual sizes is best bought in large quantities to reduce the cost and to allow for both internal and external swag. For any swag it is best to determine what swag item will be purchased for the year before the 1st month of the semester is over, and to submit orders for clothing

as soon as possible. If budget is an issue, it is best to purchase items, not of clothing but have the ability to be used by team members on and off-campus, such as stickers, koozies, or hats to support the team's identity.

Another factor that the team employees to aid in identifying itself is establishing that this is not just a technical competition project on campus but encourages the future of Science, Technology, Engineering, Arts, and Mathematicises (STEAM) development. From professionals to collegiate sports teams such as football, hockey, soccer, or baseball require members to perform community service functions or reach out to programs to provide aid or support. The EMC team performs community outreach that promotes our project while supporting the education of STEAM to the youth of America throughout the pre-competition lifecycle of each academic year. Outreach events that help support team identity require preparing, coordinating, and executing time. The EMC team has learned to try and schedule outreach events four to three months in advance, if possible, for best results. The team believes these aspects are what push the team's identity to the next level. Examples of programs to communicate with for outreach include the following:

- College outreach office
- K-12 schools (both local and far)
- County or State Fairs
- After school programs (4 H, Robotics, Women in STEAM programs, Girl Scouts, etc...)
- Local Rotary clubs
- Partnering with other programs for social media campaigns
- The college visitor center for tours

3.2.2 Team Interaction

A team can only function if team members are able to interact with one another. The modes in which teams interact in industry are ever-changing as older methods give way to newer workplace ideologies [12]. Two models of team interaction inside the industry are both traditional face-to-face communication and interaction within the virtual world. [15][16]

A natural extension of team interaction is the process of providing and receiving feedback. In industry, that could be the process of managerial reviews, mentorship, or HR evaluations. The EMC team executes feedback using similar tactics. There's a natural development of mentorship and team-member exchange that allows for free and open communication that pushes for positive feedback during collaboration throughout a semester of work. In addition, the WVU EMC team performs a series of evaluations at the middle and end of each semester. Students need to understand how they are progressing throughout the semester to improve or maintain their performance, which can only benefit the team to reach its goals and milestones. Undergraduate students on the team have three evaluations that can be completed. The evaluation the students can perform are the following:

- Faculty advisors in charge of the competition team (*Only completed at the end of each semester*)
- Peer-to-peer evaluation of team members on one's sub-team based on swimlane work ethic (in-person and virtual work), communication, and attitude (*Completed at both mid-semester and end of the semester*)
- Voluntary peer evaluation of team leadership that involves the graduate students of the project (*Only completed at the end of each semester*)

The desired effect of the feedback is to allow constant improvements in team interaction in a positive and nurturing manner to mitigate team member performance as a risk to the project. Just as in industry, the best feedback is reinforced by a descriptive narrative. Therefore, the required peer-to-peer student evaluation not only evaluates one's peers on a scale system but also requires a description of each student's evaluation. This material is never shared with peers to develop trust. Members provided feedback and allowed leadership amongst the team to make the correct actions as needed without spotlighting or calling out an individual team member if possible. An example of the team's GRA evaluation and peer-to-peer evaluation can be seen in Appendix C. A further discussion of team communication and interaction can be seen in chapter 4.

3.2.3 Team Mindset

The last factor of a team structure and organization is the ability to have a common team mindset. The members of a team need to have common ideas, values, and goals for the success and importance of the team [12]. This can be done by establishing what is deemed appropriate team behavior, how internal team member conflict is resolved, the roles and responsibilities of team members, establishing the project's scope, and the goals of swimlane and sub-team milestones [13]. Members of a team may engage in different task objectives from various locations and face unforeseen roadblocks; however, the more team member exchange that occurs, the more a team will react as a cohesive, coordinated unit for the benefit of the project [12]

There are various factors for any organization at the industry-level or senior-level capstone competition that mold the setting for the team mindset; however, three critical ideas deserve attention. Those include what the team norms, roles, and goals are. The development of the roles, norms, and goals can occur over time and be modified through a project lifecycle. Developing a role structure within a student team allows members to cope more effectively with the schedule and direction of tasks. [6]. The EMC team has not

only taken the action of developing roles for the structure of the team. However, it has developed a hierarchy tree that identifies who is in particular roles, the definition of those roles, and the ability for new additional roles to be formed within the organization as needed. Traditional team structuring on student competition team sets 1 person as the leader of a technical swimlane. ANL organizers develop the competition with set positions that follow 1 person in charge of a swimlane, whether management or technical. An example of how ANL suggests a team to set up roles is in Figure 16.

Figure 16:ANL suggested team hierarchy

However, the WVU team has adapted the industry standard of having multiple compounding managers into practice for the technical swimlanes. The practice provides a few benefits. First, as a new graduate student joins the team, the responsibilities of leading a whole swimlane are shared by another lead and

supported by the EM. Second, a new lead can learn or improve management and leadership practices under a veteran leader who has already been leading the swimlane. Finally, the undergraduate students in a particular swimlane can now communicate with two leads to get faster response times, more dedicated time with graduate leadership, and the ability to communicate with a different lead if there is a personal communication issue. An example of the Year 3 EMC team's hierarchy can be seen in Figure 17, and the definition of the roles can be found in Table 1.

Figure 17: Team hierarchy

Table 1: WVU EMC student roles and responsibilities

Position / Title	Reports to:	Responsibilities
Project Manager	All Faculty Advisors	The Project Manager (PM) is responsible for several project-level areas, including the budget, task schedule, scope management, stakeholder management, risk management, and conflict management. The PM will develop the overall project timeline and work plan and is responsible for tracking and executing all project-level activities, knowledge transfer, and recruiting/retention activities. Scheduling stakeholder visits and reserving meeting rooms is also necessary for the person filling this role. The PM must also be a graduate student with a technical background.
Engineering Manager	Project Manager, Technical Faculty Advisors	The Engineering Manager (EM) provides technical expertise and continuity throughout a large portion of the four-year program. The EM is tasked with providing technical supervision to all technical swimlanes to meet program deliverables. The EM is also responsible for providing training and executing knowledge transfer to new graduate and undergraduate students in all technical swimlanes. The EM should also be an expert to consult about the overall vehicle and subsystems design.
Communications Manager	Project Manager, Communications Advisor	The Communications Manager is to oversee all communications sub-team members and delegate tasks according to each sub-team member's specific skills. The Communications Manager is the primary media and special event contact for all events to ensure consistency and clarity between outside contacts. Particular emphasis is placed on youth outreach and the value of STEM (science, technology, engineering, and math) education.
System Safety Lead Engineer	Project Manager	The System Safety Lead Engineer develops and coordinates the information needed to ensure that the team's competition vehicle is compliant with all system safety criteria. They are responsible for completing all of the system safety deliverables for each year of the competition
PCM Leads	Engineering Manager, Project Manager, Technical Advisors	The PCM Leads are responsible for fault analysis, supervisory control strategy design, and the implementation of the control strategy.
CAVs Leads	Engineering Manager, Project Manager, CAVs Faculty Advisors	The CAVs Leads are responsible for designing, implementing, and testing software related to connectivity and automation on the Chevrolet Blazer.
PSI Leads	Engineering Manager, Project Manager, PSI Faculty Advisor	The PSI Team Leads are responsible for all work need to integrate the team's propulsion system into the vehicle. This work includes CAD packaging, component procurement, wire harnessing, component integration.

Norms are the rules a team develops on how members should behave and operate. An effective project team's norms cover team members, the project's deliverables, and how they should be produced [12]. In part, this is done in three ways within the EMC team. The first is within the MOU; a brief description of expectations is given for team member behavioral and technical standards towards performance. The second method of supporting norms is through team member ownership of a task or story that needs to be executed and progress towards the competition team's goal. With any senior-level competition capstone team, there are always students who are willing to go above and beyond; however, being frank with team members that once an area of focus is given to individuals of a sub-team group, the area of focus will be maintained by the selected team members. Team members, in turn, are responsible for the development, solution, and completion of the focus area without being stepped over by other members. The practice is not discouraging competition team members from seeking support from other students who are willing to go and help above and beyond within the competition project. The last and more critical aspect of establishing beneficial norms between team members is good leadership. For example, new members can observe and mimic the qualities of team leaders through team member exchange and mentorship.

When issues arise amongst team members, HR is called in to handle the situation in industry. For a student competition team, that is not a possibility and the person on the WVU EMC team to handle team member issues is the PM. The PM should keep an excel file on hand that allows students to record issues with fellow students as needed that the PM can only access. Having a record system allows students to feel that all issues are taken seriously and allows for proper reporting to university administration if needed. In addition, it allows the PM and EM to properly communicate with team members to resolve issues professionally with proper communication.

The goals of the project give common direction for an organization and industry or a team at the competition level [6][12]. The EMC team breaks down sub-team goals into two weeks cycles or sprint sessions in order to adapt to the agile approach of team operations. In addition, the team publicly makes aware what are the milestones throughout the academic year for the competition team. The method is done through communication, scheduling, risk management, and change management, all under the structured team organization and project management scope for the competition's success. An example of the Year 2 Milestones accomplished through project management methods and displayed to the team throughout Year 2 is in Figure 18.

Figure 18:Year 2 Team Milestone Schedule

4.0 Communication Strategies

Effective communication at the industry level or senior capstone project is what makes things happen. There can be a great deal hanging on communication whether the communication concern is through email, in person or virtual meetings, a report deliverable, a presentation, online messaging, or a group text that can prompt an agreement or an action. Communication can seal a deal, drive a complicated concept, or enhance your project for the better [17]. Communication amongst team members is important for efficient teamwork to coordinate behavior and ensure that all team members have the information needed to complete tasks [18]. To enable effective communication and thus efficient teamwork, the team utilizes traditional forms of communication and modern approaches to stay connected and up to date. All critical whole team updates, meetings, and reminders are communicated by either the PM or EM through the means of face-to-face communication or detailed emails as early as possible and often to keep all team members in the information loop. Outside of information deemed critical by the team leadership, information is only communicated through swimlane leads and peer to peer communication to not overwhelm a listener with material one finds unhelpful for the task or sub-team one is a part of. The tools used to communicate with members vary from software used for virtual meetings, more personal group text chats, or consistent traditional emails for each swimlane. During the COVID-19 pandemic, team swimlanes used both Zoom and Microsoft Teams. Both platforms have pros and cons; however, after several virtual tool usage sessions, Microsoft Teams was the better choice for the EMC capstone project. Microsoft Teams provided a tool to hold virtual meetings and was the center for the team to communicate tasks and materials required for the success of a swimlane when remote work was only possible.

4.1 Traditional Communication Tactics

The two types of traditional communication methods for engineering projects are emails and face-to-face meetings. For any system to work, regardless of the method of communication chosen, the fact remains the same that a constant style of communication is critical in order not to cause misunderstanding and loss of vision when communicating between large team projects and multidisciplinary engineering groups.

4.1.1 Email Communication

Communicating between colleagues and peers is easily done with emails since the invention of computers and the Internet. However, with a senior-level competition capstone project, there is often an increased flow of information coming from multiple sources. Second, even though undergraduates are technology savvy and are connected to smart devices, and possibly have access to the best means of communication in the most recent academic era, several students either do not check their emails frequently or find emails can be too long. Even with small hurdles in students learning to use emails in a capstone setting that is relatable to industry establishing standard emails are guaranteed an essential factor when communicating information at a senior-level capstone project. In order to efficiently and effectively communicate with students by email, WVU EMC has developed a standardized means for writing emails for our students. Having a standardized means of writing emails benefits the students receiving the emails and the new student leadership writing the emails, whether undergraduate or graduate students. For most students, emails have only been exchanged between professors as needed, so having professional industry-standard emails as an efficient and effective email can be a new concept. Therefore, the team has benefited from a professional standard when writing emails.

One of the biggest mistakes when writing an email is adding unnecessary information at the start of an email and burying the lead or the main topic of the email within the middle or the end of the email's

origin. The email writer needs to get to the point much more quickly in an email than in in-person communication. The writer saves time and miscommunication efforts for all party members involved. The concept has been added to our standard method of email communication for the WVU team. The second critical aspect of writing an email and preventing errors and professional writing is having a transparent subject header for the email. A common mistake is using phrases such as urgent in one's email header. If one writes urgent the reader or receiver of the email will think there is a big problem which can increase the stress level of the reader working on the project. The reader most likely will stop everything to read the email and will automatically assume the writer needs a quick reply preventing them from finishing task at hand or possibly responding with an amount of miscommunication based on shortening the timeframe in which one is able to gather information to pass on. Another aspect of our standardized email system is considering whether the information passed on cannot be provided through other means such as in-person communication or needs to be documented to provided future documentation. With new students entering the capstone project in communicating with either small sub-teams or larger swimlanes, a belief that everything must be communicated by email can cause problems. Understanding what is significant and why something should be included in an email is critical to having an email system within a senior-level capstone project. Understanding that information coming by email is critical and only by certain members of the program will prevent the abuse of emails for the project and maintain a professional understanding of the importance of the email received on behalf of the project. [18].

The first step is to realize that students receive numerous emails from either faculty or the university at any given time, so the email's subject matter must stand out. As a result of this, the email header needs to be consistent as well. Therefore, the WVU EMC leadership maintains a steady subject header in our emails stating EcoCAR Mobility Challenge Update followed by a set of parentheses, including the date. The standard set by the team has prevented students from not overlooking important EcoCAR emails and has made a consistent method for students to track how and when information has come out in

chronological order. Below in Figure 19, one can see an example of the EMC team's standard email subject header.

Figure 19:Email subject header

Second, critical information is only passed on by two members typically, the PM or the EM, for most cases. Third, upon displaying the information inside the email and following industry standards of professional writing and communicating with colleagues or peers, the author breaks up each information section into short headers that are bolded and then highlighted. The act of this standard in the EMC team's email writing has allowed the team to pass along large amounts of critical information that students then can pick through and determine what is critical and relative to either a swimlane or sub-team, or person. As a result, the method of writing emails has decreased the number of miscommunications. The excuse for missing information or feeling that an email was too long to read has diminished. Team members have been well informed of what a specific swimlane needs to do and better understand the progress of the overall program throughout weekly emails. Below in Figure 20, one can see an example of the end of the year email following this standard of email writing set forth by the WVU EMC team. The left justification visually shows how the header for each section is highlighted and bolded and stands out to the students allowing members to grasp what is deemed essential and inform and assess one's reaction to the email.

Figure 20 Example team email

4.1.2 In Person Meetings

Technical people such as engineers are known to have little patience with meetings; however, meetings are an essential part of organizational communication, consultation, debate, and decision-making for any project, and a project cannot thrive without a meeting. Therefore, there must be a balance between the number of meetings and efficiency of the meetings, and how a meeting operates for the constructive and beneficial factors towards the project. By having a standardized system that is healthy and good for the project in terms of meetings, a PM eliminates the thought of having meetings for the sake of meetings, and occasionally, a good meeting will occur through a series of bad ones. Poor meeting culture is not effective and therefore a standard must be emplaced for the type of meetings an organization holds. [17]

Meetings are a real work task within the industry and not just a minor task. Inside the industry, the meeting owner is accountable for the cost of the meeting. As for a competition team, the ownership of the meeting is on the PM, EM, or the team leader hosting the meeting, whether the meeting is in person

or virtual. One way of controlling the ownership and costs of a meeting and making the meetings more effective is to consider how many people are invited to a meeting and what roles individuals play during the meeting in terms of support. At the industry level, if the meeting owner was to hold a meeting with an open invite that lasted one hour with thirty people and of those thirty people salaries with benefits was a total of \$150,000, the meeting is equivalent to \$3150. However, if the meeting owner was to reduce invitations or areas of focus of the meeting to one hour and only 10 people with the same salary, the cost is only \$1050 for the meeting. [19] For a competition team, salary is not a currency value in which a team has to consider, but the currency for a team is time away from a sub-team or team member work. Therefore, having smaller meetings can be more effective in terms of cost and efficiency in getting the topic of the meeting covered.

As the meeting owner, scheduling a meeting can take some time upon trying to match up everyone's schedule to allow a time to meet. A great tool from the industry that the WVU EMC team uses to schedule meetings with members or stakeholders who have hectic schedules is to use the program Lettucemeet. The program is free and simple to work; as each person inputs their available time for a meeting, the areas that become the darkest green notes when everyone is available to have a meeting. Below in Figure 21 is an example of setting up the defense of this thesis.

Figure 21: Lettucemeet scheduling system

Another approach to increase the efficiency of meetings regardless of whether it's in industry or at a senior-level competition capstone is understanding the basics of a meeting is important to the success and execution of meetings. Four categories come from the industry on how to execute well-developed meeting practices. Those four categories include:

- Defining the type of meeting that is being executed
- The discussion objective of the meeting
- What decision will be made, and who is responsible
- Are there follow-ups

These four categories should be covered in the generation of the agenda for a meeting. It is important to remember that during the execution of a meeting, the purpose is not a status update or review completion details but to identify roadblocks the project is facing and the discussion of support. An example of the WVU EMC agenda is in Figure 22 and a meeting agenda template is in Appendix D.

GM Mentor Meeting Agenda

Attendees: GM Mentor, Dr. Andrew Nix, Dr. Brian Woerner, WVU PM, EM, PCM Leads, CAVs Leads

I. CAVs Vehicle Testing

15 Mins (End Time: 8:15)

Results from testing (Alex) (Material for Screen Sharing)

OXTS training on March 16th (Clay)

Roadblocks

II. HMI/UX

5 Mins (End Time: 8:20)

Roundtable feedback

III. PCM

20 Mins (End Time 8:40)

Roundtable feedback (Holden)

ECM (Jared)

Current Roadblocks (Jared) (Material for Screen Sharing)

IV. PM Update

5 Mins (End Time 8:45)

Upcoming week game plan (Material for Screensharing)

V. GM Mentor Questions and Concerns

10 Mins (End Time: 8:55)

Follow Up Notes:

Figure 22:WVU EMC agenda example

An additional feature within the industry in establishing well-executed meetings is setting a standard form of operation for regular and special meetings. There are two common ways in which to set a standard form of operation. The first comes from the agile method approach of using ground rules for daily standups. Standups are orchestrated with short 15 minute in-person or virtual meetings that happen on almost a daily basis. [11] The ground rules for standups include the following:

- If you have a task, you must attend
- Only those who have tasks can talk
- The speaker must speak to the team and not the scrum master
- No side conversations
- Generate a new note for each task created during the meeting
- Discuss issues after the meeting
- Solve problems offline [9]

The more traditional approach and setting of standards for meetings are using the three reporting rules. The approach handles more technical documentation evidence solutions by allowing proper presentation during a meeting if possible and not a standup or non-conference room setting. The three reporting rules cover the following:

- The performance data simply shows whether what was committed to being done is done or not
- Whoever executes the plan generates the performance data that is used to make decisions
- Expect early warnings of commitments that may be missed and never punish anyone for providing early warning [20]

Meeting etiquette is not a problem just at the student level, but it can be a struggle within an industry. The problem of meeting etiquette is not limited to in-person meetings but also can extend and become

more problematic in a virtual environment. Two of the most common industry-level meeting issues are equal to and subject to student-level meetings. The first is not paying attention or not engaging, and this could be due to the process of multitasking or eating during a meeting, which can lead to you repeating discussion topics and the lack of team member exchange. The other typical issue is a crucial individual is not present in the meeting. As a result of this issue, roadblocks can't be decided on because of a missing key participant, or even worse, an additional meeting will be held to review the topic of the meeting, which leads to potential scheduling issues. [19]

The WVU EMC team has variations of how meetings are handled for in-person groups depending on the audience of the meeting, whether it's leadership, student leadership only, or at the sub-team level. Regardless of the type of meeting, the team has developed a method unlike a strict system such as Robert's Rule of Order. The meetings established have an agenda or operating sequence depending on who is meeting. The agenda is based on industry standards and has the ability to have the flexibility for conversation and discussion. In addition, one may consider the way the meeting is set up is similar to the way the management of the project is with aspects of a traditional meeting having an agenda for regular leadership meetings or special meetings. As for sub-team meetings, the team has an agile approach of having sprint-style meetings with members doing a brief stand up upon the standard weekly work layout of operations of the team and sub-teams. A stand up is when a member within the meeting stands for one to three minutes and addresses a topic in which one is working on in order to relay roadblocks or issues to the entire sub-team and for the sub-team to spotlight a task and the benefit to the project for better team member exchange, team morale, and collaboration. The best example of all our variations in meetings comes down to when it's the student leadership without a faculty present. These meetings happen weekly in the agenda set forth at the start of every semester. Each sub team will address topics of concern, change to the planned status, and relay any problems they foresee with the schedule, request of material, or lab time.

Progressing forward throughout the semester, some aspects of the agenda may not be reached because of time allowed or the fact that a critical issue develops that engages all the sub-team leads, and a special meeting is scheduled. Regardless the meeting is still led by the PM and EM in a co-coordinated effort to mitigate the typical industry issue of someone is not here, and the discussion has to be tabled for later. The practice follows a more traditional status of a leader taking charge and initiating the progression throughout the meeting. As a result, the PM and EM maintain the progression of the meeting but hands off the topic of focus to the swimlane lead or group speaking during the meeting. The PM hands over the more detailed technical questions to the EM and jumps in when a project conflict is discussed or presented through open communication during the meetings. The process of leading a meeting in this manner is done because the EM is the technical lead asking the difficult questions playing the role of Devil's Advocate. The PM is managing the overall project to achieve efficient and effective overall work that will benefit the project and the undergraduates involved; in turn, this is the supportive engagement role. Even though the meetings are serious and benefit the team, these meetings have a behavioral system that suits the environment that relaxed daily wear and drinking coffee is acceptable. However, everyone is still focused within the meeting, not checking emails, phones, or doing additional work while listening. Preventing multitasking in this scenario allows every individual for one hour with team leadership without faculty to focus on what is honestly being discussed and not be distracted. After the meeting, the PM and EM work closely together to ensure that the schedule for the next few days is set up to prevent confusion and miscommunication.

Alternating the responsibility between the EM and PM, a post-meeting report is sent to the student leadership confirming all topics mentioned and covered during the meeting have an agree upon action just as in industry practices. The system of a relaxed setting allows student leadership to be more open with each other as one feels more comfortable in a peer-to-peer setting of communication even though their roles are distinct and defined upon acceptance of the job. This benefits an overall attitude of any

senior-level competition-based capstone project to have students on the team with a T-shaped personality; the leadership still have an area of focus, but by listening in this meeting system, team exchange and collaboration are possible in order to identify areas where a lead can provide aid for sub-team leader or swimlane lead to resolve a problem quickly and efficiently and to allow further progression for the project. As a result, a sub-team or swimlane typically benefits in roadblock resolution. Students can gain more technical knowledge outside of the swimlane or sub-teams' area of focus.

At this level, the two styles of meetings are almost hybridized between the more rigorous traditional meeting style and the more agile format. When the team moves to in-person meetings at a smaller subset of any swimlane, dealing with the sub-teams within form closely follows a stand-up meeting: communicating task objectives, results, and how small goals will be met in stand-up discussions.

On the other hand, as the meetings are more set to faculty meetings or GM mentor meetings per this competition, the meetings have a hard-set agenda that can change weekly with pre-submitted presentations or documents that reflect more towards the three reporting rules. Even though the lead person for the meeting is either the PM or EM, the lead speaking at any given time is reporting to a higher-up authority that follows more of an industry leadership meeting style.

4.2 Modern Communication Tactics

A society of young engineers entering the education level of a senior-level competition-based capstone project such as the EMC have grown up in a technical revolution and communication. Students have the touch of knowledge at one's fingertips through smart devices and recorded history; it is not prevalent that modern communication tactics have developed. Traditional communication tactics still remain relevant and have a place within senior-level capstone projects. One of the best areas to highlight the modern communication tactics used for engineering capstones and at the university level is looking at a specific

swimlane of a project or the sub-teams that are integrated within that swimlane and how they function using modern communication tactics. Communication is even more prevalent now with the push of more remote work and the fact that miscommunication and misunderstanding increase during the remote work of the COVID-19 pandemic.

Text messaging refers to the text-based message between a user in a receiver from a smartphone or tablet device. The process of group messaging allows for more than two people to participate in a text-based conversation. Group messaging allows collaborators or team members to exchange text-based communication in an efficient way from their computers or mobile devices. The ability of group messaging allows group-based texting to be a convenient way for project teams to communicate quickly and efficiently regardless of a team member's location. However, if standards are not established for professional or competition-level team communication, this efficient form of real-time communication can become ill-advised. It is up to the leadership to establish the standards in which users will operate the group messaging service in the industry. A few of the most common practiced standards for group messaging include limiting the conversation to a specific topic or area focus, using proper grammar, and limiting slang or abbreviations; and the messaging service automatically maintains a complete transcript of all conversations which is readily available for the account administrator and in leadership this prevents and supports Human resource if a conflict develops between coworkers or team members.

The ability to collaborate and communicate in real-time is not limited to text messaging services. Within industry projects, teams can collaborate using real-time screen sharing or virtual whiteboards, work simultaneously on creating, editing, and reviewing data documents or files, and share documents and files through the process of stored data on the cloud [21]

Taking a closer look at a WVU EMC swimlane, there are two modern tools swimlanes and sub-teams have chosen to use. The four swimlanes of the EMC at WVU have chosen to use different subset methods of

the two tools based on the preferences of the sub-teams within the swimlane. This has resulted in more information tracking for the PM; however, it has increased the efficiency of communication between team members and the leads that work closely with them. The base design of the modern tools of communication used for a senior-level capstone such as the EMC is a group text messaging and online communication system.

The preferred text messaging method is GroupMe, an established product with a history tracking system for team members' safety. This method is beneficial for members who are constantly on the phone or have a mobile phone near. The app is useful for day-to-day tasks and communication between team members of a sub-team and critically helpful for communication when the team or capstone is traveling for competition. It allows the direct team traveling to communicate directly to each other and an easy method of app communication while also establishing and maintaining group communication quickly with the home base team that was not able to travel for competition and still able to provide support and feedback quickly and efficiently. Below in Figure 23 example of group communication using the app GroupMe during both daily task resolution and travel communication during the competition event of the capstone. In addition, the app GroupMe and this modern tactic of communication is fast and does not have conflicts between product operating choices of smart devices

Figure 23 GroupMe app usage

The other method and modern tool used is online communication systems. The programs used by the EMC team have been Discord and Microsoft Teams and operating during the Covid-19 pandemic would not have been possible without the use of these tools. When having these tools for a capstone project, it is critical that message history can be tracked and communicated from both a PC and a smart device such as a tablet or smartphone. Each program has unique features but also has crossover functions as well. Discord and Microsoft Teams both have the ability for online messaging systems for direct communication with groups or individuals of a team as well as the ability to host meetings and share screens. For the team, Microsoft Teams is a product the team also uses for the team's virtual environment of data management, Swimlane and sub-team focused channels, Kanban, scheduling of meetings (Meetings

schedule in this method can be linked to a student's Portal page with the university), and the collaboration on written documents while maintaining format standards of the team.

On the other hand, Discord allows students to share multiple team members' screens at a given time, creating a virtual collaboration setting as if work was being performed in the lab.

In addition, Microsoft Teams works with Microsoft's OneDrive, which is a massive plus for student usage. It is important to note that when virtual collaboration occurs, it is best to limit the number of students on a document to no more than 5 and not focus on formatting. More students on the document and formatting can cause lag or the acceptance of changes throughout the document. Also, students may be new to the program, so it will require planning and correlation of training to adjust to the system. It is best to provide examples in a training document and get students registered with the system as soon as possible if IT limitations are a theme amongst the university. Below in Figure 24 thru Figure 29 can be seen how the Microsoft product can be used to support team communication.

Figure 24: Microsoft Teams Messaging Example

PSI Sub-Team Posts **Files** PSI Tasks Requirements WVU PSI Notebook Meeting Notes Y3 Pre C

+ New ▾ ↑ Upload ▾ ↻ Sync 🔗 Copy link ⬇ Download + Add cloud storage

PSI Sub-team

Name ▾	Modified ▾	Modified By ▾
CAD Training	October 18	Colin Burns
Change Management	November 8, 2020	Colin Burns
Competition EODs	March 22	Aaron Mull
Component Controls Submission	March 18, 2020	Aaron Mull
Drive Cycle Energy Consumption	April 14	Colin Kellett
EcoCAR Y3	August 23	Colin Kellett
Electrical Team Files	March 18, 2020	Aaron Mull
Fuel Tank Files	March 18, 2020	Aaron Mull
Impact Report	March 21	Austin Scott
Management Files	March 18, 2020	Aaron Mull
Mechanical Team Files	March 18, 2020	Aaron Mull
Notebooks	March 18, 2020	Aaron Mull
Pictures Needed	April 4, 2020	Colin Kellett
Requirements	March 18, 2020	Aaron Mull
Subsystem Design Report	March 18, 2020	Aaron Mull
Subsystem Part Diagrams	March 18, 2020	Aaron Mull
Thermal System Files	March 18, 2020	Aaron Mull
Tire and Rim Files	March 1	Austin Scott

Figure 25: Virtual data management system using Microsoft Teams

Figure 26: Data management file tracking

Figure 27: Teams' scheduling system example

Figure 28: Teams' Kanban system example

Figure 29: Teams' task tracking system example

As restrictions of COVID-19 are lifted, the team will maintain the execution of these products for a hybrid remote and in-person work setting due to the effectiveness of team member exchange resulting in increased team morale, collaboration, and overall communication. It is important to note that this data management system will not replace the primary system but support file management on the internal computer system, and confidential material must remain on internal computers for safety reasons.

4.2.1 Virtual Meetings

At the start of the COVID-19 pandemic, an increase in the demand for virtual meetings was a major result both within the industry and with competition-level senior capstones. Virtual meetings are not a new topic but can be a new practice for many organizations within industry or academia. The practice and handling and execution of meetings, whether it is through agendas or stand-ups with agile management practices, meetings still operate the same way, but new issues can become more visible in these settings. Successful execution of a virtual meeting requires the establishment of virtual meeting standards and online operations inside the industry.

One of the standards in the industry to operate with an efficient and effective virtual environment is to establish and adjust the leadership of the host during meetings. It has been observed in the industry, leading and hosting a virtual meeting requires even more work than in person. However, the additional work of hosting a meeting does have additional benefits for the team using virtual tools. The first standard is to indicate interest in how things are going for each individual of a team that you're meeting with in regard to business while supporting informal communication. Virtual environment teams have the potential to lose the benefit of in-person team member exchange. Another standard or practice in the industry is to make sure that all equipment required for hosting the meeting is properly working prior to the start of the meeting and be understanding when technical difficulties arise with others joining the

meeting session. Another well-established industry practice is encouraging all team members to use personal video. This process mitigates the issue of multitasking during meetings or acting in other forms of distraction and increases or maintains team member exchange. One of the last online practices that is critical in industry or with any team project is that the host must learn to understand the meaning of silence and wait to minimize it throughout the meeting. It has been observed that online meetings can reduce the desire for engagement from participants. It can be difficult to understand whether people are agreeing, disagreeing, or not paying attention. One of the best practices to resolve this is to be clear when speaking and mix up the conversation throughout the meeting to prevent the feeling of staggering sessions or numerous slide dullness. [22]

Based on EcoCAR's fall workshop practices in Year 3 and through trial and error of team operations, the EMC has established a series of standards-based on industry practices and personal growth that have resulted in effective and efficient meetings. The first is that the host and lead present in any meeting should have a camera on if possible and encourage all members to activate their cameras if team members feel comfortable. The second is to open up a meeting with a generalized question that every single person in the meeting can answer. The question is not specific to a swimlane or topic planned within the agenda of the meeting. This process gets the meeting going while mitigating an issue of delayed entry into virtual online meetings. The third and one of the most significant benefits of the virtual media environment is setting the standard of the host is in charge of recording any meeting and reposting discussion when possible on the team communication environment. This practice allows members who have time conflicts to remain connected and communicative with the issues and decisions made throughout the meeting. Lastly, just as in-person establishing a regular meeting schedule is critical to continue access while establishing time for special meetings or more personal small group meetings to provide better feedback and the aspect of team members at the competition level for the EMC project. It is important to note that

the operation of a virtual environment is new for the EMC team and is an ever-growing and changing system.

4.2.2 Knowledge transfer

At the industry level, knowledge transfer takes place by two methods. The first is through standardized documentation work, and the second is through team member exchange and mentorship.

Good common practice is an engineering practice that stands for standards and regular regulations. Evidence through the multiple forms of management to have a successful industrial operation two key element stands out: organization and standards [6]. As a result of this, the EMC team at WVU practices keeping the process simple and good common practice. We operate in a simple manner that is easy for new team members due to the turnover rate per year of competition to decrease the potential loss of knowledge and maintain the project's sustainability throughout its lifecycle. The turnover rate of team members is greater for EMC than the industry. As a result, the team has established a standard process of onboarding new team members with a start of the semester presentation to explain the program in more detail and for swimlane to highlight the previous semester progress and where the swimlane will be picking up from and the scope/goals of the swimlane and sub-teams that comprise the swimlane. In addition, having a standard sets the expectations of all team members within the organization and provides guidance and development for better engineering practice for young members.

In addition, the team provides a document that is established for knowledge transfer towards understanding in detail different integration areas of the competition vehicle. The document focuses on the methods and reasons for component integration and the process taken thus far. In order for teams to effectively continue integration and testing each new semester of a competition year, it is crucial to document various aspects of the current vehicle state properly. A team should keep in mind that the

document's intended audience is for internal team use and new members. The document is called the Vehicle Integration Status Documentation (VISD) and is a living document that is updated continuously throughout the project's lifecycle. Due to the nature of the document continually being updated and practicing good common practice, the team has established a detailed template for team members to understand what is required to complete an update to the document and what is needed to properly update the document. In Figure 30 and Figure 31 the template for VISD can be outlined in two parts. The areas the document covers are the following:

- Conventional propulsion system
- Electric propulsion system
- Hybrid thermal system
- Energy storage system
- Hybrid supervisory controller and gateway
- CAVs system
- High voltage system
- Low voltage system
- Communication wiring

The three critical question that need to be answered for any material in the document are:

- **Why** each component was integrated, including functionality of each component
- **How** each component was integrated, including design considerations and integration difficulties
- **What** still needs to be done to finalize the integration of each component. (if the component is integrated fully, design improvements are discussed)

Vehicle Integration Status Documentation:

The Vehicle Integration and Status Documentation (VISD) is a living document that fully details the team's CURRENT progress on the vehicle. All previous revisions are saved on the Z Drive under "EcoCAR 4" → "Documentation and Training" → "Vehicle Integration and Status Documentation" → "VISD Old Revisions". The previous revisions allow the team to track changes throughout each year and show the working process on how the vehicle has progressed throughout the competition. It is noted that the This document will detail when to update the VISD, what information to include when updating the VISD, and the proper format.

Follow the following Naming Convention:

VISD_ [Vehicle System] _ [Section Number] _ [Revision Number]

Example: VISD_ConventionalPropulsionSystem_Section2.0_Rev6

Vehicle System: [Conventional Propulsion System, Electric Propulsion System, Low Voltage System, etc.]

Section Number: In the "VISD Old Revisions" folder there is a "Rev 5" folder. Each section number for the full document is listed. This will help the merging process for this document at the end of the year.

Revision Number: This is the revision number listed as the "current" folder name. This can be found in the Z Drive under "EcoCAR 4" → "Documentation and Training" → "Vehicle Integration and Status Documentation" → "VISD Current"

The revision number will change once each section has been fully updated from the previous revision. For example, the team is moving from Revision 5 (previously updated at the beginning of Year 3) to Revision 6 (Beginning of Year 4). All changes made throughout Year 3 will be what is discussed and highlighted in Revision 6. Any changes made throughout Year 4 will be demonstrated in a Revision 7.

Procedure for Updating VISD:

Each section number will be assigned to two or more undergraduates with one returning member that has previous knowledge of the system. The returning student will facilitate the knowledge transfer process, helping guide the other undergraduate students through updating this document.

Step 1: As a group review the previous revision of the VISD. If the current update is going to be placed into a new document as Revision 6, you will be reviewing the work in the Rev 5 folder. If you are placing new updates moving into Revision 7, you will be reviewing the Rev 6 folder on the Z drive, and so on.

During this review, the group should familiarize with the operation of assigned system. Ask yourself these three questions and fill them out on this form. When filling out information on here be sure to **save it as a separate file** so you do not overwrite this template. These questions may seem obvious; however, they will allow you to gain a deeper understanding of the system and the vehicle as a whole.

Figure 30:VISD update template part 1

Why do we have this system in place?

(This information will be detailed in the introduction section of the previous revisions. Be sure this information is copied over into the new Revision as well.)

[Insert Text Here]

How does the system operate?

(Keep in mind that the vehicle is reliant on many different controllers and processes. Try and use this question to delve deep into the operation of the vehicle. Updating this document is intended to assist in learning the functionality of the vehicle for new students while also keeping the vehicle documentation up to date. Interact with other groups and ask questions to help guide your learning process.)

[Insert Text Here]

What sub-team is responsible for the changes made to this system?

(For example, if we were implementing a new fuel tank the change would need to go through the PSI swimlane. In this swimlane, the CAD team will be the primary sub-team responsible for changes made to the fuel tank. This question will help your team know who you can interact with to gain information on changes that may have been made throughout the year.)

[Insert Text Here]

Step 2: Now that your group has been familiarized with the system and reviewed the previous documentation, the group leader should have an idea on what information needs to be updated. The group leader will now fill out the following table on what needs to be updated.

Section Number	Description of Update Needed	

Figure 31:VSD update template part 2

There is always a ranking amongst team members with any competition team, between team leadership, veterans, or new members. Regardless of the years and experience, each team member amongst a team can transfer knowledge back and forth to better create a broader knowledge for all team members. Research suggests that team member exchange enhances individual performance and team effectiveness because team members' relationships are more willing to assist other members and share information ideas and feedback within the working team [23]. Senior-level capstone projects or the EMC at WVU have a prime opportunity to harness the power of team member exchange. The WVU team takes this opportunity and benefits by grouping students in a manner that provides layers of member experience, multidisciplinary technical backgrounds, and cultural backgrounds to result in a beneficial collaboration that has a trickle effect from sub-team to swimlane to cross swimlane communication and lastly, resulting in an efficient and effective project that is competitive at all levels.

Typically, with a competitive engineering team, a form of mentoring is developed. Mentoring has served a central role in the development of science, technology, engineering, mathematics, and medical professionals [24]. When a mentorship naturally occurs between veteran and new team members on a competition-level team and within a senior capstone, it is typically for the benefit of the new member. At the industry level, mentorships are common with early-career programs for engineers. During an initial rotational program, the new engineers are assigned a veteran manager as a mentor to support the technical development and career support needed to be successful within the company. The process holds true for the EMC's approach to mentorship. Our new members are paired with veteran team members to fill in knowledge gaps and support younger engineers and their technical development and career opportunities. A new team member who begins to show enjoyment or skill in a particular area is set into a mentorship and a shadowing program. The team typically tries to have a student shadow a team member who is in charge of a sub-team or position to better understand the leadership and management strains required to coordinate and execute the required stories. Throughout the semester, students who

are shadowing the team member they will replace will slowly be given the responsibilities of the position to be able to all a smooth transition of control upon the departure of the veteran team member. The shadowing process best works for students who are going into the graduate student's role. The team has had great success with this mentorship process that allows a more direct way of educating one's replacement with methods and tools required for the task than a traditional written lesson learned document.

5.0 Schedule Management Tactics

Program schedule management encompasses the development maintenance and control and visual representation of other projects schedules [25]. A project schedule is developed during the planning phase of a project lifecycle [7]. Developing a schedule varies from company to company in the industry, but there are core similarities throughout. Whether the PM management tactic is agile or traditional at a high level, a schedule must be formed to consider the definition of activities, sequences, and durations of tasks that are developed to achieve the milestones of the project. The aspects of a schedule require a great amount of work and organization of information to develop an integrated master schedule [3]. A master schedule should contain the necessary milestones that reflect the total integrated plan for each project within a program. In the case of the EMC, the master schedule covers at a high level all the technical swimlanes of the program and the milestones for each swimlane, and the AVTC program itself. The scope of the program must be visually represented within the program's master schedule; however, the levels of detail may vary to accommodate the management plan established for the program and project levels. The details maintained within a program's master schedule must maintain consistent and equivalent levels of detail to allow proper tracking of progression through the discrete process of measurement management visibility and critical path identification and control.

Before the initial development of the master schedule, key factors must be considered that will impact the purpose and abilities for use by the program team. Those factors include:

- the levels of schedule insight and analysis capability
- the complexity and magnitude of the data required to maintain the schedule
- the tools used for scheduled development [26]

NASA categorizes programs within the agency into four categories. Those categories include:

- single project programs - only have one project that makes up the program
- tightly coupled projects program - Contains multiple projects that have common organizational and technical similarities and require a high degree of integration between projects that can result in inter-project interdependencies in the programs master schedule
- Loosely coupled programs - that contains projects with common organizational aspect and have minimal inter-project interdependencies in the program master schedule
- uncoupled programs - projects have independence from each other project within the program [25].

The program falls under the tightly coupled projects program for the EMC team or any engineering senior-level capstone competition team. Understanding this category helps a PM with the student competition understand how different swimlanes or sub-teams will have dependencies throughout the development of the competition academic year master's schedule.

Both in industry and with the EMC team, the master schedule is supported by an intermediate level of schedules and by the lowest level of detail schedules. The master schedule is the basis for planning and performance insight of all aspects of a project and reflects the current and baseline scheduled data [25]. A project schedule should remain flexible throughout the project's lifecycle in order to adjust for increased understanding of risk, development of valued benefits, and knowledge gained [3]. In order to have a beneficial Integrated Master Schedule (IMS), a team must be able to have traceability between a detailed schedule to higher-level intermittent schedules and the master schedule. The traceability is executed by defining the milestones throughout each schedule [25]. An example of how the process of detailed schedule to intermittent schedule to master schedule traceability works can be seen in Figure 32.

Figure 32 IMS traceability

For the EMC team, the master schedule is handled by the PM. The team leadership handles the intermediate schedule, including the PM, EM, and Technical swimlane leads. The detailed schedules are handled by sub-team members and supported by the technical swimlane leads. This allows the team to present more traditional material at a higher level but allows the adaptive methods of agile to be used for better performance with project sub-teams. The master schedule between two milestones for the academic Fall to Spring semester for the WVU EMC Year 3 team is in Figure 35 and Figure 36, and the entire (initial) Year 3 master schedule is in Appendix B. The best tool for the detailed schedule is the Kanban system in Microsoft Teams, which allows team leadership to pull data virtually as needed. The detailed system can benefit from either a whole team using the online tool or giving the responsibility of updating the board in Teams to one person whom better understands the online platform. In addition, it

does not hurt to have a physical system in place that allows members to quickly see the schedule and make adjustments as needed. Figure 33 is an example of the Kanban board in Microsoft Teams.

Figure 33: Detailed scheduling example

The tool used to maintain the WVU EMC intermediate schedule has varied between years, but both tools have their pros and cons. The two tools used are Microsoft Project and an Excel template that mimics Microsoft Project (*Vertex 42 Version Gantt Chart Template 4.0*). Microsoft Project is an industry-standard tool that unfortunately does cost money for the team at WVU to use (the product can be bought typically through a university software purchasing system and at a discounted rate) and is limited by the computers selected for the license purchased and can be lost due to IT updates. However, student leadership who work with this tool become more adjust for industry standards and have more features to use when developing the schedule. The excel file that mimics Project does cost many as well and is limited to the licensed computer; however, it can be cheaper and more accessible for team leads to understand and adapt for scheduling ease. Figure 34 shows the excel system used for intermediate scheduling.

Figure 34:Intermediate scheduling example

Both approaches are allowed by the WVU EMC team for two reasons. The first is that either system can generate data and be used in virtual screen sharing settings. Second, both tools' data can be used and transferred into the master schedule tool. Since the master schedule is used to update stakeholders and track the progress of the project at a higher level, the schedule needs to be able to be presented in a presentation mode for both meetings and competition events. As a result, the team used Office Timeline Pro. Multiple programs from the industry are available for use when generating a master schedule, and Project can be adjusted to represent a master schedule, but it has been found best not to use for PowerPoint limited presentations.

Figure 35: Part 1 example of initial IMS for Year 3

Figure 36: Part 2 example of initial IMS for Year 3

Based on the team's use of a hybrid management system that correlates with scheduling, both management methods bring two different factors. Critical paths and adaptive planning come into the practice of the competition team. The critical path practice allows the PM to better track the completion of the minimum valuable products (MVP) and the overall duration of completion for the program. The red bars in Figure 35 and Figure 36 represent the critical path for the team. While the adaptive planning process allows for change as new knowledge is gained that better suits the organization and scheduling methods of the sub-teams.

The critical path method is beneficial for understanding a series of activities that determine the longest possible duration for completing a project with the least amount of slack time. If an activity that is under

the critical path takes longer than planned, correction actions must be taken in relation to resources towards the issue or evaluation of the scope. The critical path can change as the project progresses. The critical path does not account for all critical activities within the project, and there can be the potential for more than one critical path within a project if the duration of the critical activity is equal [6] Therefore within a student competition team that is broken up into multiple swimlanes, there is a critical path for each technical swimlane.

Two methods can best discover the MVP. The first is understanding what phase the current competition is in, and the second is understanding the current scope the team has set for the project. In Year 3 of the EMC, the phase is focused on finishing integration and initial vehicle controls testing before year 4 starts, focusing on the refinement of systems and CAVs testing. In addition, the team scope was to have a functional vehicle at the competition that could compete in each competition event. Therefore, the MVP was Vehicle Functionality over CAVs functionality.

Simply put, the vehicle must function before additional features can be implemented and tested. Once the MVP is understood, a competition team has to track the epic, stories, and tasks that will at the end of the competition year provide the MVP and the team with the most points to map out the critical path(s) for the teams IMS schedule. Figure 37 shows the identification of the critical path considering the competition points involved and the two areas of focus in Year 3

Figure 37: Example how to identify Critical Path

In industry, levels of unpredictability in a competitive, high-paced global market system and the scope of a program or project are becoming difficult to define. Therefore, it is becoming essential to have a contextual framework to respond to changing needs of the environment. Adaptive planning defines a plan however acknowledges that priorities may change, and the plan will need to reflect with the updated knowledge. An emerging practice for project scheduling and industry is called on-demand scheduling used in conjuncture with the Kanban system.

In the simplest form, the Kanban system is a visual board method that allows sub-team members and managers to quickly understand and track task of a story from beginning to end. The system has 3 columns that go from To Do, Doing, and Done [11]. The team at WVU uses this method for sub-teams because this process of schedule control and tracking is easy for new members to adapt and apply in practice.

Environmental factors can influence the schedule management process. Factors from the industry that relate to senior-level capstone competition teams include organizational culture and structure, team resource availability, team skills, facility availability, organization standards [3][27]. However, even with similar environmental factors, there is still a difference of impact when managing a team and schedule. Team resource availability refers to the labor force available to complete milestones throughout the

lifecycle of the project. With student competition teams, the number of students on the team can vary between semesters, especially if the team comprises only volunteers. The EMC team is mainly established through the process of courses related to the program.

Therefore, sustainability is still a concern but is mitigated by the majority of the students not being volunteers. However, the concern of sustainability through the pursuit of effective recruitment and performance is of the most utmost importance. The number of available hours a student can incorporate into their schedule for the project is of concern. The EMC team is scheduled by course registration to meet twice a week for a total of 6 hours. As a result of this, to mitigate the effect of environmental factors, students submit their potential for availability upon placement into a sub-team in order for technical leads to plan accordingly the duration required to complete a task. On the other hand, this also helps mitigate the issue of facility availability. Having students submit their flexibility allows technical swimlane leads to plan alternative meeting times for different sub-teams spreading throughout the week outside of class time. This has led to better interaction between graduate students leading the swimlane and undergraduate students of sub team completing a task on time with better understanding of the project as a whole, improved project ownership amongst swimlane sub teams, and better team member evaluations. The building of remote work it's also a considerable benefit in decreasing facility availability factors. Organization standards and team skills are two factors that are resolved by how the team structures team member exchange within a sub-team and the training produced for new members.

The tactics and methods used by the EMC team for schedule management of swimlanes can be seen in Appendix B covering the team's execution plan for Year 3.

6.0 Risk management

The number of risks and diversification of risk types in a senior-level capstone project increase simultaneously as the project ages and develops. The building for proper risk management and assessment is critical to the success of a project by preventing the costly mistakes of potential avoidable failures and mitigating the impact of when a foreseen risk occurs.

6.1 Pugh Charts

Throughout the lifecycle of a project, a decision process must be made at some point. In order to mitigate the risk of a poor decision, companies practice numerous multicriteria decision-making ideologies. One method, in particular, that is practical and useful for a senior-level competition capstone team and was used by the EMC team at WVU is the Pugh selection process. In a situation in which a decision has to be made that involves a large number of different criteria and alternatives, it can be difficult or challenging without a standard process and determining the correct process over alternatives. [28]. The Pugh concepts selection seeks to enhance the strong attributes and eliminate or improve the weakest attributes of initial concepts in the decision-making process. As a result, it leads to improved concepts and often develops new concepts during execution. Initially, the general focus of Pugh's process is about concept creation and improvement rather than the selection of the correct choice. [29] The generation of a Pugh matrix requires making only simple comparisons by three different categories. Those three categories include worse, same, or better. Because the process is simplistic, it provides ease in the selection process when detailed information is limited. It benefits new team members and a new project making rational choices with limited ability of training for a competition project.

Before the execution of the Pugh matrix, one must identify the evaluation criteria for each concept and determine the datum in which all other alternatives will be compared. Once this is done, the decision-

maker can begin the process of comparing the alternatives against the data within the decision matrix. The decision-maker begins the process of comparing the established criteria of the alternatives against the datum using only the 3 categories. Once all the alternatives haven't been compared against the datum, the decision-maker needs to sum up all the positive negatives and same marks for each alternative and determine if an alternative is better than the datum. If an alternative is deemed better, it now becomes the datum. The process begins once again until the datum remains the datum after an evaluation. All alternative concepts are of weaker or equal standing. A template example of an industry-level Pugh matrix can be seen in Figure 38. [30]

Criteria

Concepts

Put +, -, or S in each cell to represent if concept is SIGNIFICANTLY better, worse, or same as the datum concept.

Work this way →

Concepts

Criteria

Base Design

1

2

3

4

5

6

7

8

9

10

11

Resiliance to personnel changes

Amount of "Invention" required

Compatibility with provided hardware

Range of Possible Solutions

Modeling Fidelity

Modeling Complexity

Specialized Technical Knowledge

Schedule

Cost

D
A
T
U
M

Baseline

Evaluations

Comparison w/
Baseline

Σ+

Σ-

ΣS

0

0

0

0

0

0

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Figure 38:Pugh matrix template [30]

Regardless of industry, the template works for a senior-level capstone competition team. In Figure 39 an example in which the EMC team at WVU used the Pew selection concept in order to generate a Pugh matrix to determine the correct electric motor for the team's vehicle architecture.

Concepts		
Criteria	Magna eAWD	Magna eAWD w/Denso P0
Power	65 kW	S
Input Speed	2500 rpm	S
Output Torque	200 Nm	S
Inverter	Yes	S
Weight	50.6 kg	S
Ease of integration	Semi-Difficult	-
Fuel Economy when paired with 1.5L (Combined City & Highway)	30.34	+
Fuel Economy when paired with 2.0L (Combined City & Highway)	29.53	+
Fuel Economy when paired with 2.5L (Combined City & Highway)	29.21	+
Wavier Needed	No	S
Complexity of Controls	Semi-Difficult	-
Project Risk	baseline	-
Vehicle Safety Consideration	Datum	-
$\sum +$		
$\sum -$		
$\sum S$		
		1
		4
		6

Figure 39:Final motor Pugh matrix

6.2 Failures Modes and Effects Analysis (FMEA)

Risk assessment is a preventive analysis process for a product design or production and integration process [31]. Failures in design and production are costly when the process is not reliable. The longer a problem takes to detect, the more costly the problem becomes to the health of a project [32]. One method in risk assessment is failure modes and effects analysis (FMEA). FMEA is a structured process in which a project is examined in detail and evaluates the potential failure of a product or process and its effect's identity actions that can be implemented to eliminate or reduce the occurrence of the potential failure all while documenting the process [33]. FMEA should be performed early within the project lifecycle to help guide decisions concerning risk, and there is no benefit of performing an FMEA after the fact a risk has occurred [34]. The overall arching goal of an FMEA is to identify potential problems before one occurs to maintain reliability and systematically prioritize the product's risk. The process of performing an FMEA is beneficial in the industry in reducing the impact of risk and within a senior-level capstone project for a competition team. Regardless of what type of competition, it is always beneficial and less costly if a potential failure within a competition product can be mitigated or evaluated prior to the failure occurring. It is best practice to perform both project level and technical design FMEA to understand more risk involved with a project and product.

There are four common problems when trying to perform and FMEA and maintain the effectiveness for the project. An FMEA is only beneficial if the process is done correctly, and all team members and stakeholders support the method, and the development of the FMEA [33]. Maximum benefits are only possible if the culture of the team in the early stages of product or project development adapts the process of thinking of ways of product or project can fail and how it can improve. For a competition team, this correlates to students performing an FMEA for the competition product to understand and try to mitigate the risks and not see it as a higher authority or standard requirement the team practices. The

second common problem is adopting a form mentality. The second common problem comes down to not cohesively understanding of how to perform an FMEA properly, and it can be seen in the lack of a clear understanding between cause mode and effect in the development process of risk [33]. The EMC team at WVU are not professionals; however, the team leadership prevented this problem by having more than one team leadership member perform an individual FMEA. As risks were discovered to be the same during our review process, the cause mode and effect written was compared and rewritten, and agreements with all leadership were present during the development of the FMEA. After the initial FMEA, the process is repeated each quarter of the academic year with different team members who are willing to learn the process. The method allows new members to learn about FMEAs and a new set of eyes to evaluate the design and project risk.

The third common problem is simply blaming manufacturing for all failures [33]. The third problem can be resolved through training and the ability of the performer executing the FMEA to maintain a non-biased approach.

The basic elements of this risk assessment process come down to four key areas. Those four key areas include:

- preparation and functional analysis
- failure analysis
- risk evaluation
- risk mitigation

Preparation and functional analysis, and failure analysis cover multiple categories that establish a foundation of an FMEA template. Those categories include:

- project element
- project objective and or deliverables
- potential object failure
- potential effects of failure
- potential cause of failure
- current measures to prevent failure
- current measures to detect cause and time to take corrective action

In Table 2 a breakdown of what each category represents towards a project can be seen. In addition, suggestions on how to communicate within those categories can be observed, along with a general competition team example [29].

Table 2: Risk assessment elements

Basic Element	Categories	Description	Competition level example
Preparation and functional analysis	Project Element	Failures will be related to the role of this Project Element/interface in the deliverable to meet its intended function or criteria	Rule management team
	Project Objective / Deliverable	Objective/Deliverable should be expressed in a verb-noun format	Architecture selection report
Failure analysis	Potential Objective Failure	Failure to produce the intended project objective/deliverable. Can be total absence, partial, or intermittent, degradation, or unintended output	Report submitted in incorrect format
	Potential Effects of Failure	What happens if the potential failure mode actually occurs and the impact to the stakeholders.	loss of competition points for incorrect format of submission
	Potential Cause of Failure	How the failure could occur and causes must be rooted in the project element activities	Format requirements were not understood or communicated correctly

	Current Measures to Prevent Failure	What measures (controls) are in place to prevent the failure mode or the cause from occurring, or reduce its rate of occurrence during product development	The rule team must maintain veteran team members from past competition for better understanding of rules
	Current Measures to Detect Cause in time to take Corrective action	What measures are in place to detect the cause of failure before significantly affecting project cost, schedule or deliverable quality	All rule interpretations will be reviewed with the program administration to confirm correctness.

Risk evaluation comes down to determining each risk's severity, occurrence, and detection value using a scale system and the method of representation.

- Severity is the measured effect of a failure mode on the Impact the failure has on the system when it occurs
- Occurrence is the rate or probability of a failure mode occurring
- Detection is a measure of the potential chance in detecting a failure [35]

Developing the Severity, Occurrence and Detection (SOD) scales can be difficult for student competition teams. In industry, the SOD scale varies between project and design. For the project SOD scale, each category should consider the effects on the quality triangle, while for the design SOD scale, the categories should focus on the effects the product failure (risk) has on the stakeholder. For student competition teams, developing a project SOD scale can be the most difficult; however, the design scale teams can pull ideas or mimic the SOD scales from the Automotive Industry Action Group (AIAG). Figure 40, Figure41, and Figure 42 are examples of the AIAG scale for severity, occurrence, and detection from General Motors

training. When one is determining the ranking of each category of the SOD scale, the person performing the ranking should follow the following suggestions:

- Severity
 - Do not consider the likelihood of failure or the ability to detect it [29]
 - The severity of the risk only changes when the stakeholder level failure effects change
 - Always rate each risk slash failure individually while maintaining consideration of the highest severity
- Occurrence
 - consider the historical performance of similar designs or products
 - determine the occurrence without regard to severity or detection but consider the identified prevention measures of the effect
 - The currents cannot change without changing the prevention measures to decrease the chance of the failure or subsequently the failure mode from happening [29]
- Detection
 - take into consideration both the rigor required for the detection measure and time
 - Consider the effectiveness of the detection
 - identify all relative measures and rank each individually and the lowest ranking, therefore, is the overall detection ranking [29]

Effect	Criteria: Severity of Effect on Product (Customer Effect)		Rank	
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.		10	
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.		9	
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation)		8	
	Degradation of primary function (vehicle operable, but at reduced level of performance)		7	
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort / convenience functions inoperable)		6	
	Degradation of secondary function (vehicle operable, but comfort / convenience functions at reduced level of performance)		5	
Annoyance	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by most customers (> 75%)		4	
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by many customers (50%)		3	
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by discriminating customers (< 25%)		2	
No effect	No discernible effect.		1	

Figure 40:AIAG Severity Scale [29]

Rating	Probability of Failure
10	Very High: New technology/new design with no history
9	High: Failure is inevitable with new design, new application, or change in duty cycle/operating conditions
8	High: Failure is likely with new design, new application, or change in duty cycle/operating conditions
7	High: Failure is uncertain with new design, new application, or change in duty cycle/operating conditions
6	Moderate: Frequent failures associated with similar designs or in design simulation and testing
5	Moderate: Occasional failures associated with similar designs or in design simulation and testing.
4	Moderate: Isolated failures associated with similar design or in design simulation and testing.
3	Low: Only isolated failures associated with almost identical design or in design simulation and testing.
2	Low: No observed failures associated with almost identical design or in design simulation and testing
1	Very Low: Failure is eliminated through preventative control

Figure 41:AIAG Occurrence Scale [29]

DETECTION SCALES

Opportunity for Detection	Criteria: Likelihood of Detection by Design Control	Rank
No detection opportunity	No current design control; Cannot detect or is not analyzed.	10
Not likely to detect at any stage	Design analysis/detection controls have a weak detection capability; Virtual Analysis (e.g., CAE, FEA, etc.) is <u>not correlated</u> to expected actual operating conditions.	9
<u>Late in the Project (Little Recovery Time)</u>	Post Design Freeze and prior to launch Product verification/validation after design freeze and prior to launch with <u>pass/fail</u> testing (Subsystem or system testing with acceptance criteria such as ride and handling, shipping evaluation, etc.).	8
	Product verification/validation after design freeze and prior to launch with <u>test to failure</u> testing (Subsystem or system testing until failure occurs, testing of system interactions, etc.).	7
	Product verification/validation after design freeze and prior to launch with <u>degradation</u> testing (Subsystem or system testing after durability test, e.g., function check).	6
<u>Early in the Project (Time to Recover)</u>	Prior to Design Freeze Product validation (reliability testing, development or validation tests) prior to design freeze using <u>pass/fail</u> testing (e.g., acceptance criteria for performance, function checks, etc.).	5
	Product validation (reliability testing, development or validation tests) prior to design freeze using <u>test to failure</u> (e.g., until leaks, yields, cracks, etc.).	4
	Product validation (reliability testing, development or validation tests) prior to design freeze using <u>degradation</u> testing (e.g., data trends, before/after values, etc.).	3
Virtual Analysis - Correlated	Design analysis/detection controls have a strong detection capability. Virtual analysis (e.g., CAE, FEA, etc.) is <u>highly correlated</u> with actual or expected operating conditions prior to design freeze.	2
Detection not applicable; Failure Prevention	Failure cause or failure mode can not occur because it is fully prevented through design solutions (e.g., proven design standard, best practice or common material, etc.).	1

Figure 42:AIAG Detection Scale [29]

Below in Figure 43, Figure 44, and Figure 45, the WVU EMC teams project level SOD scales can be seen. These scales relate to the quality triangle due to project-level considerations. In addition, student design SOD skills may change or update throughout the lifecycle of the project however should be reflected and tracked of the risk or failure. Updating the SOD scale simply can lower or increase where the risk or failure sits in priority 2 implement mitigation tactics to reduce the risk.

Severity Scale									
1	2	3	4	5	6	7	8	9	10
No Impact	Minor	Low	Moderate -	Moderate	Moderate +	High -	High	High +	Complete Collapse
Does not impact the Team	Minor impact on subteam with effects that can be mitigated with effort from single team member. No effect on cost, scope or time for the project	Minor impact on subteam with effects that can be mitigated with effort from few team members. No effect on cost, scope or time for the project	Minor impact on team leadership with effects that can be mitigated with effort from few team members. No effect on cost, scope or time for the project	Moderate impact on full team with effects that can be mitigated with moderate effort from multiple team members. No effect on cost, or scope of the project. However the timeline of team progress for the project might be affected.	Minor impact on full team with effects that can be mitigated with effort from entire team. No effect on scope of the project. However the timeline of team progress and the budget for the project might be affected.	Significant impact on team leadership with effects that can be mitigated with effort from few team members. The scope of the project and the teams progress timeline will be affected. However, the budget for the project might be affected.	Significant impact on full team with effects that can be mitigated with effort from multiple team members. The scope of the project, the teams progress timeline and the budget will be highly affected	Significant impact on full team with effects that can be mitigated with effort from entire team members. The scope of the project, the teams progress timeline and the budget will be highly affected	Significant impact on full team with effects that can not be mitigated. The overall cost, scope and the timeline of progress are completely reshaped.
No affect on: • Scope • Budget • Time				<ul style="list-style-type: none"> • The Scope, Time, and Budget of the WVU EMC team is effect. • The effect on the triangle increase with severity 					

Figure 43:WVU EMC project level severity scale

Occurrence Scale									
1	2	3	4	5	6	7	8	9	10
Does not Occur	Remote	Unlikely	Uncommon	Occasional	Likely	Common	Often	Consistent	Inevitable
Event does not occur	Event may occur once throughout full competition	Event may occur once during a competition year	Event may occur once during a single semester	Event may occur more than once during a single semester	Event may occur monthly	Event may occur 2-3 times a month	Event may occur weekly	Event may occur on a daily basis	Event will occur daily
The WVU EMC Team consider this section to <div>Low Likelihood</div>				The WVU EMC Team consider this section to <div>Moderate Likelihood</div>			The WVU EMC Team consider this section to <div>High Likelihood</div>		

Figure 44:WVU EMC project level occurrence scale

Detection Scale									
1 Certain Detection	2 Obvious	3 Easy Detection	4 Probable Detection	5 Reliable Detection	6 Possible Detection	7 Difficult Detection	8 Unreliable Detection	9 Improbable Detection	10 Undetectable
Event can not occur without being detected	Event can be detected by overall team leadership	Event can be detected by any team member that can report to overall team leadership in a single day	Event can be detected by subteam leadership and that can report to overall team leadership within a day	Event can be detected by subteam members that can report up the hierarchy taking no more than a week	Event can be detected by with cross communication between subteams to report up the hierarchy taking no more than a week	Event can only be detected by advanced leadership oversight of overall team leadership taking no more than a week	Event can only be detected by advanced oversight of subteam leadership taking no more than two weeks	Event can only be detected by advanced oversight of individual team members, taking up to two weeks	Event can not be detected
Simple Detection				Moderate Detection			Challenging Detection		

Figure 45: WVU EMC project level detection scale

As for risk mitigation which covers the category of risk reduction actions is a process within its name. To improve the ranking of occurrence team should consider changing a project element and or interactions related to the failure or risk. To improve detection, the team should consider how the methods used to detect risk and failures could be improved. The severity of risk or failure can be mitigated potentially through the process of requirements management considering verification and validation an injunction with design verification plans.

The WVU EMC team FMEA is based on these categories. Not every FMEA is exactly generated the same way within an industry or senior competition level team. However, all stem from these same vital categories. Figure 46 highlights the features of the EMC WVU team FMEA template.

West Virginia University EcoCAR Mobility Challenge Year 2 Failure Mode and Effects Analysis
Risk #	Risk	Affected Milestone	S	O	D	RPN	Effect	Treatment	Who/What Triggers the Risk Treatment
1	Delay in making critical design decisions due to the delay in availability of critical information	Subsystem Design Complete	8	6	7	336	Re-evaluation of the teams scope based on shorted timeline and the cost of the information	Improve - Create internal deadlines based on sub-team milestones to ensure team members have necessary design information to complete assigned tasks.	Project Manager - Notification from Sub-team Leads that they are not able to complete their assignments without additional information
2	Failure to reach the Learning curve of new team members	Baseline Testing Complete, Subsystem Design Complete	8	8	5	320	Reduction in the teams scope due to the loss of the team velocity and technical expertise	Improve - Conduct training programs and provide clear documentation of previous design decisions to give incoming team members a clear understanding of team accomplishments and procedures	Engineering Manager - Make new team members aware of the availability of training programs if they are not comfortable using the tools required to complete their tasks

Figure 46: WVU EMC FMEA template

6.2.1 RPN and Risk Charts

Just like industry-level engineering fields, universities are not spared the problem related to risk management. It is a common debate on how to manage risk for a lab space or project properly. There are numerous solutions to risk management. One of the most traditional methods is fulfilled by calculating the risk priority number or RPN, which is furthermore the basis of risk ranking and prioritization to help managers make decisions efficiently [36]. RPN is calculated by the product between the probability of occurrence, the severity of consequences, and the detection of the risk. Below in equation 1 is the mathematical equation to calculate the RPN value of project risk. RPN factors are all based on a scale from 1 to 10, with ten representing the highest severity, the highest probability of occurrence, and lowest probability of detection, respectively; therefore, the range with RPN is from 1 to 1000, with one being a low priority and 1000 being a high priority.

Equation 1: RPN Calculation

$$RPN = \text{Severity}(S) * \text{Occurrence}(O) * \text{Detection}(D)$$

RPN is a widely used system at the automotive and other engineering industry levels and does have advantages. RPN is easy to understand and use because its simplicity is well documented with adequate training for the system and a systematic approach for decision-making [26]. Unfortunately, the technique has some drawbacks and its practice. The product of the RPN factors produced some holes in the scale in which 88% of the range is empty; the RPN numbers are duplicated in other words, different combinations of ranking factors produce the same RPN value, and only 120 out of 1000 numbers generated are unique. In addition, there is a high sensitivity to small changes in factor values caused by the effect of multiplication of the RPN factors [36]. Therefore, the WVU EMC team has gone a step further by using risk charts to visually understand which risks have a more critical impact based on their relative RPN value and the risk appetite of the team. By using a visual chart system to represent the danger of a risk the team match the project's risk appetite to the risk, and effectively communicate protentional risk to new or unfamiliar stakeholders about the risks the team needs to mitigate and are tracking

Generating risk graphs of occurrence and detection versus severity, as shown in Figure 21. The risk matrix is used to assess the level of risk with two separate graphs, one that compares occurrence with severity and one that compares detection with severity. These matrices utilize a red, yellow, and green color scheme to illustrate the level of risk being evaluated or in other words, the risk appetite of the project. If a risk falls within the green section of the matrix, it is likely to just be accepted. If the risk falls in the yellow section, the risk might not be accepted but is more likely to be monitored throughout the project. Finally, if the risk falls within the red section of the matrix, corrective action should likely be taken to mitigate, transfer or avoid the risk.

Additionally, risks falling in the red section of the matrix should be monitored more frequently on a schedule decided upon by the Project Manager and the Systems Safety Lead, if applicable. Examples of both risk matrices are illustrated in Figure 47 and are used in conjunction with RPN to classify and

prioritize the risks documented. It should be noted that new risks can be added to the risk management plan as they arise. Conversely, as risks currently in the red and yellow zones are monitored and mitigated, they can potentially be moved to the green zone and essentially accepted. On the project level, the principal factors to consider when determining the risk appetite of the team are impacts on the time, scope, and budget of the team. Considering the student roster, technical experience, facilities, and budget available to the team, WVU EcoCAR is willing to accept more risk in the selected architectures to attain more educational benefits from their work. The team leadership feels confident that this exposure to additional risk in the design process will result in a vehicle that sets the standard for the competition and aids in the education of the students. By appropriately planning and establishing adequate contingency plans, the team will balance the risks and benefits of the selected architectures.

Figure 47: Occurrence, Detection, and Severity risk charts

Analyzing these plots independently allows a team to recognize risks that will significantly impact the project, capstone or team more accurately. This analysis allows a team to effectively recognize and plan for potential threats to the project's success. By identifying these risks before they happen, a team can assign appropriate proactive treatments and generate contingency plans to minimize each risk's impact. The process of developing proactive treatments and contingency plans is more important now than ever

as the team is operating during a global pandemic and most senior level capstones are linked to competitions that represent a university and the work skills of the young engineers coming from these institutes. After completing the initial FMEA and analyzing the RPN values supplemented with the risk charts generated from SOD scale, a team is able to identify the current top-level risks to a project for both the Fall and Spring semester of an academic year.

The team's risk analysis and management process allows any senior-level capstone team to manage risk for all activities, including technical program and schedule. By understanding how the implied risk management process is effective will allow future projects following the current WVU EMC team to fine-tune the system for each new project in turn. Based on the results from the teams who prioritized risk, risk assessment and management are critical for the success of teams. In order to complete a task in a safe and timely manner, teams should adopt an RPN system into their program if not already doing so, as well as using risk matrices.

6.3 Risk Treatments

Using the top risks identified in the FMEA, the PM can establish proactive risk mitigation and avoidance measures. For example, Table 3 shows each of WVU EMC Year 3 top Fall semester risks with each risk associated treatment. Emphasis is placed on the proactive aspect of these actions, as a genuinely effective risk treatment strategy treats risks before they occur. As the Fall semester progresses and the FMEA is re-evaluated during the next quarter, the planning for proactive treatments for the Spring semester will begin since the information is more relative and accurate. The effectiveness of the proactive treatments can then be seen by the timeline that is generated by re-evaluating the FMEA and the risk charts every quarter.

Table 3: Top Year 3 semester risk

Risk #	<u>Top Fall Risk</u>	<u>Top Spring Risk</u>
1	Delay in making critical decisions due to the delay in the availability of critical information	Delay in making critical indecisions due to the delay in the availability of critical information (University COVID restrictions, sponsor donated component information, and competition rules)
2	Loss of team members from COVID 19 policies	Loss of team members from COVID 19 policies
3	Failure to reach the learning curve of new team members	Major sponsor component breaks
4	Major sponsor component breaks	Poor design quality that results in the loss of competition points

For the project's top risks, the team has established a contingency plan to be prepared for the worst risk if they come to life even after the proactive treatment has been applied. The team's contingency plans are a proactive strategy to be able to continue operating if or when a risk impacts the team's quality triangle (Time, Scope, Cost). In order for these contingency plans to be affected, each Tier 1 milestone completion requires a review session held by the Project Manager. The review session involves all team leads to ensure no amendments are needed, and everyone in a leading position knows how to handle the risk if or when it accrues.

Table 4:Top risk contingency plans

Risk	Contingency Plans:
Delay in making critical decisions due to the delay in the availability of critical information	Sub-teams will be assigned other tasks in order to overcome the delay based on team defined deadlines. The plan will be led by the Project Manager and team leadership.
Loss of team members from COVID19 policies	The team will operate as a hybrid system if remaining team members are allowed to be physically in labs or the garage while having students shift workloads as needed, not to delay the scope timeline.
Failure to reach the learning curve of newteam members	Team leads will assign sub-teams with training programs from previous documentation to give new team members a clearer understanding of the tasks at hand while transferring critical work to more veteran team members who have the available time for a larger workload.
Major sponsor component breaks	Sub-teams will be assigned to other tasks to maximize efficiency elsewhere. While the team leads analyze the component break, the project manager will begin fast-tracking the procurement process and re-evaluate the scope and timeline with the engineering manager's assistance.

7.0 Management of Change and Design

For any project, an initial plan that encompasses the scope budget and timeline is always certain, but how one manages the changes throughout the project's life span is critical to the project's overall success [37]. Change management skills are crucial not only in industry practices but also in capstone projects and the daily work ideology of students on any capstone competition team. Changes take many forms within a project. Sometimes a change is related to the significant shift in working locations, such as the case with COVID-19 or the rules and regulations within a student competition project.

In contrast, the change is much more minor in day-to-day operations as minor roadblocks and challenges develop for students on a sub team of a project. These two forms of change are referred to in the industry as organic change and step change. Organic change is a change on a small scale that feels organic in the sense of small incremental changes. A step change is simply a dramatic and transformational change within a project.

Figure 48: Change category [37]

Based on the understanding that both forms of change will exist within a project, the WVU EMC team has set a standard roadmap in how change is to be managed within the process of the competition project. It is important to note that each year of the competition has a primary focus during the four years of the

competition. In Year 1 of the competition, the primary goal is conceptual design and architecture selection. The main goal is vehicle integration in Year 2, followed by Year 3 of vehicle testing and Year 4 of refinement. As the years progress further, any design change in the operation of a system will change from organic to step for each swimlane as the severity and disruption towards the overall success of a project. At the industry level, changes can be classified typically within two overall branching categories. The first is a change with origins from within the organization without the influence of an external stakeholder and the second is a change brought on by an external stakeholder

These two categories of change within industry can be visually represented by Figure 49 in a generic organizational flowchart.

Figure 49:Organizational flow chart of change inputs [2]

These change categories apply to the EMC competition project or any competition capstone project. The customer or fund changes would be equivalent to any competition form of organizers, sponsors, or managers. The contractor or funded changes would, in turn, be changes desired and developed from within the competition team, whether it stems from an individual sub-team, swimlane, or overall organization management and leadership of the competition team.

The WVU EMC team manages, monitors, and tracks the two change categories using three main approaches. The first is a standard change management process for when an issue arises and the resolution of the issues that fall under the category of funded changes. The other categories are requirements management and version control, which are critical to achieving a competition-ready product.

7.1 Standard Change Management Process

The effects of a change brought on by refinement or project roadblocks can directly affect the sub team's product and have a chain reaction that can affect other aspects of the project. These effects can be beneficial or negative towards the direct or indirect origin of the change, but will always revolve around the project's scope, time, and budget.

As a result, it is critical to the success of a project to have a standard in how to deal with internal change, whether it stems from roadblocks or proposed adjustments. These changes in the industry need to be considered and approved by a select key member of the project organization before the change can be implanted. The precaution used in industry around engineering design change can predict the overall effects as reliably as possible. Within a company, the key members of a change committee will include at least two key members. The first will be a design authority, and the other will be the inspecting authority. [2].

Therefore, the WVU team has adapted a change committee into various leadership levels based on the severity of the change. The adaption of managing change within the project is hinging on trusting and filling the leadership roles amongst the team at every level. This is not a blanket statement that the trust or opinion falls to older members of a project but to the role of sub-team lead, followed by the EM, PM, and faculty advisor in order. To better visually understand the standard process developed by the WVU team for the EMC in Figure 50 the overarching template of the team's EMC management process for change.

Figure 50: EMC change management process

The team uses a 5-tier level of how change within a project should be handled. If all management tools are being executed correctly, tier 4 and tier 5 will never be looped into an active change management system. WVU EMC team has only ever gone to a tier 3 level for change management. In Table 5 the level of change within the project, how it is handled, and the effects on the project are described.

Table 5: Levels of change management

Level of Change	Level Definer	Change Criteria	Authorized Approvers	Approval Process
1 – Simple Modification	Sub-Team Lead	No impact on project scope, documentation, schedule, or budget. No impacts except on individual work	Subteam lead	Verbal Authorization
2 – Minor Change	EM	No impact on project scope, schedule, or budget. Impacts to occur outside individual work but within sub-team. Impacts on sub-team documentation	EM and Subteam lead	Change Request Form
3 – Moderate Change	EM	Minor impact on project scope, schedule, or budget. Impacts do occur outside sub-team work but within engineering team. Impacts on engineering team documentation and/or system safety plan.	Team Leadership	Change Request Form, Change Management Meeting
4 – Major Change	EM	Significant impact on project scope, schedule, or budget. Impacts do occur outside engineering team and/or system safety plan. Irreversible change.	Team Leadership	Change Request Form, Change Management Meeting
5 – Critical Change	EM	Organizers need to be notified. Change affects the overall program safety and/or adherence to the Good Faith Agreement. Change affects team vehicle development process.	University Administrator or Advisory Board and/or Organizers	Change Request Form, Change Management Meeting, potential for Administrative Meeting

7.2 Change Management Review

Once a change has reached the tier in which leadership needs to meet to review a specific change, a change design review begins. Within the industry, the committee change board will have a formal process requiring written submission and a presentation report of the desired correction based on the engineering team. It is not uncommon for the committee to have pre-established guidelines for material required within change request forms [38]

To ensure that all requests are adequately controlled and progressed, the formal change management form should be written so that the original change requestor answers all the questions that the change committee board will ask per change management review meeting. Once the document has been submitted, a key individual involved in the change management process based on industry standards and practices should have the following duties:

- Register each change request and allocate a tracking number system.
- Officially file a copy of the form and to the organization's archives and distribute it amongst the change committee board.
- Follow up upon the closure of the meeting to ensure that the author's changes are carried out and that all additional documentation affected by the change are resubmitted for later review and update.
- Confirm that all parties, the requestor of change, and the change committee board are in agreement with the outcome of the meeting. [2]

Three of the four key aspects that industry is set to place for the change management process may seem common sense. However, the 4th and the first one registering each change request now to the tracking number system is a critical aspect of the change management process. Integration of a tracking number

system for the submission of change request documents provides records for all stages. Whether it is rejection or approval or the full documentation and implementations of the change, a record of changing is towards the budget if appropriate. The most important is the ability to track back or the traceability of the original design compared to the modern changed product. The practice allows for future management changes, knowledge transfer, and a better understanding of a product for the engineering team, current and new.

The WVU EMC team adapted this practice into our formal change management system. The team established a simple serial number of three digits at the end of the submitted change management form. Therefore, the initial and very first change management form submitted during the EMC competition ever started with 001, followed by the next submission, which intended would have been 002 and thus fourth. The serial number system has allowed the team to provide traceability to changes that have occurred once or multiple times for a vehicle system or component and has been beneficial in knowledge transfer for the team's sustainability throughout the years of this competition. These documents are archived within the team's designated storage server and open for traceability using the team's Microsoft Teams account for easy access for all team members. An example of the serial numbering system can be seen and Figure 51. In addition, in Figure 52, one can see how the change management forms are distributed and copied for the organization and the process in which it is confirmed and made clear to all party members of the team involved in the outcome of the change request form.

PSI Sub-team > Change Management > Approved CM Forms
Name ▾	Modified ▾	Modified By ▾
002-LSHS CAN Converter Integration.docx	May 13	William Paul Cawth...
003-Cohda Wireless Change Document.docx	May 5	Hasan J M A Sadeq
008- Rear Electrical Center Redesign.docx	May 4	Dhary A A A Omar
013-Logger Shelf.docx	February 19	Aaron Mull
014-DB9 wire management box.docx	February 19	Aaron Mull	

Figure 51:Serial numbering system

PSI Sub-team > Change Management
Name ▾	Modified ▾	Modified By ▾
Approved CM Forms	November 13, 2020	Aaron Mull
Closed CM Forms	January 28	Aaron Mull
CM Submissions	November 13, 2020	Aaron Mull
CM Working Folder	January 27	Aaron Mull
Change Request Form Template.dotx	January 27	Aaron Mull
Change Request Form.docx	February 22	Dylan Collis
New Change Management Process.docx	January 27	Aaron Mull	

Figure 52:Distrubution of change management material

The same industry standard should be applied at a student competition level in generating a team change request form and presentation method. The WVU EMC team generated our own formal change request form based on industry methods highlighting the importance of basic design review material and configuration management.

Configuration management is the process in which it concentrates on managing technology by identifying and controlling the functional and physical design characteristics of the products. This management practice identifies configuration requirements, controls the changes of the product records, and reports the changes to the products in order to verify conformance to industry requirements [38].

Entry criteria for a design review process within the industry should include not only the updates but previous baseline design and framework of the product in our review these include the task work required for the product, the relationship to the requirements traceability matrix specifications of the product, and items describing the design prior to the start of the meeting the committee chairman should be able to submit an agenda with the specified items they are under review. The design documentation involved with this meeting will be a reflection upon the requirements traceability matrix that links all the design requirements back to the product [39].

Based on industry-standard design documentation should thoroughly cover all of the following information:

- Design description
- Models in simulation reports
- Theoretical math calculations
- Requirements and specifications
- Interface requirements and specifications
- CAD generated drawings with parts list, if applicable
- Software development folders, if applicable
- Test plans and test result documents
- Training plan in manuals

- Risk assessments and mitigation plans

As for the design review agenda from the preliminary design, the review highlights the following requirements for any design review meeting

REVIEW TOPIC	REQUIRED OUTPUTS
Project Definition <ul style="list-style-type: none"> • Customer changes to the program since last review (if any) 	Program/Team Charter Program Requirements/Deliverables Budget & Schedule Changes
Concept Approach Changes Since Last Review (if any) <ul style="list-style-type: none"> • Changes to customer requirements & specifications since last review (if any) • Specification issues (if any) • Changes to system architecture and concept approach for the system (if any) • Changes to product concept design (if any) 	Product Specifications Concept Design
Product Design <ul style="list-style-type: none"> • Review of design concept for each product • Product structure walk-through • Schematic and functional design review (if applicable) • Assembly drawing/model review • Component drawing/model review • Part specifications, significant characteristics, and tolerances • Design for manufacturability, design for assembly, and mistake-proofing review • Design and drawing/modeling standards compliance • Technical issues and risks 	Component Drawings/CAD Models Assembly Drawings/CAD Models Schematic/Net List PCB Layout Product Bill of Material

(continued)

Figure 53: Design review agenda Part 1 [39]

REVIEW TOPIC	REQUIRED OUTPUTS
Product Testing and Verification <ul style="list-style-type: none"> • Test requirements and plan • Test results • Issues in meeting specifications 	Test Requirements Test Plan Test Results
Preliminary Process Design <ul style="list-style-type: none"> • Process approach and operation flow • Feedback from engineering model build • Tooling, fixture, production equipment, and test equipment requirements • Tooling and fixture design • Tooling, fixture, production equipment, and test equipment cost estimates/quotes 	Build Report Process Flow Diagram Tooling and Fixture Design Tooling & Fixture Cost Estimates
Quality Planning <ul style="list-style-type: none"> • Quality issues on similar components and countermeasures taken • Design FMEA, reliability issues, and mitigation steps • Process FMEA, reliability issues, and mitigation steps • Control Plan for design validation build 	Design FMEA Process FMEA Control Plan
Supplier Sourcing and Status <ul style="list-style-type: none"> • Supplier selection and capability for each component • Production, capability, quality, lead-time, and cost issues for each supplier and component • Inbound packaging requirements or specifications 	Supplier Plan

Figure 54:Design review agenda Part 2 [39]

TABLE 14.1: <i>(continued)</i>	
REVIEW TOPIC	REQUIRED OUTPUTS
Product Cost and Profitability <ul style="list-style-type: none"> • Current cost estimate compared with target cost • Product profitability 	Target Cost Worksheet
Program Plan and Management <ul style="list-style-type: none"> • Project plan • Schedule issues • Resource issues • Process deviations 	Project Plan Project Budget
Review of Issues and Follow-up Actions	Open Issues List
Permissions to use the tables were granted by DRM Associates, November 8, 2006. Note the tables were primarily designed for the automotive industry; however, the tables contain general information that can be tailored to specific design reviews.	

Figure 55: Design review agenda Part 3 [39]

The WVU team hybridizes the two approaches in order to best fit the team organization structure and operations. In a fast-paced competition program involving a senior capstone, time is semi-locked for teams with no flexibility within competition deadlines and student commitments to either classwork or homework. As a result, having a full in-depth industry-level standard design review agenda is not possible and supports the reason why it's critical for teams to hybridize, adapt and merge both a design review process with configuration management. Having both systems in place allows the WVU EMC team and any senior-level capstone project to thoroughly evaluate the change of a new system or component within the competition scope, allowing for the education into change management for undergraduate students and graduate students. The ability to thoroughly investigate and concur that no competition requirements

and or rules are broken. Future roadblocks mistakes are minimized or neglected for further progression of the team success. Figure 56 thru Figure 60 is an example of a completed and approved WVU EMC team's change management request form in practice and Appendix E is a template of the change management form.

In accordance submitting a change management form begins the change management process. Once the change management meeting is established, it is best to present the case and design documentation in the best-suited format regardless of whether that is Microsoft Word PowerPoint or the software involved. Based on the EMC team's experience in change management, the preferred methodology of undergraduate students and the easiest to share virtually during the COVID-19 pandemic is using Microsoft PowerPoint. Additionally, change management meetings benefit the student to practice oral presentation skills in front of a committee that will not provide a standard classroom response but establishes a discussion of the issue and the change involved.

WVU EcoCAR Mobility Challenge Change Request Form:

CR# _____ 008 _____

Title Rear Electrical Center Redesign

Proposer Vibhat Seth, Robert Collins, Dhary Omar, Thomas Chapbelear Date Submitted
2/12/2021

Previously Related Changes (List Change Request Number, if known)

Detailed Description

The current rear electrical center does not have integrated logic to remove power from the Cohda Wireless when the CAVs Disconnect Switch is off. The current rear electrical center is only held in place by the cables that run into it. A better mounting strategy for this component is required.

Suggested Solution

An additional relay will be added to conform with rule I-2.3 (CAV Power Disconnect). A base will be used to fix the rear electrical center to existing studs on the interior of the body. Finally, a new box will be printed, and the redesigned center will be built inside of it.

Justification

This a necessary change to conform with NYSR. By rebuilding a separate rear electrical center, the vehicle will remain drivable throughout the redesign. The addition of a base will ensure that the rear electrical center is fixed to the vehicle body structure during vehicle operation.

Figure 56: Change management example part 1

Definitions of Change

Level of Change: 2
Schedule Change: 2/9/2021-2/26/2021
Budget Change: \$138
Scope Change: Electrical team.
Authorized Approver(s) Per Change Management Roles: Aaron Mull, Benton Morris, Dr. Nix, Dr. Woerner

Top View of Current System

Figure 57:Change management example part 2

Full Trunk View of Current System

New box with base that has been 3D printed

Figure 58:Change management example part 3

Figure 59: Change management example part 4

Figure 60:Change management example part 5

7.3 Requirements Management

At the highest level, requirements come from the practice of systems engineering. Systems engineering is the transdisciplinary and integrative approach to enable the successful realization use in using the systems principles and concepts and scientific technology in management methods; Simply put, systems engineering is the structured approach to solving project level roadblocks that have resulted in a change of the desired outcome. [40]

Any organization within the engineering world that offers a product or service must practice requirements management. The process of how the requirements are managed varies between small and large

companies. A small company may handle requirements in a verbal manner of daily communication back and forth between employees working on a particular product. This approach can be similar to an individual sub-team working on a component that will be integrated into a competition vehicle. However, that component becomes part of a product that had multiple sub-teams developing products at some point. The products are now being integrated into the final competition product. It can result in miscommunication and understanding of all product requirements. As a result, large corporations who deal with multiple branches of an organization during the development process have strict and rigid requirements matrix systems established and set up to prevent the cost of error [41]. That is why the best practice for a large competition team such as the WVU EMC team is to establish a requirement management system.

It is critical and problematic if the requirements management method is not established at the start of a competition project or industry-level product development. The cost for fixing errors rises drastically later in the development process in which errors are discovered [40]. Figure 61 shows how the relative costs to fix a defect in the product changes throughout the timeline of the development of the product. This example from industry can be related to a competition-level product that tracks design, integration, bench testing, pre-competition testing, and competition performance.

Figure 61:Cost of failed requirements [42]

Besides the detection of error and benefits of starting requirements management at the early level, it is more beneficial and connected to other disciplines of a project, including project management, version control, configuration management, purchases, and design architecture. Requirement management and engineering development of a product need to be aware of the dependencies of requirements throughout the product's lifespan. Requirements management also helps support the configuration change management process by supporting the implications of the change and supports to the design architecture development having a standard set of base requirements allowed for the stable development of the initial architecture and design of the product or competition product [42].

In order to better relate this to a senior-level competition capstone project, an examination of the aspects of the EMC Year 1 development phase needs to happen. During Year 1, the team must select the vehicle architecture for the remaining portion of the competition. Many factors come into play during the selection of the competition, from propulsion communication of controllers, the distribution of power,

and other aspects of operation within a vehicle. Having established requirements in an early stage allows the team to lay a base architecture that will prevent early development issues, allowing further progression and creativity during the integration and design aspect of the project. It also prevents the misunderstanding of why that process was selected due to the turnover rate of any student competition-based capstone project.

Requirements stem from two origin points within the industry for a project. The first is the requirements defined between the communication of the customer and the company handling the product. The second is internal requirements set by the company and approved by the customer [41]. As for a senior-level competition capstone project such as the EMC with AVTC series, requirements originate from two locations as well. Agile methodology places emphasis on satisfying the customer and the co-location of the customer with the development team. The customer is located at a separate operation location but can be contacted via phone, email, or video conferencing with the development team even though the two parties are at separate locations [43]. A customer in this regard is the competition organizers. The organizers' requirements for the company (development team) are the yearly or Non-Yearly Specific Rules (NYSR) for the competition that establish the rules and regulations of product development. The second stems from internal requirements based on the integrity that the team has allocated for themselves based on budget, time commitment, and the sustainability of knowledge for the project internally. However, understanding that the rules are where the majority of a competition capstone project requirements originate, a team can progress and move forward into the mechanisms required for requirement development, traceability, and validation and verification before a competition level deliverable or product level competition can be tested. And again, this still holds true at the industry level at the same process in which a company, once establishing requirements, will generate a system to define the requirements the traceability and validate and verify that the requirements have been met before the release of the product to the customer for distribution.

The information requirements provide to system design engineers can be classified into requirement types. From the industry's two origin points, the five classifications of requirements are function, performance, resource, design, and condition [44]. Relating requirements to the competitiveness or levels achievement within a competition project, the performance requirements are at the top of the list. Performance requirements relate to the requirements desired during competition performance, followed by the design constraints and condition requirements. The focus of a corporation's requirements may be more centered around resource requirements. Both industry and senior-level capstone projects such as the EMC have all forms of the classified types of requirements.

Writing good requirements is key to a successful requirements management system as many other engineers have worked on riding directly from the requirements for a specific product or system. A lousy requirement at the highest level will have a cascading effect on lower-level requirements. Thus, leading to an additional workload for every engineer involved in the project. Therefore, writing requirements correctly the first time is critical to the product's success. During one of the EMC training workshops, a sponsor from the automotive industry suggested that all competition team projects developing requirements for their teams to use the acronym SMART. The acronym SMART stands for Specific Measurable Attainable Relevant and Traceable. Not only is this acronym relative to writing reasonable requirements for a competition-level capstone project, but is a standard in writing requirements within the industry level.

Specific from the acronym SMART relates to requirements so that one should be written with no ambiguity, maintain a consistent terminology used for all product requirements, avoid double requirements, and specify units when possible.

Measurable in relation to requirements means a requirement should have a measurable target in terms of a written way to express a passing criterion for the requirement. An example of this in relation to the

EMC series would be to avoid statements such as the vehicle function shall be pleasant; therefore, write the requirement as the vehicle function shall maintain a minimum distance of 15 meters between the lead vehicle and the vehicle front bumper. This requirement is measurable and has the ability to be tested and passed.

Attainable in relation to requirements means the system or product can meet the requirement.

Relevant is simply having the appropriate level of detail for the requirement

Traceable in regard to lower-level requirements must follow logic and support higher level requirements.

Using SMART while writing requirements will help one make sure that what is being written will meet the criteria of a good requirement, but that is not all that makes for a good requirement. Requirements should be easy to read and understand. The requirements in the system specification are either for their system or the next level. Standards and guidelines form part of the process documentation on how the business processes are performed without expectations [43]. A student competition team should structure and use the grammar standards of writing requirements in a manner that is easy to comprehend, pick up and train for the sustainability of the competition team year after year. As a result, the WVU team writes the team's requirements using the phrase shall do.

An example of this is: the system shall provide (..) or the component shall weigh (...) Each of these begins with a specific system or product followed by what the product or system shall do. A requirement should generally be followed by a single precedent and not by a list.

Requirement development and requirements management are equal to an interactive undertaking of project management. PMI's definition of requirements management includes both requirements development and requirement management activities. This entails a requirement management plan that

encompasses the task of establishing requirements the traceability and maintaining a requirement, and the testing of requirements. The benefit of requirements management planning (RMP) is the guidance on how requirements will be developed and managed throughout the project's life cycle. The core components of the RMP in the industry are not limited to but can include the following:

- How requirements will be handled and developed
- What the roles and responsibilities are for those participating, and requirement activities
- What the authorization and critical decision-making process
- The method in which requirements are prioritized, approved, and maintained throughout the project lifecycle,
- Acceptance criteria during verification and validation
- The metrics used and the traceability structure that will be implemented for the project
- How requirements will be documented and communicated to external and internal stakeholders

[41]

The WVU EMC team RMP is comprised of three parts. The first is the requirement definition documentation (RDD), the second is the requirement management documentation (RMD), and the third is the requirements testing documentation (RTD). Multiple options for requirement management traceability tools include IBM doors, Jama Software, and Modern Requirements. These tools help to manage the complexity and alleviate many of the more tedious steps in requirement management. However, these software's are extremely expensive and take a significant amount of training to be proficient using the software itself. More straightforward tools such as Microsoft Word and Microsoft Excel can be used for requirements management plans at the student competition level. Unfortunately, these common well known programs by students still make the requirements management process much more cumbersome. But based on the time training and budget constraints of most senior capstone level

projects and the EMC team this is the recommended method. With the EMC being a competition rather than a traditional business, the approach to requirements management will have to fit the application. A major consideration that is important to remember is that no Requirements Management Plan (RMP) is perfect and unfortunately, a single approach may not be appropriate to meet all of the user requirements. The RMP should be versatile enough to account for these drawbacks. In the case of the EMC a significant source for requirements is the NYSR. The decomposition of these rules into requirements is the primary concern of this plan.

The RDD is utilized for the requirements development procedures, including requirements gathering, elicitation, definition, and analysis. The EMC RDD is a Microsoft Word document used to break the rules down from the organizers from a paragraph format to individual requirements. The document allows the requirements engineers to systematically break down the content of the rules while tracing the information back to the specific section, paragraph, and sentence of that version of the rules. This is a tedious process, but the work will alleviate the issue of traceability as new versions of rules are released from the competition organizers. As a result of industry standards and poor training of new students to write requirements, the team established a training standard for writing requirements for the RDD to be incorporated into the RMD quicker for verification and validation throughout the lifespan of the competition. Therefore, the standard established in the RDD naming convention and process of application of the RDD form identifies the source section system and date. Figure 62 and Figure 65 is an example of the naming convention and a completed RDD form established by the team that can be universally applied to any senior-level capstone project based on industry standards. Appendix F is a template of the RDD form.

Requirements Definition Documentation:

The Requirements Definition Documentation (RDD) is primarily a working document that outlines a systematic approach to distilling information from rules or team generated designs into usable requirements that can be easily added to the Requirements Management Documentation (RMD). After completing the process outlined below, be sure to fill out the summary page to completion to make incorporating the new requirements into the RMD quicker.

Name this document with the following naming convention:

RDD_[Source]_[Section]

Source: NYSR Rev J

Section: I-4.1

System: Energy Storage System (ESS)

Date: 9-6-2020

Procedure:

Step 1: In the area below, paste in the raw source data to be distilled into requirements. Full Justify (Be careful, pasting from PDF often does not carry through bullet points or returns)

The battery pack enclosure must be constructed with a sturdy frame that can support the battery pack. The structure of the battery pack must be securely fastened to the vehicle frame at as many points as is practical to distribute the load. The structure of the ESS enclosure must be designed to withstand 8g vertical static loading and 20g longitudinal and lateral static loadings. Under these loadings, plus a factor of safety of 1.5, the structure must not enter the plastic region of deformation.

Battery pack enclosures may be rigidly mounted to the vehicle. Hardened bolts (Class 10.9 or better) must be used and all connections must include a locking means. Battery modules must be secured in the battery enclosure. Mounting hardware must also be cable of withstanding the 8g vertical and 20 g lateral and longitudinal loadings as described above. Additionally, all mounting hardware must comply with battery manufacturer requirements (wherever applicable).

Figure 62: RDD example part 1

Step 2: Copy and paste each paragraph into the cells below to track paragraph number. Label the sentence number in each paragraph.

P	Description
1	The battery pack enclosure must be constructed with a sturdy frame that can support the battery pack. 1 The structure of the battery pack must be securely fastened to the vehicle frame at as many points as is practical to distribute the load. 2 The structure of the ESS enclosure must be designed to withstand 8g vertical static loading and 20g longitudinal and lateral static loadings. 3 Under these loadings, plus a factor of safety of 1.5, the structure must not enter the plastic region of deformation. 4
2	Battery pack enclosures may be rigidly mounted to the vehicle. Hardened bolts (Class 10.9 or better) must be <u>used</u> and all connections must include a locking means. 1 Battery modules must be secured in the battery enclosure. 2 Mounting hardware must also be cable of withstanding the 8g vertical and 20 g lateral and longitudinal loadings as described above. 3 Additionally, all mounting hardware must comply with battery manufacturer requirements (wherever applicable). 4

Step 3: Distill the paragraph into the tables below by sentence

P	S	Description
1	1	The battery pack enclosure must be constructed with a sturdy frame that can support the battery pack. 1
1	2	The structure of the battery pack must be securely fastened to the vehicle frame at as many points as is practical to distribute the load. 2
1	3	The structure of the ESS enclosure must be designed to withstand 8g vertical static loading and 20g longitudinal and lateral static loadings. 3
1	4	Under these loadings, plus a factor of safety of 1.5, the structure must not enter the plastic region of deformation. 4

P	S	Description
2	1	Battery pack enclosures may be rigidly mounted to the vehicle. Hardened bolts (Class 10.9 or better) must be <u>used</u> and all connections must include a locking means. 1
2	2	Battery modules must be secured in the battery enclosure. 2
2	3	Mounting hardware must also be cable of withstanding the 8g vertical and 20 g lateral and longitudinal loadings as described above. 3

Figure 63:RDD example part 2

1	4	Additionally, all mounting hardware must comply with battery manufacturer requirements (wherever applicable). 4
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Step 4: Copy tables from previous section and rewrite the text as requirements. Some quick tips: Requirements should be specific and clear. They should outline a measurable quality to be obtained. General nomenclature in the following format: "the thing shall do this". (For more information on how to write good requirements, see training in PSI OneNote)

P	S	Requirement
1	1	The battery pack enclosure shall be constructed with a frame
1	2	The structure of the battery pack shall be fastened to the frame at all locations
1	3-4	The structure of the ESS enclosure shall withstand 12g vertical static loading before entering the region of plastic deformation
1	3-4	The structure of the ESS enclosure shall withstand 30g longitudinal static loading before entering the region of plastic deformation
1	3-4	The structure of the ESS enclosure shall withstand 30g lateral static loading before entering the region of plastic deformation

P	S	Requirement
2	1	Battery pack enclosures shall be mounted to the vehicle using hardened bolts (Class 10.9 or better)
2	1	Battery pack shall include a locking means on all connections
2	2	Battery modules shall be secured in the battery enclosure.
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 12g vertical loading before entering the region of plastic deformation
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 30 g lateral loading before entering the region of plastic deformation
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 30 g longitudinal loading before entering the region of plastic deformation
1	4	Battery Enclosure mounting hardware shall comply with battery manufacturer requirements (wherever applicable).

Figure 64:RDD example part 3

Summary:

Source: NYSR

Version: J

Section: I-4.1

P	S	Requirement
1	1	The battery pack enclosure shall be constructed with a frame
1	2	The structure of the battery pack shall be fastened to the frame at all locations
1	3-4	The structure of the ESS enclosure shall withstand 12g vertical static loading before entering the region of plastic deformation
1	3-4	The structure of the ESS enclosure shall withstand 30g longitudinal static loading before entering the region of plastic deformation
1	3-4	The structure of the ESS enclosure shall withstand 30g lateral static loading before entering the region of plastic deformation

P	S	Requirement
2	1	Battery pack enclosures shall be mounted to the vehicle using hardened bolts (Class 10.9 or better)
2	1	Battery pack shall include a locking means on all connections
2	2	Battery modules shall be secured in the battery enclosure.
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 12g vertical loading before entering the region of plastic deformation
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 30 g lateral loading before entering the region of plastic deformation
2	3	Battery Enclosure mounting hardware shall be cable of withstanding a 30 g longitudinal loading before entering the region of plastic deformation
1	4	Battery Enclosure mounting hardware shall comply with battery manufacturer requirements (wherever applicable).

Figure 65:RDD example part 4

One of the most common causes of a product failure or dissatisfaction from the customer is the result of missing requirements or poorly executed requirements. Missing or poorly executed requirements can result from forgotten, changed, or deleted requirements throughout the project's lifecycle. Therefore, the ability to trace, track, and report the lifespan of a requirement is critical to the success of the project. The most common mechanism for tracing requirements through the lifecycle of a project is a traceability matrix. In a traceability matrix, each requirement is traced row by row. The first column would contain the requirement ID, or some form of a serial number taken from the development of the requirement, followed by a column with a brief description of the requirement origins. Next within a traceability matrix would be the requirement. Each company in industry has a unique aspect and columns to the company's traceability matrix. However, the other large portion of a traceability matrix for requirements is the columns in which the user can trace the validation and verification of the requirements throughout the lifecycle of the project [42].

The EMC RMD is constructed using Microsoft Excel and is based on industry-standard approaches to creating a traceability matrix. The various elements of each column should be present in either the RDD or the results of an RTD, so the overall construction of this document should be relatively straightforward. The key to this document is the careful transfer from the RDD and RTD to ensure that no information is mixed up or lost in the process. The RMD can be categorized into two main areas: the requirement data from the RDD and the validation data from the RTD. As with student competitions and industry, requirements may change based on new rules or industry regulation updates. Therefore the requirement data section has been designed to best suit the EMC team. The unique system has in place columns that highlight the system, subsystem of the project, and the source version of the rules. The ability to track this allows the team to trace back the origin requirements to maintain a valid system through ever-changing updates of competition rules throughout the four-year lifespan of the project. This holds true for the

validation section as well. An example of the RMD can be seen in two separate figures below due to the size and complexity of the RMD. The first Figure 66 highlights the requirement data section, and the second Figure 62 highlights the validation data.

West Virginia University Requirements Management Documentation							
REQUIREMENT DATA							
System	Sub-system	#	ID	Source	NYSR Version	Requirement	Swimlane
Interior	Structure	117	Interior-Structure-117	NYSR	J	The energy-absorbing padding on the interior of the doors shall not be altered.	PSI
Interior	General	118	Interior-General-118	NYSR	J	The vehicle shall be equipped with a production electric automotive horn capable of steady, uninterrupted sound at a level of 82 to 102 dB at a distance of 15 m (49 ft.) for 3 seconds.	PSI
Interior	Air Conditioning	119	Interior-Air Conditioning-119	NYSR	J	The vehicle's A/C system shall be capable of decreasing the ambient air temperature inside the passenger compartment at the headrest of the driver's seat by at least 5.5°C (10°F) within 5 minutes.	PSI

Figure 66:Part 1 RMD requirement data

VALIDATION DATA			
Validation Test Link	Validation Status	Who Validated	Validation Date
Y3 Pre-Inspection	PASSED	Lucas Shoults	3/10/2021
Y3 Pre-Inspection	PASSED	Lucas Shoults	3/10/2021
Air Conditioning Certification	PASSED	Colin Kellett	10/14/2021

Figure 67:Part 2 RMD validation data

Once a requirement has been developed at some point within the project's life cycle, the requirement will have to be tested. The evaluation of a requirement is supported through the process of verification and validation [42]. Many believe that verification and validation mean the same thing, but the subtle difference between them is what makes each so distinctly important.

IEEE defines **Validation** as "An activity that ensures that an end product stakeholder's true needs and expectations are met." IEEE defines **Verification** as "A test of a system to prove that it meets all its specified requirements at a particular stage of its development." [35] The difference is made clear using these two questions when conducting the testing of requirements using the validation verification process.

- Are we building the thing right? Verification
- Are we building the right thing? Validation [45]

Based on the definition of verification and validation, the terms are closely related and intertwined but are not the same. Testing requirements using verification and validation should be planned for as early as possible in the project's lifecycle. As requirements can be related to subsystems, subsystems comprise a larger portion of the test environment. If not organized in due time can cause significant delay and schedule, increasing the risk for the project's success. The validation and verification planning process is iterative, as are all other processes connected with requirements management. The testing of requirements needs to be planned throughout the lifecycle of the project and at each level of the requirement. The relationship of this process is usually pictured using the V model. The V-model summarizes the main steps to be taken in conjunction with the corresponding deliverables within a project life cycle development. It describes the activities to be performed and the results that have to be produced during product development.

The V-model provides a linear path from user wants and needs to the final product providing the necessary checks to keep a strong relationship between the start and endpoints. These checks are known as verification and validation. Therefore, the tests on each level of abstraction are planned for in parallel to the specification of the requirements of that level. As a result, the validation and verification process is

repeatedly executed throughout a product's life cycle. Figure 70 provides an example of a V-model used for both the WVU team and an EMC sponsor.[40]

Figure 68:V-model template [40]

For the EMC team, this is a set of competition writings and vehicle development process in order to have a functioning and competitive vehicle each year of the competition. In industry the validation and verification planning provide a way for the company to set a standard for test environments while maintaining the quality standards established by the company. In addition, a test plan will contain a test schedule that can be linked to the project management schedule and the requirements traceability matrix. The benefit within industry is organized test plan provides guidance and the costs of time and the process of verifying and validating the requirements of systems or products during scheduling [42]. The practice of generating test plans for a competition level team holds equivalent results for the team overall.

When generating a test plan for the test environment for requirements within the industry, a proper test plan should have a set number of questions.

- What must be tested?
- How must it be tested?
- Who will test it?
- When must it be tested?
- The cost of the verification and validation?
- The time consumption of the testing? [42]

Based on industry standards for generating a test environment and the test plan associated with verifying and validating requirements and systems to have a successful product, the EMC team generated a simple excel file that covers all 6 categories for a test plan. Based on an industry-standard of one of the most common pitfalls is the treatment that verification is merely a formality to fill in a review or feedback on a product showing no defects [43]. As a result of the common pitfall the EMC team mandates within our test environment, the test must be operated by two individuals with at least one unfamiliar with the product itself and are responsible for uploading the results of the tests and linking them back to the RMD. The information of this process does not only help eliminate the common pitfall from industry but also allows for better communication and understanding of the competition product amongst sub-teams and swimlanes for the EMC team. An example of the test plan from the example RMD for the Air Conditioning requirement completed by Colin Kellet is in Figure 71 and Figure 72. The template for standardized test plan for the test environment of requirements for the EMC team can be found in Appendix G. Having the test plan developed within Microsoft Excel allows for an easier transaction for updating the RMD and linking test plans back to the tested requirements.

<div> <div> <div>ECO CAR</div> <div>MOBILITY CHALLENGE</div> </div> <div>Testcase Documentation</div> </div>			
Testcase ID:	Interior_AirConditioning_119-123	Testcase Name:	Air Conditioning Certification
Test Type:	Visual inspection, physical verification	Testcase Edition:	1
Requirement Description:	The vehicle's A/C system shall be capable of decreasing the ambient air temperature inside the passenger compartment at the headrest of the driver's seat by at least 5.5°C (10°F) within 5 minutes.	Test Date:	3/10/2021
	A/C compressors shall not be located in the passenger compartment or the cargo area.	Test Performer:	Colin Kellett
	The vehicle shall pass the A/C functionality test with the same flash on controllers which their dynamic events were/will be tested.	No. of Test	1
	The vehicle shall not run all events and the team then reflash their controller just to get the vehicle's A/C functional.		
Required Equipment:	Thermometer, some way to attach it to drivers seat headrest	Flashed Version:	Hybrid
Testcase Author:	Billy Cawthorne	Test Location:	ESB G15
Written Date:	2/1/2021	Weather:	N/A
Setup Procedure:	Procure thermometer and determine how it will be attached to the headrest Ensure the vehicle's A/C system has not been running recently - the test needs to be run starting with ambient temperatures	Setup Issues:	None
			- The A/C Compressor is mounted to the engine near the accessory drive belt on the front side in engine bay. Pass - Starting temperature 74 F - Ending temperature 61 F after 2 minutes 35 seconds. Pass

Figure 69:Part 1 of RTD

Test Procedure:	1.Examine the A/C compressors to ensure they are not located in the vehicle interior 2.Ensure the vehicle controllers are flashed as they would be during competition dynamic events 3.Adjust the driver's seat, seat back and headrest to a normal position that is comfortable and conducive to driving. 4.Enable the propulsion system per Section G-1.1.1. 5. With the vehicle in Park and the parking brake engaged, exit the driver's seat. 6.From the passenger's seat, attach a thermometer to the driver's seat headrest and note the temperature (this will be the initial ambient temperature). 7.Using only inputs available to the driver on the dash or center console area of the vehicle (no external laptops or controllers are permitted), perform the following steps: a.Set the airflow setting to recirculate, b.Set the temperature to the coldest possible setting, c.Allow the team to select which vents are used and direct those vents as desired, d.Set the fan to maximum output. 8.Observe the thermometer for up to 5 minutes. If the temperature drops by at least 5.5°C (10°F) within 5 minutes, the A/C system passes. If not, the system fails and the team will receive the A/C penalty.	Test Results & Issues:	- No change in flash. Pass
Teardown / Post Processing:	Put thermometer away	Teardown Issues:	None
Pass/Fail Criteria:	Pass - A/C Compressor is located outside of the passenger compartment. A/C system does cool air at least 5.5C in 5 minutes or less	Test Result:	Hard Pass
	Fail - A/C compressor is located in interior A/C system does not cool air at least 5.5C in 5 minutes or less	Suggestion s:	None
Hard Pass Actions	Update RMD with passing criteria		
Soft Pass Actions			
Fail Actions	Update RMD with failing criteria, inform Engineering Manager		

Figure 70:Part 2of RTD

Once an RTD is completed and uploaded to the RMD the result must be communicated with the swimlane lead. In addition, the lead can note that the requirement has been met in a risk mitigation document to allow the next iteration of the project or design FMEA to reflect the risk or failure associated with the

requirement or system requirements. Figure 73 shows how the testing of requirements relates back to the FMEA in order to reduce the impact of risk to a design or project. If multiple potential designs are being tested in the early phases of a project lifecycle to verify and validate the requirements are being met, a Pugh chart is required afterward to determine which design is best suited for the project. If possible, and most preferred approach is for a potential design to be selected prior to the validating system requirements.

Figure 71:Requirements and verification testing risk and failure reduction

7.4 Version Control

A senior capstone course, especially for an engineering discipline, requires the use of modern design tools and programming languages. Working within programs such as Matlab, Simulink or generating code in a programming language such as Java or C for a capstone project is almost inevitable for any senior capstone course. The two swimlanes that use software-based version control for the WVU EMC team is PCM and CAVs. In order to be the most efficient in managing the tasks of a team within the modern digital workspace, one must adapt industry standards for version control. Writing code or software programs is

a fundamental part of the problem process solving a robust and ever-changing environment within the industry.

Often within industry a programmer has to revert to a previous version of a model or program in order to determine the error and root cause of the team's current roadblock. This can be the case when the team discovers a change is necessary for the algorithm to be more efficient in terms of speed, reliability, or fidelity of the model. To facilitate the ability to revert to a previous or parallel version of software, version control must be implemented in a smart and efficient manner. The basic idea of version control is to separate the program files into branches. The stable branch is the code or program that has already been tested for functionality. The experimental branch refers to the code or programs that are being actively worked on. The stable branch is only updated with code from the experimental branch when the code has been rigorously tested for bugs and errors. Once the experimental code has been verified, it can be folded into the stable branch for other team members to access. The designation between stable and experimental allow for individual team members to continue one's work without affecting the work of others on the sub-team. The stable branch or master copy is managed by the team leadership and updated as new changes are accepted, toward completing the sub team goals [46].

WVU EMC team has used two different approaches to industry-level version control. The first is using a local GitHub program that is maintained on teams' servers for data safety and allows students to pull versions of the model from the repository to ingenerate changes in the portion of the model or controller one is working on. Once one has completed the necessary change, the team member then submits change to team leadership in order to merge it into the master copy. At this time, the team leadership will detect if the changes caused an error and navigate and resolve the problem up front before pushing out a new copy of the master within the repository for new teammates to pull from. This process demands

leadership maintain dedication into constantly monitoring and pushing a new version of a master copy for traceability factors.

However, during the COVID 19 pandemic, the team could not use this version control process due to security reasons: confidential material could not be shared on an online public repository system. So as a result, the team leadership broke up the model into small individual units distributed by thumb drives for smaller sub-teams to work on individually. Once a sub-team change has been made, the sub-team can submit it to the team leadership who works with the group to test with the system or controller through a virtual meeting. After any detection of issues is resolved the new code is passed onto the master controller of the system following the same process and eventually being pushed onto the master model for hardware in the loop testing. This process allows for both in-housework and remote work to be accomplished and coordinated during the pandemic times and restrictions of laboratory use amongst senior-level capstone projects. This is very similar to the Git system but is a more in-depth and step protection of branching the models off and then truncating them back to the master copy.

7.4.1 Standard Naming Convention

Outside of the software system, every team should use another version of version control, which is a set naming convention. In global distribution to have a standard form of naming for multidisciplinary teams amongst different languages and time zones is critical to the success of the project on a global scale. The approach of global distribution amongst teams at the industry level can be relative to the exchange of information between swimlanes who do not directly communicate regularly due to operation time limits, lab space restrictions, or remote work [47]. In the key to global distribution communication related to senior-level capstone projects having multiple cross-project communication over different working hours and locations having a standard naming convention and file organization system is critical for sustainability within a project and documentation traceability for project progression and success.

In general teams should have a document on file like him be easily accessed or presented to new team members highlighting the general mapping of both hard drive data storage and cloud based as storage such as Microsoft Teams. This general training allows students to understand how to access and where to first look for information before giving up and simply asking leadership every single time where something will be located. The result will be students will explore the files and be able to manage locating desired information following a standard naming convention throughout the system. A few rules to follow based on WVU EMC lessons learned are the following:

- Do not allow individual students to save files under their name directly
- Always provide a description of the system, swimlane, or sub-team the file is related to
- Per the sub-team orchestrate some method of tracking
 - a serial number numbering system
 - version numbering system
 - date modification numbering system

Figure 74 shows an example of the naming convention used for EMC training material. In the example shown, the team uses both a version control stating the description and the swimlane affected along with a tracking method. The description EMC to state who sponsored training, Y1 or Y2 to state the year within the competition, FW or WW to state which semester the team received the training, (PM) to state which swimlane the training is directed towards follows by the description for the related training.

Figure 72:Naming version control example

On engineering-based student competition teams, there is one sub team that both uses software level version control and naming convention version control. It is possible to have multiple sub-teams in this category; however, the sub-team that best stands out for the WVU EMC team is the CAD sub-team of the PSI swimlane.

Both in industry and with student competition teams, projects involving CAD and using the product Siemens NX can you use an industry-standard tool known as Teamcenter to help support and manage daily operations of CAD design with relation to version control required for proper maintenance. In addition, Teamcenter can offer more than just version control but can aid in managing bills and materials, change management, requirements management, support electrical design that uses VeSys into CAD and can aid in project planning and execution. However, Teamcenter does cost money, and there can be issues with student users and IT management within a university. It is not recommended to try and switch to Teamcenter when the CAD workload is hectic, and best to try and implement at the start of a semester.

As a result, another approach for CAD version control is a more brute force approach. The EMC CAD team can be broken down into two areas. The first is the CAD group that works with the master copy of the full vehicle CAD model and are the only people allowed to operate a full vehicle CAD model. The full vehicle

CAD model is saved under one person's account who's deemed administrator of the group. In the case of the WVU EMC team, that administrator was the project manager who supported the CAD team. Group 1 maintains the full vehicle model by establishing a naming convention that noted when a modification was implemented into the model followed by a readme file located in the file storage area. The read me file contains a tacking log that states a description of the change, who made the change, the file name of the component added to the model. The read me file allows group 1 to recall previous CAD renderings if an issue is discovered.

The second group focused on developing any team design component that will be integrated into the vehicle. The components may vary within the second group, and students are allowed to establish their own working folder; however, outside of the working folder, a second folder indicates the final version of a component for easy tracking. In addition, a read me file with a log tracking file is required in each student working folder that tracks a description of the product, file name, date modified, and roadblocks or issues discovered. This system allows new members or the team individual to understand what changes have occurred throughout the development of the product that will be integrated into the vehicle along with a backup system noting there's a discrepancy between the final product produced for integration to the vehicle in the final CAD product designed. This process works due to the nature of the CAD team being close-knit and understanding which team members are working on particular components. For knowledge transfer, new CAD members can go back and explore files as desired and can be given a primary objective for a different design.

The product that affects the remaining team is organized and controlled by managing the final version file folder and Group 1's system. Figure 75 shows how the process of version control works.

Figure 73:CAD version control system

8.0 Supporting tools of Project Management

8.1. System Element Fault Analysis (SEFA)

SEFA is the process in which it utilizes system thinking that supports the review process of potential errors or faults of system elements. SEFA focuses on systems taken as a whole and not on parts taken separately. As a result, it is a safety technique used to identify the impact of individual system element failures upon the system as a whole. The technique is not limited to a particular area. Within a student competition-based project focused around a vehicle for the case of EMC, can evaluate elements such as the following:

- actuators
- motors
- sensors
- clutches
- controllers
- functional elements

Figure 76 shows the block diagram generated using SEFA Methodology to understand how system elements function as a whole. In Appendix H, an example from the WVU EMC team's SEFA worksheet related to the Battery Control Module (BCM) can be seen to understand how the process works. SEFA is a process used by General Motors and taught to all EMC teams to help students better understand system engineering to help prevent safety issues and system failures at the final competition.

Figure 74:SEFA block diagram

The results of a team's SEFA are used for 4 areas of a project. Those 4 areas are:

- Developed diagnostic and mitigation strategies
- Identify initial system requirements necessary to mitigate system behavior caused by system element faults
- Assist recovered states after a system fault
- Identify changes that have occurred to system architecture to ensure adequate diagnostic capability

8.2 Systems Theoretic Process Analysis (STPA)

The main objective of the STPA is to consider the safety aspects of a whole system. When developing an STPA, one generates a block diagram that documents the interaction between major subsystems and components of the final product. In addition, the process identifies the functions of each major subsystem and component. Considering the system as a whole, a person executing an STPA has the potential to understand what errors or faults could occur in the system that might lead to a potential hazard for the final product or team member of a student competition team. Furthermore, the process allows the individual to speculate scenarios that could lead to errors or faults of the system. As a result of this practice, a team can generate their own safety requirements outside of set competition requirements in addition.

When building and working with STPA, one needs to consider the following:

- Responsibilities of each component
- Control actions which can be provided
- Process model variables

A team generating an STPA can take in these three considerations first. Next, a team needs to define unsafe control actions (UCA) by using guide words such as :

- not provided
- Provided but leads to hazards state
- Too early, too late, wrong time, wrong sequence
- Stop too soon, apply too long

Once an individual or team developing an STPA defines the UCAs, they can begin to identify the potential causes or scenarios for each UCA. The end result will provide the team with design requirements that will prevent or minimize potential hazards due to the foreseen scenarios based on UCAs. Figure 77 shows the block diagram developed by the WVU EMC team to apply STPA towards the prevention of failures with the final competition vehicle. In addition, to better communicate examples that relate to a student competition team's potential UCAs, Appendix I shows WVU EMC's UCAs for driver interface. In addition, Appendix I has resolutions of 1 UCA from the driver interface set of UCAs.

Figure 75: STPA Block Diagram

9.0 Conclusion

A project management plan with various management elements is necessary for a successful industry-level project team and a senior-level competition capstone project team such as the Ecocar Mobility Challenge at West Virginia University. Application of project management strategies and tools for an efficient and successful competition-based engineering senior capstone design project details the application of industry-level project management practices for a student to adapt for any competition-based engineering project. The team has been adjusting the project management plan over the course of three years for the four-year competition. As a result of other adaptation of industry practices senior-level competition capstone project, the team has been effective and has matched all levels of success evaluated in industry.

The criteria for team success of an effective team varies from company to company. However, three of the most important factors to consider when evaluating if a team is successful are whether the team delivered the final product, the development of the team, and the team's commitment throughout the project lifecycle [12]. A project is not considered a success unless it delivers the final desired product. Efficient teams execute this by delivering project deliverables according to specification requirements by the consumer or client on time and within budget. The WVU EMC team practices and adapts industry values of the project management plan in order to execute successful submissions of pre-competition written deliverables, final competition presentations, and vehicle testing events for final competition each year of the current competition. The team never received penalty points for late submissions because the team was able to mitigate risk, schedule and develop plans, track and maintain requirement changes throughout the project life cycle using hybridized and adaptive management techniques to meet the first criteria of a successful and efficient team.

The second criteria for a team to be successful is during the team's development, the team learned from mistakes and became more efficient and better as time progressed through the project's lifecycle. The second criteria can be difficult for a senior-level capstone project team due to the high frequency of turnover between team members year after year of each competition. By adopting industry management practices for better sustainability and team structure and communication, the team has been able to harness the industry factor of human capital. The human capital factor is that team members' performance increases rather than diminishes value, unlike traditional capital. The WVU team, through successful communication, knowledge transfer practices, change management, and version control, improved the skills, knowledge, and abilities of team members through mentorship and team member exchange, resulting in a sustainable program that has been successful and efficient throughout the years of competition. The adaptation of evaluations of peer-to-peer faculty in leadership has also helped support the simple skill of improving a team's ability to work together through a multidisciplinary project to make minor corrections throughout the life cycle and order for this effective team member exchange to continue and prepare students for their future careers.

The third and last standard criteria used to evaluate the effectiveness of a project's team success is analyzing how the team feels towards the commitment to the project's end goals and a project lifecycle. The effort demonstrates satisfaction and commitment, and persistent team members make your team goals. The collegiate senior-level capstone competition team is determined to adopt industry practices into the program to achieve better results. The desire to adopt industry practices shows a clear picture of the determination and commitment of team members to have a successful program. In addition, the ability for the team to have a sustainable program through team cohesion is another factor that supports the commitment of team members to the project to evaluate success. The WVU EMC team in Year 1 went into final competition in 4th place out of 12 universities. After presentations and final competition for Year 1, the WVU team ends the year in 7th out of 12. Based on these results and the continued practice of

adapting and using practices and methods from the industry for team management and development, the team went into the Year 3 final competition in 3rd place. After vehicle events and competition presentations, the team was able to maintain the position of 3rd place. This is a prime example of the benefit of adopting industry practices and their effect on team cohesion and commitment to have a successful product and team.

Overall, any senior-level capstone project team must seriously consider the adaptation of industry practices in order to be collegiately competitive and have a standard of competition success. Once competition success is established for the program that is involved with the competition base capstone project. Adopting industry practices and methods will benefit the project and its overall success for the university and support and benefit the students involved to prepare them to be successful upon entry into the industry workforce of their choosing. The WVU team will continue adapting, hybridizing, and improving upon plans in Year 4 of the EMC and upon acceptance into the next AVTC series will perform a closeout report to determine what were the best result and methods for future graduate student leadership to adapt, explore, and hybridize both from past projects and industry in order to continue to have a successful and a sustainable project that is competitive at the collegiate level for a senior-level capstone project.

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Appendix A (Closeout Report Survey)

1.0 Introduction

The EcoCAR Mobility Challenge Closeout Report Survey is focused on surveying and analyzing all of the EcoCAR 3 Year 4 Closeout Reports to gauge the success in project management practices of all thirteen EcoCAR 3 teams who are competing in the EcoCAR Mobility Challenge and how each one executed the EcoCAR 3 competition. This Closeout Report Survey contains the overall survey and analysis of each team's organization, recruiting and retention, information storage and archiving, budget and procurement, risk analysis and risk management processes, knowledge transfer, and the architecture selection process. To develop this Closeout Report Survey, members of the West Virginia University (WVU) EcoCAR Project Management team separated Closeout Reports, from Year 4 of the EcoCAR 3 competition into sections then reviewed and analyzed each section. In order to accurately survey and analyze each report, analysis matrices were created to compare the management practices documented by each university. The goal of the report is to assess the best practices and evaluate lessons learned from each of the EcoCAR 3 teams in order for WVU to improve as a team leading into the new competition. As a result of this report, the WVU EcoCAR Mobility Challenge team will be able to learn from other's distinctive practices, common standards, and drawbacks of each team from EcoCAR 3.

2.0 Information Storage and Archiving

2.1 Overview

Information storage and archiving are critical to the success of the Advanced Vehicle Technology Competition (AVTC) teams due to the large volume of data that has to be transferred, past deliverables that have to be managed, and the need for streamlined knowledge transfer. These sections of the Closeout Reports are analyzed to establish how each team managed all of their data, including where data is archived, processes for gaining access to data stored locally, naming conventions, and version control of documents. These processes are of prime importance for current and past AVTC competitions to ensure that data is easily accessible to team members.

2.2 File Storage and Archiving

All teams in the EcoCAR 3 competition utilized a centralized file storage system to store all competition-related information. The two primary information storage systems used by the teams was a cloud based storage platform similar to OneDrive and an internal protected shared hard drive system for General Motors confidential information, including CAD and technical data. The majority of the EcoCAR 3 teams noted that they used Google share drive to organize communication surrounding the development of non-General Motors confidential material. Implementing a platform such as Google share drive for non-General Motors confidential material reduces the number of emails exchanged between team members due to frequently edited documents. Seven of the 13 teams used repositories for code management and version control. GitHub was the most commonly used repository; however, concerns about the security level of online data repositories like GitHub were not documented. A particularly unique file storage system was used by the University of Alabama. The University of Alabama used a commonly assessable thumb drive for additional storage. This system does present concerns when storing critical information since a thumb drive is prone to damage and loss. The first common issue was that teams

with a long history of involvement in AVTCs have an increased risk of lost or corrupted files in storage. The second common pitfall found on every team was a naming convention and how to navigate through the large volume of data and past deliverables of AVTCs. Teams have developed a naming system for the data stored for their teams, but turnover of leadership between competition years can result in changes in directory and file naming protocol, causing difficulty for new team members to navigate through stored files in search of information.

2.3 Regulation and Access Procedure

Every team in the competition had a control system in place allowing team members to gain access to files once a General Motors non-disclosure agreement was signed. A uniquely problematic issue that a few teams encountered was created by limiting the control of materials to only a few team members. Limiting which team members had read, write, or limited access to materials increased the pressure for communication between team leads. It also hindered the ability of new team members to learn, since a limited number of the team had full access to all documents. Another common struggle that teams faced in the EcoCAR 3 competition was interaction with their information technology (IT) departments concerning file storage systems. When university IT departments are in control of the software and computer administration for each team, hindrances can occur. Firstly, if a team is expanding the number of computers in their lab, the IT department can slow the expansion process by not updating ports, not installing necessary software, etc. Secondly, if a license file on the server needs updated mid-semester, the IT department can prevent the software from being used in a timely matter. Thirdly, if communication or relations are not healthy with the IT department, then solutions to any technology issues can be greatly delayed. This problematic concern will continue as long as university IT departments and software programs are used in the competition.

2.4 Analysis and Recommendations

Locating files in a large storage system is a problem that multiple teams faced. Based on analysis of the Information Storage and Archiving section of the closeout reports from EcoCAR 3, WVU's EcoCAR team has implemented an archiving system to organize file storage on a shared drive. A potential problem is that even though files may be well organized, newer members may lack the knowledge of how to quickly navigate through archived files. As a solution, WVU's EcoCAR team plans to develop an openly accessible manual detailing how files are named and containing a logical path for where they can be found. The Engineering Manager and Project Manager will create this logical step by step-by-step path for students to locate stored files. This document will be placed into the team Knowledge Transfer binder located in our EcoCAR labs, organized by sub-team and deliverables.

All teams should be encouraged to use repositories for code management across all swimlanes involving algorithm or software development. Repositories can help improve software quality and enable easy management for a large team. The WVU Controls and System Modeling and Simulation (CSMS) team already takes advantage of GitHub's integration with Simulink for model version control. It is important to note that through WVU's investigation of repositories, teams should verify whether or not the selected repository is appropriate for confidential General Motors material. Storage space on individual computers, or even servers, may be an issue for teams, so using modern information storage systems such as SharePoint or OneDrive can benefit the end receiver of the document and reduce the disk space used during editing.

In addition to managing archived data and access procedures, teams should take caution in regulating who has access to team data and information. Regulating who can edit documents is a safe way to maintain document integrity, however, regulating who has access to documents may be detrimental to new team members efficiently gaining access to information critical to their tasks. Issues with university or departmental should be added to every team's risk analysis system due to the fact it can be a risk for tasks and deliverable to be delayed. To mitigate the risk of interaction with IT departments, teams can improve their current relationship with IT through better communication with the department, and by notification of upcoming software changes in advance. The WVU team has established a more direct IT ticket process and improved communication by frequent visits to it to talk with IT managers in person.

3.0 Human Resources

3.1 Overview

The Human Resources section of the EcoCAR 3 Closeout Report was intended to document the process for recruiting, onboarding, and the retention of new team members. Review of how teams managed human resources will help EcoCAR Mobility Challenge teams benefit from the advantages and challenges faced by each of the teams in the four years of the EcoCAR 3 competition.

3.2 Recruiting New Members

The goal for any team is to regularly maintain quality growth rather than growth in quantity. For new member recruitment, several teams incorporate EcoCAR presentations into university-hosted events which promote projects and clubs. The problems that arise for teams using this recruitment method varies based on how well the event is attended. The success of recruitment varies based on weather, location, advertisement, and overall student engagement. Another common recruiting practice that teams employ is to speak to engineering classes on campus. However, when recruiting using this tactic, teams face three factors that determine the efficacy of direct presentations to classes: class attendance during the recruitment visit, willingness of professors to relinquish class time, and student engagement. When speaking to students, every team has two points of motivation when trying to recruit students to their EcoCAR team. The first shared point is the fact that all EcoCAR team members have the chance to earn course credit towards their Senior capstone requirement. The second speaking point that all universities have to talk about is the fact that not only are there numerous sponsors for AVTC but every student has an increased chance for their resume to be seen by these sponsors based on the notion each team gives a resume book to competition organizers.

One method for recruitment is to orchestrate interviews for prospective team members who want to join the team as an undergraduate. This method may reduce the size of a team, but it ensures that members who join are serious about the competition and understand the expectations. A potential pitfall of this recruiting tactic is that it may discourage students to join the team who otherwise could have been a significant asset. On the other hand, this recruiting tactic reduces the chance that team members will be "dead weight" to the team. The percentage of universities that held interviews can be seen below in Figure 1.

Figure 1: Percentage of Universities That Held Interviews

3.3 Onboarding New Members

A few schools have a tier-based system and require training before new members can officially join the team. This tier system is highly effective when it comes to onboarding new members. Other schools where EcoCAR is club-based have a tier system based on how team members are “ranked”: new team members have less responsibility, while experienced members take on more important responsibilities. Every team in the competition had a senior design class that was related to EcoCAR 3. WVU is the only school of thirteen teams where EcoCAR is not an organization or club for students before their Senior year. The WVU tier method of varying class levels allows sub-teams to have a mix of new and more experienced team members. This interaction allows for effective knowledge transfer. Every university must form their team based on how their campus operates; however, adopting a tier based approach where class credit is available from the sophomore through senior year is recommended.

3.4 Retention of Members

A common struggle among EcoCAR teams is the retention of team members. When surveying the retention of team members, four categories affecting students’ interest with the team were established. These categories for the retention of team members include: team bonding, opportunity with the team, involvement with the university, and continued course credit for team members. The below table (Table 1) is the analysis matrix that was developed using these four categories. Team bonding is essential for member retention. If a student feels they are unwelcome or not part of the team, this will negatively impact their work ethic, and eventually the student is likely to leave the team. The University of Washington, Embry-Riddle Aeronautical University, and West Virginia University are the only teams that addressed team bonding activities in their Closeout Reports from Year 4 EcoCAR 3. These three teams noted that students are encouraged to stop by and spend time in the EcoCAR labs between classes. Additionally the teams have out-of-lab bonding events such as barbeques, trivia/bar nights, and other team building events. One unique form of member retention employed by WVU and several other teams, is to design and implement a succession plan for graduating team leads. This system allows for team members not in a leadership position a goal to strive for while adjusting to becoming an effective member of the team.

Table 1: Human Resource Retention Analysis Matrix

University Name	Team Bonding	Team Status/Year	Oppurtunity with the Team	Involvement Within the University
ASU				
CSU		Team Growth		
ERAU	Between Classes		Training before	
GT				VIP system
MAC				
MSU				
OSU				
UA				
UTK				
UW	Slack: Ecobrew, Meme group		Small Sub-team	
UWAFT				
VT				
WVU	Cook Out, Bar Night, Stop by between classes	Classes	Bigger this Year	Tours, Poster, Classes

Legend	Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Did Not Complete Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Not Fully Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report
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A common link between the teams is some form of University involvement. However, teams such as WVU, Arizona State

University and the University of Washington excel at promoting their team as a flagship project on campus. WVU's recruitment and outreach department consistently brings tours by the EcoCAR lab not only to promote WVU's EcoCAR team as a flagship on the engineering campus but as a prime example of the type of hands-on engineering projects offered at WVU. When a university establishes their EcoCAR team as a flagship project on campus, students are more likely to stay on the team because of pride and/or bragging rights for being part of the EcoCAR team. Also, once an EcoCAR team is established and has a winning record in AVTCs, students will be more eager to join and remain on the team. The last form of retention for teams is the available class status for members. West Virginia University is unique in that it is the only team that reported offering class credit for younger members (starting at the Sophomore level). Two other teams (Colorado State University and Georgia Tech) do offer university credit for underclassmen but only as a form of a vertically integrated program. This program allows Junior level students to gain credit towards graduation but not towards their Senior design project.

3.5 Analysis and Recommendations

From the analysis of the Human Resource practices reviewed in the Closeout Reports Year 4 of EcoCAR 3, the WVU EcoCAR team has the potential to implement several new ideas gained from other competitors. Not only should WVU strive to improve how we present our project to the University to establish a better position as a flagship competition and separate ourselves as the premier student design team available to engineering students but all teams in the competition should strive for this. The

major struggle for student design teams is focused more on retention of members instead of recruiting and onboarding team members. Teams should explore how to establish academic credit for their younger team members on the project by talking with their Dean and establish team development or bonding events, as the WVU team has found this to be a key to team success. WVU will continue to maintain our current methods of recruiting, onboarding, and retention while seeking to improve each new year of EcoCAR Mobility Challenge. Recruiting, onboarding, and retention of team members overall tactics will not change from EcoCAR 3 competition leading into the EcoCAR Mobility Challenge.

4.0 Team Structure and Organization

4.1 Overview

The implementation of a detailed team structure and communication plan is critical to the success of any team. This section surveys and analyzes how each team's hierarchy, meetings, internal communications, and succession plans contributed to the success of each team in EcoCAR 3.

4.2 Team Organization

At the highest level of every team's structure was the faculty advisor. Most teams had support from only one faculty advisor; however, some teams had support from multiple advisors. It is noted that the number of advisors did not reflect how well each team performed. A unique team structure was implemented by Mississippi State University. This structure featured an internal advisory board, which was comprised of on-campus engineering and communication department heads. A pitfall of having a large faculty advisory board is increased difficulty in scheduling meetings and receiving consistent feedback.

All teams included student leadership working under the guidance of lead faculty advisors. These leadership positions included: Project Manager, Engineering Manager, CSMS Lead, Mechanical Lead, and Communications Manager. All teams had the Project Manager either directly above the Engineering and Communications Manager or on the same level. Ohio State University was the only team to have the Engineering Manager directly over the Project and Communications Manager. The Ohio State University Engineering Manager oversaw technical design aspects, while the Project Manager was responsible for overall team management and sponsor relations. Despite having this unique hierarchy, Ohio State University maintained great success throughout each year of the EcoCAR 3 competition.

Each team had a similar sub-team layout, (Table 2) which consisted of different leads to guide each sub-team. A unique structure which the University of Alabama and McMaster University featured was a redundancy in specific sub-team leads. This redundancy benefited the sub-teams in two ways. The first benefit is that by having two sub-team leads, large tasks can be simplified by dividing them between the two leads. The second benefit is that technical and managerial tasks can be separated: one lead can focus more on sub-team management while the other focuses on technical aspects. This structure is similar to the Project and Engineering Manager relationship, but on a smaller scale.

Table 2: Team Organization and Structure Analysis Matrix

University Name	Unique Roles	Meetings	Internal Communications	Mentoring
ASU		Team lead, safety manager, sub-teams (twice a week)	Emails	Succession plan
CSU	Sub-team, PM (weekly), Report to EM/PM	Weekly	Emails, Group me	Succession plan

ERAU		Weekly general, GM weekly	Share Point, A list (unique), Email, Group me	Inefficient Mentoring
GT		Weekly general, GM weekly, 1 sub-team presentation		1 semester shadow
MAC	Co-leads	Weekly	Busy Bot/Slack	
MSU		3x a week with GM leads		Sussession Plan
OSU	EM over PM	Weekly lead and EM, Bi-weekly sub-team	Email, Slack, Asana(scheduling)	
UA	Co-leads	Bi-weekly leads, weekly sub-team	Slack, Email	Sussession Plan
UTK		Weekly	Email	Sussession Plan
UW		Weekly, Bi-weekly for GM advisors	Slack	Sussession Plan
UWAFT		Weekly	Email, Slack	Sussession Plan
VT		Weekly	Email	Sussession Plan
WVU		Weekly	Email	Sussession Plan

Legend	Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Did Not Complete Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Not Fully Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report
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4.3 Meeting Times and Formal Communication

The most effective tool for ensuring efficient communication between team leads and sub-team members is face-to-face meetings. Each team in the EcoCAR 3 competition implemented team meetings; however, the weekly number of meetings varied significantly. Each team had formal meetings planned with General Motors mentors, faculty advisors, team leads, and sub-teams. The majority of the teams had at least one meeting per week between these various groups. There are a few universities which operated differently: the University of Waterloo, University of Alabama, and Ohio State University organized bi-weekly meetings. The Ohio State University scheduled bi-weekly sub-team meetings, while the University of Alabama held bi-weekly lead meetings. The University of Waterloo held bi-weekly meetings with their General Motors mentor. Based on the success of these teams in the EcoCAR 3 competition, bi-weekly meetings may have potential benefits. It is clear that communication between all levels of the team hierarchy, from the GM Mentor to the sub-teams, has been critical to the success of all EcoCAR teams, especially those who finished well.

One particularly beneficial meeting structure was implemented by the Georgia Tech team. During their team lead meetings, a sub-team member is required to give a status update presentation to the entire team. This system provides an efficient way to update the entire team on the status of different tasks. It also provides a platform for sub-team leads to gain experience with presenting. During every weekly GM Mentor conference call, the WVU team leads present PowerPoint slides from each sub-team. The presentation slides contain accomplishments, completed tasks, upcoming tasks, roadblocks, recovery plans, and the status of deliverables. Additionally, during GM Mentor visits, each team will have individual meetings with the GM Mentor similar to a weekly conference call, but with more depth of discussion.

4.4 Internal Team Communication

Email was the primary form of internal communication used by each team in the competition. The primary pitfall of using email is that messages may not be read in time to be effective. In addition to email, the majority of teams noted the use of at least one other form of internal communication such as platforms like Group Me or Slack. After a comparison of these two platforms, Slack was shown to be the more effective tool for organized internal communication. This was demonstrated by 5 of the 13 teams (Table 2). Beyond the use of communication platforms, one unique form of communication was employed by the team of Embry-Riddle Aeronautical University. They developed a team-accessible list that was posted where every team member could see it. The list was a simple way to post updates and new tasks for sub-teams. Once a task was completed, it was simply checked off. When a new task became available, it was placed right after the last task. This allowed every team member to quickly view what tasks each sub-team was currently working on.

4.5 Analysis and Recommendations

All team structures are primarily dictated by the positions required in the EcoCAR competition; however, teams have the freedom to develop their own sub-team and team lead structures. With the addition of Propulsion Systems Integration (PSI) and Connected and Automated Vehicles (CAVs) lead positions, the EcoCAR Mobility Challenge competition will require a reorganization of team lead structure. The PSI position will replace mechanical and electrical team leads, but it is recommended that teams retain these positions as sub-team leads, based on the success of the EcoCAR 3 competition. The CAVs team will need to be integrated into the competition structure through close interaction with the CSMS team. Due to these new positions, internal communication will be more important than ever. It is recommended that each team not only create a way to improve email communication, but also implement a social group communication platform such as Slack.

The structure of the West Virginia University EcoCAR 3 team performed well in the competition and is consistent with the structure of other successful teams. It is recommended to implement redundancy in sub-teams by naming co-team leads to support actual team leads. The start of a new competition allows for easier adoption of new processes. It is also recommended that team leads start adding read receipts to emails, in addition to adopting a Slack channel for internal communication. Additionally, it is recommended to maintain current team meeting structures, with the inclusion of a monthly or bi-monthly conference call with a MathWorks mentor.

5.0 Risk Analysis and Risk Management

5.1 Overview

The risk analysis and risk management section documents the process each team used to manage risk in all team activities, including technical, program and schedule risks. Each team provided a “post-mortem” analysis example to demonstrate best practices in risk assessment. This section has a higher influence on future competitions based on the fact that it focuses on the lessons learned from success and failures in risk assessment, and how the results impact the project overall. Table 3 in presents a matrix of the key aspects of the risk management process of each of the 13 EcoCAR 3 teams accepted in the new competition for comparison and analysis purposes.

Table 3: Risk Management Analysis Matrix

University Name	Detailed Process of Risk Management	Utilizes a form of RPN	Uses Severity Occurrence Detection	PM, EM and Sub-Leads Determine Risk	Weekly Meetings on identifying Risks
ASU					
CSU					
ERAU					
GT					
MAC					meeting at beginning of year
MSU				Only PM	lessons learned- utilize monthly meetings
OSU					
UA					
UTK					at start of a new task
UW					
UWAFT		$1/3(s+c)+2/3P$			
VT		likelihood*impact			
WVU					

Legend	Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Did Not Complete Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Not Fully Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report
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5.2 Meeting Times and Formal Communication

The majority of the teams in the competition utilized some form of a risk priority number (RPN), as shown in Table 3. This number is used to help rank the overall importance of each risk. Most teams used the same formula for calculating the RPN, which is the product of the severity, occurrence, and detection of each risk involved. The higher the RPN is for a risk means, the more concerning it is. The value of severity, occurrence, and detection are all based on a scale from one to ten, with ten representing the highest severity, highest probability of occurrence, and lowest probability of detection, respectively. Most teams who used RPN to assess risk also included details for each of the risk values, including guidelines for the levels of the severity, occurrence, and detection. The only teams who did not document how they used RPN were Embry-Riddle Aeronautical University, University of Tennessee, and the University of Washington. These teams did not document how risk was classified using a risk ranking system.

Teams such as the Ohio State University and the University of Alabama both re-evaluated their risks halfway through a semester. Some teams also held weekly meetings devoted to risk analysis, as shown in Table 3. Continually re-evaluating risks allows the teams to eliminate risks that become irrelevant, and treat those risks that become more of a concern, as well as documenting new risks that arise.

One team, in particular, had a few unique features that were discovered during the survey of this section. Virginia Tech applied two risk management practices well. First, the Virginia Tech team required their sub-team leaders to determine three risks involved with their specific sub-team task. By doing this, specific risks can be narrowed down immensely, allowing efficient treatment of the risks. Virginia Tech also assigned a risk manager position to each of the sub-teams. This position helps reduce the chance that the team safety-risk manager was overwhelmed in assessing and treating risks across all sub-teams.

One significant risk management difficulty that affected Georgia Tech in EcoCAR 3 was that the architecture selection was performed by the Engineer Manager only. With lack of knowledge on other risks, the team received last place in the Architecture Selection Proposal deliverable. From an engineering standpoint, this is not an effective way of handling risk. The input of the Project Manager for risk analysis is minimal compared to having many leaders or even students involved.

The sub-team leaders have specific areas that they have expertise in, which also allows more risks to be evaluated and mitigated.

The WVU team used RPN, as well as employed a more visual method, generating risk graphs of Occurrence and Detection versus Severity, as shown in Figure 2. The risk matrix is used to assess the level of risk with two separate graphs, one that compares occurrence with severity and one that compares detection with severity. These matrices utilize a red, yellow, and green color scheme to illustrate the level of risk being evaluated. If a risk falls within the green section of the matrix, it is likely to just be accepted. If the risk falls in the yellow section, the risk might not be accepted but is more likely to be monitored throughout the project. Finally, if the risk falls within the red section of the matrix, corrective action should likely be taken to mitigate, transfer or avoid the risk. Additionally, risks falling in the red section of the matrix should be monitored more frequently on a schedule decided upon by the Project Manager and the Systems Safety Lead, if applicable. Examples of both risk matrices are illustrated in Figure 2 and are used in conjunction with RPN to classify and prioritize the risks documented. It should be noted that new risks can be added to the risk management plan as they arise. Conversely, as risks currently in the red and yellow zones are monitored and mitigated, they can potentially be moved to the green zone and essentially accepted.

Figure 2: Example of Risk Matrices

5.3 Analysis and Recommendations

Based on the results from the teams who prioritized risk, risk assessment and management is critical for the success of teams. In order to complete a task in safe and timely manner, teams should adopt an RPN system into their program if not already doing so, as well as using risk matrices. Risk management will be even more challenging for the team in EcoCAR Mobility Challenge compared to EcoCAR 3 due to the increased focus on risk management and Systems Safety in the latest competition. Every team should have at least, a Risk Manager who gets constant feedback from either team leads or members on sub-teams. As a result of this feedback, the Risk Manager will be more adequately prepared to update the Project Manager, who is concerned with the overall project status, compared to the Engineering Manager who is driven to complete technical goals. The risk manager should update the Project Manager biweekly, based on the fact that tasks should be broken down into no more than 14 days in work length.

Management of changes in technical scope and tasks, schedule, and budget are critical to the execution of large research and development programs, and should be considered within the risk management process, and coordinated by the Risk Manager. To help manage and facilitate the change management process, the team should identify clear levels of change, the criteria that define each level of change, the

authorized users for each level, and the approval process that must be followed to approve or deny the proposed change. Shown below in Figure 3 below is the Change Management Control Process that was followed by the WVU team in EcoCAR 3.

Figure 3: Change Management Process Example

6.0 Financial Management (Budget and Procurement)

6.1 Overview

Financial management of any project is critical to the success and execution of the overall project. This section focuses on how budget and procurement were managed efficiently and successfully by the various teams in EcoCAR 3. It should be noted that the WVU budget and procurement process was managed well, however, practices may be adopted based on the examples of other teams. The WVU budget process will change in the new competition, as the EcoCAR Mobility Challenge funding will be processed through the WVU Office of Sponsored Programs, whereas in EcoCAR 3 the budget was managed at the departmental level.

6.2 Financial Management

Each team had a budget and procurement system that was fairly unique to their university. However, some universities described systems in place or documented how the budget process was executed in more detail than others.

As documented by teams in their Closeout Reports, the procurement process, and how each university handles the processes of buying parts and supplies, ranged from simple to extremely challenging. The University of Tennessee, Mississippi State University, and Virginia Tech were the only three teams to develop or document how their procurement process worked using graphs or examples. There appears to be a correlation with the universities that outline their entire product purchasing plan and their score on the Closeout Report of Year 4 for EcoCAR 3. A section that was not required that Virginia Tech took the liberty of including is the student reimbursement process. This is an essential process that should become standard to train students on in the future, as there will likely be instances in at least one of the

four years of the competition where someone needs to pay for supplies or travel expenses out of pocket and then receive reimbursement at a later date, especially during travel for workshops and competitions. The reimbursement process is something that universities may neglect to adequately train students on, and may subsequently lead to individuals not being reimbursed for these expenses.

Planning a budget for a multi-year project is an intimidating task, as it is difficult to predict program costs, but costs can be estimated. Detailing the methodology of how a team determined and estimated their budget requirements provides useful insight for out-year budget estimates for the new competition. Mississippi State University was the only team to document how they perform their budget estimations; their faculty advisors examined the previous 12 years of university competition experience as well as their fluid communication with Electrical and Mechanical departments. This allowed them to properly account for salaries, tuition, operating expenses, and equipment.

Of these universities, the University of Alabama does the best job of explaining their financial accounts. Schools will have money coming in from multiple different sources and the details the University of Alabama provides for their three different funding accounts has led to their financial management success. Each of these accounts have a detailed process for how funds are requested from each account, who has jurisdiction over each account, which department each account is associated with, and the funding transfer between each of the accounts. One account is used for depositing sponsorship checks, university contributions, and donations. Another is used for primary purchases, travel expenses, and student stipends. The third account is a student organization account.

6.3 Analysis and Recommendations

The financial management from EcoCAR 3 to EcoCAR Mobility Challenge should not present any new challenges to teams with managing budgets and procurement. However, it is recommended that every university improves how they document their procurement process, budget projections, and institutional financial management not only for future Project Managers to learn from but also to effectively manage program funding from year-to-year. As noted earlier, the WVU Office of Sponsored Programs will manage funding for the new competition, with the funding broken down into specific funding lines for external funding from EcoCAR, split into funding for each of the two major departments, Mechanical and Aerospace Engineering (MAE) and Computer Science and electrical Engineering (CSEE), and internal costshare funding from the Statler College of Engineering, MAE, CSEE and the Reed College of Media. Particular attention must be placed on where funding for graduate student salaries, travel and general expenses are charged to manage the four-year budget. Also, unlike EcoCAR 3, funding not used in a program year will be available for use in later years (i.e. funds will roll-over).

7.0 Knowledge Transfer Process

7.1 Overview

Transferring knowledge from experienced team members to developing teammates is the focus of this section of the

Closeout Report Survey of EcoCAR 3. Knowledge transfer is an extremely important process which is a key to the success of many teams due to the significant turnover of team membership and leadership over a four-year competition.

7.2 Knowledge Transfer

The method by which knowledge is transferred to new team members varies a considerable degree between the competing universities. Table 4 below presents a matrix analyzing key aspects of the knowledge transfer process, detailing which teams documented timeframe for transfer, on the job training for new team members, shared data access, onboarding process and use of a knowledge transfer binder. Arizona State University, Embry-Riddle Aeronautical University and the University of Washington did not document use of a knowledge transfer binder in their Closeout Reports. This method of knowledge transfer is a critical component in understanding the higher level of the competition. In addition, the majority of the teams documented some form of “On the Job Training” to teach team members the skills they needed to be competitive not only in EcoCAR, but also in the workforce after college. One aspect of knowledge transfer that the majority of teams struggled with was allowing access to information for all team members.

There are a few teams that had unique forms of knowledge transfer the worked well. West Virginia University required more than one student working on a sub-task at any given time. Redundancy of students on a task enforced that at least two people were learning an ability that in turn would ensure the task was completed but spread the knowledge further than if only one person had learned the skill or ability required to complete the task. Another highly unique process for knowledge transfer was implemented by Colorado State University, which integrated EcoCAR 3 tasks into a number of their other Mechanical Engineering classes on their campus.

Table 4: Knowledge Transfer Analysis Matrix

University Name	Knowledge transfer timeframe	On the job training	Team sharedrive	Onboarding	List/binder of important information
ASU					
CSU					
ERAU					
GT					
MAC					
MSU					
OSU					
UA					
UTK					
UW					
UWAFT					
VT					
WVU					

Legend	Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Did Not Complete Topic Listed in Year 4 of EcoCAR 3 Closeout Report	Not Fully Completed Topic Listed in Year 4 of EcoCAR 3 Closeout Report
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7.3 Analysis and Recommendations

After analyzing how each team performs their knowledge transfer, a few lessons were learned. First, teams need to give more access to past technical and project management materials for younger team members to study and learn, early on in their involvement in the program. West Virginia University plans to build upon one unique knowledge transfer feature by modifying its shadowing program. Instead of a minimum of two people working on a task; one member must be an elder team member while the other

member will be required to be a younger team member. This knowledge transfer system will help ensure that skills and abilities have a decreased risk of being lost to new generations of team members. The WVU team will also strive to implement EcoCAR related tasks as class projects in other engineering courses, or document how a work in other courses related to EcoCAR tasks. This will allow students to become interested in EcoCAR and the students will have had some experience with the project before joining the team.

8.0 Vehicle Architecture and Vehicle Technical Specifications (VTS) Selection Process

8.1 Overview

The vehicle architecture and vehicle technical specification (VTS) for all thirteen teams were defined in Year 1 of the 4year EcoCAR 3 competition, during the Architecture Selection Proposal process. Minor adjustments to the VTS and architectures were permitted in Year 3 of the competition. This section of the Closeout Report is intended to focus on how architecture and VTS selection affected team budget, timeline risks and overall team and vehicle performance.

8.2 Survey of the EcoCAR 3 Vehicle Architecture

From the past competition, the most significant common link between each team's vehicle architecture was that every team except the University of Tennessee chose to develop a plug-in hybrid electric vehicle (PHEV), rather than a hybrid electric vehicle (HEV), in order to maximize range, and reduce emissions and fuel consumption. The disadvantage for the PHEV teams was increased Energy Storage System (ESS) size compared to the HEV developed by the University of Tennessee. This resulted in an increase in weight and challenge in ESS integration for the PHEV teams. A common setback that all teams faced, with the exception of McMaster University, was the A123 battery system and the charging issue associated with this battery, in addition to limited technical support.

Virginia Tech was the only team to employ cylinder deactivation in the competition, and was the only team to increase the size of the base model engine to an 8 cylinder. This choice of engine was a unique feature that improved dynamic performance, but also caused issues with their drivetrain during competition. In addition, use of a custom electric motor presented challenges for the VT team. This emphasizes the importance of using commercial off-the-shelf (COTS) components with reliable technical support.

Diving deeper into the vehicle architecture selection, it should be noted that 7 of the 16 teams in EcoCAR 3 decided to implement a P3 architecture design as shown below in Figure 4. The P3 was the most commonly chosen motor position due to the relative ease of implementation into the rear wheel drive system and longitudinal engine and transmission design of the Camaro. Figure 4 illustrates the percentage of teams analyzed that integrated a P3 motor, as well the teams who competed in the final Endurance (Over the Road) Event in Year 4. When analyzing the top seven teams in the competition, six of the seven teams who completed the Over the Road event had a P3 design, and 70% of the teams who qualified for the event utilized a P3 architecture. The data presented makes a solid case of selecting an architecture that is easier to implement in the stock vehicle. This will most likely lead to interest in

focusing on P4 (all-wheel-drive or “through the road”) architectures in the Chevy Blazer in the EcoCAR Mobility Challenge.

Another result to garner from analysis of architecture selection is the use of sponsor supported components. Three of the top six teams in the competition used the GM donated 2.4L E85 engine, and two other teams used other GM engines. Virginia Tech used a GM 5.3L V8 engine and Tennessee used GM 2.0L turbocharged engine . Ohio State was an exception, instead using a Ford engine; however, they had experience and direct support for this engine in the competition. The benefits of using sponsor supported engines is apparent from the competition results of the top 5 teams in EcoCAR 3.

Figure 4: Electric Motor Position Compared to the percentage who participated in the EcoCAR3 Endurance Event

8.3 Analysis and Recommendations

The key takeaway from the analysis of the team architecture and VTS is in the analysis of team final rankings versus architecture chosen. The P3 architecture was the most common architecture chosen, likely based on the assumption that the design was simpler and easier to integrate into the Camaro. The Camaro was a rear wheel drive sports car with a longitudinal engine, and the new vehicle is a sport utility vehicle (SUV) with front-wheel drive, and an all-wheel drive (AWD) option and a transverse engine. The change in stock vehicle, and the correlation of simplistic, less risky designs, may drive teams to select P4, “through the road” architectures in the next competition. Another factor that teams will likely face is the adjustment to an HEV vehicle due to available battery options. Another key takeaway from the results of analysis of vehicle architectures is the benefit of the use of sponsor donated components and commercial off-the-shelf components with reliable technical support.

WVU key takeaways from surveying and analyzing the vehicle architectures, and VTS from last competition at a high-level view is to select an architecture that is easier to integrate into the SUV to increase the chances for success in the new competition. West Virginia University and any competitor

should strive to have a unique design that stands out in competition, yet has a simplistic rather than complex design.

9.0 Conclusion for closeout report survey

The survey and analysis of the EcoCAR 3 Year 4 Closeout Report allows for teams to improve their existing project management practices from previous team experience, including that of the other 12 teams competing in the EcoCAR Mobility Challenge. The Closeout Report is meant to be a roadmap for teams to hone their management practices in information storage, management and retention of human resources, analysis and treatment of program risks, budget and procurement management, knowledge transfer and assistance in architecture selection and vehicle technical specifications. Every team in EcoCAR Mobility Challenge has the opportunity to improve from the previous competition, and the intent of this deliverable was for teams to analyze the practices of other teams, and benefit from lessons learned. The new competition will bring new and unforeseen challenges to each team, however the Closeout Report Survey will enable teams to meet these challenges to promote team success. Following this report, the EcoCAR 3 Architecture Study will complement the review of project management practices and will complement this report with a more in-depth study of EcoCAR 3 team architecture selection and lessons learned.

Appendix B (Execution Plan Year 3)

1.0 Introduction

The purpose of this document is to provide the West Virginia University (WVU) EcoCAR Mobility Challenge team Project Manager (PM) and project leadership team with an effective management tool to monitor and control the project timeline, scope, risk, meeting cadence, and communications to provide status updates for the team throughout Year 3 of the competition. The Execution Plan will outline an overall project timeline with more detailed timelines for the individual subteams contained within supporting documentation. The plan will also define the project scope, potential risks involved, and strategies to mitigate these risks. Lastly, the plan will detail how the team's status and health are updated and communicated internally to the team during Year 3 of the EcoCAR Vehicle Development Process (VDP).

2.0 Project Schedule

2.1 Project Milestones

Effective project management requires careful planning and attention to detail across all project areas. In order to accomplish this desired goal, the project management team must be able to reference an effective milestone schedule. The WVU EcoCAR team will employ a top-down approach, developing a schedule with high-level milestones and working downward based on the importance and impact of the milestones. The team has selected a three-tier milestone system to cover both competition level and team milestones. Tier 1 consists of milestones that are pre-defined by competition organizers. These milestones have hard deadlines and specific task requirements that must be completed to achieve the Year 3 competition VDP and project goals. These milestones are established to have natural end criteria for the various phases of the VDP. The team defined project Phases are defined as:

- Phase 1 – Vehicle will be fully integrated and able to pass the Virtual Vehicle Technical Inspection (VVTI)
- Phase 2 – The vehicle will be tested at the Winter Workshop and Vehicle Evaluation (WAVE) event
- Phase 3 – Post WAVE testing will be complete
- Phase 4 – All necessary vehicle modifications for Year 3 competition will be complete

Tier 2 milestones consist of team milestones based on competition deliverables that are pre-defined outside the VDP of a team. Deliverables are an organic milestone for the team to follow, ensuring that competition requirements are met, and that the team remains competitive and on track. Tier 3 milestones consist of team-driven milestones developed by each swimlane on the team. These milestones are based on the major tasks of each swimlane, while considering the WVU academic calendar and any restrictions due to the COVID 19 environment. An illustration of the team's three-tier milestone schedule for Year 3 is demonstrated in Figure 1. Following the figure are details of each milestone, including the overall scope. The first two tiers of milestones for the team have only a pass or fail condition. The team will only be successful if these two tiers are met. The third tier can be adjusted based on what must be completed and what is desired.

Figure 1: WVU Team Year 3 Milestones and Glidepath

2.2 Milestone 1: Vehicle Fully Integrated & Passes Vehicle Technical Inspection (VTI)

2.2.1 Overview

Upon reaching the Tier 1 milestone, the team should have a vehicle that is functioning safely with all VTI line items addressed and operating as originally planned at the end of Year 2. From this milestone forward, any design change must follow the change management process established by the team. To accomplish this competition milestone, multiple Tier 2 and Tier 3 milestones are assigned to break up the work that must be done to accomplish the high-level Tier 1 milestone. Tier 2 and Tier 3 milestones have also been defined with relevant acceptance criteria, and team defined stretch-goal criteria (as opposed to competition stretch-goals).

2.2.2 Scope

Milestone 1: Vehicle Fully Integrated and Passes VTI (Phase 1 - End Milestone)

- Acceptance Criteria:
 - Fully integrated propulsion system components and auxiliary systems
 - Critical structural waivers complete
 - Vehicle passes virtual VTI
 - Basic level of supervisory control: internal combustion engine (ICE) with electric motor assist (P4)
 - Forward-facing perception system sensors and compute hardware integrated on team vehicle
 - Connected Automated Vehicles (CAVs)- Propulsion Controls and Modeling (PCM) control interfaces, functional disengagements, and safety checks operable on team vehicle
 - V2X system is able to transmit and receive a Basic Safety Message (BSM) on bench
- Team Stretch Goals
 - The vehicle is capable of driving under its own power using both the ICE and electric axle (e-axle) propulsion systems
 - Additional tests for CAVs sensors in various traffic conditions

Table 1: Phase 1 - Tier 2 and Tier 3 Milestone Definitions / Acceptance Criteria

Tier 2 Milestones	Tier 3 Milestones
Milestone: Execution Plan • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Communicate the team's Year 3 plan to execute the project ○ Process for monitoring the project ○ Explain team organization and structure 	Milestone: Pre VTI complete • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Propulsion System Integration (PSI) teams report any issues found after self-performed VTI ○ Issues found are shared with the team for correction ○ Critical fastener photo documentation ○ Photos captured for each row in the VTI Checklist
Milestone: Human Machine Interface & User Experience (HMI/UX) Work Plan • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Communicate the team's Year 3 plan for the sub-team ○ Overview of the sub-team's organization and structure ○ Process for monitoring the subteam development 	Milestone: Sensor Fusion Complete for Front Forward-Facing Sensor • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Base Sensor Fusion algorithm is complete ○ All forward-facing sensors are operating in the team mule vehicle
Milestone: VTI Check • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Inspect the vehicle for any obvious safety concerns ○ Photo documentation of critical fastener protocol in place ○ Photo documentation of any issue found ○ Video evidence of exhaust leak check • <u>Team Stretch Goal Criteria</u> <ul style="list-style-type: none"> ○ Pass without having to resubmit for 80% of points 	Milestone: Torque Split Algorithm (TSA) Functions Properly in HIL • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Power moding functionality in HIL complete ○ Propulsion System Active (PSA) mode testing in HIL complete ○ Constraints in HIL have been tested ○ Fault and diagnostics logic tested in HIL ○ TSA functions as intended in HIL

Milestone: System Safety Fall Update ○ <u>Acceptance Criteria:</u> ○ Submit the team version of Systems Theoretic Process Analysis (STPA), System Element Fault Analysis (SEFA), System Functional Interface Analysis (SFIA), and Requirements Traceability Matrix (RTM)	Milestone: Start Basic VIL Testing • <u>Acceptance Criteria:</u> ○ Sendyne board for high voltage isolation is working as intended ○ Communication between MabX and inverter has allowed for rear wheel spin ○ The HEV 4 battery can be charged using teamdesigned control logic ○ The newest Zebra Charlie (ZC) EMC is working as intended in the vehicle ○ Stock steering wheel buttons are communicating with MabX
Milestone: Green Garage Blog Post #1 • <u>Acceptance Criteria:</u> ○ Alumni Feature Three Photos	
Milestone: Functional Safety Check • <u>Acceptance Criteria:</u> ○ Inspect the vehicle for any obvious safety concerns ○ Photo and video documentation of high voltage and low voltage operations working correctly	
Milestone: Propulsion System Functionality Check • <u>Acceptance Criteria:</u> ○ All PCM protocols are functioning as intended ○ No safety concerns detected ○ Photo and video documentation of system working properly	
Milestone: Youth Outreach Activity #1 • <u>Acceptance Criteria:</u> ○ A 60-second video about the project and team	

2.3 Milestone 2: Vehicle Ready for Testing

2.3.1 Overview

This milestone marks the completion of all Fall VTI issues resolved, defined as Phase 2 of the Year 3 Competition. From this milestone forward, the vehicle will be ready for controls development, and testing and all forward-facing CAVs hardware has been transferred from the team's mule vehicle to the competition vehicle. Several Tier 2 level milestones have been defined with relevant acceptance criteria, and team defined stretch-goal criteria to accomplish the ready for testing phase-end milestone. Since Winter Workshop (WW) is designed as a mid-year review and preparation for the remaining Year 3 portion of the competition, the team decided that no Tier 3 milestones were required.

2.3.2 Scope

Milestone: Vehicle Ready for Testing (Phase 2 - End Milestone)

- Acceptance Criteria:
 - All issues identified during VTI in the Fall have been resolved
 - Complete a continuous drive of at least 25 miles with an average speed of at least 35 mph (closed-course or dynamometer)
 - A total accumulation of 100 miles
 - Forward-facing CAV sensors, connectivity hardware, and compute components are operable on team vehicle
 - The vehicle can accelerate and brake when receiving requests from CAVs Adaptive Cruise Control (ACC) systems
- Team Stretch goals:
 - At least 60 miles of accumulation for CAVs perception system testing for forward-facing sensors responsible for longitudinal control

Table 2: Phase 2 - Tier 2 and Tier 3 Milestone Definitions / Acceptance Criteria

Tier 2 Milestones	Tier 3 Milestones
Milestone: Green Garage Blog Post #2 • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Technical Feature Highlight ○ Three Photos 	<u>None for this phase</u>
Milestone: Fall Vehicle Evaluation • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Demonstrate functionality of Cohda wireless system through bench testing ○ Cohda wireless unit can transmit and receive BSM, Signal Phase and Timing (SPAT), and Map Data (MAP) ○ Vehicle propulsion using engine with P4 motor assist ○ Documentation of basic functionality of PCMCAs interface 	
Milestone: WW Pre-Submission: Longitudinal Controls Pre Check <ul style="list-style-type: none"> • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Develop requirements to define how longitudinal control modes will be engaged and disengaged using steering wheel buttons and pedal controls ○ Develop a test plan for longitudinal control verification 	
<ul style="list-style-type: none"> ○ Log all CAVs - PCM interface signals ○ Test all forward-facing sensors on the competition vehicle 	

Milestone: WW Pre-Submission: Testing in a Simulation Environment • Acceptance

Criteria:

- Report team status of testing environments for PCM (model and hardware-in-the-loop, leading in to vehicle testing
- Report team process for CAVs
- Acknowledge areas of issues for PCM and CAVs
- Vehicle evaluation

CAN Logs

Milestone: WW Pre-Submission: Controls Submission

- Acceptance Criteria:
 - Document and prepare team questions for lateral control
 - Report status of energy management strategies
 - Open discussion of any controls or modeling questions

Milestone: WW Pre-Submission: WAVE Test Plan

- Acceptance Criteria:
 - Develop and submit the team's test plan for the WAVE event

Milestone: WW Pre-Submission: System Safety Update

- Acceptance Criteria:
 - Status update of all System Safety tool development and execution of tools through Year 3

Milestone: WW Pre-Submission: HMI/UX Submission

- Acceptance Criteria:
 - Status update of the initial HMI/UX plan

2.4 Milestone 3: Vehicle Testing Complete

2.4.1 Overview

The Phase 3, Tier 1 milestone marks the point in which the team is ready for the Spring Vehicle Evaluation, and potentially ready for Final Competition with some minor corrections following the Spring Evaluation. Therefore, it is critical that all vehicle integration of components and systems are completed to a level that supports competition-level operations and functionality. To accomplish this Phase 3-end milestone, several Tier 2 and Tier 3 level milestones have also been defined with relevant acceptance criteria, and team defined stretch goal criteria.

2.4.2 Scope

Milestone: Vehicle Integration Complete (Phase 3 - End Milestone)

- Acceptance Criteria: ○ Accumulate 400 total test miles with the competition vehicle

- Complete a continuous endurance drive of at least 100 miles with an average speed of at least 35 mph
- Validate the vehicle can operate at all speeds up to 75 mph
- Validate the vehicle can operate at speeds up to 45 mph with CAV systems and longitudinal control enabled
- The vehicle is able to transmit and receive BSM and SPAT/MAP messages in real-time
- Stretch Goals
 - Accumulate another 150 test miles with the competition vehicle
 - Accumulate 150 miles for CAV perception system testing
 - Accumulate 150 miles for longitudinal control testing
 - Endurance run of 75 miles of continuous driving with longitudinal control engaged

Table 3: Phase 3 - Tier 2 and Tier 3 Milestone Definitions / Acceptance Criteria

Tier 2 Milestones	Tier 3 Milestones
Milestone: Youth Outreach Activity #2 • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Develop an educational PowerPoint for teachers to download ○ Hands-on module for students related to the auto industry ○ Worksheet for students about EcoCAR 	Milestone: 250 Miles Accumulated • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ 100 miles for CAV perception system testing ○ 150 miles accumulated in any testing • Team Stretch Goal Criteria: <ul style="list-style-type: none"> ○ Any additional mileage accumulated
Milestone: Green Garage Blog Post # 3 <ul style="list-style-type: none"> • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Youth Outreach Event ○ Three Photos 	
Milestone: Final Technical Report <ul style="list-style-type: none"> • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Current ACC status ○ Report on team's lateral control ○ Fusion system update ○ Vehicle energy consumption 	
Milestone: Youth Outreach Activity #3 • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Complete an outreach event 	

2.5 Milestone 4: Ready for Year 3 Final Competition

2.5.1 Overview

The Phase 4, Tier 1 milestone marks the point in the competition when the vehicle will be able to pass all competition level safety and technical inspection criteria and is ready to ship to final competition. To accomplish this Phase 4-end milestone, Tier 2 and Tier 3 level milestones have also been defined with relevant acceptance criteria, and team defined stretch-goal criteria.

2.5.2 Scope

Milestone: Ready for Year 3 Final Competition (Phase 4 - End Milestone)

- Acceptance Criteria:
 - Vehicle (as shipped) has been inspected and confirmed to meet all VTI requirements
 - Implementation of basic energy management strategy and fault detection
 - Controls are validated to be robust and reliable
 - CAV system functionality issues are resolved
 - CAV system is robust and reliable to complete all CAV dynamic events
 - Final CAV software is flashed, validated, and ready for use

Table 4: Phase 4 - Tier 2 and Tier 3 Milestone Definitions / Acceptance Criteria

Tier 2 Milestones	Tier 3 Milestones
Milestone: Green Garage Blog Post # 4 <ul style="list-style-type: none"> • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ Sponsor Highlight ○ Three Photos 	Milestone: Pre-Competition Rehearsal <ul style="list-style-type: none"> • <u>Acceptance Criteria</u> <ul style="list-style-type: none"> ○ Perform a practice run of PCM dynamic competition events ○ Perform a practice run of CAVs dynamic competition events
Milestone: Spring Vehicle Evaluation • <ul style="list-style-type: none"> • <u>Acceptance Criteria:</u> <ul style="list-style-type: none"> ○ The vehicle can operate at 75 mph for 30 seconds ○ The vehicle can operate at 45 mph with CAVs system active ○ Vehicle control can be done with V2X information 	

3.0 Project Activities and Magnitude Estimation

The Agile Management method enables teams to take milestones and simplify them into more manageable tasks for team members. In order to have a functional VDP, the WVU team has established a standard of work that best aligns with the team's attitude and health. An agile epic is a large body of work or idea that can be broken down into a more generalized set of tasks, called stories, that coordinate with the length of a team's sprint duration. Stories that form an epic can be divided further into individual tasks that each sub-team is able to quickly understand and complete. Tasks are managed using a Microsoft Teams account, a software tool based around the agile management approach of a Kanban Board System. The Kanban system provides task status of "To Do," "Doing," and "Done"; however, including too many detailed tasks can distort the vision of the critical paths and jeopardize the clarity of the overall timeline. To combat this issue, stories can be tracked on a time-dependent project timeline using the Kanban System feedback in addition with traditional team lead meeting reports to monitor story progression and the epic moving forward. In Figure 2, the team's use of the Kanban system and the feedback that goes into the tracing and monitoring of a story epic and the end result of achieving a milestone is illustrated below.

Figure 2: Management monitoring system

Before the stories can be sequenced in a management timeline, they must be defined and aligned back to an epic that has a relation to a milestone. This relationship of the various project activities in agile is illustrated in Figure 3 below.

Figure 3: Milestones to Task Relationship

Following the Agile Management approach, activities for the Year 3 competition portion of the VDP will be intertwined as epics. Epics for the team for Year 3 have been outlined and based on the team's defined milestones; however, throughout the year, some stories may be converted into epics if the workload becomes too overwhelming for the story's definition.

To manage the team's stories' timeline, the magnitude of each story and their epics must be estimated. When estimating the magnitude of a story, four items of criteria have to be considered; the amount of work to do, the complexity of the work, risk in performing the work, and time/duration. Unlike traditional project management approaches, determining the time/duration to completion is not estimated within an Agile methodology. Instead, a comparative sizing approach is used. The sizing process is simple. The team takes all the stories that need to be sized and places them into a single list. Once completed, a familiar story is selected and set aside to use as a basis for comparison. Next, another story is selected for comparison to determine if it is a significant story based on experience. If the new story is more substantial, members place it above the original and move forward. A story point is then assigned to the story instead of an hour-based estimation. The team chose to use story points because they are a high-level estimation of complexity involved in the user story. Story points reflect a higher-level project timeline instead of an hour-based estimation, which focuses on a low-level estimation. For simplicity, the team selected to categorize story points as T-Shirt Sizes to help students better

understand the timescale of story points since knowledge transfer can be an issue for newer members. Table 5 below shows the scale the team uses. An application of the scale to the team defined epics and stories for the Fall semester PCM swimlane is shown in Figure 4 and Figure 5. If a story is determined to be bigger than a 2XL shirt size, then it must be broken up into two smaller stories to allow each story to be completed in a reasonable sprint.

Table 5: Magnitude t-shirt approximation scale

XS (days)	S	M (Approximately Half a Month)	L	XL (Approximately Month)	2XL (Approximately Month and a Half)
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Figure 4: Example 1 of PCM Tier 3 milestone breakdown

Figure 5: Example 2 of PCM Tier 3 Milestone breakdown

4.0 Activity Sequencing

The project timeline and activity sequencing are presented through the stories determined by the team for each swimlane. System safety is intertwined amongst all the swimlanes. In the previous section, these stories were organized into epics, but it is useful to visualize the sequencing of these stories and their relationship to VDP milestones. The story timelines for each major milestone, broken up by swimlane, are shown in Figure 7 through Figure 10. As the year continues to progress, the team can use the Agile method to develop more stories, if required, to meet VDP milestones. Each figure of the project timeline below is also broken up by the previously determined Tier 1 Milestones, with Tier 2 and Tier 3 milestones also presented on the timeline. Figure 7 presents the story timeline through Phase 1 of the Vehicle Fully Integrated and Passes VTI Milestone. Because of the proximity of this milestone, the level of detail in Figure 6 is the greatest.

Due to a higher level of uncertainty for the Spring semester milestones, the level of detail is somewhat less for the timelines presented in Figure 9 and Figure 10, with the expectation that as the semester approaches, the epics can be divided into different stories for team members to work on.

To focus on the critical path of the team, stories that are critical paths have been color-coded as red. Figure 6 shows the legend. The critical path was determined by analyzing the logical path that each dependent story followed in comparison to the T-shirt size associated with it. The individual shirt size and the repetition of the shirt size naturally highlight the critical path or critical stories for the team across all swimlanes.

Legend

Swimlane	Story/Epic	Critical Path	Tier 2 Milestones	Tier 3 Milestone

Figure 6: Activity Sequencing Legend

Figure 7 illustrates the sequencing of stories/epics leading up to the vehicle fully integrated and passes VTI milestone. The PSI and PCM teams have been identified as part of the critical path for this milestone, and some stories from the epics in Figure 6 have been subdivided to illustrate the key activities required for completion.

Figure 8 presents the story timeline for the Vehicle Ready for Testing Milestone. Significant PCM and CAVs activities must be completed leading up to this milestone, including testing of the Blazer powertrain, hybrid communication integration, and integration of the CAVs-PCM interface.

Figure 9 shows the story timeline leading up to the completion of Vehicle Testing Complete Milestone. Vehicle Testing will mark the point in which the PSI swimlane calibrations, MIL, HIL, and VIL loop testing of the control algorithm strategies, and CAVs testing of V2X communication and vehicle control is complete. For CAVs, this will lead to the completion of the CAVs final technical report. Key critical paths will lie in the CAVs and PCM swimlanes, with completion and testing of the HMI/UX interface and the completion of CAVs diagnostics, which will support the Spring Vehicle Evaluation.

Finally, Figure 10 illustrates the story timeline for the Vehicle Ready for Year 3 Competition Milestone. Last-minute changes and documentation based on a team held practice run of Year 3 competition events will continue in all swimlanes, as well as creation of final presentations.

Figure 7: Sequencing of Phase 1 – Vehicle Fully Integrated and Passes VTI Milestone

Figure 8: Sequencing of Phase 2 - Vehicle Ready for Testing Milestone

Figure 9: Sequencing of Phase 3 - Vehicle Testing Complete Milestone

Figure 10: Sequencing of Phase 4 - Vehicle Ready for Year 3 Competition Milestone

5.0 Risk Analysis and Contingency Plans

To identify potential risks throughout Year 3 of the EcoCAR Mobility Challenge, the PM and other team leadership conducted a full Failure Mode and Effects Analysis (FMEA). Each risk is ranked based on the severity, occurrence, and detection (SOD) using the team developed scales. Using the SOD scales ranking system, a Risk Priority Number (RPN) is assigned to each risk. This system adds a fair amount of ambiguity when ranking each risk's true significance, so the team has adopted a supplemental approach to identify the primary risks associated with Year 3. This approach incorporates the team's risk appetite and risk profile for the Year 3 Milestones key risks. Using the SOD rankings of each risk, the team can generate two plots, the first addressing severity versus occurrence rating and the second addressing severity versus detection. Analyzing these plots independently allows the team to recognize risks that will have a major impact on the team more accurately. This analysis allows the team to effectively recognize and plan for potential threats to the success of the project. By identifying these risks before they happen, the team can assign appropriate proactive treatments and generate contingency plans to minimize each risk's impact. The process of developing proactive treatments and contingency plans is more important now than ever as we are operating during a global pandemic. After completing the initial Year 3 FMEA and analyzing the SOD plots generated from it, the team was able to identify the current top 4 risks to the project for both the Fall and Spring semester, as seen in Table 7. Note that for the sake of brevity, the RPN and the SOD plots are also not included for these risks.

Table 6: Top Four Risks Identified for both Semesters of EMC Y3

Risk #	<u>Top Fall Risk</u>	<u>Top Spring Risk</u>
1	Delay in making critical decisions due to the delay in the availability of critical information (University COVID restrictions, sponsor donated component information and competition rules)	Delay in making critical indecisions due to the delay in the availability of critical information (University COVID restrictions, sponsor donated component information and competition rules)
2	Loss of team members from COVID 19 policies	Loss of team members from COVID 19 policies
3	Failure to reach the learning curve of new team members	Major sponsor component breaks
4	Major sponsor component breaks	Poor design quality that results in the loss of competition points

5.1 Proactive Risk Treatments

Using the top risks identified in the FMEA, the PM can establish proactive measures for risk mitigation and avoidance. Table 8 shows each of these top Fall semester risks with their associated treatments. Emphasis is placed on the proactive aspect of these actions, as a truly effective risk treatment strategy treats risks before they occur. As the Fall semester progresses and the FMEA is re-evaluated during the next quarter, the planning for proactive treatments for the Spring semester will begin since the information is more relative and accurate. The effectiveness of the proactive treatments can then be seen by the timeline that is generated by re-evaluating the FMEA every quarter.

Table 7:Top Four Fall Risk Proactive Treatments

Risk	Proactive Treatment
Delay in making critical decisions due to the delay in the availability of critical information (University COVID restrictions, sponsor donated component information and competition rules)	With critical information missing, a decision should not be made; however, analysis to make this decision around the missing information will be expedited when that information becomes available.
Loss of team members from COVID 19 policies	Encourage all team members to follow WVU policies in and out of class while washing or sanitizing their hands before they begin work in the garage or lab and disinfect all working spaces and tools used before leaving for the day. The team will operate on a hybrid system allowing for students to work remotely when possible or schedule with their respective leads an alternative time when they can work as a small group in the labs or garage while following COVID-19 polices. In addition, leads are required to track not only attendance but log members times for contact tracing.
Failure of new team members to meet the learning curve	Adopt an effective onboarding strategy to ensure that all students who take the WVU course associated with AVTC's are both hardworking and willing to learn. With this plan in place, it is up to the team leadership to generate and provide the appropriate training tools and documentation for new team members.

Major sponsor component breaks

Be thorough with integration plans and control strategy; the System Safety Team and Engineering Manager should review and approve all integration activities to minimize the possibility of component failure.

5.2 Contingency Plans

For the project's top risks, the team has established a contingency plan to be prepared for the worst risk if they come to life even after the proactive treatment has been applied. The team's contingency plans are a proactive strategy to be able to continue operating if or when a risk impacts the team's quality triangle (Time, Scope, Cost). In order for these contingency plans to be affected, either each Tier 1 milestone completion requires a review session, which is held by the Project Manager, or the risk occurring is easily detectable. The review session involves all team leads to ensure no amendments are needed, and everyone in a leading position knows how to handle the risk if or when it accrues. Table 9 below shows the team's contingency plans for the current top fall risk.

Table 8: Top Four Fall Risk Contingency Plans

Risk	Contingency Plans:
Delay in making critical decisions due to the delay in the availability of critical information (University COVID restrictions, sponsor donated component information and competition rules)	Sub-teams will be assigned other tasks in order to overcome the delay based on team defined deadlines. The plan will be led by the Project Manager and team leadership.
Loss of team members from COVID 19 policies	<p>The team will operate as a hybrid system if remaining team members are allowed to be physically in labs or the garage while having students shift workloads as needed, not to delay the scope timeline.</p> <p>If the university stops all hybrid work for the team, the scope timeline will be re-evaluated by the team leadership, and virtual work will continue for the project.</p>
Failure to reach the learning curve of new team members	Team leads will assign sub-teams with training programs from previous documentation to give new team members a clearer understanding of the tasks at hand while transferring critical work to more veteran team members who have the available time for a larger workload.
Major sponsor component breaks	Sub-teams will be assigned to other tasks in order to maximize efficiency elsewhere. While the team leads analyze the component break and the project manager will begin fast-tracking the procurement process and with the engineering manager's assistance, re-evaluate the scope timeline.

6.0 Process for Monitoring and Controlling the Project

The approach for monitoring and controlling the project is trifold, following Agile Management practices. After defining the critical path with epics, stories, and tasks discussed earlier; the PM can allocate team resources to priority items by assessing team progress with a story burndown chart, monitoring progress of task and the team through small group meetings, and tracking and measuring risk impact with a risk register. As discussed earlier, epics are larger bodies of work that can be broken down into several smaller stories. With the combination of these three measures of progress, the project status can be compared from each method and easily evaluated at any given point to ensure the team is on track to meet the VDP milestones and be a strong competitor in the EcoCAR Mobility Challenge.

6.0 Project Monitoring Methods

6.1.1 Progress Tracking

The team elected to utilize a story burndown approach to track project status and progress. Tracking progress through stories is more accurate than following the epic level and offers agility on the sub-team level by permitting sub-teams to define tasks and internal low-level deadlines at their leisure. Story level tracking ensures the project will remain on a structured timeline while avoiding micromanaging sub-teams. Utilizing a burndown chart (Figure 11), a graphical representation of how quickly the team is working through the team-defined stories, the PM can identify if the team is on track to complete all story level activities within the defined timeline.

Figure 11: Story Burndown Chart

6.1.2 Small Group Meetings

The team leadership meets with small sub-team groups weekly, either physically or virtually. During these sessions, subteam members can easily and openly communicate areas of concern with their voice and body language during meetings based on the meetings' nature. These meetings allow leads to get a better sense of the sub-team and how it is progressing because these meetings happen consistently and are at a personal level for team members.

6.1.3 Risk Management and Tracking

Based on the past accuracy of the FMEA defined by the PM, a risk register will be used to manage project-level risks associated with the team throughout Year 3 of the VDP. The risk register identifies each risk and provides a short description along with the date of occurrence as well as mitigation action. The probability and impact of this risk are then defined for comparison with the FMEA. The mitigation action defined in the FMEA and the contingent action of the team is stated in order to address this risk. Finally, the progress of the contingent action is defined. Team members can track risks as they occur and are surprised to refine the FMEA throughout the project timeline using this process.

6.2 Controlling the Project

6.2.1 Project Adjustments Based on Project Status

Using the risk register, story burndown, and small group meetings; the team assesses the progress of the project to determine team status with respect to the overall timeline. Adjustments to the Execution Plan are made based on the number of available team members and the priority of assignments. While the PM can use this analysis to identify the project's current state, the tracking of individual sub-teams requires more information and structure. Microsoft Teams is a task management software that the team is using as a virtual KanBan board. A detailed example of the Project Management KanBan board is shown in Figure 12 in the Project Work Communication section below. As each task is completed and marked "done," the PM can track the number of tasks completed. Based on these analytics, the PM and

team leadership can reassign tasks and assign additional team members to problem areas at the task-level after identifying slowed progress at the story-level.

6.2.2 Status Updates to Team

Regular status updates to the students and faculty on the team will be delivered through virtual full team and sub-team meetings, Microsoft Teams post message feature, and email reminders. These updates are used to keep everyone informed with respect to project task, milestone, and deliverable status. Considering the size of the team (83 undergraduates plus graduate students and faculty), frequent full team meetings utilize a massive amount of lab time which is more strained now during the global pandemic. To compensate for this, team leads only host these meetings to cover critical project topics. To distribute low-level updates, the team leadership meets with individual sub-teams following team lead meetings. This system helps maximize the progress of team members during their required work hours. Any additional information on project status is sent through update emails; this efficiently disseminates updates to the entire team. Emails have the added benefit of allowing team members to have a log of these updates to access later. Status can also be ascertained from the virtual KanBan board and post is made through Microsoft Teams.

6.2.3 Project Work Communication

As the year progresses, the team will communicate upcoming work to the team through Microsoft Teams, which serves as a hub for team collaboration outside of the available facilities. This program gives the team the ability to create and distribute assignments to individual team members. Tasks are generated and placed in either the To-Do Bucket or the To-Do Backlog Bucket. The To-Do Backlog Bucket allows the team more freedom to identify tasks for the long term without cluttering the To-Do Bucket. When team members are assigned an item, that task is relocated to the Doing Bucket. All tasks in the Doing Bucket will show the team member responsible for that specific task. Once a task is completed, it is moved into the Done Bucket. Tasks in the Done Bucket must be approved by a team lead before it can be check marked and listed as complete. Figure 12 below shows an image from Microsoft Teams showing how tasks are organized, including the assigned due date, task status, who is assigned the task, and priority.

Figure 12: KanBan Board

In Figure 12, the current tracking of the PM swimlane is shown. The various buckets described above are listed with tasks distributed between them. The callouts describe the various tools used to assign responsibility, priority, status, and deadlines.

7.0 Team Organization and Structure

In order to efficiently execute the team designed Year3 schedule the roles and responsibilities of the team and each swimlane and the meeting cadence of each swimlane has to be clear and organized. The WVU team is large in size which makes such a task even more important as it is the goal of the team for Year 3 to maintain the feeling of a positive team community as we are more separated than normal and clear communication will be even more important. In the figures and tables below

the overall team and each swimlane that makes up the team will highlight the roles and responsibilities followed by the meeting cadence of each. In addition, a description of all roles and types of meetings are defined after the initial figure is highlighted for the topic of focus.

7.1 Overall Team

7.1.1 Overall Team Roles and Responsibilities

Figure 13: WVU EcoCAR Team Hierarchy

Table 9: Roles and Responsibilities of Team Leadership

Project Manager	All Faculty Advisors	The Project Manager (PM) is responsible for several project-level areas, including the budget, task schedule, scope management, stakeholder management, risk management, and conflict management. The PM will develop the overall project timeline and work plan and is responsible for tracking and executing all project-level activities, knowledge transfer, and recruiting/retention activities. Scheduling stakeholder visits and reserving meeting rooms is also necessary for the person filling this role. The PM must also be a graduate student with a technical background.
Engineering Manager	Project Manager, Technical Faculty Advisors	The Engineering Manager (EM) provides technical expertise and continuity throughout a large portion of the four-year program. The EM is tasked with providing technical supervision to all technical swimlanes to meet program deliverables. The EM is also responsible for providing training and executing knowledge transfer to new graduate and undergraduate students in all technical swimlanes. The EM should also be an expert to consult about the overall vehicle and subsystems design.
Communications Manager	Project Manager, Communications Advisor	The Communications Manager is to oversee all communications sub-team members and delegate tasks according to each sub-team member's specific skills. The Communications Manager is the primary media and special event contact for all events to ensure consistency and clarity between outside contacts. Particular emphasis is placed on youth outreach and the value of STEM (science, technology, engineering, and math) education.
System Safety Lead Engineer	Project Manager	The System Safety Lead Engineer develops and coordinates the information needed to ensure that the team's competition vehicle is compliant with all system safety criteria. They are responsible for completing all of the system safety deliverables for each year of the competition.
PCM Leads	Engineering Manager, Project Manager, Technical Advisors	The PCM Leads are responsible for fault analysis, supervisory control strategy design, and the implementation of the control strategy.
CAVs Leads	Engineering Manager, Project Manager, CAVs Faculty Advisors	The CAVs Leads are responsible for designing, implementing, and testing software related to connectivity and automation on the Chevrolet Blazer.
PSI Leads	Engineering Manager, Project Manager, PSI Faculty Advisor	The PSI Team Leads are responsible for all work need to integrate the team's propulsion system into the vehicle. This work includes CAD packaging, component procurement, wire harnessing, component integration.

7.1.2 Overall Team Meeting Cadence

OCTOBER 2020					CALENDAR MONTH		OCTOBER
					CALENDAR YEAR		2020
					1ST DAY OF WEEK		MONDAY
Monday	Tuesday Saturday	Wednesday Sunday	Thursday	Friday			
	28	29	30	1	2	3	4
				GM Mentor Meeting (9 am - 10 am)			
	5	6	7	8	9	10	11
EcoCAR Class Time (2 pm - 5 pm)	GRA Lead Meeting (1pm - 2pm)	EcoCAR Class Time (2 pm - 5 pm)	GRA/Faculty Meeting (3:30pm - 4:30pm)	GM Mentor Meeting (9 am - 10 am)			
12	13	14	15	16	17	18

Figure 14: High-Level Typical Meeting Calendar

Table 10: Whole Team Meeting Type Descriptions

Type of Meeting	Who Attends the Meeting	Description of meeting
GRA Team Lead Meeting	<ul style="list-style-type: none"> Project Manager Engineering Manager Communication Manager GRA CAVs students GRA PCM students 	Team leads update each swimlane on schedule status, areas of concern and brainstorm plans for the next week. In addition, leads communicate time they need directly with the competition vehicle or any closed-course traveling that needs to take place.
GRA / Faculty Meeting	<ul style="list-style-type: none"> Project Manager Engineering Manager Communication Manager GRA CAVs Students GRA PCM Students, PSI Faculty Advisor CAVs Faculty Advisor Comm Faculty Advisor 	During this meeting leads give a detailed update of progress and any areas of concerns or issues that have developed. In addition, the next week's plan is confirmed for each swimlane.
GM Mentor Meeting	<ul style="list-style-type: none"> Project Manager Engineering Manager GRA CAVs students GRA PCM students Technical Faculty Advisor 	During these meetings, the team updates the GM mentor on project activities, progress, and plans for future work. Questions are also asked when needed and feedback is requested on critical decisions the team must make.
EcoCAR Class Time	<p>All students who are register for the WVU EcoCAR course from any university department, which covers the following swim-lanes</p> <ul style="list-style-type: none"> CAVs PCM PSI 	During course time students work and/or meet with the swimlane leads to get project updates, schedule changes, and overall guidance on any questions a student has. As a result of COVID-19 the team has allowed groups to expand outside typical hours with the understanding students have agreed to 6 hours of working time a week.

7.1.3 Overall Team Communication Protocol

The team utilizes both traditional forms of communication and modern approaches in staying contented and up to date. All critical whole team updates, meetings, and reminders are communicated by either the PM or EM as early as possible and often to keep all team members in the information loop. For each swimlane the tools used to communicate with members vary from software used for virtual meetings, more personal group text chats, or consistent traditional emails.

Table 11: Types of Communication used by the Team

Communication Method	Description
In -Person work/meetings	These meetings are more personable and are more for students to work hand in hand with their GRA leads on the project.
Virtual Meetings	Teams use either Microsoft teams or Zoom when scheduling the meeting. Using these tools allows students to re watch a meeting session if they had a timing conflict or work hand in hand with team leads through a screen sharing program for software and deliverable development. In addition, to boost team moral, leads are required to have their video cameras on and encourage all virtual party members to turn on their cameras as well.
Phone communication	Each sub-team uses Group Me in order to quickly connect and update members on task/status.
Email Communication	Traditional method of communication by email is used consistently to provide announcements and documentation This encourages students to check their emails more than once a day and feel comfortable reaching out to a lead through email.
Purchasing	<p>The procurement process is communicated through the PM from initial purchase to tracking. To increase the ability for the team to purchase as needed and reduce internal purchasing delays. The team has established an excel file for team members to communicate what needs to be purchased and why.</p> <ul style="list-style-type: none"> • PSI <ul style="list-style-type: none"> ○ PM or EM purchase • PCM <ul style="list-style-type: none"> ○ PCM lead purchases • CAVs <ul style="list-style-type: none"> ○ PM purchases

7.2 Connected Automated Vehicles (CAVs) Swimlane

7.2.1 CAVs Roles and Responsibilities

Figure 15: CAVs Hierarchy

Table 12: Roles and Responsibilities of CAVs Sub-team

Role	Responsibilities
CAVs Team Leads	<ul style="list-style-type: none"> Assigns tasks to sub-teams and individuals Oversees the implementation of all CAVs hardware and software in the Blazer and mule vehicle Helps finalize deliverable submissions Communicates with other sub-teams for interfacing
Cohda Wireless	<ul style="list-style-type: none"> Tasked to get all training on Cohda Wireless Directly works inside of the Cohda Wireless box Make test plans on how to test the Cohda Wireless Research wireless communication abilities with Road Side Unit (RSU) and On Board Unit (OBU)
Hardware Testing	<ul style="list-style-type: none"> Tasked to carry out testing all CAVs hardware Integrate CAVs hardware into Mule vehicle to test File reports on all driving tests done and report back with a status
Hardware Integration	<ul style="list-style-type: none"> Tasked to integrate all hardware into the Blazer Creates wiring diagrams for mule vehicle hardware Creates wiring diagrams before the hardware is installed into the Blazer Corrects any diagrams after the hardware has been installed
Sensor Fusion Parser	<ul style="list-style-type: none"> Tasked to research parser techniques Tasked to communicate with other Sensor Fusion groups to see what signals they would need Tasked to create an overview document of all signals being sent and received at every part in the CAVs system Implement Parser into C++, Rust, and MATLAB languages Integrate completed Parser algorithm onto Tank
Sensor Fusion Extended Kalman Filter (EKF)	<ul style="list-style-type: none"> Tasked to research EKF theory Implement EKF into C++, Rust, and MATLAB languages Tasked to communicate with GNN to receive correct signals Integrate completed EKF algorithm onto Tank
Sensor Fusion Global Nearest Neighbor (GNN)	<ul style="list-style-type: none"> Tasked to research GNN theory Tasked to communicate with Parser to receive correct signals Implement GNN into C++, Rust, and MATLAB languages Integrate completed GNN algorithm onto Tank
ACC Integration	<ul style="list-style-type: none"> Implementing the team developed adaptive cruise control algorithm on the Intel 870 Tank and constructing the CAVs-PCM interface
ACC Optimization	<ul style="list-style-type: none"> Optimizing the team developed algorithm by researching PID controller parameter tuning, the advantages of model predictive controller algorithms, and the efficiency of a real-time Riccati equation solver
HMI Development	<ul style="list-style-type: none"> Programming the team designed solution for the human machine interface and user training
HMI Testing	<ul style="list-style-type: none"> Designing and implementing different methods of user focused research to tailor the team developing training methods and user experience technologies to the target user of the WVU vehicle
UX	<ul style="list-style-type: none"> Researching and developing user training and team developed features into the WVU vehicle

7.2.2 CAVs Meeting Cadence

OCTOBER

2020

CALENDAR MONTH		OCTOBER					
CALENDAR YEAR		2020					
1ST DAY OF WEEK		MONDAY					
Monday Saturday	Tuesday Sunday	Wednesday	Thursday	Friday			
	28	29	30	1	2	3	4
	5	6	7	8	9	10	11
Hardware Testing (3pm - 3:30pm) Development (3pm - 3:30pm) Cohda Wireless (3 pm - 4 pm) UX (3:30pm -4pm) Hardware Team (4 pm - 5 pm) ACC Team (4pm - 5pm)	Parser Team (2 pm - 3 pm) Hardware Intergration (5:30 pm - 6:30 pm)	Hardware Testing (3pm - 3:30pm) Cohda Wireless (3pm - 4pm) HMI Testing (3pm - 3:30pm) HMI/UX Team (3:30pm - 4pm) Sensor Fusion Team (4pm - 5pm) ACC Team (4pm - 5pm) EKF (5pm - 6pm)	Hardware Intergration (5:30pm - 6:30pm)	GNN (3pm - 4pm)			
	12	13	14	15	16	17	18

Figure 16: CAVs Typical Meeting Calendar

Table 13: CAVs Meeting Type Descriptions

Type of Meeting	Who Attends the Meeting	Description of meeting
Whole Sub-team Meeting	Required: <ul style="list-style-type: none"> • Single CAVs lead • Sub-team students Optional: <ul style="list-style-type: none"> • Engineering Manager • Project Manager • CAVs Faculty Advisor 	Team lead updates the sub-team virtually on general announcements and cross communication from other swimlanes.
Individual groups of each sub-team	Required: <ul style="list-style-type: none"> • Single CAVs lead • Sub-team students Optional: <ul style="list-style-type: none"> • Engineering Manager • Project Manager • CAVs Faculty Advisor 	During this meeting, leads receive status updates from team members, answer any question a student has, or schedule additional time to meet with students to help and complete task assigned to them.

7.3 Propulsion Controls and Modeling (PCM) Swimlane

7.3.1 PCM Roles and Responsibilities

Figure 17: PCM Hierarchy

Table 14: Roles and Responsibilities of PCM Sub-team

Role	Responsibilities
PCM GRA Leads	<ul style="list-style-type: none">Assign tasks to sub-teams from the critical pathFinalize deliverable submissionsMonitor/perform test cases performed in MIL/HIL/VIL
PCM Undergraduate Lead	<ul style="list-style-type: none">Shadow the PCM GRA leads to prepare for role replacementAssist in making tasks with PCM GRAsTrouble shoot issues in MIL/HIL/VIL

Sub-team n

- Teams are assigned tasks
- Tasks are loosely defined by deliverable due dates/level of difficulty/priority

7.3.2 PCM Meeting Cadence

OCTOBER		2020				CALENDAR MONTH		OCTOBER	
						CALENDAR YEAR		2020	
						1ST DAY OF WEEK		MONDAY	
Monday Saturday		Tuesday Sunday		Wednesday		Thursday		Friday	
		28		29		30		1	
								2	
								3	
								4	
		5		6		7		8	
								9	
								10	
								11	
PCM 1 on 1's (1pm - 6pm)		PCM VIL Testing (8am - 12pm) PCM 1 on 1's (1pm - 5pm)		PCM 1 on 1's (1pm - 4:30pm) PCM Team (4:30pm - 5pm)		PCM VIL Testing (8am - 12pm)			
		12		13		14		15	
								16	
								17	
								18	

PCM 1 on 1's (1pm - 6pm)	PCM VIL Testing (8am - 12pm)	PCM 1 on 1's (1pm - 4:30pm)	PCM VIL Testing (8am - 12pm)
	PCM 1 on 1's (1pm - 5pm)	PCM Team (4:30pm - 5pm)	

Figure 18: PCM Typical Meeting Calendar

Table 15: PCM Meeting Type Descriptions

Type of Meeting	Who Attends the Meeting	Description of meeting
Whole Sub-team Meeting	Required: <ul style="list-style-type: none"> • Both PCM leads • Sub-team students Optional: <ul style="list-style-type: none"> • Engineering Manager • Project Manager • CAVs Faculty Advisor • PSI Faculty Advisor 	Team lead updates the sub-team virtually on general announcements and cross communication from other swimlanes.
PCM 1 on 1's	Required: <ul style="list-style-type: none"> • Single PCM lead • Sub-team students Optional: <ul style="list-style-type: none"> • Engineering Manager 	During this meeting, leads receive status updates from team members, answer any question a student has, or schedule additional time to meet with students to help and complete task assigned to them. These meeting are in-person or virtual and last 30 minutes for each team member.

7.4 Propulsion System Integration (PSI) Swimlane

7.4.1 PSI Roles and Responsibilities

Figure 19: PSI Hierarchy

Table 16: Roles and Responsibilities of PSI Sub-team

Role	Responsibilities
PSI Team Leads	<ul style="list-style-type: none"> Assign tasks to sub-teams based on stories Finalize deliverable submissions Oversee all sub-teams and communication with other swimlanes
Electrical Lead	<ul style="list-style-type: none"> Define the critical path of all related work Assign and track tasks related to their sub-team Serve as subject matter expert on their sub-system
CAD Team Lead	<ul style="list-style-type: none"> Define the critical path of all CAD activities Serve as subject matter expert for all CAD work Takes the lead on major deliverable related tasks
Mechanical Team Lead	<ul style="list-style-type: none"> Assists EM by tracking all mechanical sub-team work Communication link between PSI Team Leads and mechanical sub-team members Relays information from competition workshops to all mechanical sub-team members
Sub-team 1	<ul style="list-style-type: none"> Work under high/low voltage sub-team leads to accomplish assigned tasks Responsible for designing and implementing high/low voltage systems into vehicle Responsible for generating documentation for knowledge transfer necessary for team continuity
Sub-team N	<ul style="list-style-type: none"> Accomplish all relevant activities to the mechanical sub-team Often made up of various groups working on specific tasks

7.4.2 PSI Meeting Cadence

Electrical (2pm - 3:30pm)		Virtual PSI Team (2pm - 2:30 pm)			
CAD (2pm -5pm)		Electrical (2:30pm - 3:30pm)			
Virtual Mechanical (2:30 pm - 5pm)	Mechanical (6pm - 8pm)	CAD (2:30pm -5pm)	Mechanical (6pm - 8pm)	Mechanical (1pm - 7pm)	PSI Alt time (1pm - 5pm)
In-person Mechanical (3:30pm - 5pm)		Virtual Mechanical (2:30 pm - 5pm)		Electrical (5pm - 7pm)	
		In-person Mechanical (3:30pm - 5pm)			

Figure 20: PSI Typical Meeting Calendar

Table 17: PSI Meeting Type Descriptions

Type of Meeting	Who Attends the Meeting	Description of meeting
Whole Sub-team Meeting	Required: <ul style="list-style-type: none"> • Both GRA PSI support leads • Sub-team students Optional: • CAVs Faculty Advisor • PSI Faculty Advisor 	Team lead updates the sub-team virtually on general announcements and cross communication from other swimlanes.
Individual groups of each sub-team	Required: <ul style="list-style-type: none"> • Single Undergraduate Lead • Sub-team students Optional: • GRA PSI support leads • PSI Faculty Advisor 	During this meeting time session, leads receive status updates from team members, answer any question a student has, schedule additional time to meet with students to help and complete task assigned to them or allow student to have space and time to work physically on the vehicle.

7.5 System Safety Working Group (SSWG)

7.5.1 SSWG Roles and Responsibilities

Figure 21: SSWG Hierarchy

Table 18: Roles and Responsibilities of SSWG

Roles	Responsibilities
System Safety Lead Engineer	<ul style="list-style-type: none"> ▪ Overlook all SS team members ▪ Hold meetings with PM, EM, and GM Mentor ▪ Compile information from all sub-team folders to form complete deliverable spreadsheets ▪ Owner of team drive and organizer of all safety documentation ▪ Maintain the Vehicle Binder with the EM and PM
PSI GRA Leads	<ul style="list-style-type: none"> ▪ Reviews system safety content ▪ Provides expertise in mechanical and electrical components evaluated in system safety
PSI Undergraduate Leads	<ul style="list-style-type: none"> ▪ Carry out system safety analysis for mechanical and electrical components ▪ Generate safety requirements specific to mechanical and electrical components
PCM GRA Leads	<ul style="list-style-type: none"> ▪ Reviews system safety content ▪ Provides expertise in vehicle controls components evaluated in system safety
PCM Undergraduate Lead	<ul style="list-style-type: none"> ▪ Carry out system safety analysis for vehicle controls components ▪ Generate safety requirements specific to vehicle controls components
CAVs GRA Leads	<ul style="list-style-type: none"> ▪ Reviews system safety content ▪ Provides expertise in longitudinal and lateral control systems evaluated in system safety
CAVs Undergraduate leads	<ul style="list-style-type: none"> ▪ Carry out system safety analysis for longitudinal and lateral control systems ▪ Generate safety requirements specific to longitudinal and lateral control systems

7.5.2 SSWG Meeting Cadence

Figure 22: SSWG Typical Meeting Calendar

Table 19: SSWG Meeting Type Descriptions

Type of Meeting	Who Attends the Meeting	Description of meeting
SSWG GRA Meeting	Required: <ul style="list-style-type: none"> • System Safety Lead Engineer (SSLE) • All technical GRAs Optional: • CAVs Faculty Advisor • PSI Faculty Advisor 	The SSLE updates all GRAs on current status of safety documentations and concerns. In addition, GRAs answer any technical questions the undergrad SSWG members could not answer or were unable to address from the previous week.
SSWG Undergraduate meeting	Required: <ul style="list-style-type: none"> • System Safety Lead Engineer • All undergraduate SSWG members from each swimlane Optional: <ul style="list-style-type: none"> • CAVs Faculty Advisor • PSI Faculty Advisor 	During this meeting time session, leads receive status updates from team members, answer any question a student has, schedule additional time to meet with students to help and complete task assigned to them, or allow students to have space and time to work physically on the vehicle.

Appendix C (Team Evaluation Forms)

Graduate Student Evaluation

1. Rate the GRA's understanding of the technical content of your sub-team *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

2. Please rate the GRA's communication with team members *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

3. How Hands-On was the GRA with the team? *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

4. Rate the GRAs engagement to the overall EcoCAR project (Not your sub-team). *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

5. Rate how well your GRA gave feedback on task *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

6. How do you rate the workload given to you by the GRA? *

	1	2	3	4	5	
Easy	☐	☐	☐	☐	☐	Too Much

7. Rate the overall performance of your GRA. *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

8. How would you rate the the level of choices for outreach events or effect of a social media campaign? *

	1	2	3	4	5	
Poor	☐	☐	☐	☐	☐	Excellent

9. How difficult was it for you to participate in social media campaign this semester *

	1	2	3	4	5	
Horrible	☐	☐	☐	☐	☐	Super Easy

10. Did you like having lab time broken up to focus on your sub-team *

- ☐ Yes
- ☐ No

11. Did you enjoy your semester with the Team *

- ☐ Yes
- ☐ No

12. Please leave your comments, concerns, and feedback about the GRA or the swimlane *

Long answer text

13. Do you think the GRA was a good leader? *

- ☐ Yes
- ☐ No

Peer Evaluations

[illegible]

Suggested Scale for A (1-7)	
1	Never assisted on EcoCAR task
2	Contributed very little
3	Contributed their time to EcoCAR task occasionally
4	Contributed work for half the semester
5	Contributed a majority to team task but slacked occasionally
6	No questions about them completing a task on time for the team
7	Willing to work on any task regardless of how many they had helped with

Suggested Scale for B (1-6)	
1	What, they were on my team?
2	I saw them less than half the semester
3	Part of the team, but communication was a struggle
4	Part of the team, yet only communicated during class
5	I was able to communicate with them outside of class
6	A quick response from them was never a issue

Suggested Scale for C (1-7)	
1	Never assisted on EcoCAR task
2	Contributed very little
3	Contributed their time to EcoCAR occasionally
4	Contributed work for half the semester
5	Contributed a majority of time but slacked occasionally
6	Contributed work consistently
7	Above and beyond on EcoCAR task

Appendix D (Meeting Agenda Template)

Location: {room-or-virtual}:
Date: :
Time: :

[Name-of-Meeting]-Meeting-Agenda

Attendees: {Mandatory-Attendees}

I. → [Topic-1]

{Duration-Length} {End-Time: x:xx}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

II. → [Topic-2]

{Duration-Length} {End-Time: x:xx}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

III. → [Topic-3]

{Duration-Length} {End-Time: x:xx}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

IV. → [Topic-4]

{Duration-Length} {End-Time: x:xx}

→ Key talking point {speaker} {Material-required-for-screen-sharing-yes-or-no}

V. → [Topic-5]

{Duration-Length} {End-Time: x:xx}

→ Meeting Q and A from Stakeholder

Follow-Up Notes:

Appendix E (Completed Change Management Form)

WVU EcoCAR Mobility Challenge Change Request Form:	
CR#	_____
Title	_____
Proposer	_____ Date Submitted _____
Previously Related Changes (List Change Request Number, if known)	
<div></div>	
Detailed Description	
<div></div>	
Suggested Solution	
<div></div>	
Justification	
<div></div>	
Definitions of Change	
Level of Change:	
Schedule Change:	
Budget Change:	
Scope Change:	
Authorized Approver(s) Per Change Management Roles:	
Signed _____	
FOR AUTHORIZED APPROVER ONLY	
Change Control Tracking Notes:	
Change Request Submittal:	
Change Request Tracking:	
Change Request Review:	
Change Request Disposition:	

Appendix F (RDD Template)

Name this document with the following naming convention:

RDD_[Source]_[Section]

[Example: RDD_NYSR Rev I_I-4.1]

Source: [NYSR Rev X, Yearly Rules Rev X, Team Generated, etc.] |

Section: [Example: I-4.1]

System: [HV system, fuel system, LV system, etc.]

Date: XX-XX-XXXX

Procedure:

Step 1: In the area below, paste in the raw source data to be distilled into requirements. Full Justify (Be careful, pasting from PDF often does not carry through bullet points or returns)

[Insert Text Here]

Step 2: Copy and paste each paragraph into the cells below to track paragraph number. Label the sentence number in each paragraph in red text color.

P	Description

Step 3: Distill the paragraph into the tables below by sentence

P	S	Description

P	S	Description

P	S	Description

P	S	Description

P	S	Description

Step 4: Copy tables from previous section and rewrite the text as requirements. Some quick tips: Requirements should be specific and clear. They should outline a measurable quality to be obtained. General nomenclature in the following format: "the thing shall do this". (For more information on how to write good requirements, see training in PSI OneNote)

P	S	Requirement

Step 5: Copy these tables to the summary page and fill out required information

Summary:

Source:

Version:

Section:

Appendix G (RTD Template)

<h1>Testcase Documentation</h1>	
Testcase ID:		Testcase Edition:	Rev 1
Test Type:		Test Date:	
Requirement Description:		Test Performer:	
Testcase Description:		Flashed Version:	
Required Equipment:		Test Location / Environment:	
Testcase Author:		Weather:	
Written Date:		Setup Issues:	

Setup Procedure:		Test Results & Issues:	
Test Procedure:			
Teardown / Post Processing:		Teardown Issues:	
Pass/Fail Criteria:		Test Result:	Hard Pass
Hard Pass Actions		Background/ Suggestions:	
Soft Pass Actions			
Fail Actions			

Appendix H (SEFA Worksheet)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
				PRIMARY Fault			RESULTING Fault			Element Operating States												
Item Number	"Operating Scenario"	Function(s) (Responsibilities)	Operating Fault	CAV's Processor	BCM	PRNDL	Brake Pedal	Accelerator Pedal	EBCM	HSC	DC/DC Converter	12V Battery	HV Battery	Inverter	Radar Sensor	Mobileye sensor	EOCM	TCM	ECM	HV Isolation Board	Raptor Gateway Module	Motor
1	BCM	Provides Cruise Control Switch State to ECM; Sends power moding signals to the HSC; Sends warning lights for MIL illumination	Cruise control/ACC state failed to be sent from BCM Forward Object alert indication signals failed to be sent from the BCM	1	0	1	1	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1

X	Y	Z	AA	AB
Impact of Element Fault <i>(Impact prior to any remedial or mitigation actions)</i>	Immediate Resulting State <i>(State of the system prior to any remedial or mitigation actions)</i>	Potential Safety Hazard(s)	Diagnostic Method(s)	Mitigation Action(s)
ECM would not receive the cruise request from BCM.	Cruise control continues to operate at last value ECM was given; Potential unintended acceleration; Acceleration isn't smooth	Flashing of warning lights for MIL illumination; Unintended acceleration	ECM and/or HSC detects loss of communication with BCM	ECM or HSC detect loss of communication with BCM, then they can disable the cruise control/ACC
ECM would lose adaptive cruise control request from BCM;	Cruise control continues to operate at last value ECM was given(ACC is turned off); Potential unintended acceleration; Acceleration isn't smooth	Flashing of warning lights; Unintended acceleration	HSC recognizes lack of forward object indication signals from BCM	HSC disables ACC and LKA

AC	AD	AE
System State After Mitigation	SAFETY Requirements	Requirement ID
Cruise Control/ACC are disabled	HSC shall detect the loss of communications with BCM within 500ms.	CAN Communication-HSC-1250
	HSC shall disable LKA when a loss of communication with the BCM is detected.	CAN Communication-HSC-1251
	HSC shall disable ACC when a loss of communication with the BCM is detected.	CAN Communication-HSC-1252
	HSC shall illuminate the MIL when ACC is disabled due to a loss of communication between the HSC and BCM.	CAN Communication-HSC-1253
	HSC shall illuminate the MIL when LKA is disabled due to a loss of communication between the HSC and BCM.	CAN Communication-HSC-1254
ACC is disabled Lane Keep Assist disabled	HSC shall detect the loss of feedback of the forward object alert signals within 500ms from detection.	CAN Communication-HSC-1255
	HSC shall illuminate the MIL when ACC is disabled due to a loss of feedback from the forward object alert signals.	CAN Communication-HSC-1256
	HSC shall illuminate the MIL when LKA is disabled due to a loss of feedback from the forward object alert signals.	CAN Communication-HSC-1257

Appendix I (STPA Worksheet)

A	B	C
Driver/Occupant Control Functions (Actions or Responsibilities)	"NOT Providing" Cause Hazard	"Providing" Cause Hazard
CA-1: Driver sets cruise control, enabling automatic speed control	UCA-1: Driver attempts to activate cruise control but fails to do so - driver thinks that the cruise control is enabled UCA-2: Driver attempts to disable cruise control but fails to do so	UCA-3: Driver unintentionally activates cruise control
CA-2: Driver sets increased or decreased cruise control speed	UCA-6: Driver intends to increase speed but fails to do so (maintaining current speed) UCA-7: Driver intends to increase speed but fails to do so (decreases current speed) UCA-8: Driver intends to decrease cruise speed but fails to do so (maintaining current speed) UCA-9: Driver intends to decrease cruise speed but fails to do so (increasing current speed)	UCA-10: Driver unintentionally increases cruise control speed UCA-11: Driver unintentionally decreases cruise control speed - rate limiting
CA-3: Driver increases or decreases ACC gap	UCA-16: Driver intends to decrease ACC gap but is already out of safe following distance (<15m) UCA-17: Driver intends to increase gap but the car in front is decreasing speed rapidly UCA-18: Driver intends to increase gap but fails to do so	UCA-19: Driver mistakenly accelerates decreasing ACC gap UCA-20: Driver mistakenly decelerates increasing ACC gap
CA-4: Driver activates lane keep assist, enabling automatic steering control	UCA-23: Driver intends to activate lane keep assist but fails to do so UCA-24: Driver activates blind spot monitoring instead of lane keep assist	UCA-25: Driver enables lane keep assist instead of blind spot monitoring
CA-5: Driver engages brake pedal to decelerate	UCA-27: Driver pushes brake pedal too hard UCA-28: Driver presses brakes instead of accelerator UCA-29: Driver presses accelerator instead of brakes	UCA-30: Driver applies brakes late due to slow reaction time UCA-31: Driver unable to apply brakes
CA-6: Driver engages acceleration pedal to accelerate	UCA-34: Brake pedal sensor has a significant dead band UCA-35: Driver unable to apply accelerator pedal UCA-36: Vehicle shuts down due to dead battery and driver fails to accelerate	UCA-37: Driver unintentionally pushes acceleration pedal instead of brakes
CA-7: Driver activates the PRNDL and selects a desired range state (Park, Reverse, Neutral, Drive, Low)	UCA-40: Driver does not press brake pedal and attempts to engage PRNDL	UCA-41: Driver mistakenly pushes PRNDL UCA-42: Driver shifts to reverse while vehicle is in forward motion

D	E
Incorrect Timing Incorrect Order	Stopped Too Soon Applied Too Long
	UCA-4: Driver doesn't hold button long enough to disable cruise control UCA-5: Driver holds cruise control button too long
	UCA-12: Driver holds down button to increase speed for too long UCA-13: Driver doesn't hold button down long enough to increase speed UCA-14: Driver holds down button to decrease speed for too long UCA-15: Driver doesn't hold button down long enough to decrease speed
	UCA-21: Driver presses the increase gap switch too long UCA-22: Driver presses the decrease gap switch too long
UCA-26: Driver attempts to enable lane keep assist while changing lanes	
UCA-32: Brake sensor fails and driver fails to apply sufficient brakes	UCA-33: Brake pedal sensor has a significant dead band
UCA-38: Driver applies accelerator pedal too late	UCA-39: Driver does not press accelerator pedal long enough
	UCA-43: Driver intends to engage Drive but only goes to Neutral

A	B	
UCA	Potential Causal Scenarios	I
UCA-1: Driver attempts to activate cruise control but fails to do so - driver thinks that the cruise control is enabled	Cruise control switch isn't accessible	(
	Faulty cruise control switch	(
	CAN Message corruption	(
		)
UCA-2: Driver attempts to disable cruise control but fails to do so	Cruise control disable switch isn't accessible	(
	Cruise control switch is not pressed enough to register action	(
	Faulty cruise control switch	(
	CAN Message corruption	(
		)
UCA-3: Driver unintentionally activates cruise control	Driver accidentally presses cruise control switch at high speeds	(
		)
	Driver accidentally presses cruise control when vehicle is stopped	(
	Fault in controller activates cruise	(
		)
	Faulty switch activates cruise	(
	CAN Message corruption	(
		)
UCA-4: Driver doesn't hold button long enough to disable cruise control	Faulty switch	(
		)
	Controller didn't recognize cruise control request	(
		)
UCA-5: Driver holds cruise control button too long	Faulty switch	(
	Driver holds cruise control button too long	(
		)

C	D
Requirements	Requirement ID
Cruise control switch shall be easily accessible and visually prominent to the driver.	Driver Interface-ACC Controls-883
Cruise control switch shall be monitored for hardware faults when cruise control is enabled	Driver Interface-ACC Controls-884
Cruise enable signal/message shall be protected when cruise control is enabled	Driver Interface-ACC Controls-885
A communication fault set by the cruise control button shall disable cruise control when cruise control is enabled	Driver Interface-ACC Controls-886
Cruise control switch shall be easily accessible and visually prominent to the driver when disabling cruise control.	Driver Interface-ACC Controls-887
Display shall clearly indicate the status of cruise control system when cruise control is disabled.	Driver Interface-ACC Controls-888
Cruise control switch shall be monitored for hardware faults when cruise control is disabled.	Driver Interface-ACC Controls-889
Cruise enable signal/message shall be protected when cruise control is disabled.	Driver Interface-ACC Controls-890
A communication fault set by the cruise control button shall disable cruise control when disabling cruise control.	Driver Interface-ACC Controls-891
Display shall clearly indicate the status of cruise control system.	Driver Interface-ACC Controls-892
Cruise control system shall prevent activation above 85 mph	Driver Interface-ACC Controls-893
Vehicle shall not decelerate greater than 3.5 m/s ² upon activation of ACC	Driver Interface-ACC Controls-894
Cruise control system shall prevent activation below 25 mph	Driver Interface-ACC Controls-895
HSC shall have internal diagnostics for cruise control switch activation	Driver Interface-HSC-896
Cruise control shall be disengaged by pressing brake pedal	Driver Interface-ACC Controls-897
Cruise control switch shall be monitored for hardware faults	Driver Interface-ACC Controls-898
Cruise enable signal/message shall be protected	Driver Interface-ACC Controls-899
A communication fault set by the cruise control button shall disable cruise control	Driver Interface-ACC Controls-900
Cruise control switch shall be monitored for hardware faults	Driver Interface-ACC Controls-901
Cruise control system should respond to switch request within 50 ms	Driver Interface-ACC Controls-902
HSC shall have internal diagnostics for cruise control switch activation	Driver Interface-HSC-903
Cruise control system should respond to switch request within 50 ms	Driver Interface-ACC Controls-904
Cruise control switch shall be monitored for hardware faults	Driver Interface-ACC Controls-905
HSC shall set cruise control switch diagnostic fault if request button is held longer than 20 seconds	Driver Interface-HSC-906
Cruise control shall be disabled until next key cycle if diagnostic fault is set	Driver Interface-ACC Controls-907