Applying the Principles of Project Management to a Collegiate Automotive Engineering Design Project

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ACADEMIC ABSTRACT

The Hybrid Electric Vehicle Team of Virginia Tech is a collegiate automotive engineering design team that reengineers production vehicles to reduce environmental impact while maintaining vehicle marketability. The team Project Manager is responsible for coordinating high-level management and planning activities with the goal of better aligning the team with business and automotive industry practices. Project management responsibilities within the Hybrid Electric Vehicle Team are divided into four categories: human resource management, schedule management, cost management, and risk management. This document outlines how project management strategies were researched and adapted from industry practices for use by the Hybrid Electric Vehicle Team in achieving its goals.

The human resource management strategy adopts onboarding principles that better prepare new students to become effective team members. By restructuring the organization and incorporating onboarding strategies, annual turnover is reduced from 71% to 44%. The decrease in turnover is enabled by the successful creation of an independent study program which trains newcomers to become effective team members. The program can be improved for the future by further developing the curriculum.

The employed schedule management strategy develops the project schedule iteratively as technical information reveals itself through task progress. Utilizing this process makes schedule management possible in an environment with incomplete information and pressing deadlines. This strategy experienced limited success due to the lack of team and project scheduling experience on behalf of several key members of the process.

The cost management strategy is designed to gather detailed financial data to perform an earned-value analysis and create improved budgets. By understanding income and expense patterns, the Project Manager can create economic forecasts to determine the economic viability of the team. The strategy was successfully implemented and allowed the team to gather valuable financial data.

The risk management strategy identifies and quantifies technical risks associated with vehicle development. By focusing more resources on high-risk activities, the team can improve preparation for competition where the vehicle is judged according engineering quality and build progress. The strategy was successful because it identified critical hazards to the project schedule and scope, but can be improved by broadening the process to account for a wider variety of risks.

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GENERAL AUDIENCE ABSTRACT

Since 1988, the U.S Department of Energy has sponsored Advanced Vehicle Technology Competitions, a series of collegiate automotive engineering contests that provide challenging, real-world experience to North American university students. While these competitions have evolved since their inception, the overall theme of reengineering and rebuilding a conventional vehicle to reduce petroleum energy use and greenhouse gas emissions, while maintaining safety, performance, and consumer appeal, has remained constant.

As Advanced Vehicle Technology Competitions grow in scope and technical complexity, formal project management techniques become more critical to ensure success. Dozens of technical reports and presentations are due each year, and the vehicle is evaluated according to industry-level standards.

To account for the rise in expectations, competition organizers formally introduced the Project Manager position during EcoCAR 3, the latest Advanced Vehicle Technology Competition. The role of the Project Manager is to provide management and planning responsibilities for the overall project so that the team may operate more efficiently and more closely align with business and automotive industry practices. On the Hybrid Electric Vehicle Team, the Virginia Tech EcoCAR 3 team, the role of the Project Manager can be understood in four distinct, yet related categories: human resource management, schedule management, cost management, and risk management.

Each project, in industry or otherwise, has unique characteristics that require a tailored project management plan. As a collegiate engineering design team, the Hybrid Electric Vehicle Team of Virginia Tech is particularly unique in that its schedule revolves around the academic calendar year and EcoCAR 3 milestones, its funding is dependent upon cash and in-kind donations, and its workforce of students have little real-world engineering experience. This document outlines the methodology, results, and analysis of the project management strategies designed specifically for the Hybrid Electric Vehicle Team and the environment in which it operates.

The human resource strategy is successful because it reduces annual team turnover from 71% to 44% through the establishment of an independent study program that trains newcomers to become effective team members. The schedule management strategy is designed to develop the project schedule using limited information, and was partially successful because team members lacked the project experience necessary to intelligently schedule technical tasks. The cost management strategy allows the Project Manager to effectively collect and analyze financial data to perform earned value analysis and evaluate the economic viability of the team. Finally, the risk management strategy is useful for identifying and mitigating project risks which could have the greatest impact on competition achievements.

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List of Terms and Abbreviations

ABC	Activity-Based Costing
AC	Actual Cost
ACP	Actual Completion Percentage
ADAS	Advanced Driver Assistance System
ADePT	Analytical Design Planning Technique
ANSI	American National Standards Institute
AVTC	Advanced Vehicle Technology Competition
BAC	Budget at Completion
BOM	Bill of Materials
CA	Control Accounts
CAD	Computer-Aided Design
CGRA	Controls Graduate Research Assistant
CM	Communications Manager
CP	Collaborative Program
CPB_f	Cost Project Buffer
CpE	Computer Engineering
CPI	Cost Performance Index
CV	Cost Variance
DFMEA	Design Failure Modes and Effects Analysis
EAC	Estimated at Completion
EE	Electrical Engineering
EGRA	Electrical Graduate Research Assistant
EM	Engineering Manager
ESS	Energy Storage System
EV	Electric Vehicle
EVM	Earned Value Management
EVMS	Earned Value Management System
GM	General Motors
HEVT	Hybrid Electric Vehicle Team
HV	High Voltage
IS	Independent Study
LCI	Lean Construction Institute
LFA	Lead Faculty Advisor
ME	Mechanical Engineering
MR	MakeReady
PEP	Production Evaluation and Planning
PM	Project Manager
PMI	Project Management Institute
PPC	Percentage of Promises Completed
RB	Risk Baseline
RFMEA	Risk Failure Modes and Effects Analysis
RPN	Risk Priority Number
RS	Risk Score
TM	Team Member
VAC	Value at Completion
WBS	Work Breakdown Structure

1 Introduction

Since 1994, the Hybrid Electric Vehicle Team (HEVT) of Virginia Tech has participated in Advanced Vehicle Technology Competitions (AVTCs), a series of collegiate automotive engineering competitions sponsored by the U.S. Department of Energy and managed by Argonne National Laboratory. The AVTC's mission is to offer an unparalleled, hands-on, real world experience to educate the next generation of automotive engineers. In these competitions, students work together on university teams to reengineer production vehicles to reduce the environmental impact while maintaining the vehicle integrity. Since its inception, over 16,500 students from 93 North American universities have participated in AVTCs [1].

HEVT is currently competing in EcoCAR 3, the latest AVTC, which challenges 16 university teams to reengineer a Chevrolet Camaro with the goal of reducing its petroleum energy use and greenhouse gas emissions while maintaining the safety, performance, and consumer appeal of the vehicle. HEVT is well-known at Virginia Tech, due to its sustained success and considerable alumni history; over 600 undergraduate and 25 graduate students have participated during the 22-year history.

During the 2015-2016 academic year, over 50 engineering students are contributing to the development of the competition vehicle. Mechanical, electrical, and computer engineering students, both graduate and undergraduate, work on five technical subteams in support of vehicle development. The mechanical subteam uses computer aided design (CAD) to package the components in the vehicle and perform stress analysis, and works hands-on with components to integrate them into the vehicle. The electrical subteam is responsible for the low and high voltage systems, and must ensure that components are properly powered. The controls and simulation subteams work closely together to develop mathematical models of the vehicle and its components, to both understand vehicle behavior and develop code which ensures the components work together properly. Finally, the advanced driver assistance system (ADAS) subteam creates the vehicle ADAS and develops technology in accordance with the stated innovation topic which the team determines at the start of each competition year. The goal of the current innovation topic, Ecorouting, is to determine a driving route that minimizes vehicle energy consumption compared to traditional routing methods that minimize travel time. Innovation and ADAS are both topics which are new to AVTCs. All subteams share the responsibility of ensuring that their work promotes vehicle safety.

To certify that the project is completed on schedule, within budget, and meets its technical scope, a series of project management strategies are devised specifically for HEVT. Project management responsibilities within HEVT can be studied as one of four categories: human resource management, schedule management, cost management, and risk management.

The HEVT human resource management strategy focuses on developing new students into productive team members with a focus on year-to-year continuity. Under the previous strategy, nearly every team member graduated at the end of each academic year, resulting in lost knowledge and slow progress at the beginning of each academic year. To combat these problems, an educational program is established which trains new students for their technical assignments and socially integrates them into the team. A detailed recruitment plan that outlines when certain students should be recruited is a key element of the strategy because it creates an environment of maximum continuity within the confines of university rules.

The HEVT schedule management strategy concentrates on the development of a project schedule which is both rigid enough to be useful, and flexible enough to allow for project variability. An accelerated vehicle development process as outlined by EcoCAR 3 establishes milestones for each annual competition, and the scoring structure is reflective of expectations. To produce a vehicle that will score well each year, a series of technical tasks must be accomplished which are often vaguely understood at the onset. As students work through their tasks, more and more information reveals itself, lending to the creation of more concrete plans. The schedule management strategy operates on this principle, that a plan can only be as detailed as the provided information, and allows for technical schedules to come into clearer focus as information is gathered.

The HEVT cost management strategy is designed to both gather financial data and guide intelligent spending. The team relies exclusively on cash and in-kind donations, and some income sources are more reliable and predictable than others. Expenses are categorized according to their function, either as overhead or a major vehicle subsystem. By understanding the pattern at which financial resources flow into and out of the team, future HEVT Project Managers (PM) can create more accurate budgets and protect team finances.

The HEVT risk management strategy is designed to mitigate vehicle development risks in order to maximize outcomes at annual competitions. Each year, the scoring structure shifts depending on the focus for that segment of the vehicle development process. During Year 2, the focus is on vehicle integration. The risk management strategy is designed to identify and monitor risks which could have an adverse effect on integration success.

The four project management strategies outlined in this document are tailored specifically to the environment in which HEVT operates, and should serve as a foundation for future HEVT PMs. Each strategy is devised based upon proven industry practices, and combined in a manner that best applies to the HEVT environment. Formal project management theories that discuss human resource management, schedule management, cost management, and risk management cannot be directly applied to any one project. Instead, a project manager should utilize ideas from these theories to prescribe their own solutions to the problems facing their organization.

A project manager can be much more effective by having experience in the same industries as those they manage because it improves communication in many regards. For HEVT, the PM is a graduate student with a background in mechanical engineering (ME) who served as a team member for one year before assuming project management responsibilities. The PM understands the experience of team members and the technical challenges they face. This knowledge and experience aids the PM in many aspects of the position. For example, regarding schedule management, the PM is able to judge the quality of proposed project schedules and determine their plausibility. Similar examples exist in all four project domains, and it would be unrealistic to expect anyone other than a former team member with a background in ME to excel in this role.

This document is organized in the following manner. First, a literature review is performed in which strategies from industry are investigated to identify potential approaches for the HEVT strategy. Next, the HEVT environment is discussed, and the strategy that is devised using industry principles is described. Third, the results of the strategy implementation are explained and analyzed. Finally, major conclusions are drawn and the recommendations are made for future project management activities.

2 Literature Review

In order to apply project management principles to HEVT, research is conducted on various industry project management strategies in the form of a literature review. While each source has merit in the context of the environment in which they were developed, the goal of the literature review is to discover strategic elements which could be effective for HEVT. To this end, a number of strategies are researched, and the most applicable elements are incorporated into the HEVT project management strategy.

2.1 Human Resource Management

The goal of the HEVT human resource management strategy is to maximize team member ability and project-relevant experience through the continuity of team members and an enhanced educational experience for newcomers. A successful HEVT human resource strategy would quickly prepare new students to become successful team members, while also considering external forces that impact team member continuity. Several strategies were researched to better understand how organizations and companies train new members and employees for success.

2.1.1 Organizational Socialization: The Effective Onboarding of New Employees

Organizational Socialization: The Effective Onboarding of New Employees discusses the concept of onboarding, the process experienced by new employees as they transition from outsiders to insiders of an organization [2]. Onboarding developed into a very important topic in the modern economy because of the rate at which individuals move among companies. Additionally, onboarding processes have the potential to greatly impact the productivity and tenure of employees.

The authors suggest a socialization model, which can be understood in three categories, each of which affect the ease and rate of adjustment of a newcomer in an organization: new employee characteristics, new employee behavior, and organizational efforts. While an organization can do its best to hire employees that possess many of the characteristics and behaviors of a successful newcomer, companies can achieve more success by focusing on their own organizational socialization programs [2].

The socialization tactics employed by these programs can be identified on a spectrum according to the complexity and depth of their structure, which differ across organizations [3]. Institutionalized tactics are structured and systematic, and consist of step-by-step plans that teach new employees about their roles and company norms. Newcomers in an institutionalized socialization program are often isolated from existing employees as they progress through the process. On the other hand, individualized tactics plunge newcomers into their environments where they begin working in their new position immediately, and are left to discover their role and company norms as they work. Newcomers in this setting are largely responsible for their own socialization success [3].

Research points to both benefits of drawbacks of each method. First, it is shown that employees are more positive about their jobs, fit better, and have a reduced turnover rate when undergoing institutionalized tactics [4] [5]. This effect is particularly pronounced among new graduates in their first job as opposed to veteran employees transitioning between organizations [5] [6]. Conversely, institutionalized tactics have been shown to limit employee creativity and role innovation [7].

Understanding the importance of organizational socialization, the various ways in which these programs can be structured, and the benefits and drawbacks of different strategies is critical to the development of an HEVT human resource strategy. The topics discussed in this paper are especially important because it is a major priority of the HEVT human resource strategy to effectively and efficiently prepare new students for membership on the team.

2.1.2 Getting New Hires Up to Speed Quickly

Rollag et al., in their article, *Getting New Hires Up to Speed Quickly*, discuss how managers and organizations quickly transform new hires into productive employees [8]. At the beginning of an employee's tenure, they are often a drain on productivity as they require routine assistance from coworkers without being of much help to others. Massive amounts of resources are funneled into talent development to prepare newcomers for their roles.

In their investigation into how companies overcome the various challenges of onboarding, researchers determined that most firms use an informational approach when orienting new hires by providing them with an agglomeration of information about company routines and technologies. Managers often assume that newcomers will easily absorb the information, and fill in the gaps by asking coworkers for assistance. In reality, however, most of the knowledge within a company resides in its employees, and newcomers must first develop a network of relationships before they can achieve their potential and feel satisfied in their roles [8].

Relational approaches solve this problem by helping newcomers quickly establish a network of relationships with co-workers which they can use as resources to obtain information. While most firms use an informational approach when onboarding new employees, relational approaches prove to be far more effective at integrating newcomers into an organization. An additional benefit of the relational approach is that it often requires fewer resources and effort to achieve, while yielding better results [8].

An important aspect to the relational approach is the assignment of a mentor, defined as someone who is directly responsible for the acclimation of the newcomer into the organization. Research shows that newcomers in positive mentor relationships are more satisfied and committed to their organization [9]. Similar to the mentor, a more informal "buddy" can also be helpful for the more mundane office tasks, such as ordering supplies or determining who to listen to when given conflicting requests. Strikingly, buddies are even more important than mentors at the very beginning of employment, primarily because newcomers initially care more about understanding organizational dynamics and routines than career development. To this end, buddies are excellent at helping newcomers establish relationships with coworkers in a way that cannot usually be done by a mentor or manager.

Similar to the distinction between institutional and individualized socialization tactics, understanding the difference between relational and informational approaches directly applies to HEVT and its need for the rapid professional development of its students. Additionally, these sources provide excellent information regarding the assignment of a mentor, and how the presence of a mentor to a newcomer greatly augments the relational socialization approach.

2.2 Schedule Management

The goal of schedule management for HEVT is to create a strategy that allows the PM to feasibly manage the project, and develop the best possible project plan for the engineering subteams using information that may be unreliable or incomplete. To create such a strategy, literature relating to the challenges of schedule management was reviewed to identify best practices. Upon review of these practices, those deemed most applicable to the challenges faced by HEVT were integrated into the schedule management strategy. A strategy designed around the organizational intricacies of HEVT and the complex technical tasks that students must accomplish must be employed to create the best possible project schedule

2.2.1 Analytical Design and Planning Technique

Analytical design planning technique (ADePT): a dependency structure matrix tool to schedule the building design process is a technique that uses a dependency structure matrix tool to help schedule a design process [10]. The authors acknowledge that traditional construction management tools do not fully apply to design tasks because traditional scheduling techniques do not account for variations and delays, both of which are expected for an iterative process such as design. Construction schedules monitor progress based upon the completion of drawing work and other design deliverables, as opposed to the availability of key pieces of information. Such techniques are not suitable for planning design work because they schedule a process on the basis of the completion of work elements rather than the production of information, and having been devised to plan sequential processes, they do not have the capability to deal with the iteration in a design process [10].

The first step in the ADePT process is to develop a matrix of all tasks in the design process. The task itself is located within the column and the information related to that task is in the row. The matrix is completed so that the commencement of tasks in the column are linked with information they need from the completion of other tasks in the row.

The second step is the partitioning of the matrix with the goal of maximizing the availability of information required, and minimizing the amount of iterations and the sizes of any iterative loops within the process. The goal is to move all of the marks close to or below the main diagonal of the matrix by rearranging the order of tasks.

The third step, tearing a loop, is defined as reducing the size of the iteration by minimizing feedbacks and identifying estimates that can be made with some confidence and therefore do not need to be revisited as part of the iterative process. The first sub-step is to schedule activities within the loop to reduce the number of required estimates and to identify a starting point for the loop. The second sub-step is to remove one or more information dependencies to reduce the size of the loop. An example illustrating the tearing a loop process can be seen in Figure 1 below.

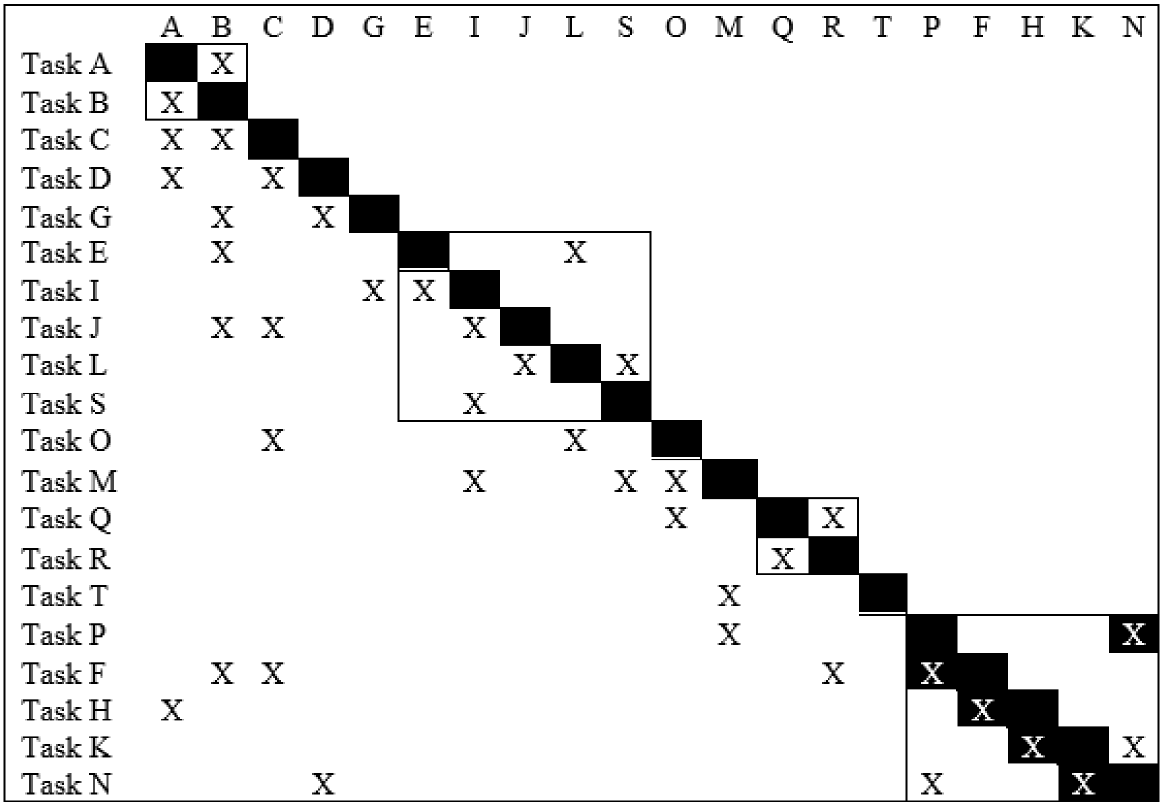

Figure 1: Tearing a loop (adapted from Austin, et. al, Construction Management & Economics *18, no. 2 (2000): 173-182)*, used under Fair Use, 2016

There are some techniques that exist which can be used to quantify how important information is to a task. A three-point dependency can be found using a flowchart, as seen in Figure 2, to determine the strength of information dependence. In this flowchart, strong dependencies lead to "A," moderate dependencies lead to "B," and weak dependencies lead to "C." Dependencies which are rated as weak can be omitted from the matrix partitioning and tearing, which assist those two processes.

While this process is very insightful regarding the idea of information-based scheduling as opposed to progress-based scheduling, it has limited applicability in the HEVT schedule management strategy. This *ADePT* technique requires that a design task be broken into many infinitesimal tasks with specific information requirements. This step alone may be too daunting for team members facing an engineering problem for the first time. Instead, HEVT would be better suited by a strategy that is both broad enough to be feasible for its engineering team members, and specific enough to ensure students are working in the right direction.

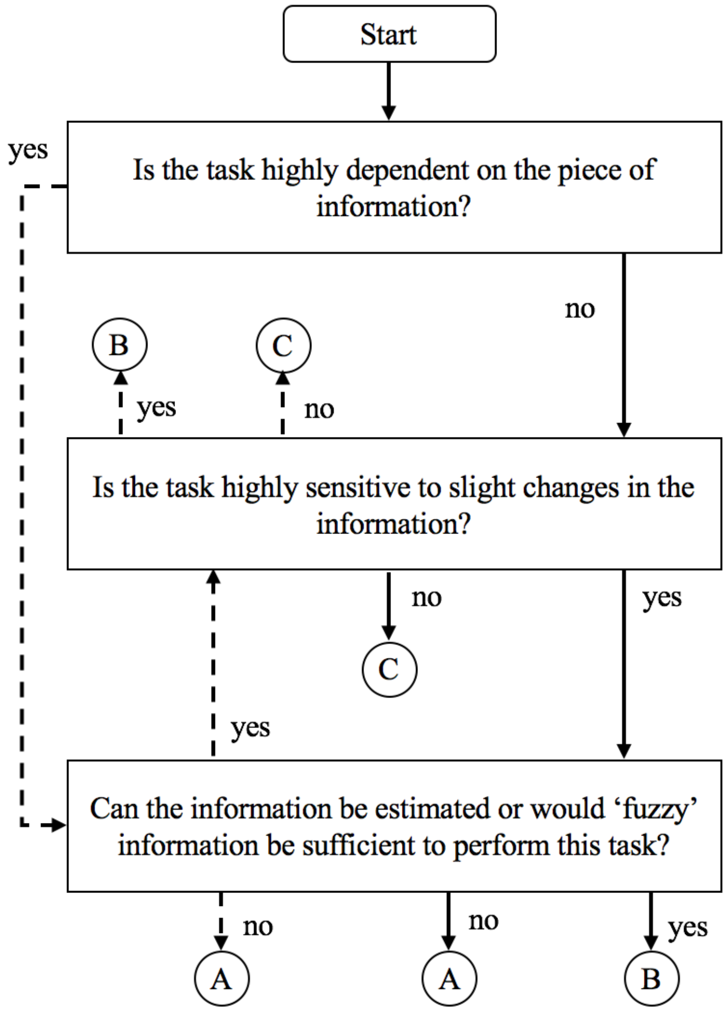

Figure 2: Decision system for allocating information classifications (adapted from Austin, et. al, Construction Management & Economics *18, no. 2 (2000): 173-182)*, used under Fair Use, 2016

2.2.2 Flexible Work Breakdown Structure

The research conducted by Jung and Woo addresses the problem of requiring too many overhead resources to utilize integrated cost and schedule management structures [11]. Jung and Woo propose a technique called the flexible work breakdown structure (WBS); its purpose is to optimize overhead effort by reducing the amount of data needing control. It does this by providing the project planners authority to select an appropriate level of scheduling and budgetary detail in the work breakdown structure of the control accounts (CA), which are defined by the American National Standards Institute (ANSI) as "management control points at which budgets and actual costs are accumulated and compared to earned value for management control purposes" and represents "the work assigned to one responsible organizational element" [12]. The critical issue here which directly applies to HEVT is making a decision on the level of WBS to be selected as a CA for the effective control and management of each task. The number of CAs determines the amount of detailed data to be manipulated for schedule, cost, and performance measurement and "the appropriate level of detail must be carefully determined considering the project characteristics."

Integrating cost and schedule control functions not only provides meaningful project information, but also improves the efficiency of control processes. The authors found that the earned value management (EVM) system is one of the best practices for integrated cost and schedule control. The need for reengineering the cost and scheduling control processes was driven by a Hong Kong survey of the construction industry [13]. This study, which notes that separated cost and schedule control is a major problem in the Hong Kong construction industry, revealed that increases in labor force and heavy project overhead were the most significant forms of overhead [13].

A flexible WBS allows management the opportunity to create an appropriate level of CAs. A traditional WBS practice establishes a rigid sequence of work breakdown levels, and the rule is strictly applied to all components. The proposed flexible WBS uses three levels, although the number of levels to use is at the discretion of the project planner. Using a construction project as an example, these three levels, are the work section, space, and facility (e.g. concrete work on the 2^{nd} floor of the main building) [13]. Each of the main three levels are divided based upon the preference of the project planners, and each level receives an account code. A traditional WBS can be ineffective for data control because compounding facets in this way makes data integration and reuse very difficult, resulting in amassed historical data of no value. For this reason, a flexible WBS needs to be capable of placing any facet of information on any level of WBS hierarchy, while keeping independency of classification facets, which enables the related raw data to be used for other business functions. This type of flexibility is beneficial to the organization and can help track both schedule and cost more effectively.

Many elements of *Flexible Work Breakdown Structure* are applicable to HEVT. First, the number of CAs for the project planner, or PM, to select is directly correlated to the feasibility of schedule management. With minimal information or knowledge of the problem, it may be necessary to begin a task schedule with fewer CAs and increase the quantity of CAs as the task progresses. Second, in the past, HEVT has not collected nor formatted the schedule and cost data in an integrated manner. The use of a flexible WBS would allow for meaningful and significant data collection, integration, and level-code creation. While many elements of this technique can be applied to HEVT, an overall process for creating and managing the schedule with other members of the team is necessary for successful project schedule execution.

2.2.3 Last Planner

Last Planner, sometimes referred to as the “Last Planner System” is a production planning system used in the programming, design, construction, and commissioning of projects to produce rapid learning and predictable workflow [14]. Developed by Glenn Ballard and Greg Howell, the Last Planner System is trademarked by the Lean Construction Institute (LCI), which licenses the use of these processes and related IP to various organizations, including the Associated General Contractors of America. Within the Last Planner system, there are six steps to successfully complete a project: Milestone Plan, Collaborative Program, MakeReady, Production Evaluation and Planning, Production Management, and Learn, as is shown in Figure 3.

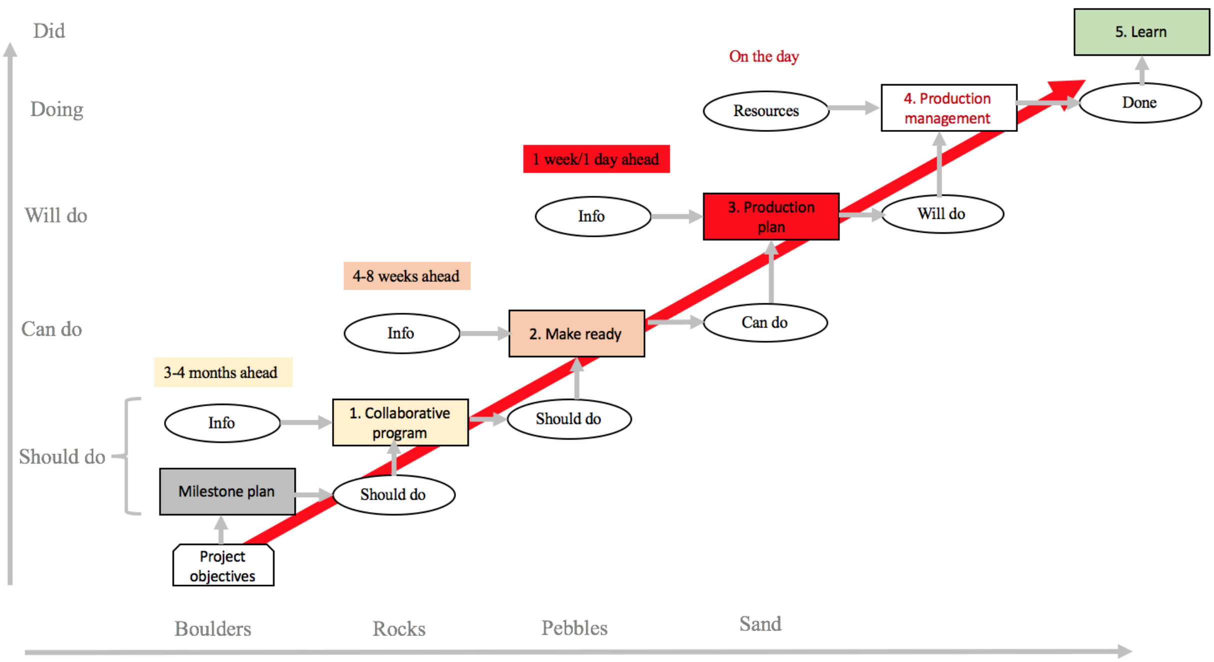

Figure 3: The Last Planner System (adapted from the Lean Construction Institute), used under Fair Use, 2016

The process used by *Last Planner* is a broad schedule management technique with many elements adaptable to the HEVT schedule management strategy. Each step in *Last Planner* is designed to make the most informed decision based upon the information available at that time with the goal of gaining enough information to make more detailed plans [14].

The zeroth step, the Milestone Plan, requires agreed upon project milestones among the participants in order for the next step to occur. These milestones could be based upon customer expectations and general durations associated with varying product phases. Determining the timing of these milestones will serve as the foundation of the project schedule.

The first step, Collaborative Program (CP), was designed to improve upon traditional "first planners" in a project. In this traditional case, first planners are project engineers who make assumptions and build slack into a schedule based upon their assumptions to account for risks. The program produced by these first planners are then generally imposed on a project which is then managed according to what should happen. CP, on the other hand, is designed to have all project participants meet during the planning phase so it is possible to discuss critical interdependencies and risks. Systemic risk analysis and program compression are critical to CP. Admitting to not knowing something is also important to successful CP [14].

The second step, MakeReady (MR), takes the "should do" plans from CP and turns them into "can do" plans. A spreadsheet is used to track the information, prerequisite activities, and resources required for each task to begin. Then, as plans become truly available to begin, they are integrated with the concrete plans.

The third step, Production Evaluation and Planning (PEP), is a regular meeting that involves all "last planners." This typically occurs weekly and lasts less than an hour. The goal is to review progress from the previous week and plan work that will be done in the coming week using the knowledge of what work can be done from the previous step. These last planners will propose programs for their own teams and explore inter-dependencies. One important aspect of PEP for the last planners is not to overcommit, which comes down to following through on promises. In this step, using accurate information is vital [14]. There are many benefits of PEPs, including better preparation by last planners and improved relationships among leaders. Last planners must have the ability to say no to a request if they do not believe it can actually be done.

The fourth step, Production Management, involves daily conversation among leaders and planners to track progress. This step is critical in the tracking of activities and helping to make work ready. These conversations are important for decision makers as this is a means to receive daily updates on the progress of the activities.

The fifth and final step, Learn, is the basis for the evaluation process in a PEP meeting. Improving the predictability of work delivery is key, and the measure for this is the Percentage of Promises Completed (PPC) on time. PPC measures the proportion of promises made that are delivered on time. "A study for a 2004 US Construction Industry Institute report showed a statistically significant correlation between PPC and productivity on engineering construction projects. Anecdotal reports show that there are step changes in productivity and probability with a PPC around 75% and 90%." [14]

The overall theme of *Last Planner*, which is to incrementally create more comprehensive project plans as details come into focus, is the strategy most applicable to the HEVT scheduling environment. The application of such a strategy would allow students to begin work with the knowledge of several major milestones, and the chance to create project plans as they understand more about the nature of their assignment.

2.3 Cost Management

The goal of cost management on HEVT is to create a process that allows the PM to feasibly manage the budget while having the tools to record, analyze, and utilize income and expense data to better manage financial resources. To help develop this process, literature focusing on the control and management of costs was reviewed to identify best practices. Many cost management strategies exist in industry, nonprofits, and elsewhere to control and measure the effectiveness of financial resource allocation.

2.3.1 An Extension of the EVM Analysis for Project Monitoring: The Cost Control Index and Schedule Control Index

Cost and schedule control indices are two measures that project managers can utilize to control and manage the costs and durations associated with a project. In EVM, these metrics can be used as indicators of project adherence to schedule and cost, and help project managers determine corrective action. Pajares and Lopez-Paredes in their 2001paper entitled, *An Extension of the EVM Analysis for Project Monitoring: The Cost Control Index and the Schedule Control Index*, discussed the integration of project variability and risk analysis into traditional EVM methods [15].

The purpose of integrating risk management into EVM is to determine if cost and schedule overruns are within the bounds of the project expected variability.

The authors' strategy is to integrate risk management within the EVM framework to improve cost and schedule control. To do so, they first introduce project risk baseline (RB), and then propose new performance indices for monitoring how far the project has fallen away from the baseline. Project RB is defined as the evolution of project risk over time, or in other words, the remaining variability of project cost and duration during the project life cycle [15]. If a project progresses as planned, project risk should gradually decrease over time.

This method begins by using a Monte Carlo simulation to generate cost and duration probability distributions for the project. Using these simulation results, the Cost Project Buffer (CPB_f) can be calculated, which is the difference between the maximum cost at a particular confidence interval and the mean cost value. Next, the CPB_f is divided among time intervals, using weights which are proportional to the risk reduction in every time interval, to estimate how much cost could deviate per unit of time from planned values [15].

Several more calculations are needed to produce all of the metrics necessary for this method of analysis, including the cost and schedule control indices, the foci of the paper. While this strategy may be best suited for a large corporation looking to gather detailed cost and schedule analytics, utilizing this method in the HEVT cost management strategy is not feasible because of its complex data requirements and overhead necessary to maintain such a system. Additionally, the multitude of benefits provided by this method would not be useful for the HEVT cost management strategy which only requires that data be accounted for and financial resources be used intelligently.

2.3.2 Activity-Based Cost Management for Design and Development Stage

Activity-Based Cost Management was another method that was explored where a methodology called Activity-Based Costing (ABC) is utilized to evaluate the cost of design and development activities [16]. The motivation for developing ABC is the downward global trend in product life expectancy, making design and development a more significant element of the overall product cost. ABC is focused on estimating design and development costs from a variety of informational sources such as customer requirements and process planning.

The ABC method follows a series of specific steps. First, the resource centers needed for the design and development are identified, and the cost associated with those resource centers is determined. Next, the cost drivers at each resource center are identified, in addition to the activities necessary to complete a design and development process. Third, the cost of these activities, based upon resource consumption, are calculated. Finally, the cost drivers of these activities are identified and calculated, and the overall process costs are estimated based upon all of the performed activities [16].

Many of the cost drivers which sum to form the overall process cost are based upon manufacturing techniques and supply chains. A technique of this sort could be used by a large corporation striving to streamline its manufacturing process and reduce costs. HEVT performs many of its own design and development activities, and the strategies discussed in this paper are not applicable to HEVT for several reasons. First, by conducting its own design and development, there is no labor cost.

Second because the team is producing one vehicle instead of an entire fleet, the relatively minute cost savings associated with this method do not apply to HEVT. Lastly, intricacies relating to manufacturing techniques and supply chain strategies have little impact on the overall HEVT vehicle development cost.

2.3.3 Earned Value Management System (EVMS) and Project Analysis Standard Operating Procedure

The Department of Energy Office of Acquisition and Project Management released an instructional document describing the purpose and application of earned value management titled, *Earned Value Management System (EVMS) and Project Analysis Standard Operating Procedure (EPASOP* [17]. EVM analysis is an excellent tool which can provide insight to project status and assist management in decision making processes. EVM utilizes both cost and schedule data in order to produce a variety of metrics which together define the adherence of a project to its schedule and budget.

When beginning a project, the creation of a schedule of tasks and a budget are necessary to perform EVM analysis. The budget initially developed for each task is known as the budget-at-completion (BAC), whereas the financial resources utilized to complete the task is known as the actual cost (AC). As a task progresses, a project manager may decide that the budget must be adjusted due to either overspending or an overestimation of required financial resources. In either case, revised budgets at the time of EVM analysis are known as estimated-at-completion (EAC).

Using these simple definitions, several important metrics can be calculated. First, the actual completion percentage (ACP) is an indicator of how far the task is progressing by comparing utilized financial resources against the revised task budget, and is defined below according to equation 1.

$$ACP\% = \frac{AC}{EAC} \times 100 \tag{1}$$

Another useful metric is earned value (EV), which indicates the value of the work completed for a task thus far, and is defined below according to equation 2.

$$EV = BAC \times ACP \tag{2}$$

Instead of strictly analyzing the EV, it is useful because it can be used to calculate both the cost variance (CV) and cost performance index (CPI). The CV is a measurement of how well as task is meeting its budget, and positive values represent favorable results. The CV is defined below according to equation 3.

$$CV = EV - AC \tag{3}$$

Similar to the CV, the CPI measures cost efficiency, and positive values represent favorable results. The CPI is defined below according to equation 4.

$$CPI = \frac{EV}{AC} \tag{4}$$

Finally, the variable actual cost (VAC) is a measure of the initial budget accuracy, and positive values represent favorable results. The VAC is defined below according to equation 5.

$$VAC = BAC - EAC \quad (5)$$

In EVM analysis, there are several metrics that can be used to define the status of a project in more detail. These metrics, however, represent an ideal level of detail for HEVT use and can play a major role in the HEVT cost management strategy.

2.4 Risk Management

The goal of risk management for HEVT is to identify and mitigate technical risks that may impact the success of the project. Identifying best practices associated with risk management is critical to the development of the HEVT risk management strategy.

A risk, as defined by the Project Management Institute (PMI) is, "an uncertain event or condition that if it occurs, has a positive or negative effect on a project's objectives" [18]. Managing technical and project-level risks through identification and mitigation is necessary to maintain the project schedule, scope, and budget. Many of the technical risks revolve around an accelerated vehicle development process and strict design constraints, both of which are functions of the rules and milestones of EcoCAR 3. Other technical risks may be the result of student-designed components or engineering decisions made by students. Literature relating to risk management is researched to better understand how industry risk management strategies can be applied to HEVT.

2.4.1 Design Failure Modes and Effects Analysis

The classic Design Failure Modes and Effects Analysis (DFMEA) is a tool used by engineers when considering design risk, and considers three factors: severity, occurrence, and detection. Severity is defined as the consequence of the failure mode, occurrence relates to its probability of failure, and detection is defined as the transparency of the failure. Each of the three factors are rated on a 10-point scale, whose product is risk priority number (RPN). Risks with higher RPNs are given more consideration than those with lower RPNs.

While this strategy could be very useful when considering the technical risks of one component within a larger design, it fails to consider the context of team objectives, a necessity of the HEVT risk management strategy. Additionally, assigning severity, occurrence, and detection values to the design of one component may be feasible, but doing so for an entire vehicle requires much more manpower than is available to the HEVT Project Manager. An approach using DFMEA principles which is more manageable and tailored to the context of EcoCAR 3, however, could prove effective.

2.4.2 Project Risk Failure Modes and Effects Analysis

Carbone and Tippet in their 2004 paper titled *Project Risk Management Using the Project Risk FMEA* utilize DFMEA principles to create a similar process for project-level risks [19]. The Project Risk Failure Mode and Effects Analysis (RFMEA) is similar to the classic DFMEA, but modified to better fit a project environment. Technical risks, however, can still be accounted for using project RFMEA. The authors suggest that creating a new risk management strategy from DFMEA is beneficial due to its ease of use, familiar format, and comprehensive structure [19].

In project RFMEA, likelihood is defined as the probability that a risk will occur, and detection is defined as the ability to detect the risk event with enough time to plan for a contingency and act upon the risk. The final risk attribute, impact, has a more complicated definition because the impact is measured according to schedule delays, cost increases, and technical detriments of the final product. The schedule, cost, and technical impact values are averaged to determine the final impact value. Each attribute must be quantified in order to calculate the risk score (RS) and RPN. To do so, the authors recommend creating standardized values for likelihood, detection, and the three measures of impact that make sense given the context of the project.

Once the attribute values are assigned from the standardized values, the RS and RPN are then calculated. The RS is a product of impact and likelihood, while the RPN is the product of RS and detection. While it may seem redundant to calculate an RS and RPN, both are required for accurate assessment; the advantage of calculating the RS is the ability to detect the risk with enough time to develop a response plan, but it is not very valuable if the impact is so severe that it renders the project a failure. Thus, the RS and RPN values must both be evaluated, as each number serves a distinct yet related purpose. The remaining steps of the project RFMEA process involve using Pareto charts to identify the most pressing risks according to both RPN and RS, creating detailed response strategies for risks above a critical value, and recalculating RS and RPN based upon the devised response strategies [19].

The RFMEA strategy is preferred to DFMEA because of its applicability to an entire project rather than one design. Measuring impact across a variety of project-level dimensions could prove valuable when assessing the consequences of various engineering decisions. Additionally, the concept of utilizing standardized values that are designed specifically for the context of the project could make the RS and RPN calculations more meaningful when analyzing how resources should be allocated to various risks.

3 Methods

This section begins by describing the set of conditions that will drive the strategy for each of the four HEVT project management domains. The environment in which HEVT operates is unique for several reasons. First, the team is comprised exclusively of students, most of whom have little to no prior professional engineering experience. Second, the schedule revolves around predetermined milestones established by EcoCAR 3 which dictate the timing and pace of the schedule. Third, the team relies exclusively on cash and in-kind donations to purchase everything needed to complete tasks. Finally, the success of the project is based upon scoring criteria developed by EcoCAR 3 which shifts every year. With an understanding of the HEVT environment and various strategies from industry, the HEVT strategies are developed and described in full detail.

3.1 Human Resource Management

The purpose of human resource management on HEVT is to maximize talent and annual continuity among the team members. This goal was derived from observations of previous problems that existed within HEVT prior to the implementation of this strategy. This approach utilizes an onboarding strategy which is both relational and institutional to make the most of limited training time.

3.1.1 Environment

The HEVT human resource environment consists of a series of constraints that are based upon the technical requirements of the project and university rules regarding student enrollment. To better understand how the human resource strategy is shaped by these constraints, the team organizational structure must first be understood.

3.1.1.1 Organizational Structure

The HEVT organizational structural is based upon the structure recommend to teams by EcoCAR 3 organizers, and can be seen in Figure 4. The lead faculty advisor (LFA), in blue, is a university professor who established the team over 22 years ago, and specializes in automotive engineering. The LFA works closely with team leadership to help orchestrate engineering activities, and acts as a liaison to the university and competition organizers.

The five members of team leadership, in orange, serve as both team leaders and subject matter experts. While the PM is responsible for managing HEVT as an organization, the Engineering Manager (EM) is specifically responsible for managing the engineering activities. The Controls Graduate Research Assistant (CGRA) oversees all activities within the controls and simulation subteams, and the Electrical Graduate Research Assistant (EGRA) oversees all activities within the electrical and ADAS subteams. The final member of team leadership, the Communications Manager (CM), directs all public relations efforts. All team leaders are graduate students who typically serve for two years in these roles, except for the Communications Manager who is an undergraduate student and typically serves for one year.

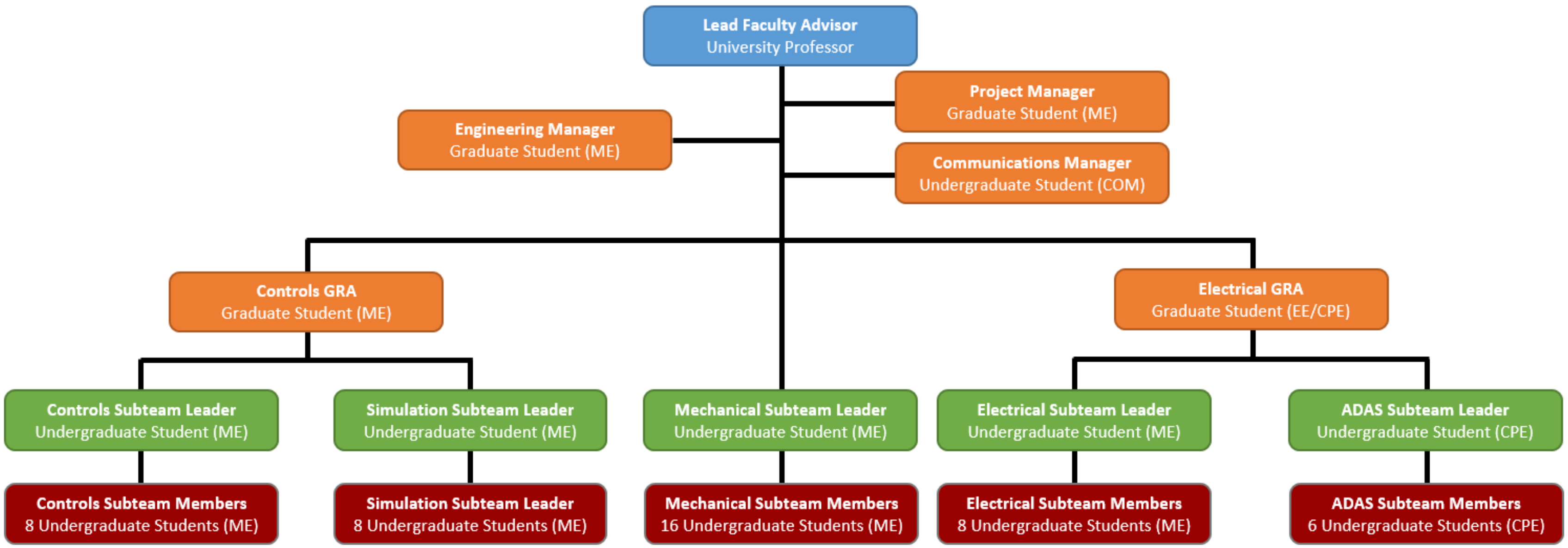

Figure 4: HEVT organizational chart

The EM and CGRA must have an academic background in mechanical engineering (ME), while the EGRA must have a background in either electrical engineering (EE) or computer engineering (CpE). While the PM can have a background in either engineering or business, the former is preferred because it helps the PM effectively communicate with the rest of the team, particularly for schedule and risk management efforts. Finally, the CM must have an academic background in communications.

The five subteam leaders, in green, manage their subteam and serve as facilitators of information between team leaders and team members. These students are undergraduate seniors who serve for one year in these roles. All subteam leaders require an ME background except for the ADAS subteam leader who requires a CpE or EE background, and the electrical subteam leader who may study either ME or EE. While subteam leaders have a different role from team members, they are ultimately classified as team members for human resource management purposes because they are undergraduate engineering students.

Team members (TM), in maroon, perform engineering tasks under the direction of their subteam leaders. ADAS subteam students need a CpE or EE background, electrical subteam students need an EE or ME background, and all others need an ME background. Depending on their academic class, they may be referred to as either junior or senior TMs.

Finally, independent study (IS) students operate and train separately from the team members and do not contribute to current project goals. Under the current strategy, this training is subteam specific, and the IS students' academic backgrounds must match that of their prospective subteam.

These knowledge requirements limit the pool of individuals from which HEVT can choose their leaders and team members, and play a role in the challenges associated with knowledge transfer and continuity. In addition to academic background challenges, the team also must work within the limits of the university and department.

3.1.1.2 Academic Credit and Limitations

HEVT must operate within the confines of university rules, specifically of the Department of Mechanical Engineering. First, as a large senior capstone project within the Department of Mechanical Engineering, at least 25 team members should be mechanical engineering seniors. On the other hand, it is a rule of thumb that HEVT should strive to have no more than 40 total team members, and should never exceed 50 total team members to ensure that each student has an appropriate workload.

Second, there are several regulations regarding both the amount and timing of academic credit that students can earn through HEVT participation. First, no student can receive any type of credit that counts towards graduation requirements or impacts their grades until their junior year. This makes it difficult to recruit freshman and sophomore students because under the current strategy, the designed workload within IS corresponds to three credits worth of work. Next, students studying ME may receive three technical elective credits per semester during their junior year and three capstone credits per semester during their senior year, all of which count towards their graduation requirements and grades. On the other hand, CpE and EE students may only receive a maximum of nine capstone and technical elective credits during the span of their junior and senior years that count towards their graduation requirements and grades; for CpE and EE students to receive the same number of credits (12) as ME students, the final three credits must be free elective credits which impact the students' grades but do not count towards graduation requirements. This poses a small challenge regarding the recruitment of CpE and EE students for their junior fall semester, and ME students for their sophomore spring semester, but not enough to make it unfeasible. For this reason, the HEVT student progression model, which is later discussed in more detail, sets the earliest enrollment periods for ME and CpE/EE students to be the sophomore spring and junior fall semester, respectively. Together, these limitations make it difficult to have enough junior team members each spring to replace the graduating senior team members.

While the existing human resource strategy strives to maximize team member ability and project-relevant experience through continuity of team members, the previous strategy was to fill the roster according to the 25-student suggestion by recruiting 25 senior ME students at the start of each academic year. An IS program existed, but was not organized in a way that maximized team member continuity and the students' educational experience.

3.1.1.3 Previous Independent Study Program

Throughout most of the HEVT history, the strategy for staffing the team was to have only senior ME students participate; most of these students participated for only one year unless they returned for graduate work and became a team leader. The result of this strategy meant that during a typical school year, 25 undergraduate and four graduate students served on the team, and all but four students departed at the end of the academic year via graduation. This high turnover rate caused a plethora of organizational problems, and is the reason for team member continuity being a central theme in the existing human resource strategy.

Although helpful in preparing a handful of students each year to become successful senior team members, many problems existed with the previous IS program. First, the program was unable to accommodate a significant number of students because the previous team leaders had difficulty providing students with work, and did not actively recruit students for the program. Team leadership spent time creating new projects each semester for the IS students, and the projects were selected primarily for their feasibility as opposed to educational value. This created an inconsistent experience for the IS students, as each individual undertook different projects and received varying amounts of oversight and support from team leadership. Competition-related work that needed attention from team leadership was almost always prioritized over IS student support.

Second, many IS students were not retained to become team members. This occurred because students received a mixed experience in the IS program, and because students as young as freshman participated in the program. While students cannot begin earning academic credit that counts towards their degree through HEVT participation until junior year, it is possible to receive academic credit that does not count towards their degree or grades as early as freshmen year. Team leaders welcomed the enthusiasm from younger students who were willing to work without degree-counting credits, but they failed to consider that many students would not be able to sustain this pace. As a result, many young students who participated in the IS program early in their college careers never became team members as seniors. This led to wasted effort on behalf of team leadership, because they worked with students who never applied their skills to competition-related tasks. These problems were seriously considered during the development of the existing human resource strategy, which includes the revitalized IS program and its role within HEVT.

3.1.2 Strategy

The human resource strategy revitalizes the IS program, and reorganizes HEVT to maximize student continuity. A major component of the reorganization is careful recruitment planning which dictates when students of various academic levels and technical backgrounds should be recruited.

3.1.2.1 Revised Independent Study Program

The only similarity between the previous and existing IS program is that team leadership continues to direct the IS program, whose projects do not directly contribute to current HEVT goals. The first difference is that HEVT recruits all of its future team members directly to the IS program as opposed to primarily recruiting them to join as senior team members. If the IS student demonstrates that they have the skills necessary to become a valuable addition to the organization, they are extended an invitation to continue with HEVT as a team member; therefore, to become a team member, students must first successfully pass the IS program. Second, all IS projects are repeatable and can be recycled each semester. There are several projects that the students can choose from that align with applicable HEVT work. This change reduces the workload of the team leadership by eliminating the need to conceive new project plans each semester, and ensures that the IS students have a consistent experience. The final change is that ME students cannot enroll in the IS program until their sophomore spring semester, and CpE/EE students cannot enroll until their junior fall semester. For each major, students can only enroll one semester prior to being eligible for degree-counting credits. This limitation is placed on students to increase the likelihood of newcomers participating in HEVT each semester until graduation, which maximizes continuity.

Not only is the IS program itself different, but so is its standing within HEVT. Now that students must first pass through the IS program to become a team member, a careful strategy was developed that maximizes team member continuity while accounting for university regulations, and IS program retention rates. The student progression process for ME students can be seen in Figure 5 below. This student progression model for ME students assumes that 80% of IS students in a given semester join the team. This value is based upon the observations from the fall 2015 semester. In this model, 26 senior TMs, 4 junior TMs, and 14 IS students comprise all of the ME students within HEVT during a given fall semester, on the left side of the diagram. Of the 14 IS students, 11 are retained and join the team during the spring semester. Now, there are a total of 41 ME TMs during the spring, in the center of the diagram, 15 of whom are junior TMs. Next, 14 junior and five sophomore IS students are recruited. Assuming all senior TMs graduate, all junior TMs return for senior year, and 80% of the IS students return for the following semester, the following fall semester has the same distribution of students as the previous fall semester, which allows HEVT to maintain a steady state enrollment. A similar progression model exists for the CpE and EE students as seen in Figure 6.

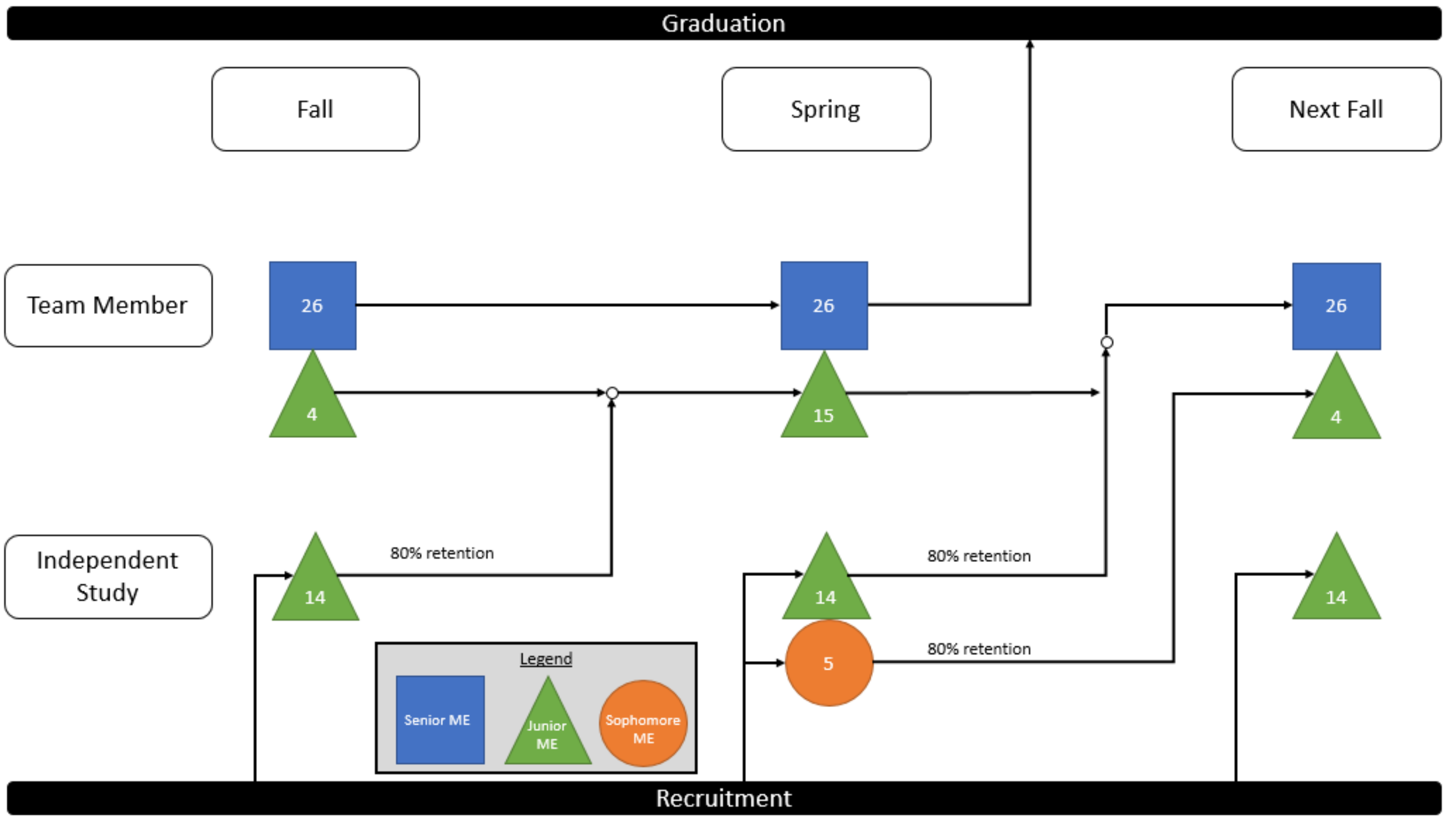

Figure 5: ME student progression

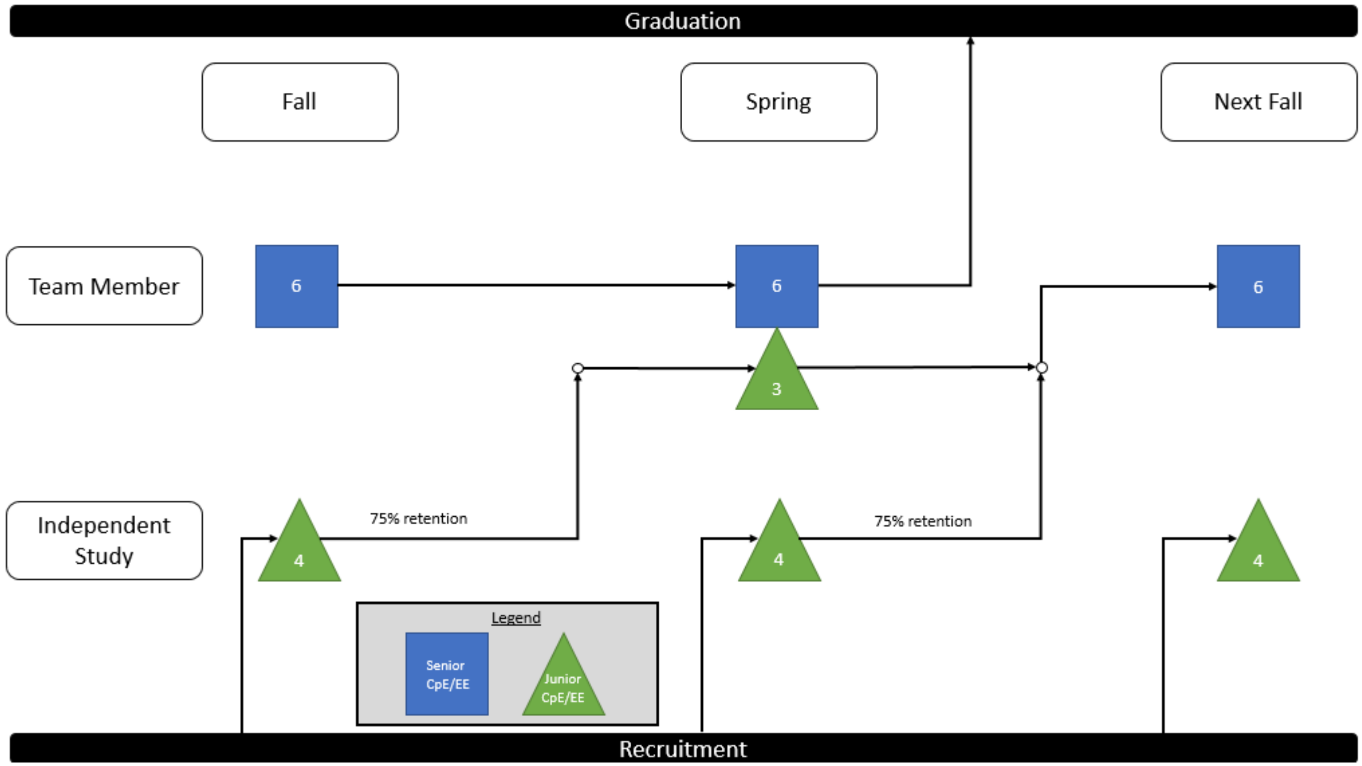

Figure 6: CpE and EE student progression

The CpE and EE student progression model is similar to the ME model, but there are fewer students overall, no sophomores, and a similar retention rate (75%) is assumed.

3.1.2.2 Knowledge Transfer and Onboarding

The second goal of human resource management for HEVT is to maximize team member ability and project-relevant experience through an enhanced educational experience, which is accomplished by modifying the IS program curriculum and focusing on preparing students to be successful team members.

Efficient onboarding is critical to HEVT's success, because of the frequency at which new students join and their relatively short tenure in the organization. Within the IS program, team leadership leads the students through an ultra-rapid onboarding process that not only trains them to be technically sound via their projects, but also acclimates them to team membership on HEVT. A study by Mellon Financial Corporation found that, on average, new hires in professional jobs need 20 weeks, or 800 working hours, to reach full productivity [20]. Students in the IS program work approximately 160 hours during a semester, only 20% of the time allegedly required to achieve full productivity. Thus, the IS curriculum must be designed intelligently to maximize their preparedness.

Successful HEVT team members exhibit several common skills, some of which are developed in engineering classes, and others which the team works to develop via the IS program. Most importantly, the best HEVT team members relentlessly pursue solutions to their problems. Similar to an engineering job in industry, answers rarely readily present themselves on HEVT. Thus, the employee, or team member, must use available resources to craft the best possible solution. The IS program is designed to replicate the HEVT environment in this regard. Second, successful team members have a firm understanding of the basic principles from the wide variety of engineering courses mandated by their degree requirements. For various HEVT tasks, it may be necessary to understand circuits, thermodynamics, mass transfer, mechanical design, or any other topic covered in the mechanical, electrical, or computer engineering curriculum. The team does its best to recruit students who show excellence in their classes, and utilize the IS program to complete their skillset.

To make the most of the limited onboarding time, HEVT is adopting a strategy that is primarily institutional and relational in nature. Clearly defined expectations are an institutional aspect of the IS program, which are presented at the beginning of the semester, so that students understand what they must accomplish to become a team member. The students' grades are calculated with the known weights and common grading rubrics for all major assignments. This standardizes the evaluation process used by team leadership to determine which students possess the necessary skills to join HEVT as team members, and is a substantial upgrade from the previous evaluation measures which only considered a candidate's resume. The projects develop the students' technical skills and provide experience relevant to their prospective subteam, and the reports and presentations educate them about how HEVT completes EcoCAR 3 deliverables.

The onboarding strategy also has aspects which classify it as relational. While some basic information regarding team processes and automotive engineering are conveyed to the IS students in formal presentations, much of the information is obtained through an assigned mentor. Mentors are utilized because many skills necessary to become a successful team member cannot be learned via classroom instuction. The most experienced and knowledgeable team members are assigned the role of mentor to maximize the value of their efforts, and the mentors teach their students various skills relevant to their prospective technical team. Mentors on the mechanical subteam teach their students about the proper use of hand tools and power tools to perform work on the vehicle, or the fine details of the CAD program to perform packaging and stress analysis tasks. Electrical subteam mentors teach their students about safely working with electrified components, electrical analysis, and standard wiring practices. Mentors on the controls and simulation subteams educate their students about the current state of the vehicle computer model and the process for creating, testing, and implementing control code. ADAS mentors show students how computer engineering principles are being used to develop the ADAS and Ecorouting technology. What all mentors have in common, however, are that they serve as a resource to the IS students for their projects to lessen the burden on the technical team leaders. This is a vast improvement from the previous structure, where the newest students had no contact at all with previous team members, and returning members of team leadership served as mentors to all other team members.

Ideally, students have a positive experience in the IS program, prove themselves as valuable additions to the team, and return to HEVT as a junior or senior team members to continue their automotive engineering education and contribute to EcoCAR 3 tasks. Retaining students was a problem in the previous structure because there was no clear path from the IS program to team membership. Now, students understand what they are working towards, and they have the tools necessary to accomplish this task. This reduces the turnover rate within the IS program and for HEVT as an organization. Additionally, the repeatable projects and standardized evaluation methods allow the IS program to accommodate more students without overburdening team leadership, improving the quality of team members and further lowering the turnover rate. All of these efforts improve team member continuity and the educational experience for IS students in particular.

3.2 Schedule Management

The purpose of schedule management on HEVT is to create the best possible project schedule using available information, and continuously improve the schedule as information reveals itself through task progress. Understanding the challenges faced by the team is critical to forming a credible strategy.

3.2.1 Environment

Scheduling activities within HEVT is particularly challenging because many of the team members responsible for scheduling these activities lack the core knowledge and experience necessary to create credible plans, such as subtask dependency relationships and approximate subtask durations. An improved human resources management strategy seeks to increase the experience level and knowledge base of team members; however, most of the problems faced by the team have several novel elements that create confusion and uncertainty during planning. For this reason, the Project Manager cannot rely on scheduling data provided by team members to be either accurate or complete, and new information must be continuously discovered and incorporated into the project plans.

Many project scheduling techniques used in industry are designed for organizations and projects with characteristics quite different from HEVT. The construction industry, for example, exists at the opposite end of the planning spectrum from HEVT; its activities can be planned with relatively high confidence because data from previous projects with similar features can be used to schedule new projects. HEVT, on the other hand, competes in a competition that adds new requirements each year and has a project lifecycle that is twice the length of the longest possible tenure of a team member. For this reason, scheduling techniques that rely on tasks with clear durations and dependencies are not effective for HEVT.

3.2.2 Strategy

The HEVT schedule management strategy uses principles primarily from *Last Planner* due its applicability to the HEVT scheduling environment. This strategy also contains elements of *Flexible Work Breakdown Structure* because the number of CAs are monitored and limited in order to reduce the overhead effort required from the PM.

The first step of the HEVT schedule management strategy takes place at the start of each semester. Team leadership and subteam leaders meet to determine the current state of each primary engineering task and what progress must be made by the conclusion of the semester. This helps all individuals engaged in planning of the project to understand the framework of each task in the context of the upcoming semester. This is analogous to the first step of the *Last Planner* system "Milestone Plan," where the planners and managers use project objectives to agree on a set of milestones.

The second step of the HEVT schedule management strategy is to use these agreed-upon semester-end goals to create initial plans for each primary engineering task in the form of a Gantt chart. The details of these plans use a limited number of CAs due to the limited amount of information known about these tasks in addition to the limited managerial resources available to HEVT. This is analogous to the "Collaborative Programming" step of *Last Planner*, where all managers, suppliers, and contactors are engaged in the beginning phases of the planning process to identify risks and create tentative plans. A key element of this step is not to impose the project plans created during Collaborative Programming because "Projects are then managed in terms of what the program says should happen. It often requires work to be done that cannot be completed as programmed because one or more of the flows is broken" [14]. Additionally, Mossman emphasizes the importance of identifying project areas that are difficult to plan because, "When you admit you don't know you allow other people to help you be successful" [14].

The third step of the HEVT schedule management strategy is for team leadership and subteam members to meet weekly with the goal of understanding task progress and new developments. This information is used to update the reported progress on tasks and alter the schedule as necessary, which may include modified durations, dependencies, and new tasks altogether. As one phase of a task gets underway, detailed planning for the next phase begins. For example, many component-based tasks follow a similar development pattern: design, procure, bench test, install, and vehicle test. When the first draft of a component design is complete, a preliminary bill of materials (BOM) is created and continually updated as the design becomes finalized. This allows procurement to begin immediately after design completion, and bench test plans become more detailed while parts are in transit. Once all necessary parts are procured, bench testing can begin, and detailed installation and vehicle testing plan discussions can commence. The goal is for an installation plan to be approved as bench testing nears completion, and for a vehicle testing plan to be finalized prior to installation. In summary, each phase of this component development process allows the opportunity to plan for the subsequent phases, which is often difficult to do at the start of each semester. This is analogous to a consolidation of the third, fourth, and fifth steps of *Last Planner* which are "MakeReady", "Production Evaluation and Planning", and "Production Management." MakeReady is simply a checklist that is used to determine when everything is in place for the next phase of the project to begin, Production Evaluation and Planning is used to create detailed work plans, and Production Management is the daily monitoring of task progress.

The final step of the HEVT schedule management strategy is to review progress at the end of each semester with the goal of determining which milestones were met and what work will need to carry over into the following semester. This time is also used to review the schedule management process with the aim of identifying what worked well for the team and which aspects can be improved. This transitions well into the first steps of the schedule management process for the next semester where new milestones are established. This is analogous to the final step of *Last Planner,* "Measurement, Learning, and Continual Improvement" where the goal is to contribute to more predictable and reliable workflow. The team will systematically learn how to work more effectively together by adding continual improvement processes that make the work program ever more predictable.

3.3 Cost Management

The goal of the HEVT cost management strategy is to create more accurate future budgets to better control spending and understand the financial standing of the team. This strategy focuses on gathering cost data to link the schedule and budget, and performing EVM analysis to understand how well the team is meeting its benchmarks.

3.3.1 Environment

To build a hybrid Camaro, HEVT must spend money to acquire components and pay professionals to fabricate complex custom parts. Financial resources are also expended on a variety of overhead costs, such as facility maintenance and travel. Students identify needs as they progress through tasks and develop bills of material. When a team member is ready to make a purchase, they can either submit a purchase request to the university, where an administrator purchases the item on behalf of the team using HEVT money, or the student can purchase the item themselves and submit a reimbursement request to the university. All purchases must first be approved by a member of team leadership with knowledge of the task, and the LFA.

The team receives financial assistance in the form of cash and in-kind donations from various entities inside and outside of the university. Each entity makes donations in varying amounts at different times, and these donations comprise all HEVT income.

For HEVT to responsibly manage its financial resources, the PM must have a firm understanding of both income and expense patterns, and the PM must ensure that funds are being utilized responsibly. Most of its current funding comes from a small handful of sources which poses a significant risk in the event that one or more of these sources abruptly cancel funding. For this reason, the intelligent use of team funds is critical in order to preserve the financial health of the team for future students.

3.3.2 Strategy

Apart from EVM analysis, cost management strategies found in literature did not lend themselves to adoption in the HEVT cost management environment. The HEVT cost management process should meet the team needs of allowing the Project Manager to feasibly manage the budget while having the tools to record, analyze, and utilize income and expense data to better manage financial resources. To meet this objective, the HEVT cost management strategy focuses on income and expense tracking to produce data, and a simplified EVM to analyze data and create more accurate future budgets.

3.3.2.1 Income and Expense Tracking

The HEVT cost management strategy is heavily intertwined with the schedule management process. As discussed in *Flexible Work Breakdown Structure for Integrated Cost and Schedule Control*, integrating cost and schedule control functions "not only provides meaningful project information, but also improves the efficiency of control processes." Additionally, the authors state that "the earned value management system …is one of the best practices for integrated cost and schedule control" [11]. Similar to the schedule management plan, relatively little managerial resources are available to HEVT compared to the technical scope of the project, which drives the need for a system that is not only effective, but manageable by one person.

In order to perform EVM, income and expense data must be acquired and categorized. These transactions are labeled according to primary and secondary category. Income is the first primary category, and every secondary category of income is listed below in Table 1 with a brief description.

Table 1: Income categorization

Secondary Category	Description	Estimated Amount	Period
Alumni Donations	Cash donations from HEVT alumni during the annual fundraiser	\$1,000 - \$2,000	Annually
EcoCAR Awards	Cash winnings from competition awards	Variable	Annually
EcoCAR Outreach Funding	Cash donation to all teams for outreach expenses	\$1,500	Annually
EcoCAR Seed Money	Cash donation to all teams at the beginning of each new competition series	\$20,000	Quadrenially
EcoCAR Sponsors	In-kind donations, primarily from Snap-On and GM	GM: \$5,000 Snap-On: \$5,000	GM: Annually Snap-On: Quadrenially
Local Corporate Sponsors	Cash and in-kind donations for a variety of components and services	\$100 - \$5,000	Varies
VT Dept. of Mech. Eng.	Cash donation to design teams	\$2,000	Annually
VT Engineering	Cash donation	\$15,000	Annually
VT SEC	Cash donation to student-run engineering organizations and design teams	\$1,500 - \$2,000	Quarterly
VT Ware Lab	Cash donation to Ware Lab design teams	\$1,500	Annually

It is important to understand that several income categories are not tracked. First, travel allotment cash provided by EcoCAR 3, which funds team travel to annual workshops and competitions, is not tracked because those funds are used in their entirety for travel. If the travelling money exceeds the allotted amount, those extra expenses are accounted for in an expense category. Similarly, cash provided by both Virginia Tech and EcoCAR 3 to pay leadership position stipends are not tracked because all of those funds are used to pay the students. If more funds are used than provided by EcoCAR 3, the extra expense is accounted for in an expense category. Third, the donation of the Camaro by General Motors (GM), the energy storage system (ESS) by A123, and software by NX and MathWorks, all of which are competition sponsors, are not tracked because they are provided to every team. Finally, the motor system provided by InMotion and small in-kind donations from other local corporate sponsors, such as Panduit, are not tracked because they are entirely in-kind, whereas the other in-kind donations from competition sponsors are in the form of a gift card that can be redeemed for components, parts, and tools.

Expenses are also tracked and categorized, and are attributed to one of four primary categories: conventional; electric vehicle (EV); controls, ADAS, and innovation; and overhead. Conventional corresponds to all components required for conventional vehicle operation, and EV corresponds to all components required for the electrification of the vehicle powertrain. Parts that are purchased for the vehicle controls system work with both conventional and EV components, and form their own category. Because innovation and ADAS costs are relatively minor and are not suited to be placed with either conventional or EV, they are merged together with controls. Finally, all non-technical expenses form the overhead primary category. Furthermore, each primary expense category contains a number of secondary categories. The relationship between primary and secondary categories for expenses can be seen below in Table 2.

Table 2: Expense categorization

Primary Category	Secondary Category
Controls, ADAS, and Innovation	ADAS
	Control Code and Hybrid Vehicle Supervisory Controller (HVSC)
	LV and Controls Wiring
	Innovation
	MIL, HIL, and SIL
	Required Switches and Indicators
Conventional	Engine and Transmission (6S)
	Exhaust System
	Fuel System
	Trailer Hitch
	Transmission (8S)
EV	Charger & Charge Port
	DC/DC Converter
	ESS
	HV Power Wiring
	Position-3 (P3) Motor System
	Suspension Wheels and Tires
	Thermal System
	Vacuum Pump
Overhead	Facilities
	Leadership Funding
	Outreach
	Student Support
	Travel

When income is received or a purchase is made, the data is recorded in a spreadsheet and categorized appropriately. Additionally, the item description, vendor, cost, and shipping status are recorded. The income and expense amounts are used to update the overall account total and provide the data necessary for simplified EVM.

3.3.2.2 Simplified Earned Value Management

Using this data, HEVT can utilize a simplified EVM strategy to analyze data, produce cost performance reports, and make future budgets more accurate. The traditional EVM process, as discussed in *Earned Value Management System (EVMS) and Project Analysis Standard Operating Procedure (EPASOP)* [17] requires each task to have a concrete start and end date. Due to the challenges discussed in the schedule management section, EVM is simplified by treating the start and end of each semester as the start and end dates of each vehicle modification (secondary category) for technical tasks. Budgets are determined at the start of each semester for every vehicle modification to determine BAC values. This makes EVM possible for HEVT, and the metrics used in HEVT EVM are listed below in Table 3.

Table 3: HEVT EVM metrics

Metric	Definition
BAC	Initial amount budgeted to a task at the start of each semester
AC	Actual costs accrued by a task during each semester
EAC	Re-estimated budget, as necessary
ACP	Completed work: AC/EAC
EV	Value of completed work: BAC*ACP
VAC	Difference between initial budgeted cost and new cost estimate: BAC-EAC
CV	Difference between earned value and actual cost: EV-AC
CPI	Cost efficiency: EV/AC

Because there is little data from previous years for the PM to draw from, the BAC values are currently estimated with little confidence. By carefully recording and storing this cost data, however, future PMs may be able to create BACs with much more confidence and accuracy.

As the vehicle modifications accrue costs, these expenses are recorded as discussed in the income and expense tracking section. The costs for each task are summed to calculate the actual cost (AC), a vital component of cost performance measurement. When team leadership meets with the subteam leaders each week to discuss the schedule, the AC is compared to the BAC, and used to calculate a new estimated cost at completion (EAC), as necessary. Because each task is only being scheduled within the context of the current semester, the baseline days and actual days are not recorded because they would be identical for each task. The remaining metrics (ACP, EV, VAC, CV, and CPI) are then simple functions of the BAC, AC, and EAC, and are automatically calculated in the spreadsheet. Additionally, HEVT receives its funding from a limited number of sources in known amounts at predetermined intervals each semester. All of this information allows the PM to easily produce reports that summarize income, expense, and cost performance data, as the one shown below in Figure 7, which represents the final report for the Year 2 fall semester. Because it is the final report for that semester, the EAC matches the AC, and the EV matches the BAC. During the course of the semester, however, these metrics are more valuable and informative.

Primary Task	BAC	AC	EAC	ACP	EV	VAC	CV	CPI
				Controls, ADAS, and Innovation				
ADAS	$ 250.00	$ 80.69	$ 80.69	100%	$ 250.00	$ 169.31	$ 169.31	3.1
Control Code and HVSC	$ 250.00	$ -	$ -	-	$ -	$ -	$ -	-
LV and Controls Wiring	$ 250.00	$ 649.18	$ 649.18	100%	$ 250.00	$ (399.18)	$ (399.18)	0.4
Innovation	$ 250.00	$ -	$ -	-	-	$ -	-	-
MIL, SIL, and HIL	$ 500.00	$ -	$ -	-	-	$ -	-	-
Required Switches and Indicators	$ 250.00	$ 96.42	$ 96.42	100%	$ 250.00	$ 153.58	$ 153.58	2.6
				Conventional				
Engine and Transmission (6S)	$ 10,000.00	$ 8,733.12	$ 8,733.12	100%	$ 10,000.00	$ 1,266.88	$ 1,266.88	1.1
Exhaust System	$ 500.00	$ -	$ -	-	$ -	-	-	-
Fuel System	$ 250.00	$ 26.76	$ 26.76	100%	$ 250.00	$ 223.24	$ 223.24	9.3
Trailer Hitch	$ 100.00	$ -	$ -	-	$ -	-	-	-
Transmission (8S)	$ 5,000.00	$ 2,310.00	$ 2,310.00	100%	$ 5,000.00	$ 2,690.00	$ 2,690.00	2.2
				EV				
Charger and Charge Port	$ 250.00	$ 2.60	$ 2.60	100%	$ 250.00	$ 247.40	$ 247.40	96.2
DC/DC Converter	$ 100.00	$ -	$ -	-	$ -	-	-	-
ESS	$ 1,500.00	$ 1,189.35	$ 1,189.35	100%	$ 1,500.00	$ 310.65	$ 310.65	1.3
HV Power Wiring	$ 1,000.00	$ -	$ -	-	$ -	-	-	-
P3 Motor System	$ 1,000.00	$ 4,456.82	$ 4,456.82	100%	$ 1,000.00	$ (3,456.82)	$ (3,456.82)	0.2
Suspension, Wheels, and Tires	$ 250.00	$ -	$ -	-	$ -	-	-	-
Thermal Systems	$ 250.00	$ 280.95	$ 280.95	100%	$ 250.00	$ (30.95)	$ (30.95)	0.9
Vacuum Pump	$ 100.00	$ -	$ -	-	$ -	-	-	-
				Overhead				
Facilities	$ 7,500.00	$ 5,938.95	$ 5,938.95	100%	$ 7,500.00	$ 1,561.05	$ 1,561.05	1.3
Leadership Funding	$ 7,500.00	$ 7,058.00	$ 7,058.00	100%	$ 7,500.00	$ 442.00	$ 442.00	1.1
Outreach	$ 500.00	$ 258.03	$ 258.03	100%	$ 500.00	$ 241.97	$ 241.97	1.9
Student Support	$ 1,000.00	$ -	$ -	-	$ -	-	-	-
Travel	$ 2,500.00	$ 1,748.46	$ 1,748.46	100%	$ 2,500.00	$ 751.54	$ 751.54	1.4

Cost Performance Legend

Budget at Completion (BAC):
The initially budgeted amount to complete the task.

Actual Cost (AC):
The amount actually spent thus far to complete the task.

Estimated at Completion (EAC):
The re-estimated budgeted amount to complete the task.

Actual Completion Percentage (ACP):
The percentage of funds spent relative to the initial budget (AC/EAC).

Earned Value (EV):
*The value of the work completed thus far (BAC*ACP).*

Variable Actual Cost (VAC):
A measurement of the initial budget accuracy (BAC-EAC). Positive values are good.

Cost Variance (CV):
A measurement of how well a task is meeting its budget (EV-AC). Positive values are good.

Cost Performance Index (CPI):
A measurement of cost efficiency (EV/AC). Positive values are good.

Figure 7: Final EVM report Year 2 fall semester

3.4 Risk Management

The goal of the HEVT risk management strategy is to mitigate technical risks related to the development of the competition vehicle in order to maximize performance at annual competitions. A variety of external and internal factors create a set of risks that are impossible to completely control, but impacts to competition results can be minimized by quantifying risks and focusing on those with the greatest potential of resulting in lost points at competition.

3.4.1 Environment

Project risks on HEVT are numerous and change on a weekly basis. As students work through their tasks, unknown challenges emerge, leading to the changing nature of each risk. As a design team that is tasked with developing the best-engineered competition vehicle, the technical scope of the vehicle is the primary concern, and is the focus of all risk management efforts. While the PM has the ability to monitor and manage organizational risks alone, technical risk management must be a team effort and requires clear cross-functional communication. Additionally, failure to address technical risks will result in lost points at competitions, where team success is truly measured.

Risk management on HEVT is considered in the context of current competition objectives. For example, while the EcoCAR 3 Year 1 scoring structure was exclusively focused on success in presentations and reports, Year 2 begins to incorporate vehicle events at competition, which account for 23% of the total available Year 2 points. As EcoCAR 3 progresses into Years 3 and 4, vehicle competition events will account for 38% of the available points, making technical vehicle development an increasingly critical task. Thus, when discussing risk management strategies on HEVT, it is important to consider the strengths and weaknesses of the team relative to the available point distribution. Several risk management strategies practiced in industry were researched in order to form the HEVT risk management strategy.

3.4.2 Strategy

The HEVT risk management strategy utilizes project RFMEA principles, and is tailored to the context of EcoCAR 3. A central theme of the HEVT risk management strategy is that while the overall approach will remain constant each year, the details will likely need to change annually depending upon the scoring criteria for that given year. This HEVT risk management strategy can be adapted to any scoring criteria, and the one developed this year shows the overall process. This year, the strategy is designed around the EcoCAR 3 Year 2 scoring distribution with a focus on technical vehicle development.

During EcoCAR 3 Year 1, 100% of the available points were allocated to reports, presentations, and demonstrations. During Year 2, that number decreased to 77%, and will decrease again to 62% during Years 3-4 to make room for technical vehicle development points. While reports, presentations, and demonstrations will always constitute the majority of available points, HEVT has traditionally scored very well in this aspect of the competition. During EcoCAR 3 Year 1, HEVT placed 2nd overall out of 16 teams when reports, presentations, and demonstrations constituted 100% of the available points. These types of deliverables are the historical strength of the team due to the series of checks and level of scrutiny that each deliverable undergoes prior to submission, in addition to the low level of risk relative to technical tasks.

As the overall distribution of available points can change between competition years, so can the nature of those points. For example, the points during Year 2 that are allocated to vehicle events are divided in the following manner: vehicle integration (58%), functional safety (27%) and on-road evaluation (15%). In Years 3-4, a higher fraction of the vehicle event points will be allocated to on-road evaluation, and the value of integration and functional safety points will decrease. During Year 2, to qualify for any of the functional safety points, all vehicle integration requirements must first be met. Likewise, to qualify for any of the on-road evaluation points, all functional safety requirements must be met. For this reason, the HEVT risk management strategy is focused on the first portion of the vehicle events, vehicle integration, and the risk register lists the top five risks for this category.

Several RFMEA principles are incorporated to quantify and monitor each risk. First, the likelihood of each risk is rated on a four-point scale as shown below in Table 4. The four-point scale is used because it is simple enough to be useful, whereas a 10-point scale would offer too much detail for the often-vague understanding of risk event likelihood.

Table 4: Standardized likelihood values

Description	Highly unlikely	Somewhat unlikely	Somewhat likely	Highly likely
Rating	1	2	3	4

Next, the impact on competition points is determined using the scorecards for the safety technical inspection, the competition event where vehicle integration is judged. These scorecards list the amount of points earned for every satisfied vehicle technical requirement. The integration requirements focus on the presence and professional installation of all components in the design. Each risk can be aligned with one or more items on the scorecard, and translated into a quantitative value according to competition points. The RS, the product of likelihood and points impact, can then be calculated, and is used to determine the precedence with which risks should be monitored. Schedule and cost impacts are not included on the risk registry because they do not directly influence outcome at competition. The utilization of standard likelihood and impact values is a principle adapted from *Project Risk Management Using the Project Risk FMEA.*

The final two elements of the risk register comprise the overall response strategy, which list likelihood reduction and impact reduction strategies. Likelihood reduction answers the question, "How will the team reduce the chances of this risk event occurring?" while impact reduction answers, "How will the team reduce the points impact if this risk event becomes very likely, inevitable, or true?"

In traditional project risk management, likelihood and impact reduction would both be classified as part of mitigation, one of four response strategies. The other three strategies, which are avoidance, acceptance, and transference, are all in one way or another irrelevant to the context of HEVT and EcoCAR 3. Avoidance, which means to eliminate the cause of a risk, is often not a useful risk response option for one of the top risks. For any risk to be of such a high priority that it is listed on the risk registry, the risk exists because an avoidance measure was already enacted and failed, or was not available for use. Risks that are being accepted, where nothing is being done about them, do not need attention in the risk register, which is focused managing the risks identified. Finally, transference is never an option, because HEVT is ultimately always responsible for all of its risks. Even if the team works with a sponsor to design or fabricate a part, the responsibility still rests with HEVT that it was done correctly and in a timely manner.

By focusing on the top five risks for integration, this risk management strategy allows the PM to effectively track the most pressing risks that could impact competition results. This exercise helps subteam leaders properly allocate resources and assign tasks that give the project the best chance for success. Additionally, records of previous risks can be used in future projects to identify unforeseen problems.

4 Results and Analysis

The strategies discussed in the previous section were enacted at various stages of EcoCAR 3, and each faced its own unique set of challenges during implementation. Some strategies yielded more success than others. Those that achieved mixed results should receive the most attention from the next HEVT PM during Years 3-4. This section will provide quantitative and qualitative results of the project management strategies from all four domains, and provide a discussion on those results.

4.1 Human Resource Management

The goal of the HEVT human resource management strategy is to maximize team member talent and project-relevant knowledge through an enhanced educational and onboarding program, and through maximizing continuity. Of the four project management domains, human resource management yielded the most success. The results are discussed in terms of team and IS program demographics, and the evolution of the IS program curriculum.

4.1.1 Team and Independent Study Program Demographics

Since the implementation of this human resource strategy, the team demographics have considerably shifted so that CpE and EE students, junior team members, and IS students represent a larger portion of HEVT. Additionally, the HEVT turnover rate has significantly decreased, allowing for smoother transitions from one competition year to the next.

First, since the establishment of the ADAS and innovation requirements by EcoCAR 3, HEVT has responded by recruiting more CpE and EE students to work on these tasks. The team was unsure of the exact requirements at the start of Year 1, but began recruiting students for IS and the team during the Year 1 spring semester. A line graph showing the increase of CpE/ EE team members and IS students during EcoCAR 3 is shown below in Figure 8. For reference, Year 1 of EcoCAR 3 began in the fall of 2014, and the competition will conclude in Year 4, the spring of 2018.

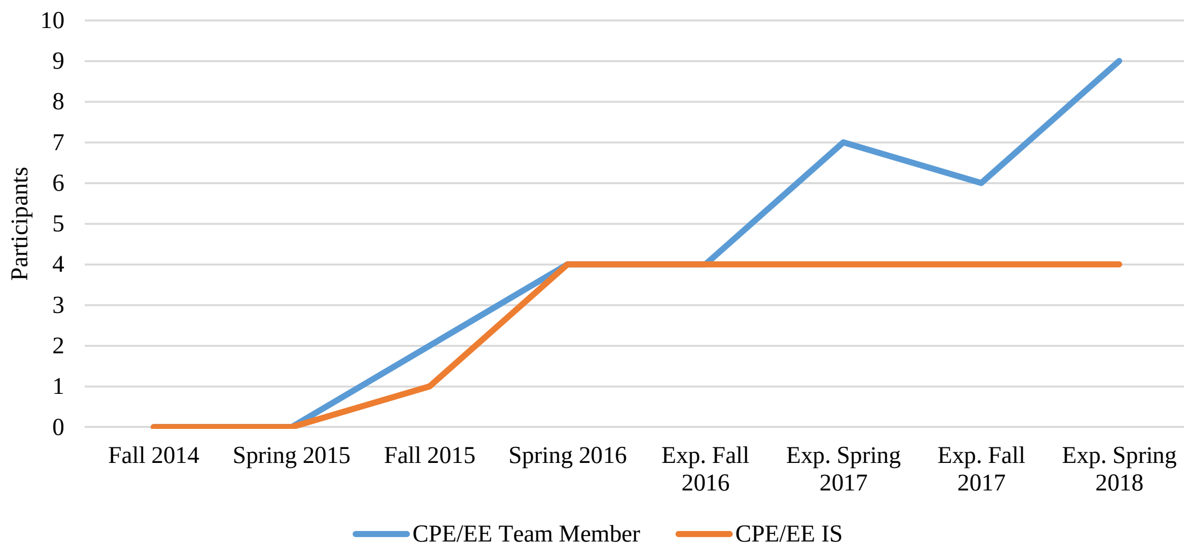

Figure 8: CpE and EE team members and IS students during EcoCAR 3

CpE and EE students comprise the ADAS subteam, and several EE students work on the electrical. The increase in CpE team members and IS students is allowing the ADAS subteam to make improved progress on their tasks, which are often separate from the rest of the engineering team. In particular, the four CpE students in the IS program are performing exceptionally well, and three are expected to return to the team for Year 3.

The increase of junior team members is enabling HEVT to reduce its turnover rate and maintain productivity during the fall semesters. For HEVT to have junior team members under its human resource strategy, students must first participate in the IS program during their sophomore spring or junior fall semesters. Due to the university rules regarding credit hours, it is difficult, but not impossible to recruit sophomores MEs during their spring semester and CpE/EE juniors during their fall semester, and expect the same effort and results from them relative to the IS students receiving degree-counting credit. Thus, the goal to have 5 ME sophomores out of a class of over 400 students each spring is realistic and enables the possibility of a small amount of junior team members on HEVT each fall. A graph showing junior team members, senior team members, and junior team members as a percentage of all team members is shown below in Figure 9.

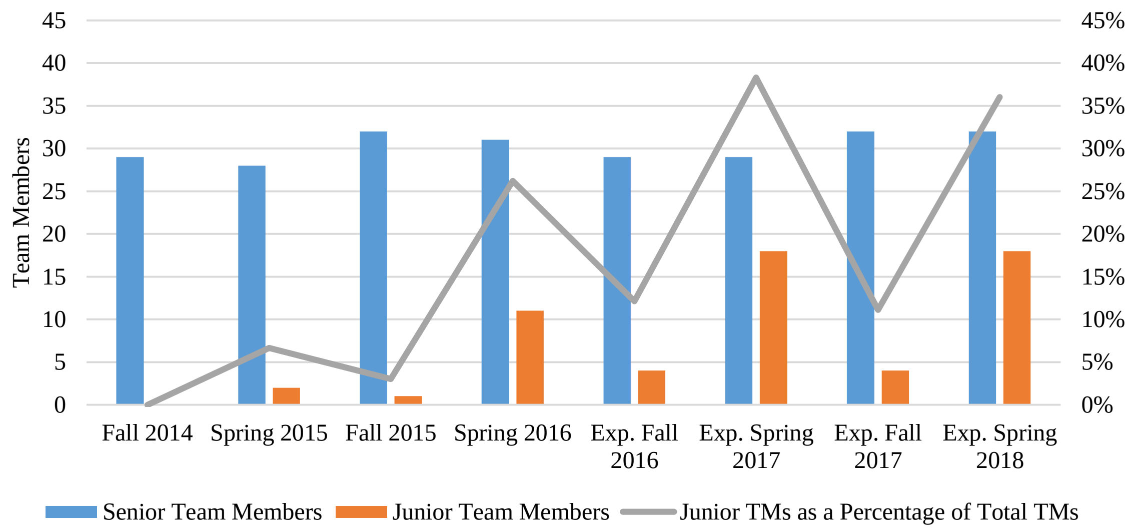

Figure 9: Senior and junior team members during EcoCAR 3

Additionally, the increase in non-senior participants, as both team members and IS students, enables a significant decrease in turnover rate, as seen below in Figure 10.

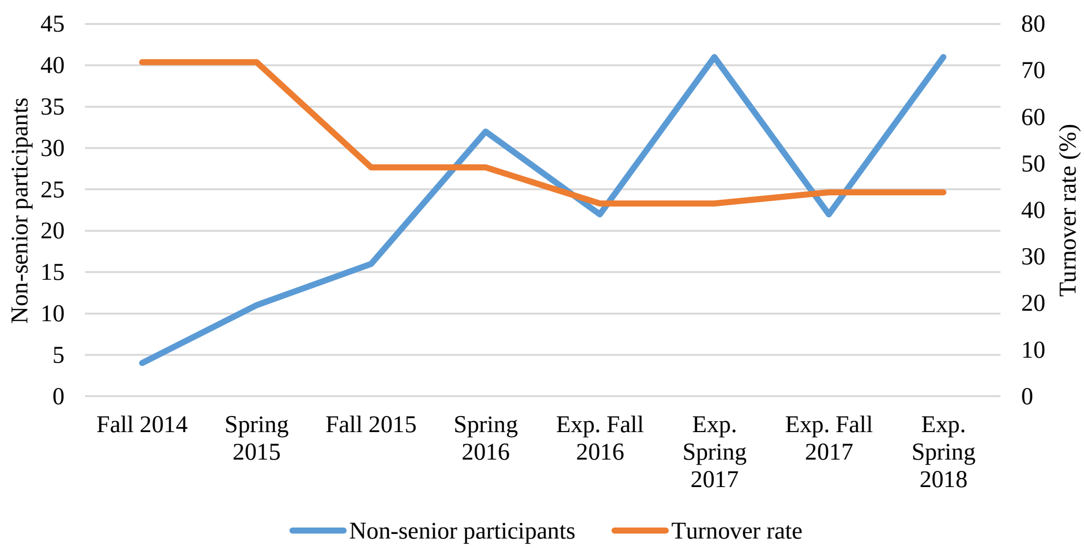

Figure 10: Non-senior participants and team turnover rate during EcoCAR 3

The revitalized IS program has an increased capacity relative to the previous structure where only a handful of students participated each semester. An early form of the revitalized structure was first attempted during Year 1 spring, and has since progressed to its current form. With the increase of young students on HEVT with relevant experience to build upon, the team is in a better position to succeed for the remainder of EcoCAR 3.

4.1.2 Independent Study Program Curriculum

The revitalized IS program was first attempted during the Year 1 spring semester, but didn't reach its current form until Year 2 fall. During Year 1 spring, the number of students increased from approximately six to fifteen students, and students worked on various projects according to subteam. During the first semester, however, freshman and sophomores comprised 50% of the participants, and most of the projects were not repeatable. Regarding the participation return rate, 75% of the juniors returned for their senior year, and only one sophomore returned as a junior team member (17%). Additionally, there were no CpE participants. Since then, the IS program has focused much more on junior MEs with a select number of sophomores, and an increase in CpE and EE participants. There has also been an increased focus on projects that provide educational benefits to the students and are repeatable. Additionally, these projects can be improved upon each semester in addition to adding general automotive engineering education, and technical report writing and presenting.

Several key success and failures of the revitalized IS program have been noted after almost two full semesters of true implementation. First, the students have developed technical writing and presentation skills not seen before from IS program participants, a result of midterm and final reports and presentations which are graded in the same manner as team member reports and presentations. These skills will allow future team members to have an increased role in the development of competition deliverables, work that was previously done primarily by graduate students. Second, a new team initiative called Peer Presentations assigns every team member and IS student an automotive engineering topic to research and present at team meetings once per semester. Students work in groups of 3-4, and each group is a mix of team members and IS students. Each week at the IS meetings, students are given a graded learning assessment to ensure their understanding of the material, followed by a discussion of the assessment answers to clear any confusion. The Peer Presentation initiative has seen excellent results, as both team members and IS students are more knowledgeable about many automotive engineering concepts. This initiative is also a great way to improve the relationships between team members and the IS students, and vice versa, furthering the relational approach of the process. Third, the return rate of IS students to the team has been better than expected: 13 of the 15 Year 2 fall participants returned to the team, and 19 of the 21 Year 2 spring participants are expected to return.

While the revitalized IS program has seen many successes, several failures were noted and must be improved upon for future semesters. First, students felt confused by the lack of organization they saw in the program during the Year 2 fall semester, primarily due to a course syllabus without predetermined due dates for assignments, a norm in many other engineering classes. At the start of the Year 2 fall semester, the PM did not request that the technical team leaders create predetermined due dates because each repeatable project was being tried for the first time. For Year 2 spring, the situation improved and the problem was solved because the technical team leaders published due dates during the first week of the semester using the knowledge and experience they gained about how quickly the students completed the projects from Year 2 fall.

The second failure was in regards to the consistency of the projects across the subteams, although each project had many elements of its own success. The mechanical project during the Year 2 fall semester, a re-creation of an EcoCAR 3 Year 1 deliverable called "Baseline Waiver," was beneficial because it gave students a firm understanding how to use the CAD software, NX. This software program is used by team members to perform modelling and stress analysis tasks, and the IS students gained a firm understanding of both applications. Issues stemmed from the troubled NX program files provided to the students, who spent far too much of their time troubleshooting. To resolve this, the EM created a new project with the help of several senior team members that covered more topics and contained healthy CAD files. The students seemed to learn better from this new project, and it will be critical to document the project so it can be re-used for Year 3.

The controls and simulation project, which is based on a graduate automotive systems modeling course project taught by the HEVT LFA, provides students with an excellent introduction to Simulink, vehicle and subsystem modeling, and simulation data analysis. Simulink, along with its parent program, MATLAB, are the two programs most used by controls and simulation subteam members to create mathematical models of the vehicle and develop control code. Each of the IS students from Year 2 are far more prepared to begin controls and simulation work as team members than any previous incoming controls and simulation subteam members. The primary problem with this project during the Year 2 fall semester, however, was that the pace and breath of the project was both too difficult for the students to learn, and for the CGRA to teach to undergraduates. This problem was partially resolved during the Year 2 spring semester by lengthening the project deadlines, and assigning each student a team member mentor who was intimately familiar with the controls IS project. The negative consequence of this adjustment regarding the lengthened deadlines is that students did not have time to complete the last 25% of the project, although these modifications allowed them to better understand the engineering principles behind the work they did complete.

Prior to the Year 2 fall semester, the EGRA did not create repeatable projects, and instead decided to rely on students contributing to competition-related work for the electrical and ADAS subteams. The benefit was that some productive work was accomplished, but the cost was that students had very inconsistent week-to-week workloads; inconsistent workloads was the primary reason that the new human resource strategy called for repeatable projects which can be modified and improved upon each semester. The EGRA must still create repeatable projects so that the electrical and ADAS IS students can participate in a way that aligns with the IS program goals. The long-term goal is to create an IS project for ADAS and electrical students comparable to the mechanical and controls projects.

4.2 Schedule Management

The purpose of schedule management for HEVT is to create a strategy that allows the PM to feasibly manage the project, and develop the best possible project plan for the engineering subteams using information that may be unreliable or incomplete. At the start of EcoCAR 3 Year 2, the PM worked to integrate the schedule management strategy into the fabric of HEVT operations. While there were many benefits to its implementation, the schedule management strategy also faced many challenges which limited its effectiveness.

4.2.1 Strategy Integration: Successes

The schedule management process, which iteratively completes the project schedule as information reveals itself through task progress, works well for HEVT for several reasons. First, it helps team leadership understand the full scope of the project because it divides the project into dozens of vehicle modifications, and assigns the responsibility of each vehicle modification to a subteam. Additionally, it allows team leadership to start and end each semester on the same page in terms of goals and milestones during the first, second, and fourth steps of the strategy. Re-engineering and rebuilding a conventional vehicle into a hybrid electric vehicle is chaotic, and dividing the project schedule into logical work packages according to vehicle modification makes the schedule much more understandable.

Second, using a limited number of CAs allows schedule, cost, and performance management activities to be heavily integrated. This eases the burden on the Project Manager by allowing efficient management of the schedule and budget. This practice is based upon concepts outlined in the *Flexible Work Breakdown Structure* approach and proves to be very useful for cost management activities and when publishing financial reports for EcoCAR 3 assignments. While the schedule management strategy was successful for several reasons, its integration was not without its challenges.

Third, schedule management is feasible for the PM using this strategy, although subteam leaders strongly influence its success. The first, second, and fourth steps of the strategy, which deal with big-picture planning, can be done by team leadership with the assistance of the subteam leaders. The third step, however, relies heavily on the subteam leaders to develop plans using more detailed task information based on the progress of their subteam from the previous week. Subteam leaders who have excellent technical knowledge and a pulse on their subteam were much more beneficial to the process than those without an understanding of how tasks are accomplished. Additionally, subteam leaders with an understanding of project scheduling were much more effective than those without planning experience. While strong subteam leaders contributed to the success of the strategy, weaker subteam leaders contributed to its failures.

4.2.2 Strategy Integration: Challenges

The first challenge stemmed from inconsistent technical knowledge and project planning ability of the subteam leaders. Without a full understanding of these concepts, the student role in the schedule management process was beyond their level of capability. This resulted in the creation of ineffective schedules that rarely reflected reality. Because it was such a burden, it was often seen as something to simply submit to the PM without actually considering what tasks must be accomplished for the week.

Second, because the process was unproven and being attempted for the first time, there was never a complete buy-in from either the subteam leaders or team leadership. While the graduate students in team leadership had the ability to help their subteam leaders create useful schedules during the third and most difficult step of the strategy, it was not viewed as a priority. The graduate students were also not concerned about inaccurate schedules being published and circulated.

Finally, cross-functional work was difficult to schedule and coordinate. This occurred because there was overlap between many of the vehicle modifications during component testing and integration, and arranging the cross-functional collaboration was made difficult by the divided nature of the schedule.

4.3 Cost Management

The goal of cost management on HEVT is to create a process that allows the PM to feasibly manage the budget while having the tools to record, analyze, and utilize income and expense data to better manage financial resources. The cost management strategy, which was implemented during EcoCAR 3 Year 1 and reached its current state during Year 2, is very successful for a variety for reasons. First, it produced a detailed record of all income and expenses, which are being utilized for cost analysis and can be used in the future to forecast accurate budgets. Second, maintaining this system has been manageable for the PM, a key requirement of the strategy. Third, it encourages responsible and intelligent spending by creating budgets for vehicle modifications that the students must work within. For all of these reasons, the current strategy is an improvement from previous cost management efforts. The current cost management strategy can be compared to previous strategies to fully appreciate its value.

4.3.1 Comparison to Previous HEVT Cost Management Strategy

The previous HEVT cost management strategy was less robust because it failed to categorize expenses, which did not enable the team to perform EVM. Budgets were not created for vehicle modifications. Instead, only income and expenses were recorded, although with much less detail than the current method. A raw sample of expense data from EcoCAR 2 Year 2 can be seen below in Table 5, which includes the first 10 of the 76 total entries.

Table 5: Raw sample of EcoCAR 2 Year 2 expense data

Vendor	Purchase Description	Date	Cost
Discount Hitch & Truck Accessories	CURT Trailer Hitch #12001	09/20/2012	$145.73
Charlotte Airport Parking	Parking Cost for Fall Workshop	10/03/2012	$25.00
Shelor Motor Mile	Clutch Disk #55587035	10/15/2012	$80.45
McMaster-Carr	87195K33 Electrical Protection Neoprene/SBR Sheeting, Yellow, 1/32" Thick, 36" Wide	10/16/2012	$162.19
Discount Hitch & Truck Accessories	CURT Trailer Wiring #59200	10/18/2012	$89.20
Grainger	ESS Parts	10/29/2012	$668.18
Graybar	ESS Parts	10/30/2012	$258.00
Metals Depot	ESS Parts	10/30/2012	$201.36
State Electric Supply Co	L6-30 plugs and receptacle	10/30/2012	$97.60
McMaster-Carr	ESS Parts	10/30/2012	$47.93

To contrast, a sample of 10 recent expenses from EcoCAR 3 Year 2 under the current strategy are shown below in Table 6.

Table 6: Raw sample of EcoCAR 3 Year 2 expense data

Date	Member	Primary Category	Secondary Category	Item Description	Vendor	Amount	Ship Status
2/2	D. Claytor	EV	HV Power Wiring	SG-14-03 Clear Cover Enclosure	Polycase	-$29.38	Arrived
2/2	D. Claytor	EV	HV Power Wiring	SG-14P Mounting Plate	Polycase	-$9.29	Arrived
2/2	S. Reinsel	Controls, ADAS, & Innovation	Required Switches	4x EAO 704.910.4 Switching Element	Allied Electronics	-$37.00	Arrived
2/2	C. Dolan	Conventional	Fuel System	12" x 12" unpolished aluminum 5052 sheet 0.5" thick, serial: 88895K313	McMaster Carr	-$60.97	Arrived
2/2	C. Dolan	Conventional	Fuel System	8" x 8" unpolished aluminum 6061 sheet 0.25" thick, serial: 9246k11	McMaster Carr	-$14.80	Arrived
2/5	P. Brew	Overhead	Facilities	Gas for travel to Lynchburg to repair mig welder	Murphy USA	-$26.00	N/A
2/5	D. Chadwick	EV	P3 Motor	2x 11GA (.120 thick) Hot Rolled Steel Sheet 2x2 ft.	Metals Depot	-$50.80	In-Transit
2/5	D. Chadwick	EV	P3 Motor	11GA (.120 thick) Hot Rolled Steel Sheet 1x2 ft.	Metals Depot	-$15.20	In-Transit
2/8	J. Buellesbach	Conventional	Engine and Transmission (6S)	2016 Camaro SS LT1 Oil Cooler #12660180	Shelor	-$181.34	In-Transit
2/9	K. Szczepaniak	EV	Thermal Systems	50 ft extruded heater hose 5526-18900	Federal Hose	-$280.50	In-Transit

The new method for tracking transactions is more detailed, which allows for a successful EVM analysis and better future budgets. The date shows how costs are distributed over time, and the team member who made the purchase is listed so that any related questions can be directed to the correct person; often, these questions pertain to shipment tracking. The third column, Primary Category, is useful for cost analysis, and shows how funds are being distributed across the main technical functions and overhead. The fourth column, Secondary Category, is useful to understand how funds are distributed across technical tasks and overhead categories. Additionally, the technical tasks in the cost management strategy are linked to the schedule management strategy, which aides EVM. The detailed item description and vendor, in the fifth and sixth columns, will be helpful in future years so that students can quickly create BOMs and identify vendors to provide those items. Finally, the shipping status is used to verify that orders arrive, and the purchasers of late or missing shipments can be notified to contact the vendor for an updated status.

4.3.2 EcoCAR 3 Year 1-2 Data

Using the data captured in Table 6, the PM is able to analyze cost information according to income sources and expense categories for a variety of purposes. The data presented below is for EcoCAR

3, and is updated as of February 19, 2016. During EcoCAR 3, HEVT raised $87,335.06, as shown below in Table 7.

Table 7: HEVT income EcoCAR 3 Years 1 & 2

Source	Amount
Alumni Donations	$ 1,236.78
EC3 Outreach Funding	$ 381.00
EC3 Seed Money	$ 20,000.00
EC3 Sponsors	$ 14,672.23
Local Corporate Sponsor	$ 3,716.05
VT Department of Mechanical Engineering	$ 3,000.00
VT Engineering Dean Support	$ 30,000.00
VT Student Engineering Council	$ 11,100.00
VT Ware Lab Stipend	$ 3,229.00
Total	**$87,335.06**

As stated previously, this income does not include travel allotments provided by EcoCAR 3, and team leadership funding provided by EcoCAR 3 and Virginia Tech.

Expenses can be first analyzed according to their primary category, which is the vehicle mode that the purchase supports, and overhead. A total of $76,970.49 has been spent by HEVT during EcoCAR 3, and the distribution of these expenses across the primary categories is shown below in Figure 11.

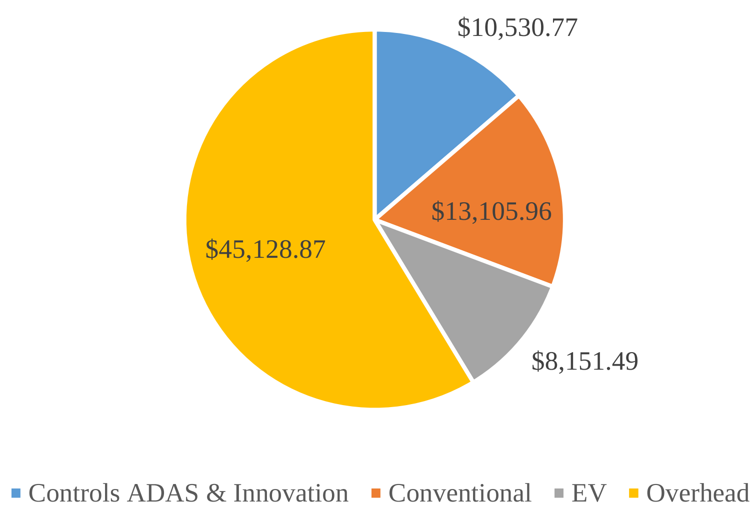

Figure 11: Primary category expenses during EcoCAR 3

Understanding the rate at which the team spends money for each category will be useful in future years to forecast expenses, and in the event that the team is low on funds, it will be useful to schedule purchases and raise funds to account for expenses. The expense timeline for controls, ADAS, and innovation is shown below in Figure 12. The items for this primary category support the wiring, development tools, and processors necessary to maintain the controller network; specialty parts required for the innovation and ADAS efforts are also included in this category, but represent an insignificant amount of spending. Complete details for this primary category and all other primary categories are detailed in Table 2. The timeline includes all of EcoCAR 3 Year 1 and the first half of Year 2. The data represents the total amount of funds utilized for this category at a given point in time. Expenses deplete funds, and are representing by the data moving downward, whereas income increases funds and is represented by the data moving upward.

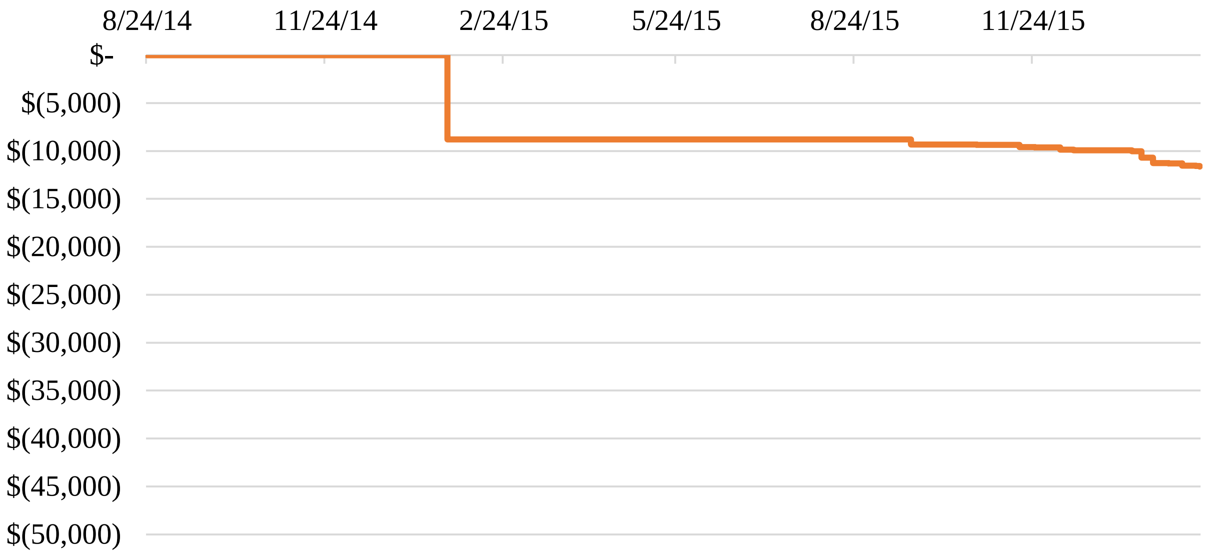

Figure 12: Controls, ADAS, and innovation spending over time

Most of the spending in this primary category was completed during the middle of Year 1 to purchase the HVSC, which cost $8,790 and accounts for 87% of the total expenditures for controls, ADAS, and innovation. Since then, many smaller purchases have been completed on specialty wires, connectors, and vehicle controllers. The expense timeline for conventional spending, which includes components such as the engine, transmission, and exhaust system, can be seen below in Figure 13.

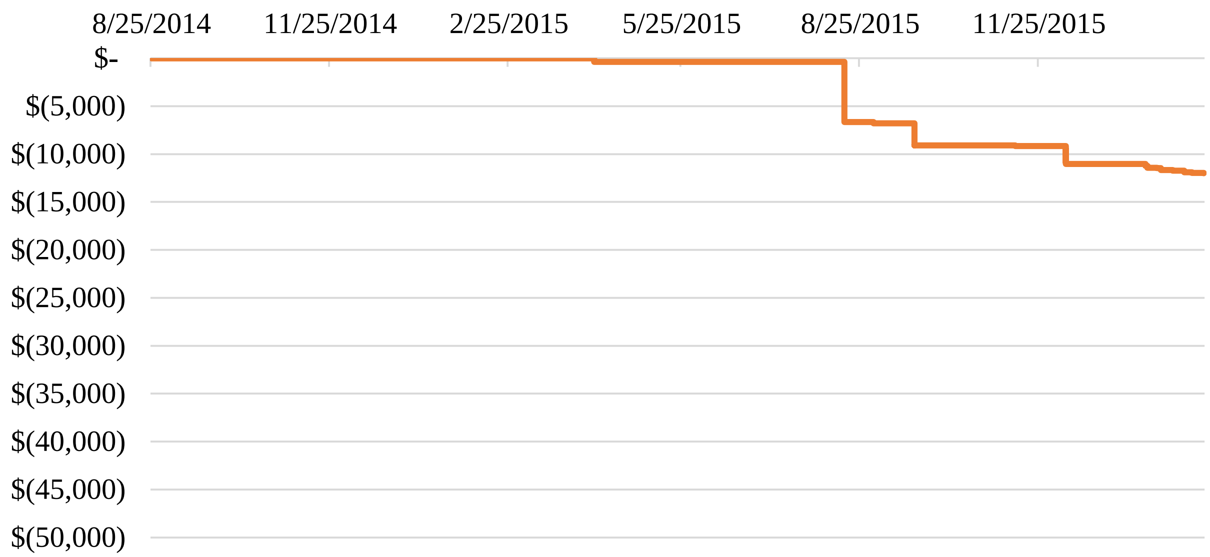

Figure 13: Conventional spending over time

Spending for this primary category did not exceed $1,000 until the start of Year 2, when the Chevrolet Silverado engine was purchased. Since then, most of the purchases made have been for engine and transmission related hardware to complete bench testing and prepare for vehicle integration. The expense timeline for EV mode, which include the ESS, battery charger, and DC/DC converter, can be seen below in Figure 14.

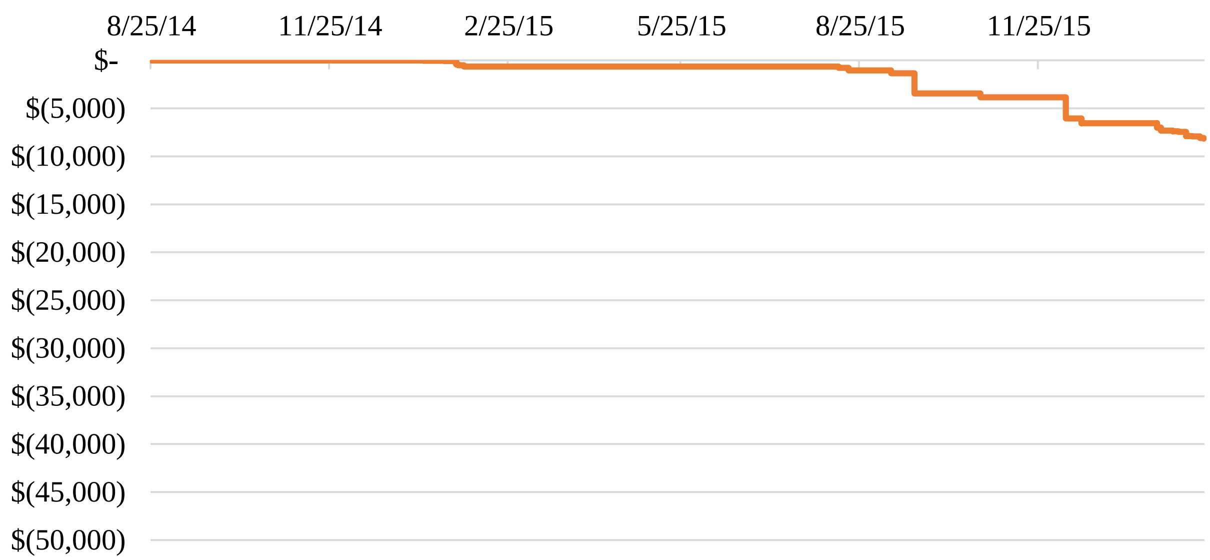

Figure 14: EV spending over time

EV spending is the lowest of the four primary categories, largely because the two keystone components for powertrain electrification, the ESS and P3 motor, were donated components by

A123 and InMotion, respectively. Most of the EV spending was accomplished on two purchases during Year 2, both of which were for differentials that are being used to create the HEVT differential. The value of these differentials together is $3,557.98, or 44% of the total EV expenses. Most of the other spending has been to support the ESS fabrication, which requires students to build the frame and housing around the battery modules. The overhead primary category represents non-technical expenses such as travel, conference fees, and facility upgrades. The overhead timeline is shown below in Figure 15.

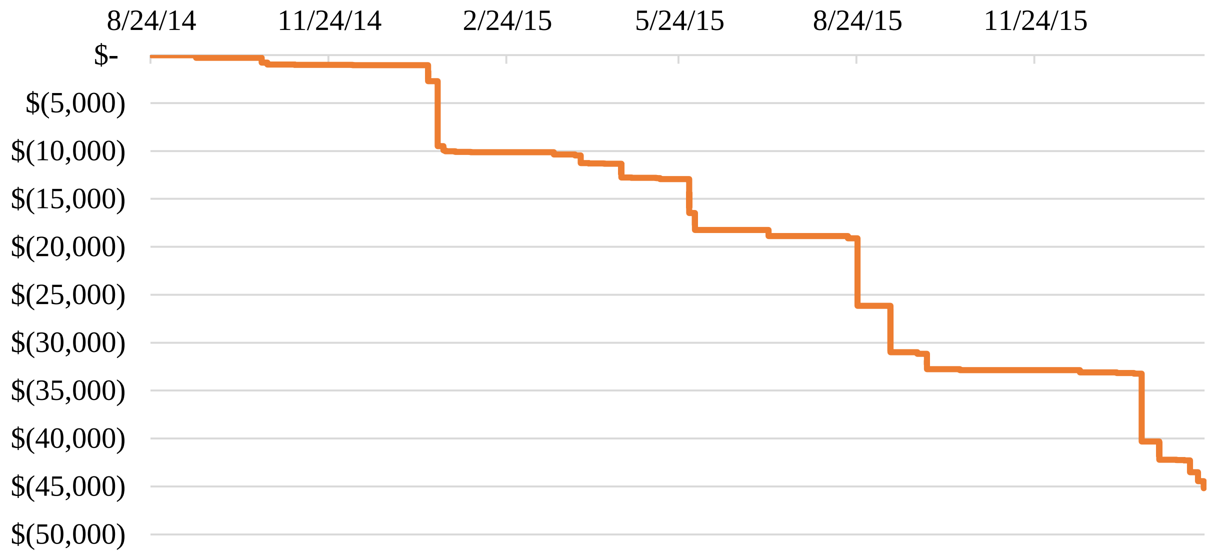

Figure 15: Overhead spending over time

The overhead expenses have been relatively steady throughout EcoCAR 3. Travel expenses are incurred for every EcoCAR 3 workshop and competition, of which there have been six thus far, totaling $9,469.46, or 21% of overhead spending. The other major source of overhead expense has been leadership funding, which has cost the team $20,909.00, or 46% of total overhead costs, to cover the CGRA tuition. Previously, this expense was covered by the university, but became no longer available at the start of the Year 1 spring semester. For this reason, stakeholder management and fundraising are incredibly important to maintain current funding relationships and establish new ones for the future.

Expenses can also be analyzed according to their secondary category, which is defined as the vehicle modification for technical tasks and overhead category for non-technical expenses. This data is shown below in Table 8.

Table 8: HEVT expenses EcoCAR 3 Years 1 & 2 (thru 2/19/16)

Primary Category	**Cost**	**Secondary Category**	**Cost**
Controls, ADAS, and Innovation	$10,530.77	ADAS	$101.22
		Control Code HVSC	$8,853.86
		LV and Controls Wiring	$862.82
		Innovation	$0.00
		MIL, HIL, and SIL	$543.75
		Required Switches and Indicators	$169.12
Conventional	$13,105.96	Engine and Transmission (6S)	$9,628.45
		Exhaust System	$210.17
		Fuel System	$140.79
		Trailer Hitch	$0.00
		Transmission (8S)	$3,126.55
EV	$8,151.49	Charger & Charge Port	$2.60
		DC/DC Converter	$0.00
		ESS	$1,637.19
		HV Power Wiring	$734.09
		P3 Motor System	$4,906.48
		Suspension Wheels and Tires	$0.00
		Thermal System	$846.30
		Vacuum Pump	$24.83
Overhead	$45,182.27	Facilities	$11,075.15
		Leadership Funding	$20,909.00
		Outreach	$1,556.67
		Student Support	$2,171.99
		Travel	$9,469.46
Total			**$76,970.49**

Creating and maintaining a budget is necessary to control costs. The first HEVT budget was created during the Year 2 fall semester, and is shown below in Table 9. The tasks that ran over-budget are highlighted.

Table 9: Year 2 fall budget results

Primary Category	Secondary Category	BAC	AC
Controls, ADAS, and Innovation	ADAS	$250.00	$80.69
	Control Code and HVSC	$250.00	$0.00
	LV and Controls Wiring	$250.00	$649.18
	Innovation	$250.00	$0.00
	MIL, HIL, and SIL	$500.00	$0.00
	Required Switches and Indicators	$250.00	$96.42
Conventional	Engine and Transmission (6S)	$10,000.00	$8,733.12
	Exhaust System	$500.00	$0.00
	Fuel System	$250.00	$26.76
	Trailer Hitch	$100.00	$0.00
	Transmission (8S)	$5,000.00	$2,310.00
EV	Charger & Charge Port	$250.00	$2.60
	DC/DC Converter	$100.00	$0.00
	ESS	$1,500.00	$1,189.35
	HV Power Wiring	$1,000.00	$0.00
	P3 Motor System	$1,000.00	$4,456.82
	Suspension Wheels and Tires	$250.00	$0.00
	Thermal System	$250.00	$280.95
	Vacuum Pump	$100.00	$0.00
Overhead	Facilities	$7,500.00	$5,938.95
	Leadership Funding	$7,500.00	$7,058.00
	Outreach	$500.00	$258.03
	Student Support	$1,000.00	$0.00
	Travel	$2,500.00	$1,748.46

These budgets were created rather vaguely because no useful cost data existed beforehand to reference and use in the creation of these budgets. Due to this uncertainty, many of the budgets were given slack. Several tasks, however, still managed to go over-budget. Most notably, the P3 motor system went more than four times over-budget. This occurred because the budget was created before the team knew it would have to acquire several differentials to create the post-transmission portion of the driveline. As discussed earlier, these expenses totaled $3,557.98. Without the purchase of these differentials, the P3 motor system would have finished the fall semester $101.16 under-budget. The long-term benefit of recording cost data now will be that future PMs will be able to create more accurate budgets in the future. If a future HEVT PM uses this information, it will be important to look at the individual transactions that summed to create the total expense for a given component to account for differences in the overall nature of the project. Future competition vehicles may not require certain components used in EcoCAR 3, and the configuration of the components could reshape integration expenses.

4.3.3 Future Economic Viability of HEVT

Understanding HEVT income and expense patterns can help the PM forecast the team balance and determine whether increased fundraising or conservation measures are necessary. The total HEVT expense timeline, income timeline, and account balance since the start of EcoCAR are shown below in Figures 16-18. The figures show that, during EcoCAR 3, HEVT has spent $76,970.49 while managing to raise $87,335.06, a surplus of $10,364.57.

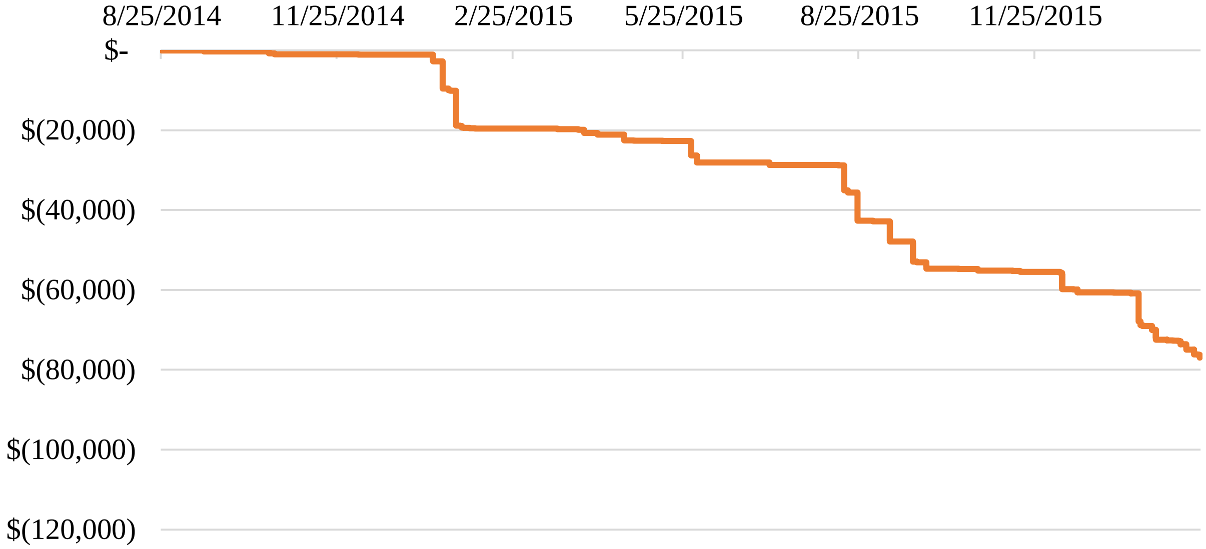

Figure 16: Total expense timeline

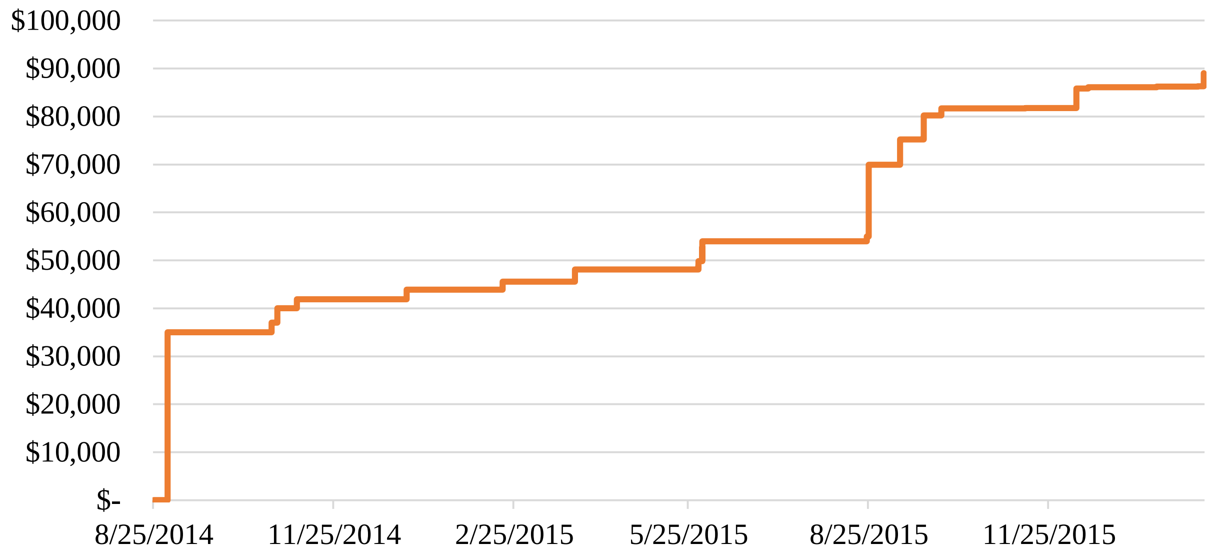

Figure 17: Total income timeline

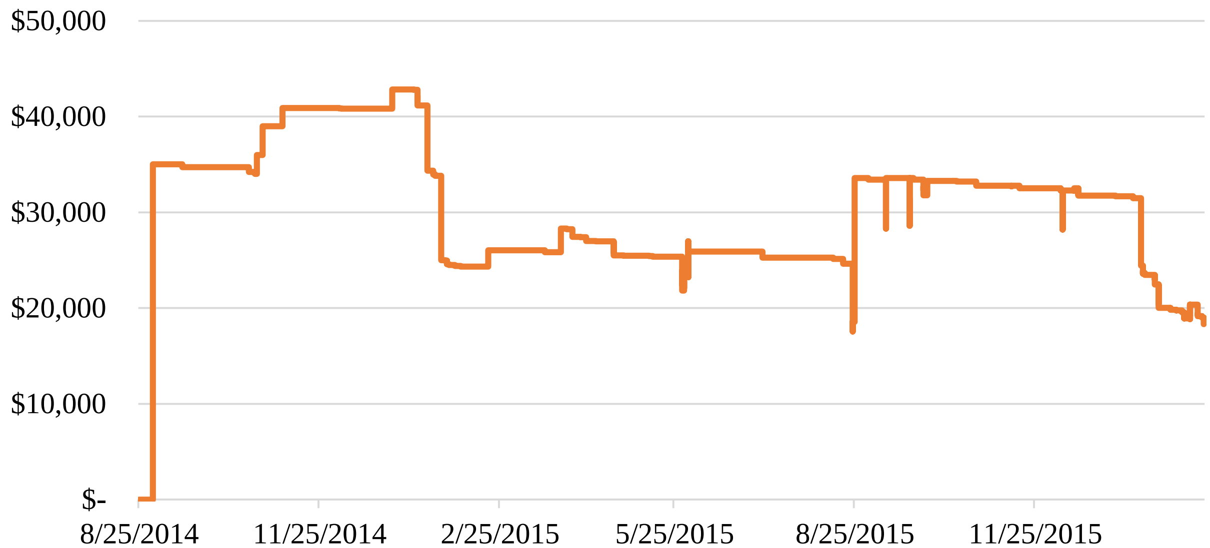

Figure 18: Account balance timeline

The HEVT balance should remain positive for the remainder of the competition due to the current surplus and funding agreements. During the potential times that the balance may become negative, the team has savings which can be used. To reach this conclusion, future incomes and expenses were estimated, and several conservative assumptions were made to create these forecasts. In this sense, conservative means that the costs were overestimated and funding was underestimated. For the remainder of Year 2, the model assumes no more income apart from a possible $5,000 in cash winnings from competition awards, and technical expenses from January and February are extrapolated to account for remaining technical expenses. The remaining Year 2 overhead expenses can be estimated based upon the one remaining trip, which is to Yuma, AZ and San

Diego, CA for the Year 2 competition. Together, these assumptions result in predicted remaining Year 2 expenses as shown below in Table 10, resulting in a net loss of $8,471.32.

Table 10: Forecasted remaining Y2 income and expenses

Controls, ADAS, and Innovation	Conventional	EV	Overhead	Income
($3,359.90)	($1,944.06)	($3,195.36)	($4,972.00)	$5,000.00

In the forecast timeline, the remaining Year 2 technical expenses are distributed evenly through mid-May, when the team plans to leave for competition. The overhead expenses are placed one month before competition when trip reservations are typically made.

Many income and expense assumptions were made for Years 3-4 to predict the end-of-competition balance. For the three technical primary categories, it was assumed that the team will spend 25% of what it spent during Years 1-2 during each of the remaining two years. This is because the vehicle should be fully built by the end of Year 2, and Years 3-4 are dedicated to careful refinements. The overhead expenses will match those from Year 2, and will occur each of the next two years.

Several income categories are not expected to generate any funds during Years 3-4. First, no income is predicted for EcoCAR Seed Money because that payment is only made to each EcoCAR team at the start of each competition series. The other income source predicted to result in no income for Years 3-4 was the Department of Mechanical Engineering, because the team did not receive any Year 2 funding and it’s uncertain if the funding received in Year 1 will ever resume. Apart from the VT Engineering funding, which assumed full funding for Years 3-4 due to a commitment letter from the university, the remaining income sources assumed a conservative amount relative to data from Year 1 and Year 2. An annual donation of $15,000 was assumed for VT Engineering because that was has been a longstanding agreement between HEVT and College of Engineering. These assumptions are summarized below in Table 11.

Table 11: Total income and expense assumptions Y3-Y4

Expenses		
Primary Category	**Estimate**	**Allocation Period**
Controls, ADAS, and Innovation	$6,945.34	Continuously
Conventional	$7,525.01	Continuously
EV	$5,673.43	Continuously
Overhead	$50,154.27	Quarterly
Income		
Secondary Category	**Estimate**	**Allocation Period**
Alumni Donations	$2,000.00	Annually, mid-spring
EcoCAR Outreach Funding	$2,000.00	Annually, end-of-year
EcoCAR Seed Money	$0.00	N/A
EcoCAR Sponsors	$10,000.00	Quarterly
Local Corporate Sponsors	$1,000.00	Biannually
VT Dept. of Mechanical Engineering	$0.00	N/A
VT Engineering	$30,000.00	Annually, start-of-year
VT SEC	$8,000.00	Quarterly
VT Ware Lab	$2,000.00	Annually, end-of-year

Using these assumptions, the overall balance timeline for the remainder of EcoCAR 3 can be estimated, as shown in Figure 19.

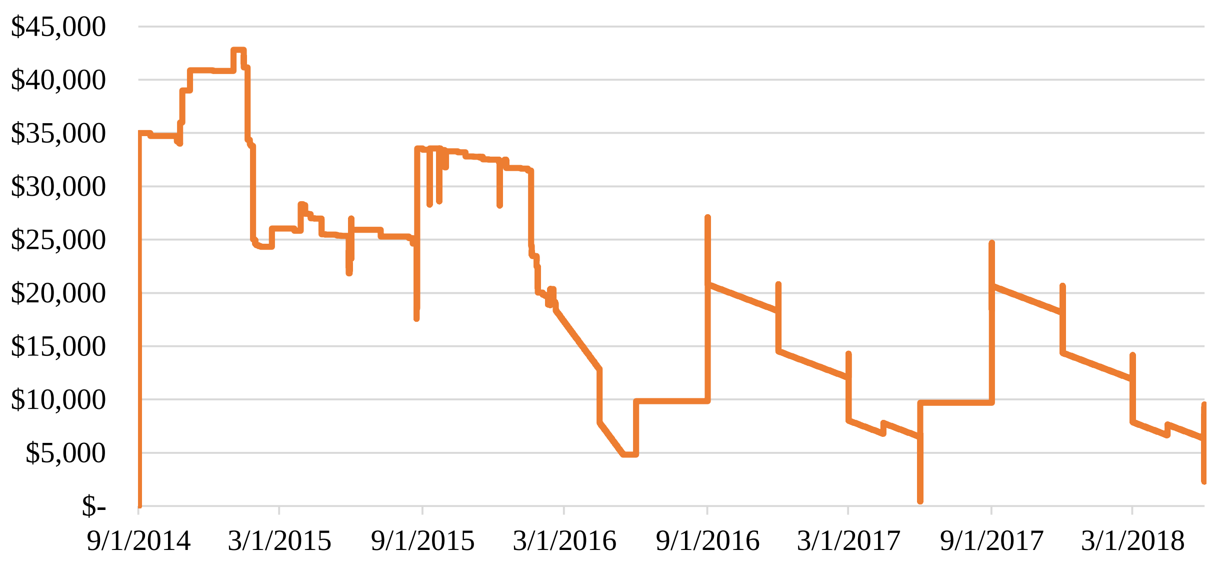

Figure 19: Overall balance timeline

Using these assumptions, the team's balance since the start of EcoCAR 3 is expected to approach zero during June 2017. It should be noted, however, that the assumptions used to create this model assumed a worst-case scenario for funding and excessive spending for the remainder of Year 2.

4.4 Risk Management

The purpose of the risk management strategy is to mitigate the most pressing technical risks related the development of the competition vehicle that could negatively affect team performance at competition. The strategy entails identifying and monitoring the top five technical risks, and quantifying the risks according to their points value at competition. Initial risk assessment information and their updates are gathered through discussions at weekly leadership meetings, and the PM is responsible for maintaining the data and communicating risk response strategies to team members. The risks discussed in this section are current as of six weeks prior to the date that the vehicle ships for competition, and are classified as integration risks.

4.4.1 Integration Risks

The integration portion of the safety-technical inspection is worth 58% of the available vehicle competition event points. Integration requirements must be met to be eligible for further vehicle event points. The vehicle will be evaluated and scored upon arrival at the competition, known as the as-shipped status, and then will be further evaluated as students make last-minute modifications to the vehicle, known as the final status. For teams that do not meet all of the integration criteria for the vehicle as-shipped, they must eventually meet all of the integration criteria for final status to proceed to earn points for functional safety. The top five integration risks, according to risk score, are shown below in Table 12. These risks have the highest potential to disrupt success during stage 1 of the safety-technical inspection at Year 2 competition.

Table 12: Integration risk register

Integration Risk Management					
Risk Event	**Likelihood**	**Points Impact**	**Risk Score**	**Likelihood Reduction**	**Impact Reduction**
If bend radii for HV cables in the ESS are not followed to specifications, the ESS may not be eligible to pass inspection.	2	41	82	Closely monitor the build process and update CAD to foresee any bend radius problems. Adjust the design as necessary.	Travel to competition with design files and all materials necessary to make last-minute ESS modifications.
If the polycarbonate lid is not manufactured correctly, the ESS may not be eligible to pass inspection.	2	41	82	The team received a donation of twice as much material than is necessary so the student fabricators have two chances to fabricate correctly.	Fabrication will be done very soon, and more material will be purchased with expedited shipping if necessary.
If the motor fabrication delays further, it may not be available for integration.	2	35	70	Daily emails and weekly meetings with InMotion.	Fabricating a motor housing to insert as a non-functional motor.
If the mass of the vehicle is too high, consumer-friendly components may need to be removed.	2	18	36	Purchased light, medium, and heavy-grade scales to gather mass data prior to, and during, vehicle integration.	If the vehicle is overweight following integration, specific components will be removed that will allow the team to pass inspection while meeting weight requirements.
If the installation of the floor-pan is not done correctly, then the vehicle may be damaged.	2	4	8	A sponsor fabricated the floor-pan according to team specifications. A licensed welder was recruited to assist he team for installation.	Continue working with the licensed welder to repair any problems that may arise until the floor-pan is correctly installed.

The two highest risks are related to the ESS. While electrical subteam members received design approval from competition organizers in the fall semester, several problems have emerged since then that are causing manufacturing and integration slowdowns. The highest integration risk is that errors in the CAD design of the ESS are causing the team to make last-minute changes which alter the routing paths of the high-voltage (HV) cables. These HV cables are thick copper with manufacturer-recommended minimum bend radii to prevent corrosion and maintain safety. Among many other technical requirements, the competition organizers will be inspecting the bend radii of the HV cables inside and outside of the ESS, and the vehicle will not pass integration if the bend radii are not in compliance with the manufacturer specifications. At competition, 20 points will be deducted if the ESS is not properly integrated, approximately 6 points may be deducted when judging the quality of the HV system integration, and 15 points will be lost for not passing the integration phase of safety-technical inspection, resulting in a total loss of 41 points. The odds of the ESS failing to pass safety-technical inspection are somewhat low because the build phase is underway and the electrical subteam feels that the issue is currently under control; however, unexpected problems arise from what the students do not know, so there is still a chance that a major problem may occur. To reduce the likelihood of any bend radii problems, the team is closely monitoring the build process and updating the CAD design as necessary. If it becomes apparent that the team will not have time to correct these issues prior to vehicle shipment, then the team will come prepared to competition with all design files and materials necessary to resolve the issue.

The second highest integration risk is also related to the ESS, and concerns the polycarbonate lid used to seal the high-voltage contents within the housing. The material is expensive to procure and manufacture. To reduce costs, the team initiated a new sponsor partnership with a chemical company, who will donate the material. The team requested twice the required quantity of material as is necessary so that the the student fabricators will have two chances to fabricate the lid correctly using Ware Lab tools. The fabrication process requires two 90-degree bends, and the student fabricators feel comfortable that they can do this after practicing with scrap polycarbonate. The risk stems from the fact that once the material is bent, it cannot be unbent. For each polycarbonate sheet, the student fabricators will have one chance to correctly execute the process. Because the students were able to practice with scrap polycarbonate and have two chances to correctly fabricate the lid, the likelihood of this risk event is somewhat low. The points impact is identical to the previous risk with the bend-radii of the HV ESS cables. The likelihood of this risk event was reduced by procuring twice as much material as is necessary, and the impact can be reduced by requesting or purchasing more material with expedited shipping, if necessary.

The third integration risk, the timeline of the motor fabrication, has been a concern since the end of Year 1. The motor design and fabrication schedule has been delayed repeatedly since the task began. The team is developing this motor with InMotion, a local sponsor, and several unexpected obstacles caused these delays. First, two different InMotion engineers who were working with the team left the company, requiring that InMotion place new engineers on the project and for the students to inform these engineers about the design intentions. Second, there was a miscommunication regarding the balance of responsibilities between the students and the InMotion engineers. During the design phase of the motor, there were many instances when the students felt that they lacked the support they needed to complete the design on their own, and many weeks passed where the students would send updated design files to InMotion only to be notified of problems that were not previously discussed. Currently, the motor is expected to be complete by mid-April, leaving only two weeks between motor fabrication and vehicle shipment. Once the motor arrives, the team feels confident that it can be easily installed due to its location in the vehicle. Any further delays with InMotion, however, will result in the complete absence of a main powertrain component for competition, and will cost the team 20 points for its absence and 15 points for a failure to pass the integration phase of safety-technical inspection. To reduce the likelihood of this risk event, the team is meeting with InMotion weekly and sending emails almost daily to keep an open line of communication. As a back-up plan, the team is producing its own motor housing to substitute for the motor in the vehicle, which would allow the team to pass safety-technical inspection, although up to 6 points could be deducted for mechanical integration quality. Additionally, the motor would be non-functional, as it would simply be an empty housing.

The fourth integration risk concerns the vehicle mass, which must be under a certain limit, known as the curb weight, in order to pass safety-technical inspection. The vehicle mass was an important constraint during the design phase of the project because it limits the size and placement of components. Not only must the vehicle be under-mass, but the weight cannot be too unevenly distributed between the front and rear of the vehicle. Failure to have an under-mass or balanced vehicle would result in a three-point deduction, and a failure to pass safety-technical inspection, a 15-point deduction. The likelihood of this happening is somewhat low because the team has been proactive about managing the vehicle mass, but some uncertainty remains because the mass of several components which have yet to be fabricated or procured are still unknown. To reduce the likelihood of arriving to competition with an over-mass vehicle, the team purchased three scales, each with a distinct purpose, to gather mass data on components that would be integrated into the vehicle. Two mechanical subteam members are responsible for tracking the vehicle mass, and keeping the team up-to-date on mass estimates. They currently predict the vehicle to weigh 40 pounds under the limit after integration is complete. In the event that unforeseen circumstances cause the vehicle to be over-mass, the team is prepared to remove the audio system and seat electronics in order to reduce mass.

The installation of the custom floor-pan is the focus of the final integration risk on the register. In order for the motor to be installed into the vehicle, a portion of the floor-pan needs to be cut and replaced with a custom floor-pan that was shaped specifically for the integration of the motor underneath the vehicle. First, the students were planning to create and install the floor-pan, but all of the risks regarding this process were reduced by creating a new sponsor partnership with a company that fabricated the floor-pan, and by working with a licensed welder to assist in the installation of the floor-pan. The likelihood of the team shipping a vehicle with a damaged floor-pan area is somewhat low because the mechanical subteam has taken every precaution possible by working with a sponsor to fabricate the floor-pan, and working with a licensed welder to install it. Proper alignment of the floor-pan is critical to vehicle operation because the motor must be concentrically aligned with the driveshaft. If the floor-pan area is damaged by the installation, the team will continue to work with the welder to clean up the damage as much as possible. If there is damage to this area, approximately three points may be deducted when organizers judge the quality of the mechanical integration. While other risks have been identified with higher risk scores, this risk is included in the register because it could cause permanent, multiyear damage to the vehicle.

5 Conclusions and Recommendations

This section details the major conclusions reached in each of the four project management domains, as well as make recommendations for how future Hybrid Electric Vehicle Team Project Managers can improve upon these strategies. Overall, these strategies are improving the future of the team by cultivating more talented and experienced team members, organizing project activities into a consolidated schedule, controlling spending and understanding long-term economic health, and reducing risks which could greatly impact performance at annual competitions.

5.1 Human Resource Management

Ensuring the success of the human resource management strategy was the highest project management priority, and success, during Years 1-2 of EcoCAR 3. This desired achievement was emphasized because it was believed that by solving the problem of inexperienced team members, the entire team stood to gain by the vast increase in knowledge and experience from all team members for the remainder of EcoCAR 3 and beyond. The focus of the human resource management strategy, the revitalized Independent Study program, is the greatest success of the overall project management strategy. In just two years, the Hybrid Electric Vehicle Team transformed its roster from a group of inexperienced seniors to EcoCAR veterans who understand the competition, the team, and the vehicle they are tasked with building.

An element of the independent study program that is often questioned by its students and team members alike, the semester-long repeatable projects, is one of the chief reasons why the program is so successful. Keeping in mind the goal of at least 25 senior mechanical engineers, and the need of a small advanced driver assistance system subteam led by computer engineers, the team cannot achieve both continuity and a well-run team without the independent study projects. Having as many junior team members as senior team members working on the vehicle would achieve improved continuity by allowing junior team members to work under senior team members for one year, but would also result in a roster that is far too large for leadership to handle and for tasks to be delegated appropriately. As it stands, this strategy is pushing the limits of a healthy roster size during the spring semester by having 50 team members after fall semester independent study students join the team. By having these students train via projects as opposed to working on the vehicle, the roster can remain manageable and the Hybrid Electric Vehicle Team can maximize its continuity between academic years.

The semester-long repeatable independent study projects are also effective because the graduate students that administer the projects are not required to conceive new projects each semester. Furthermore, future members of team leadership will have completed the projects themselves as independent study students. The graduate students become intimately familiar with the projects in addition to the graduates of the independent study program, who can later serve as mentors. The mechanical and controls projects should be improved upon as necessary, and the electrical and advanced driver assistance system projects need to be formalized. A leading priority of future Project Managers and other members of team leadership should be to create those projects and iteratively improve the overall independent study program using feedback from students.

With more help from mentors, it may be possible to increase the capacity of the independent study program. Doing so would allow the team to be more selective regarding who is invited to join as a team member. Because the team was transitioning to this new model during Year 2, almost all of the independent study program participants were invited to join as a team member because it was necessary to fill the roster requirements for Year 3. It should be noted, however, that while almost all of the independent study students were invited to return, a number of those invitees may not have been asked to join as team members had there been additional competition from more independent study students. While many students excelled in the independent study program, some put on a lackluster performance, but were invited to join the team because it was decided that an ordinary student with relevant team experience would be better for the team than a promising yet inexperienced and unproven student.

Finally, a qualitative benefit of the human resource strategy is how it has impacted the team culture and overall experience. Now that students are on the team for longer periods of time, they develop closer relationships with their peers, which makes the experience more enjoyable for everyone. The sophomores and juniors have students to emulate, and will be able to mentor younger students once they become skillful contributing team members. Additionally, the requirement to pass through the independent study program to become a team member makes the Hybrid Electric Vehicle Team a more exclusive and desirable design team, and is creating more excitement among engineering students at Virginia Tech, particularly during recruitment cycles; during the past four recruitment cycles, over 260 students applied to the team for approximately 90 open positions. This allows the Hybrid Electric Vehicle Team to be more selective and invest time into Virginia Tech's most promising engineers.

5.2 Schedule Management

While the schedule management strategy was seen as another top priority by the team Project Manager, it did not achieve the same level of impact as the human resource strategy. Schedule management was less formalized on the team prior to EcoCAR 3, and great potential benefits were identified for incorporating an all-encompassing process that helped organize technical work; tasks would be assigned intelligently, fewer deadlines would be missed, and everyone on the team would have a better understanding of the true vehicle development process. While the outlined process worked well in theory, it faced many challenges in practice that contributed to its ineffectiveness.

The key reason it was not successful was because other members of team leadership and the subteam leaders did not buy into its potential benefits. Currently, each member of team leadership operates in their own territory, and there is very little keeping the five engineering subteams together. The Engineering Manager focuses primarily on the mechanical subteam, the Controls Graduate Research Assistant focuses on the controls and simulation subteams, and the Electrical Graduate Research Assistant focuses on the electrical and advanced driver assistance system subteams. Schedule management was intended to be a unifying force among the technical subteams, but was instead seen as a burden by team leaders and subteam leaders since it did not immediately help complete technical tasks. During Year 3, all of team leadership will be new in their roles, and it will be a great opportunity for the next Project Manager to attempt this strategy again with a clean slate. As part of this effort, the Project Manager should emphasize the intended roles of their positions, specifically of the Engineering Manager. EcoCAR 3 organizers designed these roles to be complimentary; the Project Manager should be responsible for overseeing the Hybrid Electric Vehicle Team as an organization, and the Engineering Manager should be responsible for overseeing engineering within the team. Currently, the Engineering Manager assumes many project management responsibilities instead of focusing on serving as a unifying force among all technical subteams. If the Engineering Manager and Project Manager assume more traditional roles, it should be possible for the Project Manager to receive direct and regular assistance from the Engineering Manager in the creation of the project schedule.

While the team members and future subteam leaders will have more technical experience than current or previous subteam leaders, there is no reason to expect that they would have a better understanding of project scheduling. Understanding the theory behind project scheduling is not difficult, but it is also not intuitive to most people. The Project Manager should review basic project scheduling theory with the subteam leaders and the Engineering Manager prior to the start of each semester or academic year to ensure that everyone can meaningfully contribute to the project schedule. Scheduling courses at the local Project Management Institute chapter could be a valuable resource. Additionally, reviewing these topics with all team members may be helpful since they will be relaying information about their tasks to their subteam leaders.

Finally, if the strategy is achieving more success but is a burden due to the shear amount of work required to maintain the schedule, it may be in the best interest of the EM and PM to focus on scheduling tasks with the greatest degree of risk. Using the risk register, tasks that carry more significance regarding competition success should receive more scheduling attention than those with faraway deadlines and fewer consequences.

5.3 Cost Management

Midway through Year 1 of EcoCAR 3, the Hybrid Electric Vehicle Team was focused on ensuring that it would have adequate funds for the vehicle build during and refinement during Years 2-4. All of the support for the graduate student funding came from external sources, the team was receiving $15,000 annually from the College of Engineering, and the Student Engineering Council and Department of Mechanical Engineering were making generous contributions.

Beginning in the spring semester of Year 1, the team unexpectedly lost its tuition funding for the Controls Graduate Research Assistant, resulting in a required payment of approximately $7,000 per semester to pay for graduate in-state tuition. During the fall of Year 2, the Department of Mechanical Engineering stopped providing stipends to senior design teams, and a misstep on behalf of the Project Manager and a team member resulted in the loss of one Student Engineering Council payment. Suddenly, the team’s financial future felt less certain, prompting the creation of the current cost management strategy.

One of the key differences between previous cost management efforts on the Hybrid Electric Vehicle Team and the current strategy is the organized collection of income and expense data. Data from EcoCAR 2 was only useful for simple record keeping, which made it difficult to confidently create budgets during EcoCAR 3. The necessity of financial data collection to create more accurate future budgets with the goal of better controlling spending was the motivation behind the current cost management strategy.

The most difficult aspect of the cost management strategy was determining how to categorize income and expenses. Once the system was established, it was easy to maintain. In the future, it is recommended that the Project Manager utilize data from EcoCAR 3 Years 1-2 to produce more accurate budgets that are enforced more strictly. Budgets should be created at the beginning of each semester for each secondary category, and earned value management reports should be produced monthly.

Analyzing the team's financial future is important to maintaining its viability. Funding sources could erode, as seen with the Controls Graduate Research Assistant tuition funding. For this reason, stakeholder management, fundraising, and budget enforcement should be given a higher priority in the overall project management efforts to maintain existing funding relationships, generate new income, and prevent wasteful spending. One of the greatest causes of unnecessary spending is on the rushed delivery of purchased items. When team members do not plan their activities in advance, which should not happen under a successful schedule management strategy, parts are ordered with overnight or two-day shipping, often doubling or tripling the cost of a shipment. This highlights just one example of how the successes and failures of each of these strategies have a direct and significant impact on other elements of project.

5.4 Risk Management

This risk management process was implemented during the Year 2 spring semester, and provided the team with guidance leading up to competition. By highlighting which activities were more prone to problems that would result in lost points at competition, team leadership was able to focus on these problems and ensure that the best students were working towards solutions. As a measure of accountability, students working on these tasks were invited to a weekly team leadership conference call with the General Motors mentor, an advocate of the team who can provide technical assistance and direction. By bringing these undergraduate students into a meeting with all of team leadership and the General Motors mentor, it helped them discuss their progress and problems, and put additional responsibility on them to complete their tasks.

This process is a unique assessment tool that has not been used before on the Hybrid Electric Vehicle Team, and is based upon best practices from industry. Elements from the project risk failure modes and effects analysis strategy were utilized, and the impacts from that strategy were substituted for the points impacts of EcoCAR 3, making it particularly valuable for any EcoCAR 3 team.

The major pitfall of this strategy is that it only considers the top five risks for one portion, albeit the most significant portion, of the safety-technical inspection. This takes focus away from a series of other risks, which although are less precarious, could still pose problems for the team at competition. The strategy was designed this way to make it manageable for the Project Manager to conduct using the limited time and resources available for these efforts, but could be more useful if the Project Manager was able to receive assistance from other team members in order to consider a wider breath of risks.

To improve the process in the future, more risks could be considered if subteam leaders were involved in risk management. For example, it may be possible for the Project Manager to train each subteam leader to act as the risk manager for their particular subteam. The student would analyze the scorecards for the upcoming competition, and identify the most pressing risks that their subteam is responsible for mitigating. To utilize the subteam leaders to gather more risks, the Project Manager would need to invest time at the beginning of the competition year by training these students to think about project risks in this manner, and by doing so, would expand the reach of the risk management strategy. This process would provide added security to the success of the Hybrid Electric Vehicle Team at competition each year, and allow the PM to spend more time analyzing the risks and making big-picture decisions, as opposed to gathering information directly from subteam members.

Overall, the process is effective, but could be refined to become more robust. The process for each year should remain the same, but the impact valuation must change along with the annual scoring structure. The Project Manager should also be sure to be transparent about these risks with all team members in order to ensure clear cross-functional communication, because risks from one area of the project could have an unexpected impact somewhere else.

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