UAS Loss of Link (UL2) Standardization

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I. Introduction

A. Background

An Unmanned Aircraft System (UAS) is an aircraft that is controlled by a pilot who is not present within it. UAS do not have a see-and-avoid capability; they are piloted remotely from ground stations via a real-time command and control (C2) data link. Therefore, the risk of contingency maneuvers in case of a loss of link situation differs greatly from aircraft with a pilot onboard. If the link between the ground station and UAS is lost, the aircraft becomes autonomous until the link is re-established. In the event of a loss of link situation, the Unmanned Aircraft (UA) uses pre-programmed procedures for situations that require autonomous flight, which differ depending on the manufacturer and operator of the UA. These autonomous lost link procedures have an impact on the operations of the UAS, ground stations, and Air Traffic Control (ATC).

B. Problem Definition and Need

When a UAS becomes autonomous, it becomes unpredictable to ATC due to the large set of possible loss of link procedures. This unpredictability may result in an increase in controller workload if additional coordination with pilots or other controllers is needed. For example, a neighboring aircraft may need to be rerouted in order to avoid the unresponsive UAS. A reroute often requires additional controller-pilot transmissions on busy radio frequencies, and additional communication with controllers responsible for neighboring airspace. A loss of link situation also increases the risk of a loss of separation or collision which is a critical safety hazard.

Standardized procedures for loss of link situations are desired to make these events more predictable and easier to manage for ATC. The standardization of procedures could also assist in commercializing the use of UAS.

C. Sponsors and Stakeholders

This project is being sponsored by the MITRE Corporation, a not-for-profit organization that manages Federally Funded Research and Development Centers (FFRDCs). The team will be working directly with Andrew Lacher, who is the UAS Cross-Center Coordinator and Research Strategist at MITRE's Center for Advanced Aviation System Development (CAASD). He is the team's customer and will be evaluating the team's work at the final presentation and providing feedback throughout the project period.

In addition to the sponsor, this topic involves many members of the UAS community including ATC, UAS manufacturers and operators, as well as UAS researchers. The team's sponsor will facilitate meetings with a subset of these stakeholders so the team can gain an understanding of different stakeholder views.

1. The UL2 Team

Sahar Sadeghian-
Sahar Sadeghian has worked at The MITRE Corporation since 2010, when she graduated from George Mason University with a Bachelor's Degree in Systems Engineering. At MITRE, she works at the Center

for Advanced Aviation System Development focusing on Aviation Safety. She will be graduating with her Master's Degree in Systems Engineering from George Mason in May 2012.

Steven Lubkowski-

Steven Lubkowski has worked at The MITRE Corporation as a Systems Engineer since 2010. He received his Bachelor's Degree in Systems Engineering specializing in Aviation Systems from George Mason University in 2010 and is currently pursuing his Master's Degree in Systems Engineering, graduating in 2012.

Rob Dean-

Rob Dean has worked at The MITRE Corporation since 2007 when he graduated from the University of Virginia with a Bachelor's Degree in Mathematics. While working at MITRE, he has earned a second Bachelor's Degree in Airport Management from Vaughn College of Aeronautics and Technology, and is pursuing his Master's Degree in Systems Engineering from George Mason University. He expects to graduate in May of 2012.

Rohit Paul-

Rohit Paul graduated from George Mason University with a Systems Engineering Bachelor's degree in 2009. He has worked at the Federal Aviation Administration as an engineer for the En Route and Oceanic service unit. Currently, he works at the MITRE Corporation as a Systems Engineer and Enterprise Architect in support of the Next Generation Air Transportation System and is planning to graduate with his Master's Degree in Systems Engineering in May 2012.

II. Scope

A. In Scope

The UL2 team will be developing a methodology for evaluating UAS loss of link procedures. Once a methodology has been established, the team will test and evaluate the approach with a sample procedure. The focus of the project will be on UAS flying within non-segregated civil airspace in the National Airspace System (NAS). This refers to airspace commonly flown through by commercial aircrafts controlled by the Federal Aviation Administration, as opposed to special use military airspace that has been blocked off. The Team will consider UAS that are capable of extended flight operations in Class A airspace (above 18,000 feet Mean Sea Level (MSL)).

B. Out of Scope

The team will not be responsible for the identification of an optimal procedure in loss of link situations. Any optimal solution would have to be discussed and agreed upon within the UAS community and is dependent on the many stakeholders. Because of this, allocation of weights to the identified metrics will be out of scope. The sponsor has emphasized this point and stipulated that the methodology and metrics are the important elements in this project.

III. Assumptions

For the purpose of this project, the team will make the following assumptions:

- All functions on the UAS other than the C2 link are functioning correctly.
- The aircraft is not constrained by its current capabilities because it may need modifications to perform future procedures.

IV. Preliminary requirements

These preliminary requirements have been developed to document the team's initial understanding of the sponsor's needs. The Project Requirements define the team's required work for the duration of the project period. The Functional Requirements define the expectations for the UAS loss of link procedure evaluation methodology that will be documented and delivered at the end of the project period. These requirements are expected to evolve as work progresses.

Project Requirements

- The UL2 team shall solicit input from UAS Subject Matter Experts (SMEs) including Air Traffic Controllers, UAS Pilots, and MITRE UAS experts.
- The UL2 team shall define the required criteria to be used in the evaluation of UAS loss of link procedures.
- The UL2 team shall define an appropriate metric for each evaluation criterion.
- The UL2 team shall develop a methodology that uses the defined criteria and metrics to evaluate sample UAS loss of link procedures.
- The UL2 team shall demonstrate the applicability of the developed metrics and methodology on sample UAS loss of link procedures.
- The UL2 team shall prepare a final report detailing the work performed throughout the duration of the project period, the final evaluation criteria, and the evaluation methodology that is developed.
- The UL2 team shall prepare a final presentation that explains the work to SEOR faculty and the project sponsor.

Functional Requirements

- The developed evaluation methodology shall provide a means for ranking UAS loss of link procedures.
- The developed evaluation methodology shall allow weighting of the metrics based on analysis and stakeholder input.

- The developed evaluation methodology shall be capable of incorporating new evaluation criteria that may become important after the initial project period.
- The developed evaluation methodology shall be repeatable.
- The developed evaluation methodology shall include modeling and simulation of at least two of the defined evaluation metrics.
- The developed evaluation methodology shall be adaptable to include future modeling and simulation.

V. Technical Approach

The UL2 team will use systems engineering processes to elicit metrics and will apply them to a simulation that will be used to rank order procedures. The high level overview of this process is documented in Figure 1 below.

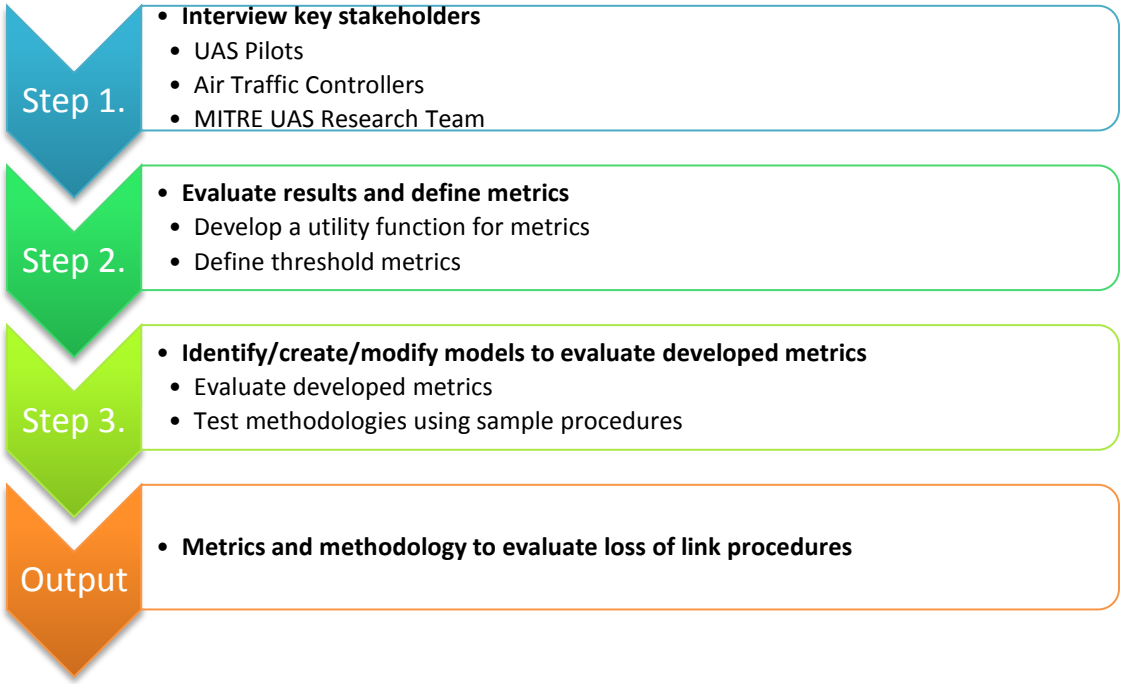

Figure 1- Process Diagram

This project will impact many different stakeholders of the UAS community. As a result, the team will first focus on conducting interviews with key stakeholders that are made available by the sponsor. The UL2 team will develop a set of questionnaires that will be used to elicit appropriate metrics. These metrics will then be used to identify models or other tests that can be performed to evaluate and score sample procedures. The evaluation score will be used to rank procedures in accordance with stakeholder preferences. The output will consist of a list of metrics and a methodology to evaluate loss of link procedures.

The team will identify tools or measures that may be used to determine the score for metrics. In some instances, the tool that may be needed to evaluate a metric will be developed by the team. Figure 2 is a notional view of the methodology, which has identified four metrics of interest when evaluating a procedure.

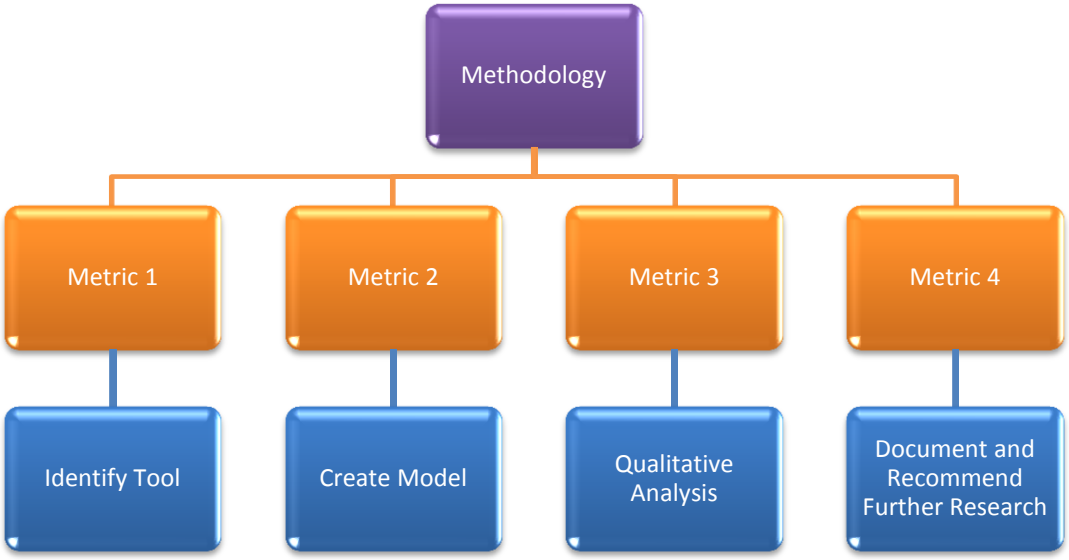

Figure 2: Notional Methodology

In this notional methodology, Metric 1 could be evaluated using a tool that must be identified by the team. Metric 2 could be evaluated by developing a model. The team would develop the model to determine a score for the metric. Metric 3 could be evaluated by a qualitative analysis. Metric 4 could be identified as a metric that is out of the scope of this project but worthy of pursuing with further research.

To demonstrate an example of a model that may be developed, the team has used the example of a safety metric, predictability, in Figure 3.

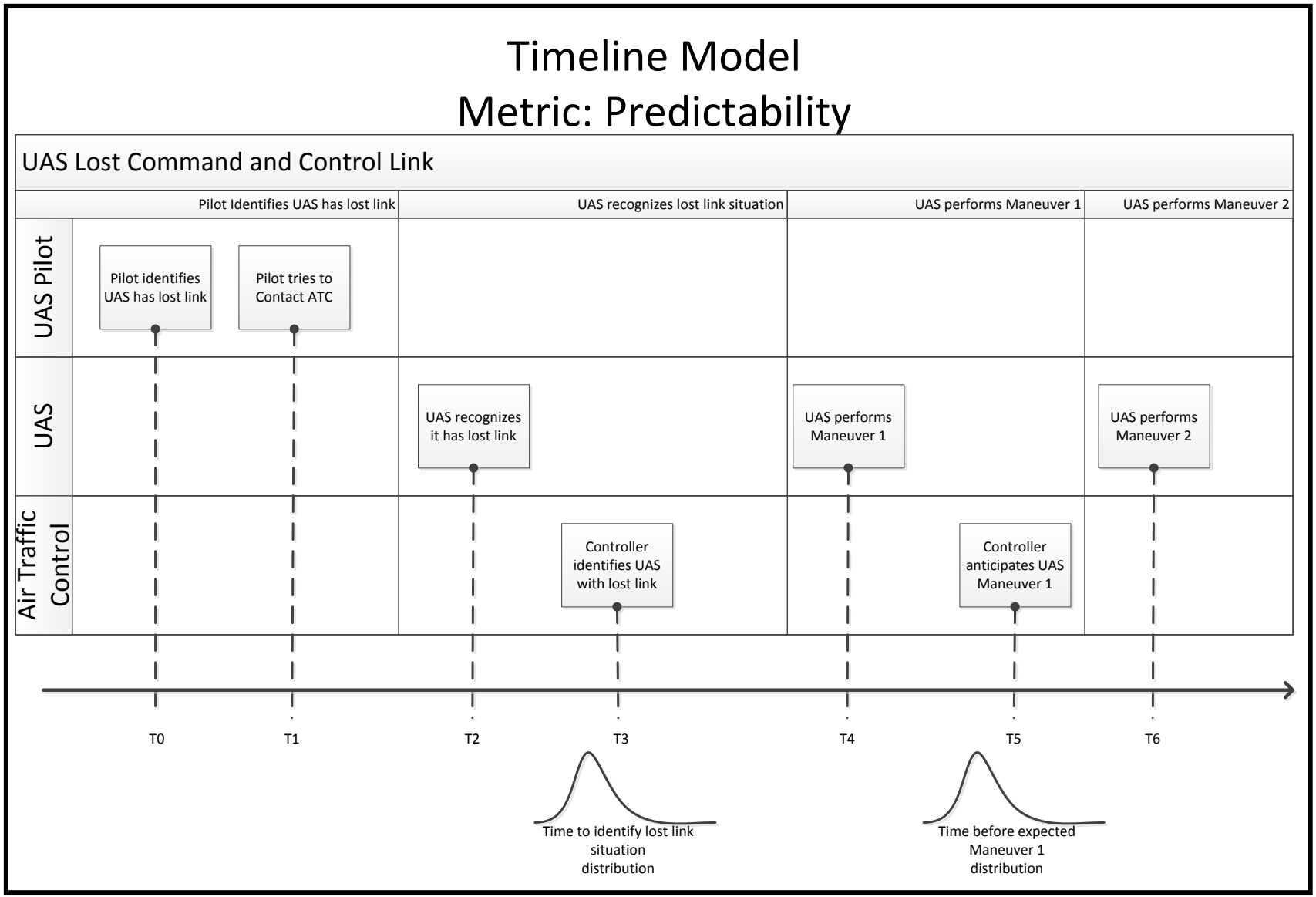

Figure 3- Draft Timeline Model (Metric: Predictability)

Figure 3 details a draft version of a model that may be used to evaluate the metric of predictability of a loss of link procedure. The model provides a time sequence to show key events in a lost link situation. Once the UAS has lost the C2 link, the controller must identify the UAS and then anticipate the next maneuver in order for the procedure to be considered predictable. Data that may be fed into this model includes a distribution that models the length of time it may take a controller to identify the UAS as an aircraft that has lost link (T3 – T2). Another distribution of importance is the time before the expected Maneuver 1 will occur (T5 – T4). The time before the expected Maneuver 1 can be captured for data analysis as a pseudo-metric for predictability. It can be assumed that the smaller the time interval, the more predictable the procedure is for the controller.

This model is in draft form and can be further extended by introducing more complexities such as the risk of having a UAS in conflict with another aircraft while it has lost link. As the team acquires metrics from the stakeholders, the team will then further refine this model and identify other models as needed.

VI. Expected results

The UL2 team expects to elicit a set of metrics that are important to the major stakeholders in this project. Using this set of metrics, the team expects to develop a methodology that can be used to evaluate loss of link procedures for UAS. This methodology is expected to be adaptable to various loss of link procedures with repeatable results. The methodology will be capable of adding new components to meet the sponsor's future research needs.

The final products of this project will include the defined metrics, the process of determining the metrics, the methodology for evaluating loss of link procedures, a final report documenting all the work done within the project period, and a final presentation.

VII. Project Management Plan

A. Deliverables

Below are the project's critical deliverables along with their scheduled dates of delivery. Along with the final report, the team will deliver a report detailing the project methodology to the sponsor.

Table 1- Deliverables

	Deliverables	Delivery Date
Presentation	Problem Definition	February 2, 2012
	Scope Definition	February 9, 2012
	Progress Reports	March 8, 29
	Final Presentation	May 11, 2012
Reports	Project Proposal	February 16, 2012
	Final Report	May 6, 2012
	Methodology Report	May 6, 2012

B. Work Breakdown Structure

The team separated the project into the phases shown in Figure 4 below.

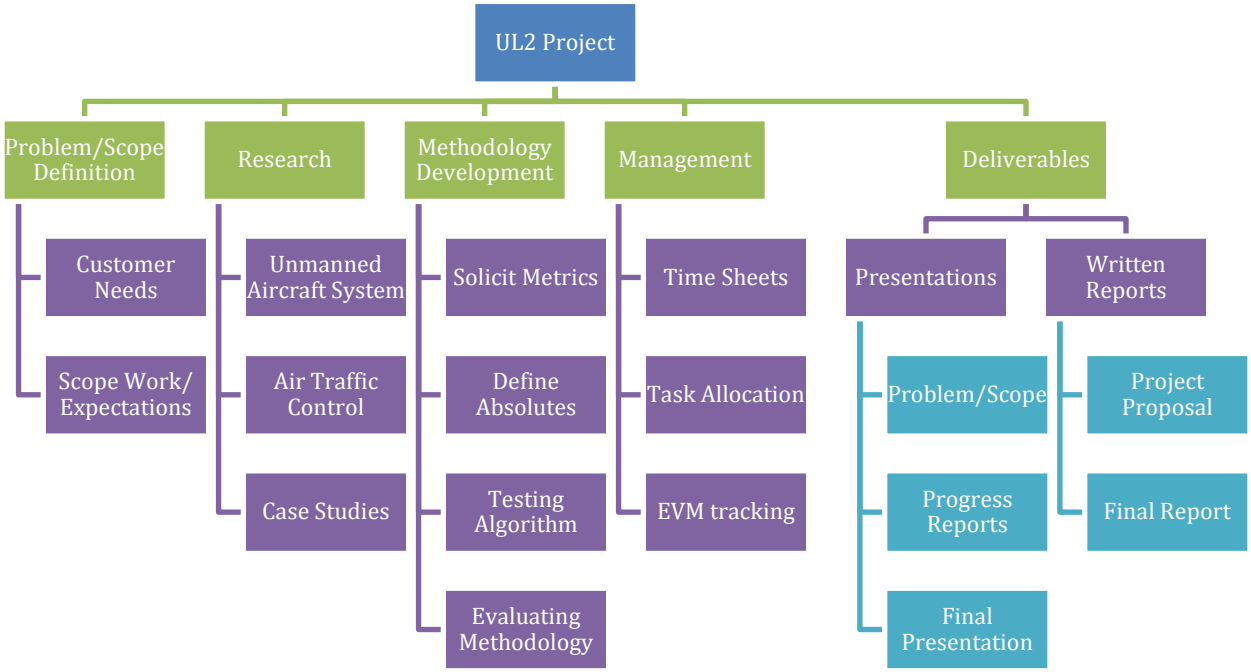

Figure 4- UL2 Work Breakdown Structure

1. Problem/ Scope Definition

In this phase, the team will meet with the sponsor and determine what outcomes are expected. The project will be scoped through discussion with the sponsor and Dr. Laskey.

2. Research

The UL2 team will gain a better understanding of the problem by learning more about UA and the UAS community.

3. Methodology Development

This phase consists of the bulk of the project's work. The UL2 team will work with the sponsor and UAS SMEs to identify metrics and develop a methodology to evaluate those metrics. The team will determine the software that is most suitable for this analysis. This phase also includes performance analysis.

4. Management

The management phases consist of developing the WBS and allocating resources to itemized tasks. The team will schedule regular meetings with the sponsor.

This phase also consists of project monitoring to ensure that the project is on track in terms of schedule, cost and results.

5. Deliverables

The deliverables section in the WBS outlines the key milestones throughout the project period including documents delivered to the sponsor and interval presentations to Dr. Laskey. The project will conclude with a final document delivery both to the sponsor and Dr. Laskey, and a final presentation to the GMU Systems Engineering faculty and the sponsor.

C. Project Schedule

The team used Microsoft Project to plan this semester-long project. The project schedule was developed to document and track the tasks needed to complete this project. Each individual task serves as a step for a major team goal or deliverable. The resources available were the four team members who were assigned to tasks. The tasks and their allocation can be found in Table 2 below, and the corresponding schedule is shown in Figure 5.

Table 2- Tasks

WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	**UAS Lost C2 Link**	**234 hrs**	**Tue 1/24/12**	**Fri 5/11/12**		
1.1	**SEOR Class Milestone**	**228 hrs**	**Thu 1/26/12**	**Fri 5/11/12**		
1.2	**Group Meetings**	**215 hrs**	**Tue 1/24/12**	**Thu 5/3/12**		
1.3	Define Problem Statement	26 hrs	Thu 1/26/12	Tue 2/7/12	3	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.4	Define Project Scope	10 hrs	Tue 2/7/12	Wed 2/15/12	31	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.5	Identify Approach	20 hrs	Fri 2/3/12	Tue 2/21/12	32	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.6	Project Proposal	20 hrs	Thu 2/9/12	Thu 2/16/12	33	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.7	**Define Methodology Process**	**115 hrs**	**Thu 2/16/12**	**Sun 4/8/12**		
1.7.1	Solicit Metrics	30 hrs	Tue 2/21/12	Tue 3/6/12	33	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.7.2	Define Absolutes	15 hrs	Tue 3/6/12	Tue 3/13/12	36	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.7.3	**Simulation**	**115 hrs**	**Thu 2/16/12**	**Sun 4/8/12**		

1.7.3.1	Define Simulation	20 hrs	Thu 2/16/12	Fri 2/24/12		Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.7.3.2	Build Simulation	40 hrs	Fri 2/24/12	Wed 3/14/12	39	Rob Dean,Rohit Paul[80%]
1.7.3.3	Test Simulation	30 hrs	Thu 3/15/12	Wed 3/28/12	40	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.7.3.4	Validate Results	25 hrs	Thu 3/29/12	Sun 4/8/12	41	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8	**Write Report**	**92 hrs**	**Fri 3/16/12**	**Sat 4/28/12**		
1.8.1	Problem Statement	10 hrs	Fri 3/16/12	Wed 3/21/12	31	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8.2	Project Scope	10 hrs	Thu 3/22/12	Tue 3/27/12	32	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8.3	Project Process	15 hrs	Wed 3/28/12	Tue 4/3/12	33	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8.4	Analysis	15 hrs	Mon 4/9/12	Mon 4/16/12	42	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8.5	Outcomes and Conclusions	15 hrs	Mon 4/16/12	Mon 4/23/12	47,42	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.8.6	Recommendations	10 hrs	Tue 4/24/12	Sat 4/28/12	48	Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.9	Research Hours	100 hrs	Mon 1/30/12	Thu 3/15/12		Rob Dean[25%],Rohit Paul[25%],Sahar Sadeghian[25%],Steve Lubkowski[25%]
1.10	Web Site Design	35 hrs	Wed 1/25/12	Tue 4/3/12		Steve Lubkowski

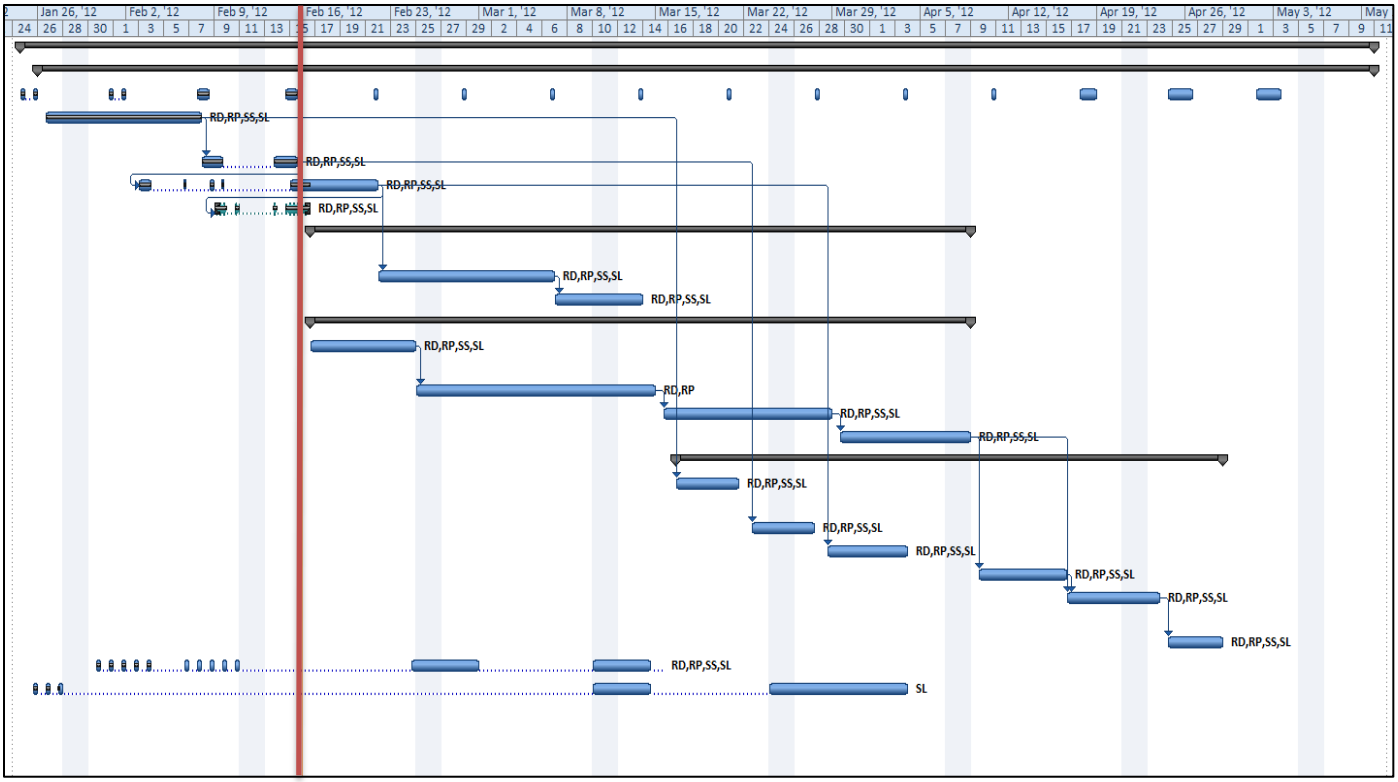

Figure 5- Gantt Chart

D. Earned Value Management (EVM)

Once the UL2 team assigned resources to the tasks mentioned above, a budget was determined for each task. The overall budget estimate for the project came to $28,000. This estimate includes the labor from the team members at $40 per hour as well as a slack of approximately $3,000. The UL2 team started discussions with the sponsor the week before the project officially started so the EVM chart in Figure 6 starts on January 19, 2012. This EVM chart will be maintained throughout the project period. The team will check weekly to ensure that they are within cost and schedule parameters.

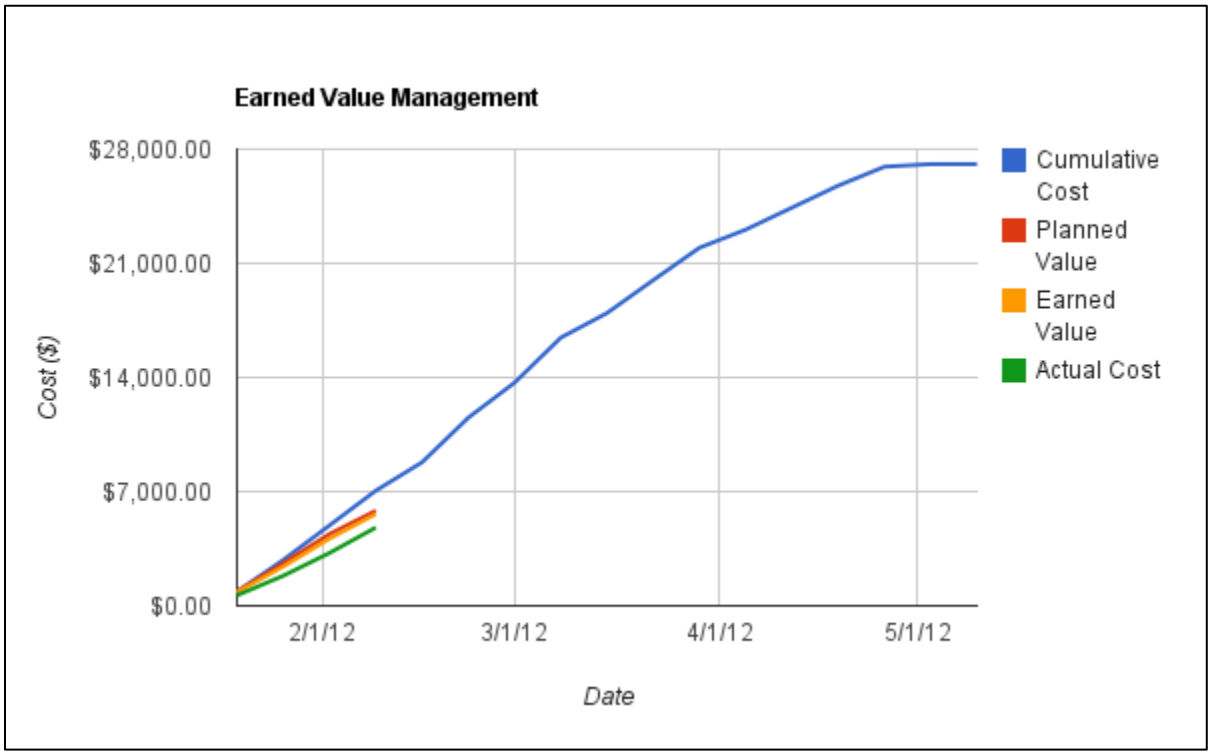

Figure 6- EVM Tracking