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Directional-Based Cellular e-Commerce: Undergraduate Systems Engineering Capstone Design Project*

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This paper describes the framework of an innovative style of mentoring for a capstone design course offered in the Systems Engineering Department of the George W. Donaghey College of Engineering and Information Technology at the University of Arkansas at Little Rock (UALR). The course is focused on a pedagogical approach to teach systems engineering design by establishing a client-based, industrially inspired, experiential teamwork learning environment, which allows students to think divergently to create a convergent solution using creative approaches. A team from the Computer and Telecommunications Systems Engineering Options addressed aspects of the design and development cycle of a directional-based cellular e-commerce project including system mission, architecture, operational scenarios, design, prototyping, and validation. The team considered relevant stakeholder needs and constraints, contrasted viable design alternatives against project requirements, followed a sub-system breakdown to fulfill the requirements identified in the Request for Proposal (RFP) to which system functions and properties can be mapped, and examined potential implementations within a constrained budget while ensuring system level compliance. A classroom environment, which is conducive to creative engineering design, is initiated by nurturing novel thoughts, encouraging autonomy, individual learning styles, self-reflection, assessment, and expanding students' ability to reason on original thought processes. Overall, the students felt they were provided with a unique and valuable experience that would be beneficial to them in their careers. Nearly all students were enthusiastic about the hands-on use of CAD for modeling and simulations and other professional systems engineering tools to solve real-world problems.. Although some students were frustrated at times, in the end, the experience gained was considered valuable. Assessments based on interviews conducted by the industry sponsor with individual students, results from quantifiable metrics and rubrics, comments from alumni, and the industrial advisory board on the course instruction have been overwhelmingly positive, supporting our conclusion that the course structure provided an effective learning experience.

Keywords: capstone design course; systems engineering education; industry sponsorship project; project-based learning; creative engineering design

1. INTRODUCTION

INFORMATION DELIVERY to customers, based on their location, offers the potential for a broad range of service offerings and consequently increased revenue for telecommunications operators and other service providers [1–4]. A service that has an even better potential for revenue generation, which is the subject of the capstone design project under consideration in this paper, is one that could determine the location and direction of motion of customers, anticipates arrival at a certain location, and delivers a list of Points-of-Interests (POIs) based on customer profiles.

The Systems Engineering Department at UALR offers a two-semester capstone design course during the senior year: SYEN 4385: Systems Engineering Capstone Design I, and SYEN 4386: Systems Engineering Capstone Design II. During a two-semester period, a directional-based cellular e-commerce project, termed *eViator*, was offered to a team consisting of six undergraduate students from the Computer and Telecommunications Systems Engineering Options. The team investigated the design and implementation of *eViator* with special emphasis on speed estimation, preplanned versus on-demand services, and infrastructure integration. Students examined available supporting technologies, determined the most suitable method of implementation, designed a system that can be easily integrated with an existing cellular infrastructure, and developed a suite of platform-independent, software algorithms to deliver the vital elements of *eViator*.

Providing an engineering design experience to

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student teams working on industry-inspired/sponsored capstone design projects is not novel [5–10]. The literature is replete with numerous journal articles and conference proceedings addressing the role of a capstone course for traditional electrical, computer, mechanical, civil, and industrial engineering programs [11–20] with excellent discussion of the methods and techniques as well as challenges associated with objective evaluations to gauge student attainment of outcomes [9]; [16–17]; [21–23]. However, considerably less literature has tackled issues related to a capstone design course in the realm of systems-centered disciplinary programs [24–26]. It is this latter area that this paper is focused on. More specifically, our objective is to enhance the creativity of undergraduate systems engineering students by bringing a concept into reality through evolutionary design and novel thoughts to develop organization skills, taping both needed domain knowledge and systems engineering tools and processes to rapidly and effectively architect, design, integrate, and validate complex systems that involve humans, organizations, and technologies. We have tested two hypotheses in this regard. The first is how to break away from the traditional role of industry involvement that is centered on "taking industry into the classroom" and focus instead on "injecting the student into the industry environment." The concept of placing students into real-world scenarios facing contemporary business challenges was reversed and, instead, students were treated as strategic business partners in a mock business scenario to transfer research in emerging technologies into potential marketplace success. The second hypothesis employs a system engineering paradigm as an intricate cognitive process that uses creativity to bring new thoughts into the design and implementation of a feasible product. Creativity, in our context, is the process of developing and expressing novel ideas that are likely to be useful whereas innovation refers to synthesizing or bridging ideas from different domains [27–28].

Laboratory-intensive suites of system-level simulations have been offered early in SYEN 4385 to familiarize students with technical topics required to support the project. Students were given the opportunity to use professional CAD tools, experience day-to-day social, ethical, and political real-world challenges, and become more proficient at writing technical reports for managers in response to realistic situations, rather than writing for professors in contrived situations. These activities assisted students to synthesize novel ideas into implementation that is realistic and functional in the context of standard systems engineering development processes: problem definition, concept design, system-level design, detailed design, test, and verification. Participating in activities such as project planning, performance analysis, reliability, human interfaces, cost, execution, validation, and tradeoff studies provided students the opportunity to acquire proficiency in interpersonal, teamwork, economics, conflict management, decision making, ethics, social issues, and entrepreneurship [29].

The instructional team consisted of two faculty members, the industrial sponsor, guest lecturers, and four graduate teaching assistants. The instructional team provided the resources for knowledge acquisition, established a close relationship with and within the students' team, proactively advised and counseled the students in technical, time, and team management, assessed ties among the students without imposing methods, views, or solutions. The industrial sponsor from AT&T provided the students with a RFP, which builds the objectives and specific aims that the final deliverable must be complied with. He also assisted in the design of laboratory experiments and participated in informal learning experiences such as seminars and conference calls. Moreover, he contributed to determining a framework of skills needed, and evaluation by assessing the appropriateness of the content of the laboratory experiments in producing learning, which are functional in an industrial environment, and evaluated the outcomes of the project and the processes by which the course contents were developed and delivered. This active involvement resulted in an increased awareness of employer expectations, constraints involved in the design, and how students will be expected to perform in their future careers. It should be noted that the involvement of the industrial sponsor in the evaluation process (grading and assessment) enhances competition among the students and motivated them to seek excellence [30].

The instructors assisted students during brainstorming, mind mapping, and recombination of ideas sessions. The instructional team delivered two groups of lectures. The first group covered topics pertaining to project planning such a feasibility study, conceptualization, reduction of concepts, formulating open-ended design problems, discovering system requirements, system evaluation, project management, replying to RFPs, team performance, and protection of intellectual property. The second group of lectures covered technical topics of specific interest to the project such as WLAN and cellular systems, wireless geo-location algorithms based on linear path estimation, database programming and management, VXML, and OPNET [31]. Building experience in these multidisciplinary domains makes it possible to approach a solution for each subsystem of *eViator* with a flexible mind set, willingness to try new perspectives, and search for new combinations. Students submitted individual status reports and conducted project meetings on a weekly basis to evaluate their progress, describe actions that have taken place, schedule issues, debate new ideas, and play the roles of project managers and direct liaisons to the industry sponsor and faculty on a two-week rotational basis to ensure that each student had an opportunity to practice firsthand what it is like to be responsible for a complex project.

The rest of the paper is organized as follows. The problem statement submitted to the students in the form of a formal proposal is described in Section 2. In Section 3, we introduce the systems engineering approach followed by the students for the *eViator* concept development, which culminates in defining the systems architecture. A brief stakeholder analysis and the requirement hierarchy developed using the Vitech systems engineering and architecting software CORE [32] is presented through an in-depth analysis from requirements definition through architecture to systems verification. Section 4 summarizes the two phases followed for system-level design: research, and implementation. In Section 5 we briefly describe the three algorithms developed to estimate the time-of-arrival at the POI. In Section 6, the conceptual and system-level design are integrated together to generate a novel functional system with particular emphasis on the engine and database. The role of the industrial advisor and outcome assessment strategies are introduced in Sections 7 and 8, respectively. Finally, Section 9 concludes the paper.

2. PROBLEM STATEMENT: REQUEST FOR PROPOSAL (RFP)

eViator delivers services notification and content to wireless devices carried by travelers of an interstate highway that may be interactive, real-time, on-demand, planned, or spontaneous. A key benefit of *eViator* is its use of existing cellular infrastructure to deliver services information, traveler location, and directional information, to a wide array of wireless devices. eViator's features include:

- Services information in various media formats from textual messaging to streaming audio and video.
- Versatility in methods of purchase:
  - Pre-Planned—user visits a website prior to an automobile trip and requests to be notified of specific services of interest.
  - On-Demand—user initiates search from a wireless device for a specific service while in route to a destination.
- Infrastructure and target device independent.
- Billing methods tiered to allow businesses to maximize their advertising budgets.
- On-demand searches that can be initiated in a number of ways.
- Targeting information to proven markets.

Another goal of the RFP is to enlist the research of a firm to complete two projects associated with this service:

- Location Estimation—develop a method (software), which will track a device as it travels along a linear path passing through a series of hotspots, associating the location of the device as it relates to the fixed location of the hotspot tower. A database should be included in the design which would collect this information for the additional purposes of:
  - Determining the direction of the device's travel as it relates to the linear series of hotspots.
  - Estimating the approximate speed of travel of the device based on information collected from a series of wireless hotspots.
  - Estimation of the arrival of the device at the next subsequent wireless hotspot based on the information collected regarding the device's time and duration in previous hotspots.
  - By monitoring the device's travel through hotspots and approximating the estimated time of arrival in the next cell, determine if the device has stopped moving in a linear manner, and provide alerts of this situation.
- Device Identification—monitor a series of wireless hotspots, aligned in a linear manner, to identify when new wireless devices enter the hotspot and associate with the access point by tracking the unique ID of the device. Monitor a particular device as it enters the first hotspot and then progresses along a linear path, through a series of hotspots:
  - Actively monitor all devices associated with a particular wireless access point.
  - Determine when a device enters or exits the coverage pattern of the antenna of a particular access point.
  - Develop a method by which alerts would be generated once a wireless device enters or exists a particular wireless hotspot.

3. CONCEPT DEVELOPMENT

3.1 Systems engineering approach

Development of the *eViator* project is aligned with the following objectives: adequately define the system over its life cycle; define clear-cut intermediate development stages to ensure successful system acquisition. Students followed two complementary systems engineering perspectives for the integration of subsystems to meet design requirements defined in the RFP. The first is through a series of discrete steps occurring sequentially over time; the second is that of a set of technical activities that occur throughout the life cycle. Project tailoring is achieved by controlling the number of iterations of the discrete steps and the technical activities to distinguish phases and establish control gates between groups of activities. The students relied on an iterative process that comprises the following seven tasks: state the problem, investigate alternatives, model the system, integrate, launch the system, assess performance, and re-evaluate. These functions can be

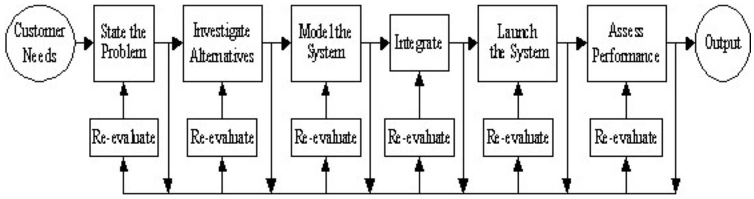

Fig. 1. The SIMILAR process.

summarized with the acronym SIMILAR [33] in Fig. 1.

3.2 Systems architecture

The approach followed to translate the RFP into a system encompasses: developing functional and physical interfaces, verifying that the design meets the users' perceived needs, and conducting tradeoff and risk analysis. The following statement inspired this approach, "The problem statement should be in terms of what must be done, not how to do it." [34]. Several brainstorming sessions were conducted involving interaction and exchange of ideas to refine the final design of the *eViator* system by invoking individual inputs and feedbacks to influence the students' creative minds. At this stage, the industry sponsor played a significant role in constraining the generation of ideas on the intended scope of the project and to initiate a mapped solution to the problem.

Dynamic marketplace, globalization, and fast changing technologies require the *eViator* to be developed quickly to stay ahead of competition. Fast system evolution driven by a half life of technologies significantly shorter than system life cycles or even system development cycle times, leading to further problems for system architectures. Therefore, steady insertion of new technologies is necessary to keep the system competitive. The *eViator* must accommodate integration at all levels since it is incorporated into external networks that experience different levels of technological evolutions at different times. The overall design needs to account for these aspects to produce a long life cycle for the developed platform. These major drivers require that the system architecture be: *Flexible*—ability to be changed easily and rapidly, and *Transparent* – ability to adapt to changing environments.

The *eViator* model depicted in Fig. 2 was developed to provide guidelines for research and design, and to prevent type three errors: working on the wrong problem. Confirmed by the client through a response to the RFP, this model was the basis for generating requirements, acted as a baseline for abstract modeling, and drove the development stages for the project to progressively reduce the level of abstraction. Research conducted by the students revealed that the three major drivers that demand immediate systems development are: dynamic marketplace, technological evolution, and variety of environments.

A key component of the *eViator* is the engine, which controls the whole *eViator* service. The engine performs the following tasks:

- locate users;
- direction determination;
- initiate service;
- initiate users' travel database;
- authenticate and authorize customers;
- verify and update customers' preferences;
- update customers' travel log.

An attribute essential to the system's success is that the engine must interface well with the database. Moreover, the engine has to run independently from other components, but at the same time collaborate and interwork with them.

The database provides storage for user accounts, tracks progress during a trip, and stores user preferences to ensure the services are applicable to their individual trips. There will be multifunction reading and writing to the database. The *eViator* project is supported by an educational budget; therefore the cost of developing and running the database needs to be minimal. Taking all these factors into consideration, MySQL is the best option for the project. The design needs to be tailored to the Database Management System (DBMS) needs, requiring more control and flexibility in the infrastructure. This is not available in "closed system" architecture [35]. The open source nature of MySQL allows modification of equipment and services, and development of applications and services personalized to each user. Tracking the user's progress requires that the database be updated in real time. One type of interface for the *eViator* is voice to ensure user safety while on a trip. VXML was chosen as the functioning language due to its ease of portability and to leverage industry consortia trends, such as the World Wide Web Consortium (W3C). Another interface is that between the user and the database. This interface must effectively work with the MySQL database and HTML. The user registration component is HTML because it is the most widely used Internet language. The SNMP and WML are the interfaces chosen for communications with the user's wireless device.

3.3 Requirements analysis

Requirements analysis allows for a generalized problem to become more focused. The first step is to identify the various stakeholder groups from which feedback is sought for the validation process to meet expectations. A stakeholder analysis

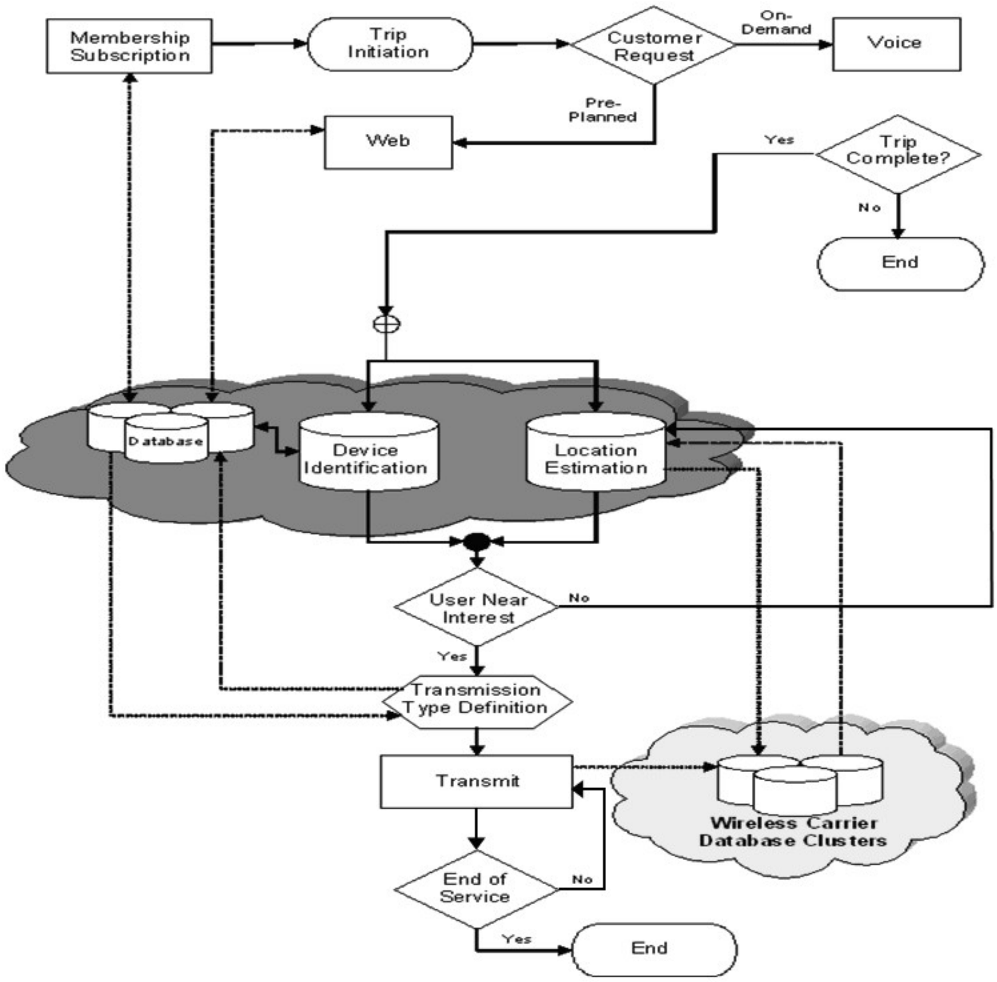

Fig. 2. Overall *eVaitor* system.

allows proper shaping of the design space for project expectations. To meet these expectations, requirements are listed for each of the groups involved.

3.3.1 Stakeholder analysis

Figure 3 depicts the primary stakeholders: customers and clients (organizations that use *eViator* to deliver content to the customers). The secondary stakeholders are AT&T and the capstone team. The external stakeholders consist of UALR and support staff.

Table 1 shows the rankings (scale of 1: lowest to 5: highest) which indicate relative priority that the project should give to each stakeholder in meeting their interests. Each stakeholder bears an influence to each aspect of the project: to control which decisions are made, facilitate its implementation, or exert positive or negative influences. Influence is perhaps best understood as the extent to which people, groups or organizations (i.e. stakeholders) are able to persuade or coerce others into making decisions, and following certain courses of action. Furthermore, this influence is an extension of the power of that stakeholder group. Power may derive from the nature of a stakeholders' organization, or their position in relation to other stakeholders.

Consideration was given to the secondary stakeholders, but by definition, these were sorted into direct contributing groups. The assignment of relative priority was also ranked to reflect the

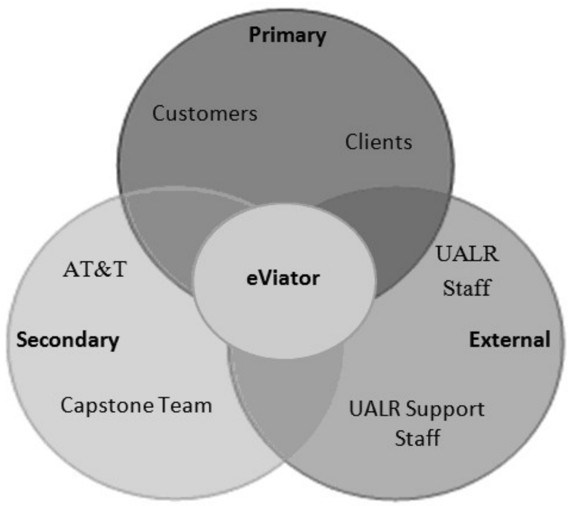

Fig. 3. Primary, secondary, and external stakeholders.

Table 1 Stakeholder analysis

	Interests	Potential Project Impact	Relative Priority of Interest
Primary Stakeholders			
Clients	* Reliability	(+)	5
Customers	* Ease-of-use	(+)	5
	* Safety	(+)	5
Secondary Stakeholders			
AT&T	* Portability	(+)	5
	* Modularity	(+)	4
Student Team	* Timeliness	(–)	4
	* Skill sets	(+)	5
	* Achievement of targets	(+)	4
External Stakeholders			
UALR Staff	* Achievement of targets	(+)	4
	* Control over activities	(+/–)	5
	* Public image	(–)	4
UALR Support Staff	* Availability	(+)	3

importance of these areas for fulfillment. External stakeholders are listed to the extent of their priorities and to demonstrate their interests. These interests can be catalogued in areas such as advisors, assessment, sponsorship, and availability.

3.3.2 CORE

The CORE environment [32] synchronizes system requirements, behavioral models, architectures, and design solutions with system specifications and test procedures. In order to train students in how to represent the problem definition through various contexts of creative thoughts, they are required to document their experience, organize thoughts, and express ideas using professional systems engineering tools during the incubation of the project. CORE was used in requirements analysis and organization portions of the design phase, in particular to implement hierarchical design requirements. To allow the creative process to have direction and purpose, the general and functional requirements developed for the CORE implementation in response to the RFP are listed below.

- General requirements
  - 1.0 The product must adhere to federal, state, and local government regulations.
  - 2.0 The customer (user) shall be given the option to choose the type of service.
    - 2.1 The customer shall be able to acquire service access at any given time (on-demand).
    - 2.2 The interface to the service shall be simple and interactive.
    - 2.3 Content delivery shall be timely and accurate.
    - 2.4 Content delivery shall be indiscriminate of the type of device.
  - 3.0 The product must make provisions for different user devices and be platform independent.
    - 3.1 The product shall be portable.
    - 3.2 The service shall be applicable to a variety of wireless devices.
    - 3.3 The product should self-monitor for system redundancy.
  - 4.0 The product should account and bill customers accordingly.
    - 4.1 The system shall distinguish between on-demand versus pre-planned customers.
    - 4.2 The system should be flexible to the extent to distinguish between text and other forms of content delivery.
- Functional requirements
  - 1.0 The *location estimation* component of *eViator* must estimate customer position. System components shall determine the direction of travel.
    - 1.1 System components shall estimate the approximate speed of travel based on data gathered from wireless carrier systems.
    - 1.2 The system shall determine if the device has stopped moving in a linear manner.
    - 1.3 The system should provide an estimate for the time of arrival at the next subsequent wireless access point.
    - 1.4 The system must determine the delivery time of content prior to site arrival.
    - 1.5 The system shall be able to provide geographic placement of 'on-demand' users.
  - 2.0 Device identification component of eViator must identify active service customers.
    - 2.1 System components shall actively monitor wireless access points.
    - 2.2 A method should be developed by which alerts will be generated once a member device becomes active in any wireless access area.
  - 3.0 The customer interface must be simple to use no matter the type of customer.
    - 3.1 The system should provide an option for virtual hands-free access.

In order to create the CORE requirement hierarchy of how the *eViator* should function, the team developed "use cases" that describe possible uses of the system. A use case depicts the set of interactions that take place when an external party (e.g. a user, an operational system such as authentication center) uses the system. The following is an example of one of the use cases developed in an attempt to define the missions of the system:

> I sit at my computer planning a cross-country road trip. As I log onto my cellular carrier's web site, I enter my starting point and destination along with my favorite restaurants, gas stations, and approximate gas mileage of my car. In addition, the website generates a checklist of POIs that I might visit during my trip. Viola, my trip is planned, but instead of printing out directions, I just set my phone into a hands-free device and begin to drive my route. As I begin, the local cell tower picks up my signal and begins to estimate my distance traveled. As I travel through different cells, I begin to get notifications that I am approaching POIs that I might want to stop at, such as nearby gas stations when needed, or restaurants at times when we might want to eat. Also, our progress is tracked and reported back to a website that my family can securely log onto see if we are traveling safe and well.

Using this scenario and others that describe different parts or different functions of the *eViator* system, a list of requirements that the system must meet in order to be considered successful has been developed. The preliminary list was very broad and attempted to encompass all functions of the system. This was based on the description provided by the industry sponsor, and the discussions between the instructional team and students. The first thoughts on the system included precise location identification, indoor versus outdoor implementation, network security, and marketing strategies. All of these requirements were gathered and organized into a source document to use for the CORE requirements hierarchy. Here is an example of one CORE source document.

3.3.2.1 Scope

There are two related designs available using the idea of directional-based services. System 1 (*Highway billboard system*) shall act as a mobile billboard for customers traveling down a highway and will alert users only when they enter the vicinity of a desired service. System 2 (*Theme park direction system*) shall be capable of operating on a smaller scale inside a building or small perimeter with more specific location estimations in order to provide detailed directions to the user. Both systems could be tailored to either users' or business' requests.

3.3.3.2 Requirements

2.1 System 1 (Highway billboard system)

1. The system shall be able to determine a user's estimated time of arrival to POI.

1.1 The system shall have a method of determining a user's general location (i.e. within a radius of two miles).

1.2 The system shall determine the user's direction of travel.

1.3 The system shall determine the user's approximate speed of travel.

1.4 The system shall be able to detect when a user has deviated from his/her predicted travel pattern and adjust its estimated time of arrival accordingly.

2. The system shall provide accurate, meaningful, desirable information to the user.

2.1 The system shall be able to deliver alerts early enough for the user to make a decision, but not so early that the user forgets what was available.

2.2 The system shall be able to not only convey simple messages such as store names, but should also be able to convey more detailed information about the services based on what the business clients wish to broadcast.

3. The system shall provide a user-friendly interface for the customer to interact with.

3.1 The system shall consist of a computer-based interface that provides the customer a method to plan his route and choose what types of services he is interested in getting alerts about.

3.2 The system shall consist of an interface on a mobile device that is easy to use while driving a car in order for users to dynamically request services from the system.

4. The system shall maintain an accurate database containing services that are available for alerts and information regarding user trip data.

5. The system shall have a profitable philosophy consisting of either charging the individual users, the businesses who advertise, or both.

6. The system shall be secure.

6.1 The system shall be able to secure the data from a user's computer at the time of trip planning so that no outside party can access that information without the user's consent.

6.2 The system shall be able to secure the data relating the user's location at all times unless otherwise allowed by the user.

6.3 The system shall be able to secure all transmissions from the system to the user's mobile device at all times.

7. The system shall provide a method to expand or retract the services provided by the system in order to ensure future growth and/or optimization of the system.

2.2 System 2 (Theme park direction system)

1. The system shall be able to determine a user's specific location (i.e. within a five foot radius).

1.1 The system shall have a method of determining a user's location in three-dimensional space.

1.2 The system shall determine the user's movements in real time.

2. The system shall provide accurate, meaningful, and desirable information to the user.

2.1 The system shall be able to deliver detailed directions as a user moves toward the POI.
2.2 The system shall be able to not only convey simple messages, such as names of places, but should also be able to convey more detailed information about the location based on what the business clients wish to broadcast.
3. The system shall provide an interface on a mobile device that is easy to use in order for users to dynamically request services from the system and receive information based on their location.
4. The system shall maintain an accurate database containing all information about a site the business client deems necessary.
5. The system shall have a profitable philosophy consisting of either charging the individual users, the businesses who advertise, or both.
6. The system shall be secure.
6.1 The system shall be able to secure the data relating the user's location at all times unless otherwise allowed by the user.
6.2 The system shall be able to secure all transmissions from the system to the user's mobile device at all times.
7. The system shall provide a method to expand or retract the services provided in order to ensure future growth and/or optimization.

4. SYSTEM-LEVEL DESIGN

4.1 Phase I—research

Fundamentally, the design process did not evolve in a linear manner. Rather, it has been conducted in phases of reflective thinking. During SYEN 4385, the team identified alternative designs that meet user needs in whole or in part, and conducted tradeoff studies among these designs such as wireless geo-location technologies and supporting interfaces/software tools in terms of performance, reliability, availability, convenience, and cost. Investigation in the initial stage of the design involved defining the problem, familiarization with the project objectives, and scope of work. The deliverable of this phase is an in-depth understanding of *eViator's* functions, approach to create a working *eViator* system, alternatives available for the subsystems, and the reasons for selecting the baseline design. During these activities, communication played a vital role in deploying the necessary courses of action. The following research topics were conducted during Phase I:

- Protocols and standards for WLAN and cellular systems;
- Integration, portability, and device identification in cellular networks;
- Effects of shadowing, multipath, and antenna radiation pattern on cellular coverage;
- Interface design for seamless operation;
- Database architecture and design techniques;
- Software applications and implementation techniques;
- Modeling and simulation techniques for geolocation;
- Hand-off mechanisms for location determination;
- Capabilities and utility of GMLC;
- VXML as a viable interface solution.

4.2 Phase II—implementation

This phase marks the transition from conceptual level design to prototyping. After a critical design review, the start of SYEN 4386 brought the final design and detailed testing plans to verify the system performance. Every major component is described in terms of input, output, and function. The most critical components, the engine and database, were given the utmost importance. Once completed and analyzed, the task of designing other subcomponents becomes evident. The deliverable of this phase is a detailed design of the *eViator* including: engine and its functions, database and queries associated with engine, website, PHP, and VXML.

Each student was given the responsibility of the components and subsystems that she/he wanted to specialize in and implement. For every component there were at least two students working on it to ensure its completion. This phase is not only the most difficult, but also the most important since the deliverable is a working prototype. The implementation phase encompasses: writing and debugging engine function codes, integrating functions into the main program, writing and debugging database code, writing queries for the engine functions to call information from the database, integrating the engine and database, writing HTML for the user registration website, writing the PHP code to support the website and input data into the database, integrating HTML, PHP with the database, writing VXML for the on-demand scenario, integrating VXML with the engine, installing access points for demonstration by parsing a user's unique ID, running tests on APs set-up, integration with the engine, setting the wireless device to receive messages from the engine, and testing the *eViator* system with scenarios.

5. ESTIMATING THE TIME-OF-ARRIVAL (TOA)

Three algorithms were proposed to estimate the TOA at the POI in scenarios involving a linear-path, one-way trip with potential delays and variations in radiation pattern coverage of the base station antennas. The three algorithms developed to estimate the average speed per trip $S_{\text{trip avg}}$ are:

$$S_{\text{trip avg}} = \begin{cases} \frac{[S_{\text{trip avg}} \cdot (\text{cell count})] + S_{\text{current cell avg}}}{(\text{cell count})}, & \text{cell count} < 1 \\ \frac{[S_{\text{trip avg}} \cdot (\text{cell count})] + S_{\text{current cell avg}}}{(\text{cell count}) + 1}, & \text{cell count} > 1 \end{cases} \quad (1)$$

$$S_{\text{trip avg}} = \frac{S_1 + S_2 + S_3 + \ldots + S_{\text{cell count}}}{\text{cell count}} \quad (2)$$

$$S_{\text{trip avg}} = \frac{D_{\text{total}}}{T_{\text{total}}} = \frac{D_1 + D_2 + D_3 + \ldots + D_{\text{cell count}}}{T_1 + T_2 + T_3 + \ldots + T_{\text{cell count}}} \quad (3)$$

where D is distance, and T is time. Algorithm (1) computes a cumulative weighted average of the speed per trip. Algorithm (2) computes the average speed by performing a summation as the user passes through each cell. Algorithm (3) utilizes time stamps to compute the average speed through each cell.

The algorithms are applied to the scenario shown in Fig. 4 where it is assumed that the coverage patterns of adjacent base stations do not overlap. This allows for the entire distance traversed during the trip to be accounted for by predefined coverage patterns. The average coverage area of a macro cell is 10 square miles [36]. Size fluctuations (e.g. terrain environment) are accounted for by assuming that the pattern coverage is uniformly distributed between two and four miles. A total of 115 cells were used to define the trip length. This number results in an average of 345 miles for each one-way trip as reported by the Bureau of Transportation Statistics in 1995 [37]. Driving patterns are difficult to quantify due to the unavailability of a reliable source that could provide reliable statistical data with any amount of certainty. Based upon claims in [38], which reported 74 mph as the average speed on the highway and that 68% and 20% of the drivers exceed 70 mph and 80 mph, respectively, we assume that the speed is uniformly distributed between 60 mph and 90 mph.

Random stops were introduced during the trip to account for tank refills, fast/long-term dining, and possible rests during the trip. "Dwelling" time is assumed within cells by distributing a number of stops from 0 to 4 per user trip. Each stop consists of dwell times uniformly distributed between five minutes and 30 minutes.

The simulations were executed over 50 times assuming 1000 users for consistency. In keeping with the functional flow of the proposed design, the customer's trip begins at the exiting of cell #1 in order for *eViator* to capture the entering and exiting times to compute the speed of the customer. The simulation is terminated upon delivery of alert at the edge of the cell containing the POI. Success

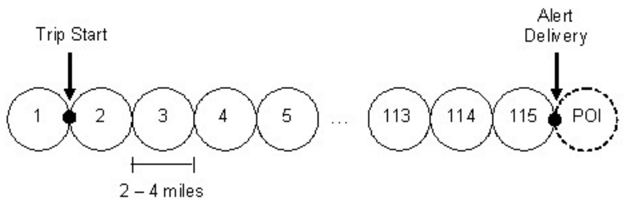

Fig. 4. Simulation scenario.

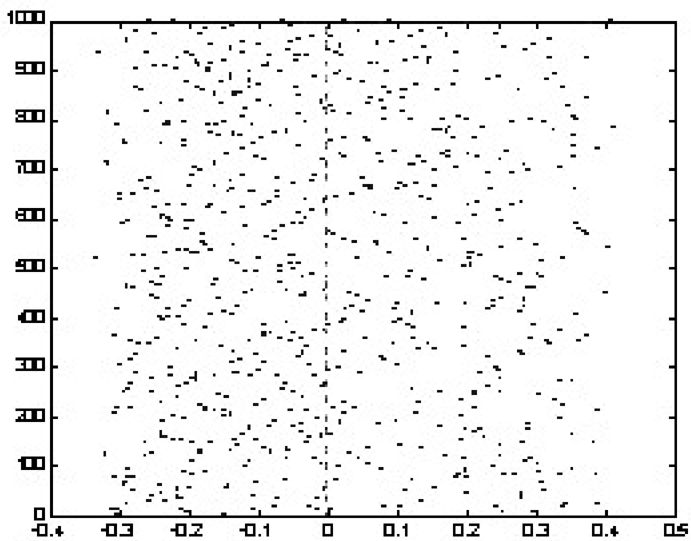

Fig. 5. Results from Algorithm1: y-axis is the number of users; x-axis is the difference between the actual and estimated arrival times in minutes.

Table 2 Simulation parameters used to generate the results in Fig. 5

Parameter	Value			
Speed	60–90 mph			
Cell diameter	2–4 miles			
Users	1000			
Number of cells	115			
Dwell quantity	0–4			
Dwell time	5–30 minutes			
Random cells selected for Dwell	16	41	62	97
Random length of dwell time	20	14	14	23

is measured by comparing the time of alert versus the actual trip time.

For the three algorithms, the alert time was found to range from –0.3 to 0.4 minutes compared to the time when the alert should have been delivered. A positive value indicates an early delivery of an alert, whereas a negative value reflects a late delivery of an alert. An extended stop time was applied to assess the performance of the three algorithms. It has been found that algorithm (3) has a much slower reaction time during an extended dwelling time. Other constraints were next applied to algorithms (1) and (2) to gauge the better of the two. It is concluded that algorithm (1) should be used in *eViator* due to the higher system overhead for algorithm (2). Furthermore, it should be noted that more computations would be needed for Algorithm (3) to update the average trip speed for each customer.

Figure 5 displays results from simulations conducted using Algorithm (1) and the parameters displayed in Table 2.

6. DESIGN OF ENGINE AND DATABASE

To increase productivity and reassurance for reliable results, students applied contradiction to utilize and combine existing technologies in ways that spark a novel overall design. *eViator* needs to be flexible enough to handle changes in user needs and financial models. Moreover, *eViator* must be designed for system evolution by adopting a flexible architecture. There are four aspects of changeability: flexibility, agility, robustness, and adaptability. The system should be flexible so that changes can be made easily; and be agile so those changes can be made rapidly. The concern is the trade-off between the robustness and adaptability aspects. Can a system deliver its intended functionality under varying operating conditions without being changed, or does it need to adapt itself towards changing environments to deliver its intended functionality? To resolve this dilemma, the team provided an adequate design margin to account for uncertainties over the life cycle.

The Open Systems Joint Task Force in 1998 defined an open systems approach to allow this flexibility while keeping overhead costs down [35]. To optimize a product, we might need only to modify one facet instead of redesigning the entire product. Furthermore, an open system could lead to easier insertion of technology and better interoperability of mixed technologies. *eViator* is a specialized product and no one commercial product could solve the different and difficult challenges; however, as an example, we could substitute well-developed mapping software to provide route selection in the trip-planning aspect as long as the system interfaces are properly defined. This openness allows for changeability while maintaining high reliability once the service market starts to respond.

Application along these guidelines dictates that the functional blocks should be extracted into separate file spaces. This will maintain the flexibility of an open system model so that these separate files can be modified on an as-needed basis to allow program optimization without total overhaul of the *eViator*. The overall program is simplified into separate function calls to handle the challenges of *eViator*. To meet other requirements, the system runs several of the functions simultaneously. A benefit of this structure is scalability. By allowing these functions to run in parallel on a multi-server platform, *eViator* will be able to meet higher demands without suffering computational slowdowns.

Decomposition of the model into a high-level architecture requires several iterations of the system's engineering process to assign high-level functionality properties. These functions consolidate the results out of the evaluation of the design alternatives. At higher levels, architecting methods, experience-based heuristics, abstraction, and integrated modeling must be used [33]. This evolution is described by the 'rule of ten' stating that with each subsequent program phase the implementation of change becomes ten times more costly (e.g. time, manpower, money) [34]. Figure 6 depicts the high-level architecture, which guided the development in the implementation phase.

For the software to know what each user needs, it must have a bank of information to poll and update user information. As the user travels, the service learns more about where the user is going, speed, and services requested. A MySQL database holds this information and manages the data manipulation using SQL queries. The real world entities are mapped within the database including user, trip, POIs, cells, billing, provider, devices, and trip history as shown in Table 3. Each entity is described by its attributes, where only one value is given for each instance of an attribute. To poll for information, constraints are placed upon the database to distinguish instances of attributes. For example, a user ID distinguishes multiple users stored within the database.

Each query utilized frequently by multiple functions will be called as a separate function from an include file. All of the specialized queries that ask for certain information from the database with

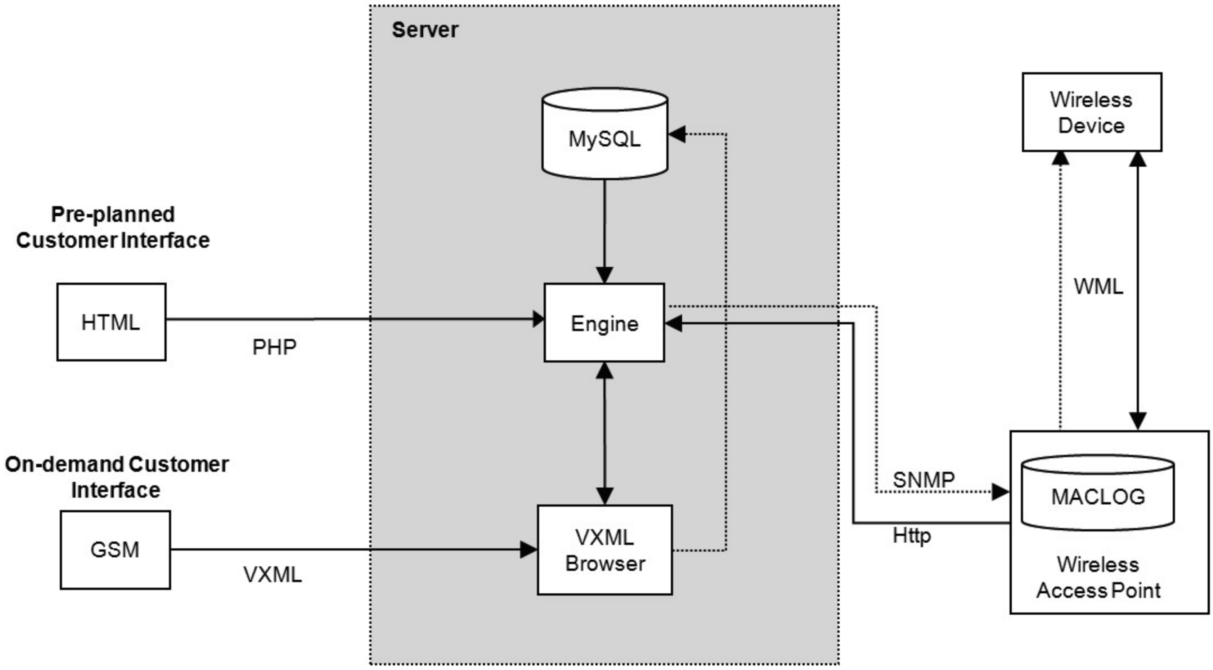

Fig. 6. High-level architecture.

distinct conditions are embedded into the software as a function or part of a function. This creates a direct connection from the engine to the database. Next, the students analyzed how the engine manages the *eViator* using three scenarios, which are briefly described below. The first scenario is a pre-planned user traveling through POIs without stopping. Secondly, an on-demand user scenario that ends successfully at first attempt. Finally, we consider an on-demand user scenario that did not have a successful first attempt and becomes a pre-planned user.

6.1 Pre-planned scenario

In the pre-planned scenario, the user schedules a trip via the web interface. The *eViator* system is in

Table 3. Entities and their attributes

User	Trip
Userid (Primary Key) • Password • First name • Last name • Address • Phone number • Email	**Trip_id (Primary Key)** • Name • Description • Start_location • End_location • Duration • Active(Boolean) • User_device_id • Alert_type • Average Speed • Points of Interest
Points of Interest • POI_id (Primary Key) • Altert_time • Arrival_time • Category (food) • Cell_id • Exit_Number	• **Cell** • Cell_id (Primary Key) • Cell_distance • Description

the process of locating the user according to the trip information. Once the user is found, the *eViator* begins the process of estimating the time before the user approaches the first POI. As the user travesl along, *eViator* provides more accurate estimations. When the user approaches the POIs, *eViator* delivers the appropriate message to the user's device. These actions continue until the user reaches a final destination, as determined by the trip information.

Figure 7 identifies the function arrangement for the pre-planned user. In *start_ trip*, the user's trip begins when the requested time to start trip matches with the current time. Then *update_arrival* locates the user, determines average speed, and updates alerts for the chosen POIs. Next, when the user comes in range of POI, an alert, i.e. text message, is sent to the user by *sched_alert*. Once all POI alerts are sent and the user has arrived at the destination *delete_trip* will end the service.

6.2 On-demand

In the on-demand scenario, the user has not scheduled a trip, but wants to request information during the current trip. The user calls the *eViator* service from the cell phone, through which the user is identified. The user is guided through a series of voice prompts to extract the information being requested. Once the *eViator* service determines the POIs that the user is requesting, it responds by giving all of their locations within the serving cell. The reason for providing all locations is because the user's direction of travel is unknown at the time of the request. The *eViator* service then checks to see if any of the given POIs are relevant to the user. If any are relevant, the initiated call is

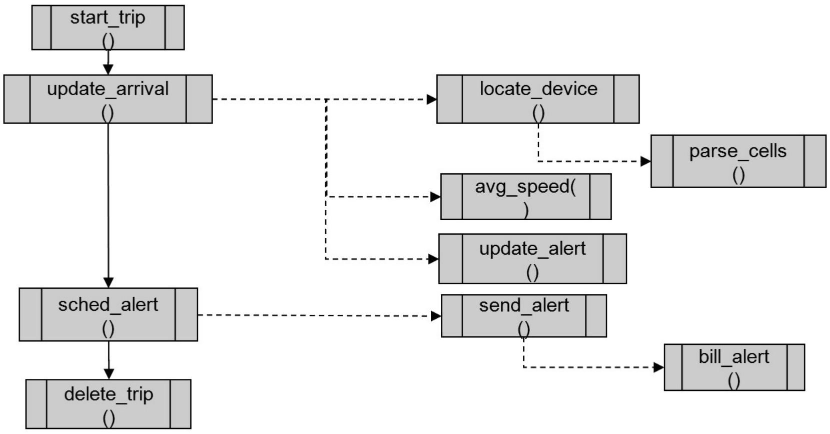

Fig. 7. Pre-planned scenario.

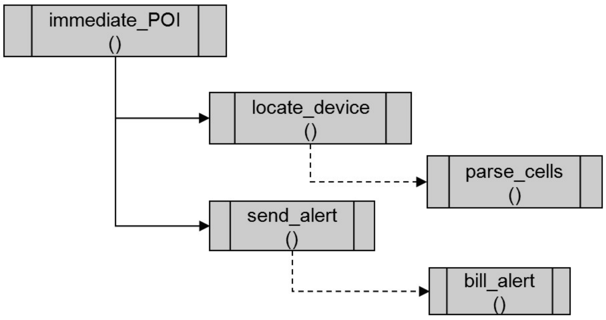

Fig. 8 On-demand scenario.

then terminated. If none of the given POI is convenient for the user (i.e. the user has already passed them on), the third scenario begins.

Figure 8 shows the functional flow of the on-demand scenario. Notice how it shares the same functions as the pre-planned scenario, except for the immediate POI function. The scenarios are initiated differently and therefore need different triggers. The user calls the *eViator* service for a particular POI. The user is located and receives an alert with the information. The customer is satisfied with the result, and then the scenario ends.

6.3 On-demand to pre-planned

In the on-demand to pre-planned scenario, the on-demand scenario has already taken place. Unfortunately, the desired POIs were not provided. In order to properly service the user, the *eViator* system places that user into a pre-planned trip. During this process, speed and travel information are acquired to determine when the user might arrive at a POI. Once the user arrives at the, the trip is considered over.

7. ROLE OF THE INDUSTRY PARTNER

By design, the roles of the instructors and the industry sponsor were developed to simulate roles which would be encountered should the scenario have been a real-world experience. Specifically, the instructors pressed students for assignment completion, provided guidance for design efforts, constrained the students in some areas while empowering them in others, and previewed students' status reports before they were presented to the industry sponsor. It was made clear that the instructors provide technical information when needed, but otherwise play the role of an observer, noting progress and individual performance. The lecture time was used for round-table group meetings that were run by the students. The instructors participated in these meetings primarily by raising questions, when considered necessary, pertaining to technical issues, team logistics, or planning—all of which were addressed and answered by the students. Each student submitted a brief weekly progress report summarizing achievements and presenting challenges to be resolved during the next round-table discussions.

To make the academic experience as close to an industry experience as possible, the industry sponsor was portrayed as a customer who hired the student team as contractors to perform research and development. By integrating components of the project such as RFP documents, which were vague about some requirements, but specific about others; mandatory conference calls; status reports; and demanding timelines for completion, the students were able to experience factors which would be encountered in industry.

From an industry perspective, involvement in partnerships such as the one described in this paper carries not only a great deal of responsibility, but also a great deal of value on many levels for all involved. Aside from the opportunity to observe students currently enrolled in a degree program as potential hires for a business, the role of an industry sponsor in this particular partnership required a unique level of commitment and involvement quite different than the traditional academic advising role. Before integrating the *eViator* project into SYEN 4385 and 4386, the industry sponsor worked closely with the instructors to delineate responsibilities and roles of both parties. Beginning with articulating the intended overall goal of the partnership, the industry partner then evaluated resources available that might enhance the academic experience. Each industry and indeed each individual business can bring its own unique value to a partnership, and the industry partner's assessment of the value it can provide is the crucial starting point for a successful partnership.

Based on experience, industry sees first-hand from employees any trends in acquisition of skills or commonalities in skills they possess as well as in their deficiencies and strengths. The industry sponsor helps to integrate this experience into the partnership and make suitable recommendations to students, faculty and staff so that the observed gaps in skills can be filled by students while in school, skills that will likely make them invaluable to the industry upon graduation. A particular skill needed is the understanding and application of systems engineering methodologies, including requirements analysis, systems life cycle, integration, testing, and upgrading.

Historically in industry, methodological approaches to design are defined in technical disciplines such as software programming and telecommunications engineering, while in some areas, the concept of the importance of how to solve a problem is sometimes lost in the effort *to* solve a problem. In the instance of the *eViator* project, a great deal of time was spent by the students evaluating the various methodologies available to them. Students were not only able to articulate the details of the selected methodology, but also the reasons why the selected methodology would be the most effective for the project assigned. Clearly, this systems engineering approach demonstrated that a focus on the choice of methodology is as important as the solution itself.

In successful engineering projects much of the intended focus revolves around a holistic view of the stated problem and the proposed solution. Key design considerations, such as cost, are not always weighted with the same importance by an engineering team as by the customer. Details regarding challenges in industry with regard to competitive situations, customer relations, and technical guidance on the design of the solution were provided to students allowing them to benefit from experience. An example of this mentoring was provided when "the customer" asked if a feature could be added to the system which was not defined in the RFP or project requirements and in their effort to win the business, students openly offered to add the requested feature. A subsequent discussion was conducted with the students about the "dangers of scope creep" and how by agreeing to add the feature, their costs had increased radically without any consideration for charging these costs back to the customer (the mock price to complete this project had already been agreed between the student team and the "customer").

8. ASSESSMENT

The success of the capstone design course should be judged on how well student needs are met. Students were asked to evaluate the benefits derived from their experiences with the course, find out whether the level of the material matched their abilities, the intellectual challenge, and interest of the course, and the suitability of the workload. The instructors evaluated participation of group members and evaluated the capstone design course using rubrics developed by the assessment committee of the Systems Engineering Department. Additional data were collected based on feedback from the industrial advisory board, surveys from alumni and employers, as well as senior exit surveys. Moreover, an outcome-based grading scheme has been followed which emphasizes team performance, product development process, project management, communications, and interpersonal skills [23], [39].

It should be noted that the students faced challenges in fulfilling some of the requirement of the two-term design sequence. The first challenge is that they often did not have all the requisite technical skills to solve the problem posed to them. It is the first course in the curriculum where they are introduced to the concept of "learning how to learn." In other words, they soon discovered that they had to research a technical topic on their own, instead of being presented in a textbook. The second challenge is the "soft skills" that are required of them to perform the project, ranging from teamwork to formulating a business plan. Again, these ideas are not necessarily introduced in a textbook. The third challenge is the significant responsibility that falls on their shoulders—the fact that they are managing their own "enterprise," the success or failure of which is determined by the efforts that they exert. Each member is responsible not only individually, but for the entire team.

8.1 Key questionnaire

As a part of the industry involvement role, the industry sponsor met with each student, and asked a series of questions intended to gauge the student's experience and overall engineering ability.

- Question 1. How would you characterize the importance of industry involvement in this project?
  Overall, students provided a very positive response to this question. The majority stated that the experience of designing a solution based on a project developed by industry enhances their ability to acquire a job upon graduation and subsequently perform successfully in the marketplace.
- Question 2. What challenges were created by industry involvement, if any?
  Many students interviewed felt the most compelling challenge from industry involvement was the complexity of the project within the timeline imposed. Students stated they felt the pressure, albeit self-imposed, to perform well. Clearly, these students felt a strong obligation to not only achieve a good grade, but also represent his/her team, the systems engineering program, and UALR to the outside world.
- Question 3. How much of the workload would you say you individually performed as compared to your fellow student team members?
  Interestingly, all of the students responded that the workload was evenly distributed among the student team members. Some pointed out that in some instances, students who were struggling with assigned tasks received assistance from other team members voluntarily and that any assistance given by one student was balanced out at some later time by that same student receiving assistance in areas in which he or she was struggling.
- Question 4. What did you find the most rewarding about this project?
  Most of the students responded to this question by saying this project was rewarding because it challenged them in skill areas learned in the systems engineering program. In some instances, skill areas in which they perceived themselves as being strong were challenged. In other cases, the students quickly realized their skills were better than they had perceived. Specifically, software programming was mentioned as an area in which many students felt they did well. Other comments from students included how their time management skills were applied effectively because of this project, and how the documentation skills taught in this course were extremely important in communicating the solution recommendation to the industry partner.
- Question 5. What aspect of the industry involvement would you recommend be changed?
  The overwhelming response from students was that there were no recommendations on how the industry partnership could have better served the project.

What are the additional instruments employed to implement the salient features of the *eViator* project? Here are some details. First, the industrial sponsor was involved in grading the students. In this case, the sponsor evaluation weighed 20% of the final grade. Also, peer evaluation is emphasized to characterize the distribution of efforts on project planning, development, presentation, and deliverable. This approach assists in enhancing teamwork, since those that simply "ride along" will be uncovered through such peer evaluation. Peer evaluation constitutes another 20% of the course grade. Another way to enforce teamwork is the instructors' requirement that individual contributions should be clearly specified in the final report, so that there is accountability for team effort. Finally, the instructors made it clear that to get an "A" or a "B," students must show exceptional (i.e. outstanding, or above average) in initiative and creativity—completing what is required is enough to earn only a "C". Second, a project presentation rubric is developed and employed to evaluate each teamwork presentation. An example rubric includes the following to measure soft skills:

- knowledge of subject;
- body language;
- eye contact;
- introduction and closure,
- delivery of material, poise;
- elocution (enunciation, voice).

The capstone course plays a key role in achieving the ABET-2000's "Professional Component" criterion [39], which states that "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."

Aside from the survey instrument, an objective evaluation procedure has been set up to measure how well the capstone design achieves ABET's program outcomes. As shown in Tables A.1 and A.2 of the Appendix, course objectives are related to ABET's outcomes. The capstone project provides an excellent assessment measure. Indeed, the majority of the ABET's program outcomes are assessed in the capstone design. Most importantly, the appendix prescribes how each outcome-objective incidence pair is being measured quantitatively. As depicted in Table A.3, all the scores satisfy the threshold of 60% or three points. However, the instructors notice that Program Outcome h can be improved further above 3.5. Efforts will be made to ensure that students become aware of the need to apply their broad background to comprehend the need for environmental, economical, and societal impacts of their engineering design earlier on during their design phase and incorporate suitable solutions. Apparently, in spite of our diligent efforts, more can be done to further this cause. The instructors will take this into full account in the next offering of the capstone design.

In all, the involvement in this project was extremely rewarding from an industry perspective as well as valuable for the students. The results of the research performed were exemplary and demonstrated a strong understanding of systems engineering skills and discipline. Along with some of the core skills taught in our systems engineering program, students were also very competent in the "soft skills" of presentation and documentation. From the feedback provided by the students during the end-of-the-course survey, students expressed how they developed a great deal of confidence in their abilities to communicate, both orally and in writing, as a result of the project, a skill in combination with an engineer's technical skills that will prove to be of immense value to the industry.

Since the *eViator* project has reached a design that is mature enough to be patented by the industrial sponsor, another project has been adopted for the subsequent capstone design. The "Dynamic Airport" project is about improving the operations in the airport gates [40]. The RFP submitted by the Little Rock Airport Authority seeks a system that provides dynamic, on-demand assignment of ticket counters to airline carriers and an automated assignment of the incoming aircraft (already landed and identified by the air traffic control) to the airport gates. This is subject to passengers' traffic, gate availability, timing and dimensional constraint, combined with an automated identification of the aircrafts. Moreover, an information system is requested that automatically bills the airliners a penalty fee when the time allocated for docking has passed but the aircraft is still at the gate.

It is clear that the new project has a very different flavor than the *eViator* project. Nevertheless, the prevailing philosophy remains the same, including industrial sponsorship and the emphasis on soft and technical skills not covered in the regular courses. In the Airport Project, more emphasis is placed on imparting entrepreneurial experience to the capstone design team. Finally, it should be noted that since 2005, the systems engineering program has added mechanical and electrical options. The emphasis on interdisciplinary design becomes even more pronounced under the expanded program where the current course sequence serves as the capstone for undergraduate degrees in telecommunications, computer, mechanical, and electrical systems engineering.

9. CONCLUSIONS

This paper presents an innovative capstone design course aimed at equipping students with systems engineering methodologies and tools essential to solving complex engineering problems; experiences they will be expected to exercise shortly after graduation. The *eViator* project is the first effort by the Systems Engineering Department of UALR to develop a product from concept to operation with a group of undergraduates who focused not only on individual subcomponents, but also collaborated on integrating the entire system utilizing expertise gained from their particular option emphasis area within a formal course framework. The course has produced many different impacts of importance to systems engineering degree programs. Creating a team from students in the Telecommunications and Computers Systems Engineering Options and using an industry sponsor who exerted influence on their grades and course assessment helped to engage the students, encouraged competition, maintained their focus throughout the two-semester course, and ensured that the students and instructors were aware of current issues, practices, and procedures. The early identification of the project provides students with ample time to understand the problem and develop conceptual solutions. Results show improved post-course knowledge compared to pre-course knowledge for all learning objectives assessed in the course. Significant improvements were observed in student preparation and confidence for the development of an integrated entrepreneurship–engineering capstone. More importantly, the instructional team eventually convinced the students that there is no single solution to a real-world problem. Instead, a reasonably good design that meets customer needs and fits within economical, financial, marketing, safety, and regulatory constraints, as well as technical and functional performance criteria stated in the RFP, is an acceptable solution.

In all fairness, it should be mentioned that the above accomplishments have been made with some unselfish responsibilities taken up by students and instructors. With any new or redesign of courses, there are usually obstacles to overcome and areas to improve upon. Often, students were not happy with the pressure imposed by instructors during the conduct of the capstone design. The idea of "learning how to learn" takes time to be conveyed to the students—the fact that for all the courses they have taken, and for all the assignments provided, there remain technical issues that students need to resolve on their own. Many requirements in the RFP were completely new to the students. Initial serious debates and confrontation among team members quickly disappeared as students organized themselves and converged towards a unified theme which allowed them to develop a sense of leadership, responsibility, and ownership of the project.

For the instructors, there were frustrating moments as well, when the students simply did not accomplish what was expected. The instructors conducted their own "soul searching" to discover where the curriculum could be improved, whereby more cogent skills can be instilled in students to face such open-ended design projects as the capstone. There were debates among the faculty regarding the tradeoffs between breadth versus depth in the curriculum. Accordingly, the systems-engineering core requirements have been re-adjusted vis-à-vis that of the specialty options. The sequencing of courses has also been tightened up to allow basic technical skills to be covered prior to the capstone design course. However, more remains to be done, and there is serious doubt whether there will ever be any substitute for "learning on one's own" when the situation arises.

It is safe to say that at the minimum, the capstone should be a course that complements the remainder of the curriculum in terms of student exposure. For example, project management, including the use of tools such as CORE, has not been provided to the students in their curriculum. The capstone is a natural place to introduce it. Similarly, such entrepreneurial skills as configuring a business plan should be part of the capstone experience, if it has not been introduced previously. When we observed such phenomena in a systems engineering program, the authors would surmise that it is even more relevant in a more traditional engineering program, when students do not have the advantage of a systems engineering core.

Finally, it should be noted that after decades of increasingly specialized undergraduate engineering curricula, there is a recent trend to provide more breadth in the bachelor degree program. As a systems engineering department, we have conducted a timely study of this philosophy. For that reason, our experience may very well shed some light for other more traditional engineering programs regarding their curricula improvements or reforms. Continuing the industrial flavor of the capstone design project, current seniors partnered with students from the UALR Business College to put together a business proposal to the Donald W. Reynolds Cup, which is a statewide entrepreneurship competition. The competition, complete with cash award, further supplements the business skills required of engineering students in today's environment.

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APPENDIX A: ASSESSMENT SAMPLE

SYEN 4385—Systems Engineering Capstone Design I

Table A.1 depicts the learning objectives the instructors have established for SYEN 4385. Achievements of these course-learning objectives helps prepare the students to achieve ABET program outcomes that are required for graduation from the systems engineering program.

Table A.2 lists the systems engineering program outcomes that the capstone design course contributes to via the established course learning objectives.

Table A.3 indicates how the learning objectives for this course lead toward the systems engineering (ABET) program outcomes. The numbers in each cell indicate, on a scale of 1 to 5 with a score of 5 representing the highest possible achievement of an outcome, calculated based on students' work in the course and the grades assigned to them, For example, the table below illustrates that course learning objective (1) contributes to program outcome (c) through students' response to RFP and assignments and the average achievement of the outcome is 4.35. (Numbers within each cell gives the objective assessment of that outcome on a 5-point scale)

The contribution of this course to satisfying the systems engineering program outcomes were measured directly by student performance on designated assignments, RFP responses, research, and final presentation as prescribed in the above Course Learning Objectives vs. SYEN Program Outcomes mapping. Minimum acceptable individual performance is an average total score of 60% on the designated assignments and reports for all students who receive a final course grade of 'C' or better in SYEN 4385.

Table A.1 Learning objectives of SYEN 4385

SYEN 4385 Course Learning Objectives
1. Ability to design a high-level architecture of a system given user specified requirements. 2. Ability to function in a multidisciplinary team to synthesize a complex system by determining interfaces or protocols required using diverse components constituting the system. 3. Effective communications skills, both oral and written, by writing a response to client specified requirements and to communicate the response to the client orally. 4. Ability to apply the broad and well-rounded background in arts, humanities, science, math, and engineering to understand that engineering design incorporates solutions appropriate in a societal context that ensure privacy and security, and that are economical to implement. 5. Ability to engage in research/self-study to learn contemporary issues (e.g., data bases, designing voice-based systems) 6. Ability to use multiple state-of-the-art tools to design components of a telecommunications/computer system (e.g., CORE, VXML, PHP)

Table A.2 Program outcomes that the capstone design course contributes to via established course learning objectives.

Systems Engineering Program Outcomes Assessed in SYEN 4385
(c) an ability to design and test systems in response to user requirements, (d) an ability to function on multi-disciplinary teams that synthesize engineering solutions from diverse components, (e) an ability to identify and formulate systems engineering problems, and to develop and implement solutions to these problems, (g) an ability to communicate effectively, both orally and in writing, (h) broad and well-rounded education necessary to comprehend the impact of engineering designs and solutions in global, economic, environmental, and societal contexts, (i) a commitment to life-long learning and a desire to keep abreast of latest developments in the engineering field, (j) a knowledge of contemporary issues and an understanding of the role of the systems engineer in contemporary society, (k) an ability to use the techniques, skills, and state-of-the-art engineering tools necessary for professional practice.

Table A.3 Objective assessment of program outcomes

Relationships between Course Learning Objectives and Assessed Program Outcomes		**Systems Engineering Program Outcomes Assessed in SYEN 4385**			
		(c)	**(d)**	**(e)**	**(g)**
SYEN 4385 Course Learning Objectives	**(1)**	√ (Response to RFP, assign.) 4.35		√(Response to RFP and Final Presentation) 4.41	
	(2)		√(response to RFP and Final Presentation) 4.41		
	(3)				√(Response to RFP and Final Presentation) 4.41
Relationships between Course Learning Objectives and Assessed Program Outcomes		**Systems Engineering Program Outcomes Assessed in SYEN 4385**			
		(h)	**(i)**	**(j)**	**(k)**
SYEN 4385 Course Learning Objectives	**(4)**	√ (response to RFP, research to identify system components & interfaces, final power point report) 3.5			
	(5)		√ (response to RFP, research to identify system components & interfaces, final power point report) 4.5	√ (response to RFP, research to identify system components & interfaces, final power point report) 4.5	
	(6)				Assignments involving state-of-the-art tools 4.36

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