ABSTRACT

Development of a Sustainable Infrastructure Management System for a City
"Better Infrastructure for a Better Community"

City governments face great challenges to protect the public when critical events expose the weaknesses in their infrastructure network. In 2006, a flood disaster triggered a long-term project agreement between the University and the City to develop a "Sustainable Infrastructure Management System" (SIMS) integrated through a Geographic Information System (GIS). The two main components already developed for the City are the "Storm Water Drainage Infrastructure System" (SWAD), and the "GIS Fiber Optics Asset Management System" (GFOAMS). The integration of a third component to manage the "Transportation Infrastructure System" is currently under discussion. The SIMS project has involved the successful collaboration of faculty, students, licensed professional engineers, and technical personnel. This project served as model to establish the program "Engineering in Practice for a Sustainable Healthy Living Community" (EIP) at the College of Engineering. The objective of the program is to address the current and future challenges faced by a healthy living community with the aim of providing a better quality of life.

Benefit to public health, safety, and welfare

SIMS includes practical tools to better manage infrastructure assets, minimizing the impact of undesired events as flood and communication disruptions. With SIMS, the City is able to visualize the overall infrastructure network as well as zoom into specific sections of interest, enhancing planning, construction, and maintenance capabilities. Maintenance down-times are now reduced by providing maintenance crews with this powerful interactive tool which has demonstrated substantial benefits to safety. Using SWAD, the City can assess the potential for flood throughout the network and detect under-designed drainage structures. Using GFOAMS, the City can quickly access information on crucial facilities such as Police and Fire Stations as well as Emergency Response Systems and Administrative buildings. SIMS has allowed the City to develop more reliable maintenance and rehabilitation action plans providing the community with a healthier and safer infrastructure system.

Knowledge or skills gained

Graduate and undergraduate students were exposed to a real-world engineering challenge expanding their knowledge on surveying, hydrology, fiber optics, GIS, infrastructure planning, and project management. They learned how to work as a team applying critical thinking to identify, formulate, and solve problems; and to effectively communicate solutions. Students worked jointly in a multidisciplinary team composed of Licensed Professional Engineers from public and private sectors, and Faculty from the Departments of Civil Engineering, Industrial Engineering and the Geospatial Center, receiving guidance in infrastructure, GIS, environmental science, construction, transportation, law, ethics, and entrepreneurship. Seminars were delivered in these disciplines and visits organized to public and private organizations to discuss all aspects related to a sustainable infrastructure system. This exposure gained by the students allowed them to conclude that any changes on infrastructure's performance will impact the health, safety, and welfare of the community, understanding that engineers of the 21st century need to work in multidisciplinary teams to address the technical, economic, social, and environmental conditions faced when solving an engineering problem.

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I: PROJECT DESCRIPTION

Introduction

Engineering in practice means engineering in service to solve current problems and anticipate future challenges that may pose a threat to a healthy community. There is a strong relationship between infrastructure and well-being of communities. Life is even at risk when infrastructure fails. Critical events expose the weaknesses in infrastructure systems and City governments face great challenges to protect the public knowing that infrastructure's performance will directly affect the health, safety, and welfare of their communities.

The drainage infrastructure system of the City was put to the test in 2006. The City usually receives less than 2 inches of rain during the month of August but in 2006 the City received seven inches of rain in one day. The unexpected amount of rain led to several areas in the City to flood causing destruction in homes, roads, and businesses. The damage to public infrastructure was estimated about $21 million, $77 million in private property, and $3.5 million in flood control landfill. 295 houses were destroyed and 495 received major damage.

Figure 1. Flood Damage and Destroyed Streets in the City (2006)

This event triggered a project within the framework of a long-term cooperation agreement between the City and the University for the "Development of Sustainable Infrastructure Management System" (SIMS). SIMS has involved the on-going cooperation of a multidisciplinary team of students, faculty, licensed professional engineers, and engineer interns to foster best engineering practices and to develop practical tools. SIMS can assist the City to better manage infrastructure while enhancing its awareness of the impact of engineering practices and management decisions on the health, safety, and welfare of the community."

The Project

The project focuses on critical infrastructure components for the City and includes: drainage, communications, and transportation. The first component of the integrated infrastructure management system is the "Storm Water Drainage Infrastructure System" (SWAD). The development of this component started in May 2007 and was fully implemented in June 2009. The second component is the "GIS Fiber Optics Asset Management System" (GFOAMS) which started in August 2009 and completed in April 2011. The third component is the "Transportation Infrastructure System" which planning stage started in November 2010. All these components are integrated through a Geographic Information System (GIS).

This project has had the continuous participation of undergraduate students from surveying, hydrology, and senior project courses as well as graduate students from infrastructure management, infrastructure planning, geographical information systems, and seminar courses. Since fall 2007 until the present, the faculty teaching these classes has selected students to work on the project, enhancing their education through experience beyond the classroom. Seminars were offered in environmental, construction, transportation disciplines to complement their overall knowledge and understanding of what a sustainable infrastructure system means. Licensed professional engineers have served as mentors in the different disciplines of the project.

Storm Water Drainage Infrastructure (SWAD)

The development of the SWAD involves collecting data from historical records, performing field surveys, and building a database with analytical and visualization tools. SWAD includes drainage data with location, material, and dimensions. Photographs were taken to record the condition of the drainage components. Inlets, manholes, watersheds, streets, ponds, and basins are included in SWAD. Data and tools are integrated in GIS.

The GIS database contains watershed data used to determine the regression peak discharge including mean annual evaporation, basin storage, basin development factor, and impervious surfaces. The GIS database also contains the capacity of the drainage section. The capacity is obtained using HY-8 software. The performance of the drainage system is determined by subtracting the expected peak discharge from the capacity. SWAD is used to prioritize maintenance interventions for the drainage infrastructure system based on their hydraulic performance. The performance tool calculates expected peak discharges which is compared to the drainage hydraulic capacities displaying the results in GIS color-coded maps. The GIS visualization tool is able to identify parts of the drainage system that are likely to fail based on rainfall intensity. The tools designed by the University can be used with two types of GIS databases: personal geodatabases and ArcSDE databases.

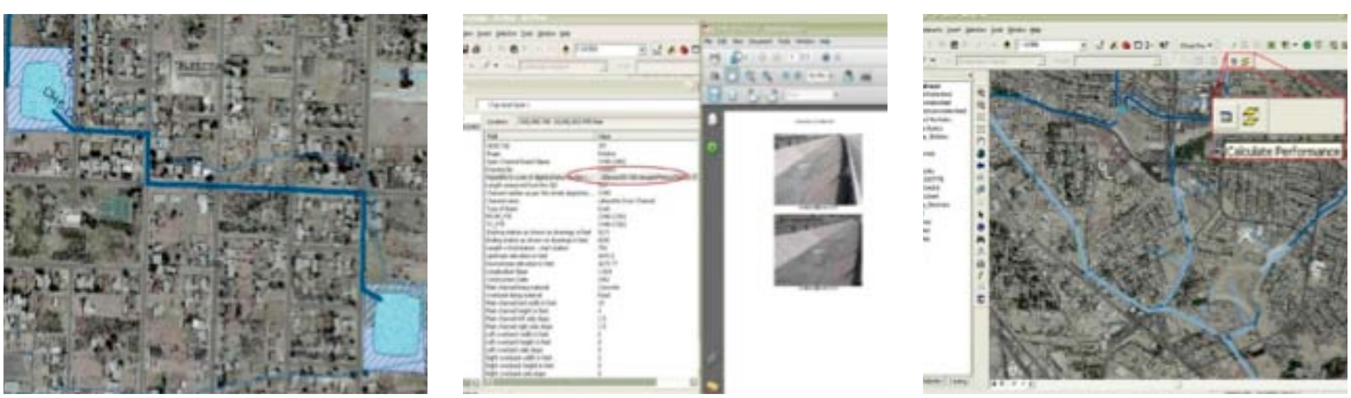


Figure 2. SWAD Showing Actual Condition and Capacity of Infrastructure Drainage Assets

GIS Fiber Optics Asset Management Information System (GFOAMS)

The development of the GIS Fiber Optics Asset Management System (GFOAMS) component involved: (1) review existing records to extract data for the fiber optics network, (2) perform a field survey to verify and collect data for the fiber optics network, (3) integrate fiber optics data into GIS and adding attribute information, (4) development of the GIS Fiber Optics Asset Management System (GFOAM).

The major challenge was to locate fiber optic conduits in the field and identify their routes. Existing information from current maps were reviewed prior to the field surveys. Field surveys were conducted with the assistance of technical staff from the City. A team composed of a graduate student leading undergraduate students went to the field with technical personnel from the City. Elements for the fiber optics network were located using a global positioning system (GPS). Junction boxes, fiber points, conduit runs data were incorporated into GIS. GFOAMS includes 317,428 feet of conduit that house fiber running through 10 systems across the City.

The developments of tools to facilitate access to the data inventory and visualize the fiber optics conduit network was finalized in April 2011 being followed by an implementation plan. GFOAMS will be fully implemented by the City in June 2011. These tools allows the generation of a master plan of specific sub-systems in the fiber optics network. If a system surveyed was servicing more than one entity, a subsystem was added so the City can easily identify them in the future. GFOAMS allows the City to access reliable information which can in turn enhance their maintenance program to avoid any disruptions in the communication of the fiber optics network system.

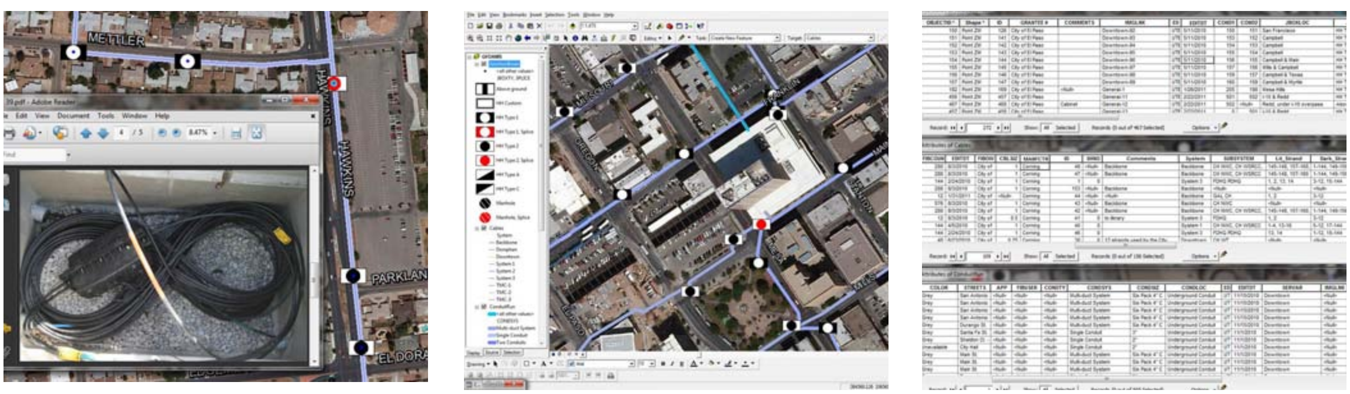


Figure 3. GFOAMS Fiber Optics Tools to Manage the Fiber Optics Network Owned by the City

Transportation Infrastructure System

The City metropolitan area is experiencing significant growth in traffic congestion and delay on area roadways and consequently it requires an increase in roadway capacity. In the last two years the City has invested over 40 million dollars in the mass transit infrastructure system such as construction of new state of the art transit terminals. A new Metro Depot will be completed in 2012. There are also plans to implement a Bus Rapid Transit (BRT) system as an alternative travel model. Four BRT corridors have been selected to provide mass transportation connectivity within the City. The four BRT corridors are planned to be completed within 4 years.

Being located on the border, the City faces additional transportation challenges. The City owns and operates international bridges. These bridges generate approximately $50 billion worth of international commerce between the United State and Mexico. This makes the international crossing through the City, USA and Mexico one of the busiest international crossings in the country. In a broader sense, these facts present financial significance to this international crossing. To capitalize on the benefit of having these bridges, the City Council formed the International Bridge Department (IBD) to maintain and to improve cross border mobility.

The level of investment currently being put into the City transportation system is unprecedented. To capitalize on these investments, it is essential to implement an infrastructure management system to maintain and prolong the life expectancy of these assets. Coordination to incorporate a "Transportation Infrastructure System" component into SIMS started in November 2010.

II: COLLABORATION OF FACULTY, STUDENTS, AND LICENSED PROFESSIONAL ENGINEERS

The project involved the participation of students, faculty, licensed professional engineers, and technical personnel in the development of a "Sustainable Infrastructure Management System for the City". A multidisciplinary team was assembled to perform the tasks required in the project. Faculty from the Departments of Civil Engineering, Industrial Engineering, the Regional Geospatial Center, and Licensed Professional Engineers worked with the students and provided advice in infrastructure, environmental, construction, transportation, law, ethics, and entrepreneurship. Seminars were delivered in these disciplines for a better understanding of what a sustainable infrastructure system means and to increase student's awareness of its impact in the health, safety, and welfare of the community. Students from liberal arts joined engineering students to develop a web site and promote the project.

Field surveys were conducted by two teams of undergraduate students led by a graduate student and supervised by personnel from the City. Another team of students supervised by faculty members worked in the development of the GIS system components. Students were recruited from surveying (undergraduate), hydrology (undergraduate), senior design (undergraduate), infrastructure management (graduate), and GIS (undergraduate and graduate) courses. Mentoring was provided by licensed professional engineers from the City who guided the students on how to apply concepts learned in class into practice. In addition to the customized GIS systems developed for the City, the team prepared technical reports and made formal presentations. Theses and journal papers have resulted from the work developed in this project.

Figure 4. Team of Students and City Staff Performing Field Surveys to Collect Fiber Optics Data

Engineering in Practice for a Sustainable Healthy Living Community (EIP)

SIMS served as model to establish the program “Engineering in Practice for a Sustainable Healthy Living Community” (EIP) at the College of Engineering. The objective of the EIP program is to address current and future challenges faced by a healthy living community. Under this program, different problems that affect the community are analyzed to propose practical solutions based on engineering principles. With the aim of providing a better quality of life, the program merges education, research, and professional practice through a synergistic approach in which a multidisciplinary team of graduate and undergraduate students, faculty, and licensed professional engineers work jointly to solve specific infrastructure problems.

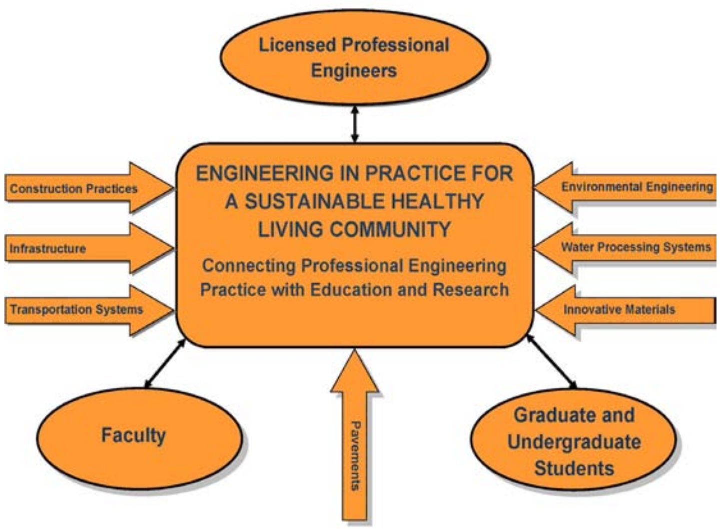


Figure 5: Overview of Participants in the Engineering in Practice Program for a Sustainable Living Community

Guest speakers are invited to cover potential areas of collaboration including construction practices, environmental engineering, innovative materials, infrastructure, water processing systems, and transportation systems. Visits to public organizations, and private companies are followed to better understand engineering practices. The program currently involves the Department of Civil Engineering, Department of Industrial Engineering, the Geographic Information Systems and Geospatial Applications Center, the City, and a number of other private and public organizations.

Figure 5 illustrates the interaction among students, faculty, and licensed professional engineers in the program.

The project “Development of a Sustainable Infrastructure Management System for the City” is under the Engineering in Practice program.

III: BENEFIT TO PUBLIC HEALTH, SAFETY, AND WELFARE

Preserving our infrastructure assets is essential for a sustainable healthy living community. Quality of life is heavily affected by poor infrastructure management. The “Development of a Sustainable Infrastructure Management System for a City” has benefited the community by providing a safer and healthier infrastructure system while minimizing the impact of undesired events as flood and communication disruptions.

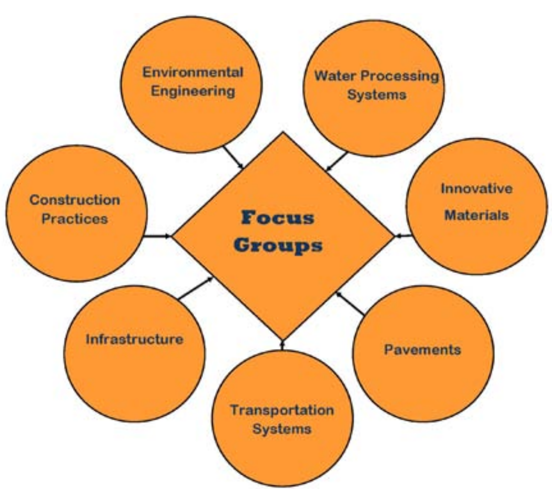
Having an integrated infrastructure management system in a GIS platform provides the City with the ability to visualize the overall infrastructure network as well as zoom into specific sections of interest, enhancing their planning, construction, and maintenance capabilities. Likewise, economic savings from a better engineering, planning, and management result in a positive overall impact on the welfare of the community.

The Storm Water Drainage Infrastructure System (SWAD) can rapidly assess the potential for flooding throughout the city. SWAD can detect under-designed drainage structures and develop maintenance and rehabilitation plans to prevent future disasters and avoid economic loss due to infrastructure damage. These enhanced capabilities have resulted in a direct benefit to the public by identifying weak areas in need of intervention, and providing quick response to emergencies to minimize accident risk to the public.

GFOAMS was designed with efficiency in mind. The ability to better visualize the fiber optics network has greatly increased planning and maintenance capabilities. The City can reduce maintenance down-times by providing a very powerful interactive tool to the maintenance crew. Having quick and interactive access to the fiber optics network has substantial benefits to safety. The fiber optics network plays a large role in controlling and managing traffic intersections. Having an efficient method of reviewing the network to act immediately is critical to ensure safety to those on the road. The City is currently able to quickly access information on crucial facilities such as Police and Fire Stations as well as Emergency Response Systems and Administrative buildings with a significant role in emergency 911 systems. Another safety concern for the City is its proximity to the United States-Mexico border. Not only does the fiber optics network monitor traffic intersections, but it maintains communications and video surveillance for critical points along the border. The City overall foresees an increased usage of fiber optic systems to provide services to the public. Presently, educational facilities and libraries within the City limits are linked together using fiber optics, and needs an up-to-date fiber optic management system to maintain the communication routes.

IV: MULTIDISCIPLINE AND/OR ALLIED PROFESSION PARTICIPATION

A multidisciplinary engineering team approach was used to successfully address the challenges faced in the project. The project started with the participation of Civil Engineers in a jointed effort with GIS specialists. As the project expanded, industrial engineers and environmental specialists participated in the project. Awareness of the need to respect the environment led to look at topics such as: Life Cycle Assessment (LCA), Carbon Footprint Management, and Design for Sustainability, and Ethical Consumerism. Use of alternative sources of energy for infrastructure systems was discussed by the industrial engineering group including solar energy, hydrogen, and biodiesel. Students from Civil Engineering, Industrial Engineering, and Liberal Arts play different roles in the project.



Focus groups composed of students, faculty, and licensed professional engineers were assembled in different areas of expertise as shown in Figure 6, to discuss all aspects involved in a sustainable infrastructure system for the City. Seminars were delivered by licensed professional engineers to better understand critical areas including: environmental, water processing systems, innovative materials, pavements, transportation systems, infrastructure, and construction practices. Visits were conducted to the City, as shown in Figure 7, to assess current needs and resources available to address the problems.

Figure 6. Focus Groups Assembled to Discuss Needs for a Sustainable Infrastructure Management System

Figure 7. Group of Civil and Industrial Engineering Students Attending Seminars on Sustainability. Seminars were developed at the University followed by Visits to the City for further Discussion.

The project was aligned with the City's core values that include: "Excellence, Integrity, Respect and Accountability" and its commitment to provide quality customer service to the public.

V. KNOWLEDGE OR SKILLS GAINED

Engineers are problem-solvers by nature and the development of critical thinking skills to identify, organize, and analyze information becomes crucial when formulating solutions to engineering challenges. In the 21st century, engineers are called to become leaders in our society contributing to the creation of a sustainable world that values the quality of life. With this role in mind, the project has provided students the opportunity to develop technical, leadership, team work, and communication skills. Undergraduate students were exposed to engineering practices expanding the lessons learned in class. Graduate students had the opportunity to use all their creativity to come out with practical solutions and develop their communication skills. Specific knowledge and skills gained during the SIMS project can be summarized as follows:

- Practice the principles and methods learned in engineering and management courses including surveying, GIS, infrastructure planning, and project management.
- Operate specialized equipment and software including: ArcMap, ArcCatalog, ArcPad, and Trimble Geo XT GPS.
- Interpret "as built plans" realizing that infrastructure evolves over time and plans not always reflect reality on the field. The dynamic nature of infrastructure implies the need of conducting regular field surveys to update records stored in the system.
- Identify, formulate, and solve critical infrastructure problems participating in multidisciplinary teams to foster healthy sustainable living communities.
- Be a team player when working on multidisciplinary teams, acknowledging professional responsibility in the practice of engineering, and maintaining an ethical conduct at work.
- Communicate effectively when presenting potential solutions in oral and written reports.

Students were able to understand that engineering in practice is not only about technical knowledge; engineers must work in multidisciplinary teams to address the economic, social, and environmental conditions faced when solving a problem. Having faculty and students from civil engineering, industrial engineering, geospatial center, and liberal arts interacting with Licensed Professional Engineers was a unique experience and brought different perspectives in benefit of the project. Students ultimately learned that beyond technical aspects, licensed professionals engineers are responsible for delivering engineering solutions that will impact the health, safety, and welfare of their communities.