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Learn by Doing: Lessons Learned from the Ten-Year Senior Projects through University-Agency Partnership

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Abstract

Over the past ten years, the Civil Engineering Department of California State Polytechnic University, Pomona (CPP) and District 8 of California Department of Transportation (Caltrans) have been partnering on real-life, learn-by-doing senior projects where a group of 10-20 senior students have designed and analyzed a variety of freeway interchange alternatives for an actual interchange project location in either San Bernardino or Riverside Counties in California.

Supervised by both CPP faculty and Caltrans Engineers, each team has conducted various studies including Planning Study, Traffic Analysis, Geometric Design, Construction Staging, Environmental Impact Study, and Cost Benefit Analysis. These studies have covered a wide range of the core courses related to transportation emphasis of Civil Engineering. More importantly, each senior project has followed the Caltrans project development process and addressed contemporary transportation issues including technical aspects of interchange improvements, formulation of project purpose and need, project scheduling, team building strategies, and public speaking techniques.

Project teams have made multiple presentations of their results to several groups including a panel of District 8 Deputy District Directors, District 8 Design staff, local chapters of Institute of Transportation Engineers (ITE) and the Caltrans Design Management Board, and the engineering professionals. The presentations have been very impressive. Also, as one of the final products of each senior project, each team has created a website to highlight the objectives, scope, team, and various documents of the project.

So far more than 150 students have been successfully trained with this senior project model. These students, currently working in various transportation agencies and consulting firms in California, have been major contributors to providing a safe, sustainable, integrated and efficient transportation system to enhance California’s economy and livability.

1. BACKGROUND

In February, 2006, Dr. Xudong Jia, Professor of Transportation Engineering at the Department of Civil Engineering at California State Polytechnic University, Pomona (CPP), contacted California Department of Transportation (Caltrans) Headquarter about the possibility of providing technical assistance for a real-life senior project. In June 2006, Dr. Jia met with Caltrans top management and senior design engineers to discuss the possibility and options of working together on a transportation senior project with a team of Civil Engineering seniors at CPP. Caltrans recommended that the team prepare a Project Study Report where they would design and analyze different geometric alternatives for a real-life interchange project and then compare those alternatives to select the best solution. This started a partnership between CPP and Caltrans District 8 that has continued for ten years. Caltrans District 8 covers Riverside and San Bernardino Counties in Southern California with 49 incorporated cities. It is the largest of 12 Caltrans districts and covers approximately 28,650 square miles of land, four interstate highways and 32 state routes totaling 7,200 lane miles within its boundaries.(1)

2. SCOPE OF WORK

Each team is tasked to analyze a project location for operational and capacity issues using actual traffic and surveying data available from existing highway projects planned by Caltrans. Each team then develops several alternative interchange designs which require an analysis of operational characteristics, present and future traffic volumes and patterns, environmental and community impacts, and an estimate of construction costs. Each team makes a recommendation for which alternative they believe would be the best solution to the problem and defends their selection. Each team uses a weighted matrix method to select the best solution to solve congestion and operational problems for the specific interchange.

Table 1 shows the ten senior projects that have been completed for the past ten years. It is worth noting that these real-life projects have either been built or in various stage of development.

TABLE 1. A List of Ten Senior Projects

Academic Year	Project Name	City	Current Status
2006-2007	Live Oak Canyon Road Interchange on I-10	Yucaipa	Built
2008-2009	4th Street Interchange on I-215	Perris	Built
2009-2010	Duncan Canyon Road Interchange on I-15	Fontana	Built
2010-2011	Tippecanoe Avenue Interchange on I-10	San Bernardino/Loma Linda	Built
2011-2012	Grove Avenue Interchange on I-10	Ontario	In PAED
2012-2013	Cajalco Road Interchange on I-15	Corona	Design complete, construction funds pending
2013-2014	Franklin Street Interchange on I-15	Lake Elsinore	In PAED
2013-2014	Railroad Canyon Road Interchange on I-15	Lake Elsinore	In PAED
2014-2015	Theodore Street Interchange on SR60	Moreno Valley	In PAED
2015-2016	Limonite Avenue Interchange on I-15	Eastvale/Jurupa Valley	In design

Note:

1. There was no senior project in 2007-2008;
2. There were two senior projects in 2013-2014
3. PAED=Project Approval/Environmental Document

3. PROJECT PREPARATION

Prior to the senior projects, all students in the Civil Engineering department at CPP are required to take CE222/L (Highway Engineering Lecture/Lab) and CE223/L (Transportation Engineering Lecture/Lab). It is worth noting both lab classes are separate courses which provide excellent hand-on experience to students. The labs also require significant amount of efforts from both faculty and students. In CE222L, students are asked to use MicroStation/InRoads to design a freeway segment with interchanges following the Caltrans Highway Design Manual (HDM). For ten weeks, faculty and students meet twice a week and three hours each time, and students need to put in significant amount of extra hours to complete the task. In CE223L, students are asked to use VISSIM, a prevailing traffic micro-simulation software product, to model, simulate and analyze a freeway segment or urban signalized intersection for ten weeks.

Some students have also taken technical elective courses such as CE428/L (Urban Transportation Lecture/Lab) and CE429/L (Traffic Engineering Lecture/Lab). These courses provide further technical guidance to the students so that when they are about to start senior project, they have enough background knowledge. For example, CE428/L teaches students how to build a four-step travel demand model to forecast the short-term/long-term travel demand for an area or a facility with TransCAD, a prevailing travel demand forecasting software product in the industry. CE429/L can help students properly evaluate benefits (for example, in terms of vehicle delays) across various scenarios using micro-simulation software such as Synchro, VISSIM or TransModeler.

4. DELIVERABLES

Each team is asked to provide the following deliverables:

1) Alternative Layouts (Geometric Approval Drawings)
2) Traffic Modeling
3) Signal Plans (Phasing)
4) Construction Staging Plans
5) Cost Estimates
6) Advanced Planning Study (APS)
7) Intersection Control Evaluation (ICE)
8) Project Schedule
9) Project Study Report (PSR) Narrative
10) Website

On the website, in addition to the above project information, team members are asked to post their live resumes for job hunting.

5. TIME COMMITMENT

Over consecutive three quarters, students typically spend approximately 300 hours each working on their senior project. For a team of 12 students this would equate to 3,600 hours. One faculty from the Civil Engineering department meets with the senior project team once a week and spend approximately 80 hours working with the senior project team over the course of the school year. The two senior design engineers from Caltrans meet with the team about twice a month and spend approximately 50 hours (each) over the course of the school year. Meetings with the students begin in late September when the fall quarter starts and there are additional meetings at the conclusion of the senior project in early May. Senior project team members also have access to and work with Caltrans subject matter experts as well as Consultants.

6. TOPICS COVERED IN MEETINGS

At the beginning of the senior project, faculty member and senior design engineers take the student project team to the project site to collect all related information. Before Purpose and Needs can be identified, the project team needs to contact local city for its general plan as well as local communities for their concerns, which often include severe traffic congestion and poor accessibility. Throughout the whole year, the following topics are covered in various meetings between faculty, senior design engineers, and the project team.

1) Caltrans Methods and Processes
2) How Caltrans Delivers Projects

3) Teamwork and Networking
4) Communication
5) Presentation Skills
6) Value Analysis and the Weighted Matrix Method
7) Interchange Types and other Geometric Issues
8) Construction Methods and Practices
9) Caltrans Structures Processes including Advance Planning Studies (APS) Preparation
10) Project Purpose and Need/Environmental Issues and Concerns
11) Caltrans Right of Way (R/W) Processes and Needs
12) Current Issues with Caltrans – Bicycles, Pedestrians and American Disabilities Act (ADA) Needs

7. PRESENTATIONS

Each team makes 6-7 presentations to a wide variety of governmental and professional organizations such as Caltrans, Caltrans Design Management Board, Caltrans Professional Liaison Committee (formerly ACEC) and ITE (Institute of Transportation Engineers).

Over the past several years, senior project teams from CPP have well performed in several student competitions such as RSB ITE Student Presentation Competition and Southern California ITE Student Presentation Competition. The competition was among six ITE Student Chapters in Southern California Section (UC-Irvine, UCLA, USC, Cal Poly Pomona, Cal State Long Beach, Cal State Fullerton) as well as UC-Riverside and Cal State Los Angeles.

Also, at the end of the senior project, teams are asked to present and defend their work in the Senior Project Symposium held in the Civil Engineering Department. A big crowd of the audience are invited to attend the symposium, including but not limited to faculty, Caltrans senior project advisors, professionals/engineers from other firms/agencies, students as well as parents/friends.

It is worth noting that firms/agencies that are interested in hiring students are invited, too. By doing so, students get the opportunity to talk to the professionals from these firms or agencies in person before and after the presentation. Those professionals will collect students' resumes and project information and take them back to their firms or agencies. This has created an efficient communication channel to facilitate the hiring process.

8. OUTCOMES AND ASSESSMENT

So far more than 150 students have been successfully trained with this senior project model. Over 95% of these students are working full-time after graduation. Approximately 10% of them are working in public agencies such as Caltrans and 90% are working in consulting firms in transportation/civil industry across California. They have been major contributors to providing a safe, sustainable, integrated and efficient transportation system to enhance California's economy and livability.

The education outcomes include:

1) Deep understanding of the entire highway project development process at Caltrans
2) Strong engagement with faculty member, Caltrans engineers and other consultants
3) Great team effort
4) Enhanced project management skills (set up meeting agenda, group discussion, keep track of the progress, etc.)
5) Familiar with cutting-edge technologies (3D printing, 3D visualization, 3D micro-simulation, etc.)
6) Improved presentation skills
7) Continuous bonding efforts. Many team members became friends in the learning process and the friendship is maintained very well after graduation.

The student outcomes are based on the standard ABET a-k outcomes.

a: Apply Knowledge—An ability to apply knowledge of mathematics, science, and engineering

b: Experiment Analysis— An ability to design and conduct experiments, as well as to analyze and interpret data

c: System Design— An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

d: Teamwork— An ability to function on multidisciplinary teams

e: Problem Solving— An ability to identify, formulate, and solve engineering problems

f: Professionalism & Ethics—An understanding of professional and ethical responsibility

g: Communication— An ability to communicate effectively

h: Global Impact— The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

i: Life-Long Learning— A recognition of the need for, and an ability to engage in life-long learning

j: Contemporary Issues— A knowledge of contemporary issues

k: Engineering Tools— An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In rubrics used in the senior project assessment, for each of the twelve areas, a score between 1 and 4 is assigned by each evaluator during the senior project symposium. The twelve areas (outcomes) are:

1) Ability to apply knowledge (a)
2) Use of engineering techniques and tools (k)

3) Ability to gather data and solve engineering problems (e)
4) Ability to design a system (c)
5) Understanding of outside constraints & contemporary issues (h)
6) Quality of visual presentation (g)
7) Quality of oral communication (g)
8) Ability to function on an interdisciplinary team (d)
9) Level of design experience
10) Would you hire this student or team to work for you or your company?
11) Lifelong Learning: Ability to recognize the need for and be able to pursue lifelong learning (i)
12) Contemporary Issues: Awareness and understanding of contemporary issues and their interactions (j)

The scores are defined as:

1. Unacceptable (Quality level is not acceptable)
2. Marginal (Acceptable Level Quality for Graduating Senior, but room for improvement)
3. Proficient (Good Quality for Graduating Senior)
4. Exemplary (Professional Level Quality)

The evaluators include each qualified attendee in the symposium, which includes faculty members, advisors, Caltrans design engineers, and other invited professionals.

The past ten project teams received an average of 3.5 out of 4. In other words, overall the quality of the student projects were between Proficient (Good Quality for Graduating Senior) and Exemplary (Professional Level Quality).

Starting in spring of 2009, as part of the senior project presentations, students were asked to individually prepare a one-page document describing their contributions to the senior project team and describing their personal achievements during the project. A rubric was developed for evaluating these documents and a small group of faculty, including faculty from the English department, conducted a normed assessment of the student performance. Writing was evaluated in the following four areas:

1) Clarity and quality of technical content
2) Style
3) Exhibits evidence of growth and personal development
4) Mechanics

Each area was rated from 1 to 4, where 1=unacceptable, 2=marginal, 3=proficient, and 4=exemplary. The goal was set to a score of 3.0. This assessment is considered a direct measure of student performance.

These senior projects also received feedbacks from Caltrans. Each meeting session with Caltrans senior design engineers has been recorded such that Caltrans management team can review it later. At a later stage, each student project team is asked to present in front of Caltrans Management team and defend their work. The sample questions are:

1) What's the design exception?
2) What's the source for traffic volumes?
3) How was value of time defined?
4) What's the detour plan and construction phasing plan?
5) What's the Right of Way?
6) How to engage local communities?
7) What are the standards used in the study?

9. LESSONS LEARNED

1) Faculty

University staff (i.e., Civil Engineering faculty, Department Chair and Dean of the College of Engineering) must be committed to making the program successful. Faculty in charge of the senior project needs to help guide students through the design process. Even though students are supposed to be trained through their previous lecture and lab courses, usually they need a jump start to put pieces of knowledge together to get the real life project done. Ideally, the faculty in charge should have some practical experience gained from the industry, which will make the whole process much more streamlined.

2) Agency

Agency staff should be at the design senior level and must be relatable and have the requisite experience and knowledge to provide guidance and mentorship to college seniors. Agency management must allow for the necessary overhead resources to support the Partnership and participate in project meetings and provide feedbacks to students and University staff.

3) Students

Students are given the best opportunity when advised by both faculty and senior engineers from the transportation agency. Students need to be highly motivated to take advantage of the opportunity to observe and learn by doing. By assigning each member to be either project manager or engineers who are in charge of certain tasks, the whole project team is organized in a very similar way as a real project in the industry. Students need to learn how to manage the tasks and how to collaborate with other team members to get the project done. Any delay in one team member could lead to the failure of the whole project.

4) Projects

Agency needs to provide current project data for a specific project location including 3-D topography, current and forecasted traffic data including turning movements, a brief project outline and environmental issues for the area.

The senior project team needs a list of all relative design information including the Caltrans Highway Design Manual (HDM) and other Caltrans manuals, Design Information Bulletins (DIB), current cost estimating information and so on.

10. CASE STUDY

1) Project Description

In fall of 2014, eighteen seniors from the Civil Engineering Department formed two senior project teams to work on “Improvement of the Existing Interchange at the I-15 and Railroad Canyon Road in City of Lake Elsinore”. Figure 1 shows the project location, Figure 2 outlines the project design boundary.

The City of Lake Elsinore, in cooperation with Caltrans District 8, proposes to improve the existing interchange at Railroad Canyon Road and to design a new interchange in close proximity to Franklin Street. Two senior project teams delivered a Project Study Report (PSR) for their respective interchanges. Due to the close proximity of the two interchanges and their impact on each other, both project teams worked closely together in order to develop several design alternatives that meet the State, City, community, and future needs.

In each team, there are two Project Managers and seven Project Engineers. Within each team, there are three functional groups: geometrics team, traffic analysis team, and environmental analysis team. Each team member is assigned with specific tasks and works closely with other members.

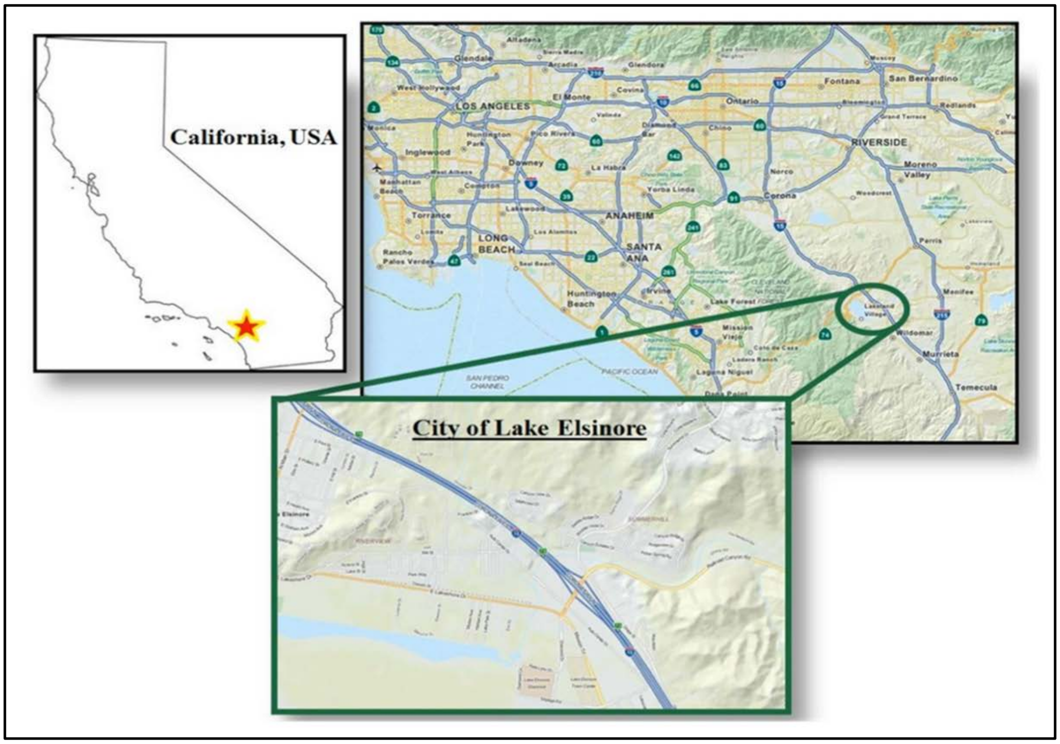

FIGURE 1 Site Location

FIGURE 2 Project Study Boundary

2) Purpose and Need

The project team studied the background information and identified the Purpose and Need as follows: Railroad Canyon Road is experiencing operational problems caused by high peak periods of traffic volume. The combination of the current tight diamond geometry and closely spaced ramp and city street intersections produce congestion during morning and evening commute times (AM/PM peak).

The project team also studied the general plan from the city where the project is located and performed a preliminary traffic forecasting analysis to obtain the projected traffic volumes for both year 2020 (the project completion year) and year 2040 (20 year design life) under a reasonable assumption on growth over the next 20 years.

The deficiencies of the interchange at I-15 and Railroad Canyon include high congestion, substantial traffic delay, and lack of safe accessibility for pedestrians and bicyclists.

3) Alternatives

After a completed analysis of numerous alternatives, and with consideration of project needs and existing constraints, it was determined that the following alternatives be selected as viable project alternatives:

- Alternative 1: No Build
- Alternative 2: Continuous Flow Interchange (CFI) (see Figure 3)

- Alternative 3: Diverging Diamond Interchange (DDI) (see Figure 4)
- Alternative 4: Single Point Urban Interchange (SPUI) (see Figure 5)

The only structure work needed for Alternatives 2 and 3 is the removal of existing sloped paving and a retaining wall, and the construction of two new retaining walls with tiebacks. The structure work required for Alternative 4 is extensive, and requires four new bridge structures.

For each of the four alternatives, the project team studied the pros and cons: including benefit, cost, projected traffic level of service. The level of service (LOS) of each intersection using the projected 2040 traffic volumes was calculated at all intersections for both AM and PM peak hours.

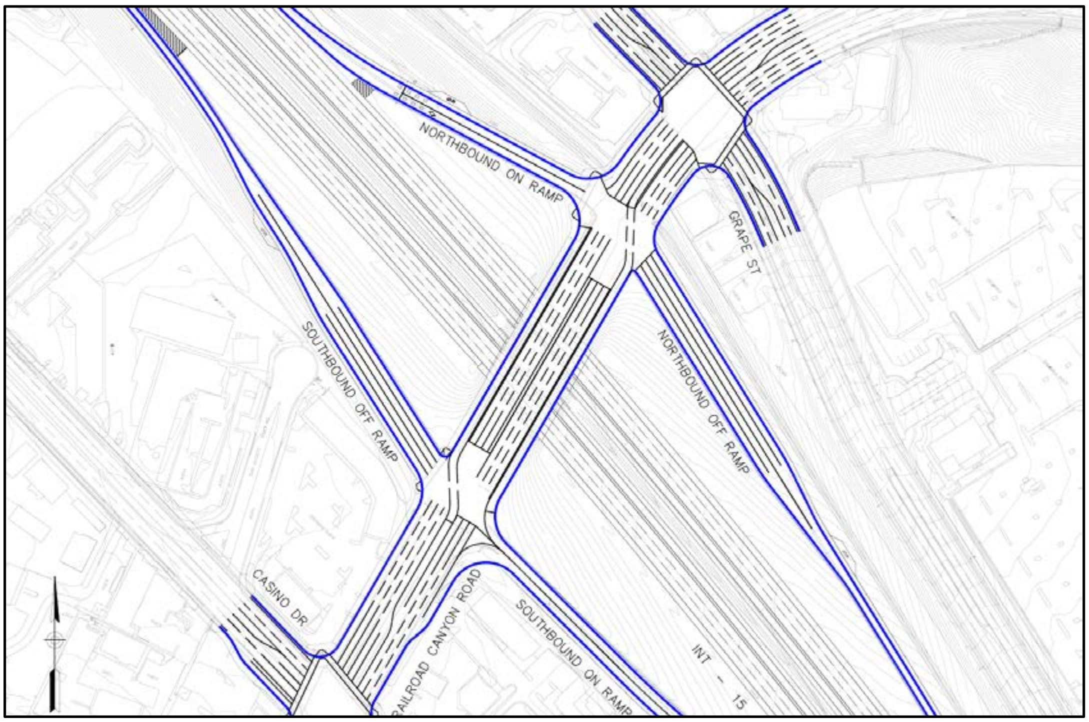

FIGURE 3 Alternative 2

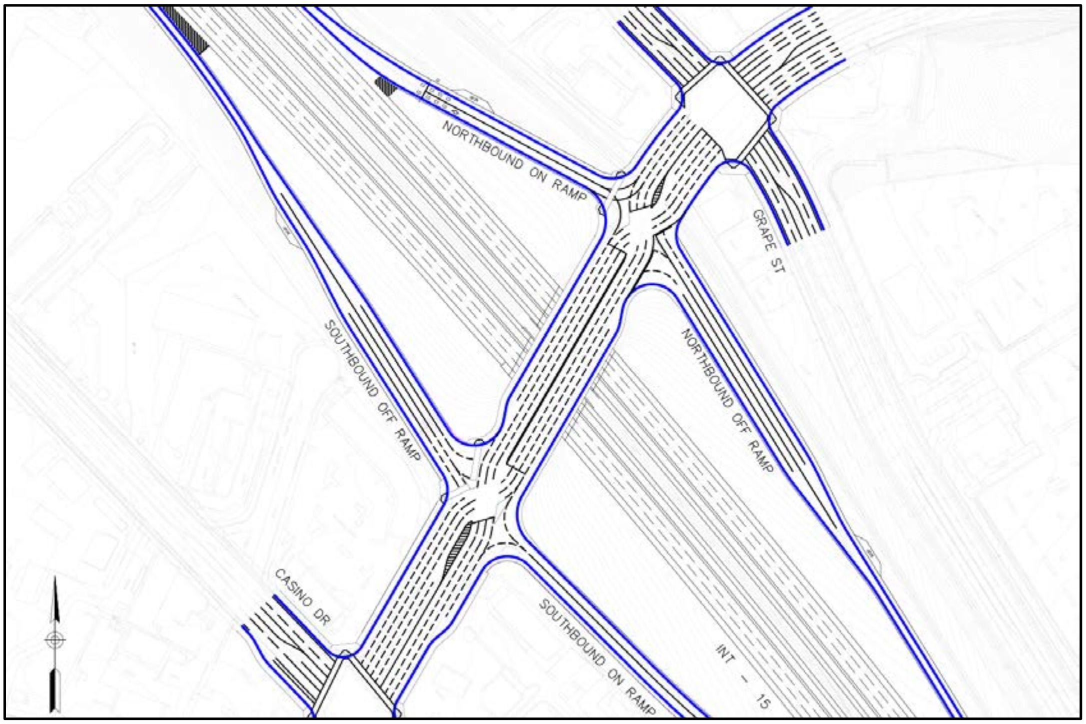

FIGURE 4 Alternative 3

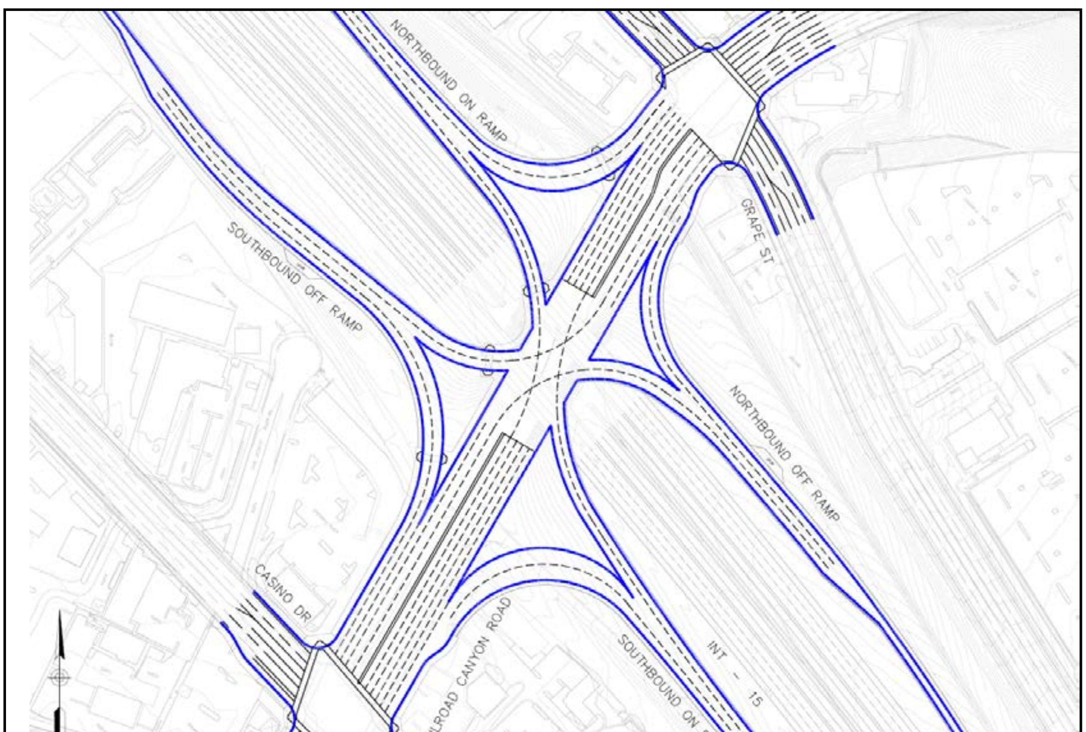

FIGURE 5 Alternative 4

Proper striping and signage will be used to assist drivers as they make this new traffic movement through the interchange. A concrete barrier will be used to separate the crossover left vehicles and opposing traffic. This is to ensure safety to the possibility of head on collisions with opposing vehicles.

All turning radii were tested using AutoTURN to ensure that Surface Transportation Assistance Act (STAA) semi-trailer trucks could make all movements on and off the interstate safely. Pedestrian and bicycle access is provided on the northerly side of Railroad Canyon and all designs conform within Design Information Bulletin (DIB) 82-5 standards.

4) Benefits and Costs

A preliminary cost estimate and complete benefit analysis of each alternative was performed. The main purpose of the cost-benefit analysis is to quantify the total benefits of alternative compared to the total cost. To ensure the comparison was valid, all monetary values are in 2014 dollars.

The cost of each alternative was separated into several main categories which include: roadway, structure, right-of-way, design, construction and administration, and contingencies.

The benefits of each alternative were calculated using Synchro measures of effectiveness. The total benefit was based on the reductions of vehicle stops, vehicle delay, fuel used, and carbon dioxide emissions compared to the No Build alternative. These reductions were assigned a monetary value using projected market rates for the facility’s 20 year design life, and a present worth calculation was performed to calculate the total benefit of each alternative in 2014 dollars.

A Cost-Benefit analysis is conducted and the cost and benefit are two main design factors used when selecting the recommended alternative for project implementation.

5) Recommended Alternative Selection

To select the recommended alternative, the team used a weighted decision matrix as shown in Table 2. The first step was to list significant design factors, such as “Local Circulation”, “Freeway Operations”, “Benefit”, and “Cost” and then put them in the order deemed most important based on Caltrans, City, and Community needs.

TABLE 2 Weighted Decision Matrix

Importance	Design Factor	CFI Score	DDI Score	SPUI Score	Weight	CFI Weighted Score	DDI Weighted Score	SPUI Weighted Score
1	Local Circulation	8	6	9	8	64	48	72
2	Freeway Operations	7	5	8	7	49	35	56
3	Benefit	5	3	9	6	30	18	54
4	Cost	9	9	4	5	45	45	20
5	Ease of Construction	8	8	3	4	32	32	12
6	Maintainability	7	8	3	3	21	24	9
7	Adaptability	6	6	2	2	12	12	4
8	Ped./Bike Friendliness	6	8	4	1	6	8	4
Scoring: 10 = Best 1 = Worst					**TOTAL:**	**259**	**222**	**231**

Each alternative was then scored from 1 to 10, as to how well they met each factor. For an example of the scoring methodology, "Local Circulation" was based on the average intersection level of service in 2040. From the data, the CFI was scored an 8, the DDI a 6, and the SPUI a 9.

After giving a score to each alternative, numerical weights were assigned to each factor, giving the most important the highest weight. These weights were then multiplied by the scores to get "weighted scorings."

To obtain reasonable weights for each design factors, project team consulted with Caltrans senior designer engineers to finalize the values. A decision-making tree was also created to consider intangible benefits.

After totaling these weighted scores, the CFI had a total of 259, the DDI, 222, and the SPUI, 231. The team formally selects the Continuous Flow Interchange as the recommended alternative to the Improvement of the Existing Interchange at the I-15 and Railroad Canyon Road in City of Lake Elsinore.

6) Final Deliverables

Deliverables included a project study report, traffic modeling/simulation from Synchro, geometric approval drawings, intersection control evaluation, truck turning movements analyzed with AutoTURN, advance planning studies, construction staging, environmental analysis, cost benefit analysis, and project website.

7) Presentations

- May 2, 2014 - Caltrans District 8 Upper Management Presentation, at CPP

- May 8, 2014 - Caltrans Design Management Board Presentation, San Bernardino TMC
- May 15, 2014 - RSB ITE Student Presentation Competition (1st Place), Bombay Restaurant, Ontario
- May 21, 2014 - Southern California ITE Student Presentation Competition (2nd Place), Knott's Hotel, Buena Park
- May 30, 2014 - 14th Annual Project Symposium, College of Engineering at CPP
- May 30, 2014 - 75th Anniversary Event, Engineering Showcase at CPP
- June 16, 2014 - Caltrans District 11 Executive Board and Senior Staff Presentation, San Diego
- June 19, 2014 - American Council of Engineering Companies Presentation
- June 19, 2014 - Caltrans Design Staff

It is worth noting that two students were hired because of the June 19, 2014 American Council of Engineering Companies presentation.

Typical questions the project team receives include (but not limit to):

- How much time did you spend on this project?
- Did you get involvement or input from the City and/or community?
- How did you devise the decision matrix and how was each factor weighted?
- Where was safety factored into the project?
- Were roundabouts considered?
- How did you determine your costs?
- Which environmental considerations were studied?

8) **Website**

The project team developed their project website http://railroad-franklini15project.com/ , which includes all the information related to this project.

11. SUMMARY

Over the past ten years, the Civil Engineering Department of California State Polytechnic University, Pomona (CPP) and District 8 of California Department of Transportation (Caltrans) have been partnering on real-life, learn-by-doing senior projects where a group of 10-20 senior students have designed and analyzed a variety of freeway interchange alternatives for an actual interchange project location in either San Bernardino or Riverside Counties in California.

Supervised by both CPP faculty and Caltrans Engineers, each team has conducted various studies including Planning Study, Traffic Analysis, Geometric Design, Construction Staging, Environmental Impact Study, and Cost Benefit Analysis. These studies have covered a wide range of the core courses related to transportation emphasis of Civil Engineering. More importantly, each senior project has followed the Caltrans project development process and addressed contemporary transportation issues including technical aspects of interchange improvements, formulation of project purpose and need, project scheduling, team building strategies, and public speaking techniques.

With detailed description of the pedagogical approach, assessment methods, and outcomes, this paper systematically reviewed the successful implementation of the senior project model and the lessons learned from the ten-year experience. It is intended to provide conclusions to inform other peers in engineering education in the U.S. and other countries.

In May 2016, the Civil Engineering Department of CPP celebrated the great success of the CPP-Caltrans partnership at a reunion reception. Faculty in the Civil Engineering Department, Caltrans Deputy Chief Executive Officer, Caltrans District 8 management team and engineers, and the students who have been involved in this program were invited. As shown in Table 1, it was exciting to see many of these senior projects have been completed, under construction, or in the design phase. The reception further promoted this senior project model which has empowered the students and young engineers and help them develop their careers in civil engineering across Southern California and the country. Students and graduates who attended the event all agreed that the senior project made them job ready and substantially helped them find a job in the industry and be successful in their professional development.

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