Mark Schar, Emily Cao, Bethany Chaffin, Shane Clarkson and KJ Chew

Yosemite Bridge

CLICK. Brandi McKuin reached over and flipped OFF the power button on her Hobart 140 MIG (Metal Inert Gas) welder and lifted her face mask to inspect the weld. "That's it! After this cools down, let's paint this. I think we'll be ready for on-site installation tomorrow."

"That's great," said Janna Rodriguez who had been watching Brandi finish her weld through a spare welding mask. "The sooner we get this job finished, the sooner we can send them the bill. We need the cash!"

Almendro Iron Works

Brandi and Janna graduated from the Mechanical Engineering program at UC-Merced. They became friends in Statics class during their sophomore year, roommates later, then study-abroad partners. Janna had grown up in Merced, CA and was very connected with the local community, even going as far as opening a local taqueria food truck that became a popular lunch stop on campus. Brandi had grown up in Southern California and had fallen in love with the Central Valley and its proximity to the Sierra Nevada mountains, which you could see from almost any classroom window at UC-Merced.

As their senior project, Brandi and Janna designed and built a steel replica of an iron gate that surrounded the baptistery in the historic Old Mission in San Juan Bautista, CA. This required historical research on designs, working with the Diocese of Monterey, sourcing funds, and then cutting, bending, welding and installation. This hands-on work and the ability to see a project from conception to installation was very appealing, so as graduation approached, Janna asked Brandi if she would like to join her in starting an iron works business. Almendro Iron Works was born.

Almendro
Iron Works

Almendro Iron Works, named after the almond orchards that surround Janna's home, focused on structural steel projects that also required a design sense. This included safety railings at a local winery, a balcony in a historical theater in downtown Merced and security doors and windows at local high-end residences. Each job was between $5,000 and $30,000 and Janna and Brandi had generated about $100,000 in sales over the two years from graduation. This was enough for them to secure a workshop in the outskirts of Merced and equip it with used equipment that included a shear table, press brake, rotary pipe bender, pipe roller and several MIG and TIG (Tungsten Inert Gas) welding rigs. It was also enough for them to live on, but barely.

The important next step for Almendro Iron Works was hiring employees. It was necessary at the start for Janna and Brandi to be selling, designing, constructing and installing their projects just as they were doing at UC-Merced, but if they ever hoped to make this a bigger business, they would need employees and more of them. "I just don't want the responsibility of someone's family in my hands," said Brandi, "and that's what you get when have employees." "Yes, and …" said Janna, pausing to emphasize that she was using her design thinking training, "you are also a giving a family a chance to exist and grow here in Merced. We can't really make this a sustainable business until we are willing to take the risk of hiring and training employees. We need to set our sights on bigger, more complex jobs."

BEEEEP. Brandi's text message signal goes off on her smart phone. "Hey, look at this. It's a text message to UC-Merced's School of Engineering Alumni. The National Park Service is requesting proposals for a design-and-build bridge project at Yosemite. The project is in cooperation with the Small Business Administration, and they are

offering grants up to $1 million." Janna, now looking at the same text on her phone, says, "and there's an informational meeting Wednesday night on campus. This could be the break we are looking for."

Yosemite National Park - Glen Aulin Bridge

Don Neubacher, the Yosemite Park Superintendent, stepped inside his office just behind the Yosemite Valley Visitor Center, hung up his "Smokey The Bear" campaign hat and settled in behind his desk. Neubacher, a 33-year veteran of the National Park Service (NPS), was named the Park Superintendent in 2010, one of the most prestigious positions within the NPS. "Victor is on line three," called Lorena, Neubacher's assistant, and he reached for the phone.

"Don, how's it going?" said Victor Knox, the Associate Director of Park Planning, Facilities and Lands of the NPS. Knox, a long-time friend of Neubacher, was promoted to his current position in 2012 and oversees the management and maintenance of all NPS park assets with a direct staff of 3,000+ people and a budget of $500 million per year. "Just another perfect day in paradise," replied Neubacher. "What can I help you with?"

"I want to talk with you about this SBA (Small Business Association) grant program," said Neubacher. The SBA recently announced a $10 million grant program to benefit the development of small businesses working in the infrastructure sector. The intent was to work with The Departments of Interior, Transportation and Housing and Urban Development to channel capital funds to start-up and small businesses who worked on infrastructure projects like roads, bridges and mass transit systems. The goal was to redirect a portion of committed capital funds to small businesses (less than 20 employees), where the SBA would help them bid, staff up and complete the project. The SBA would offer each Department a 2-to-1 match, so for every capital dollar committed to the program, it would fund $3 of capital projects.

"Yes," said Neubacher, "I'm thinking we can use some of that money. In particular, The Glen Aulin Bridge up in Tuolumne Meadows. That's in desperate need of repair and we have it on the schedule for next year."

Tuolumne Meadows is one of the most popular areas of Yosemite Park outside of the iconic Yosemite Valley. An alpine meadow at 8,600 feet, it is the starting point for many wilderness treks, particularly into the Hetch Hetchy valley. The popular Glen Aulin campsite (37.909274, -119.420292) is on the Pacific Crest Trail about 7 miles north of the Tuolumne Meadows trail head on the banks of the Tuolumne River and just below the beautiful Tuolumne Falls. The camp was established in 1927 and the 1970's timber-built bridge crossing the Tuolumne River is long overdue for replacement.

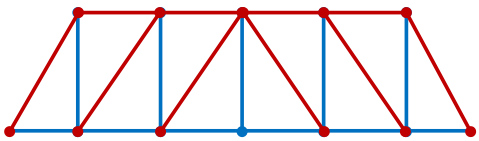
"I'm all for the extra funding," said Knox, "my concern is quality. Can we get quality design and construction out of a 'mom & pop' operation? It's twice the trouble if we build something and it falls apart, let alone hurts a guest." Knox is known as a stickler for safety and quality. A BSE in Civil Engineering from Colorado State University, Knox puts engineering integrity in the center on all NPS capital improvement projects. "I agree," said Neubacher, "but isn't that what the bid process is all about? We'll sort it out in the proposals."

"Of course we will, I'm just wondering if we can't do something to improve the quality of the proposals before we get them," said Knox. "I've been tracking an engineering program at MIT (Massachusetts Institute of Technology) called CDIO. It stands for **Conceive-Design-Implement-Operate** and these are the steps built into the proposal process. They believe that the modern engineer must have a range of skills from hands-on design-build projects to skills in communication and teamwork. That's why I'm thinking of a *'bake off'*."

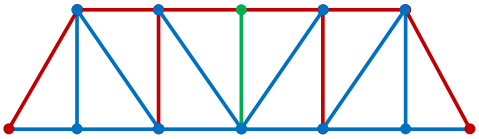
"A bake off? What's that?" asked Neubacher. "You know, like a Pillsbury Bake Off," replied Knox, "where folks develop a recipe, make the dish and then it's judged against other entrants." "Sort of like 'may the best pie win!" chuckled Neubacher. "Well, sort of … we would ask the bidders to build small, quick prototypes of the bridge," continued Neubacher, "we would evaluate how they conceive of this project and their design ideas. Then the fun begins! We would load test their prototype bridges to failure to see if they can meet our engineering specifications, which is the implement and operate activities of CDIO." "Breaking stuff," said Neubacher, "I thought

good engineers built things that didn't break." "Oh quite the contrary," replied Knox, "good engineers know exactly when something will break, so they don't under design for safety or over design and waste materials."

"Let's talk about the design of the bridge. Our preliminary site survey of the Glen Aulin says that the bridge has to span 24 meters over the Tuolumne River, from pin to roller," said Neubacher. "Exactly," replied Knox, "which is why we would specify that the prototype bridge span at least 24 centimeters, a 100-to-1 scale down." "I see," said Neubacher, "and what about load force?" "Well, that's a bit tricky," continued Knox, "we'd build the actual bridge out of cold-rolled, low carbon steel tubes like we did with the Rainbow Falls bridge, but for the quick and cheap prototype, we would use 3.175mm x 3.175mm balsa wood strips. Obviously, the balsa wood has different material properties than steel, so we will have to adjust the force parameters. I'll have my staff engineers work up the specifications for the competition."



Howe Truss Design (patented 1840)



Pratt Truss Design (patented 1844)

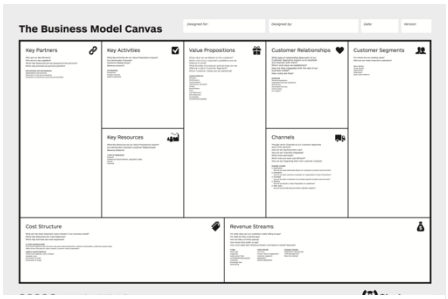
"Great!" said Neubacher, "and while they're at it, let's add in something about the design look. I'm partial to truss bridges in the park given our longtime heritage with railroads. Still, I'd like to see something beyond the standard Howe and Pratt designs." William Howe patented a truss design in 1840 where the diagonal members were in compression where wood is an excellent construction material. This made the Howe truss design a favorite for railroad construction in the Northwest US where there were longer spans and wood was plentiful. Thomas and Caleb Pratt patented a modification of the Howe truss in 1844 which placed the diagonal members in tension where iron or steel is an excellent construction material. Iron and steel were widely available and cheaper in the Eastern US, so Pratt truss design became a favorite for railroads in this region. "No problem," replied Knox, "there are over 30 types of truss designs … the K truss, the camelback truss and my favorite, the Pennsylvania Petit truss. We'll work in a bonus for truss designs that aren't the standard Howe or Pratt."

"One last thing," said Knox, "the SBA wants applicants to describe their 'business model' using something called a 'canvas.' I have no idea what they're talking about." "Me neither," replied Neubacher. "I'll see Carlos Mendoza, the SBA Director for the Central Valley, Tuesday morning at our Rotary meeting in Fresno. Let me ask him."

The Fresno Rotary Club - Business Model Canvas

Don Neubacher set his plate of bacon and eggs on the table and sat down next to Carlos Mendoza. "Carlos, I'd like to talk with you about this SBA grant program for small businesses. I think we have a great project to consider." "Fantastic!" replied Mendoza," I was hoping we would get a chance to talk." Carlos Mendoza serves as the District Director of the Small Business Administration's Fresno District Office. Mendoza is a 40-year veteran of Federal service in the field of business, housing, and community development with degrees from the University of California – Berkeley and Princeton University.

"We have a high profile project, the Glen Aulin Campsite Bridge in Tuolumne Meadows that could be a great candidate for this program. We are looking for a group, preferably from the Central Valley, that might design and build it," said Neubacher. "Of course, we'd need to confirm that whoever got this project had the engineering skill to complete it, so we are thinking of a pre-bid qualification process where teams would build and test a small prototype model of their proposed design." "That's interesting," said Mendoza, "how can I help?" "Well, the SBA instruction refer to some sort of 'canvas.' What the heck it that?"



businessmodelgeneration.org

"Ah, you are talking about a **Business Model Canvas**," replied Mendoza. "It's a way to show how a business makes money. Think of it as a blueprint for a business model." "OK," said Neubacher, "tell me more." "At the SBA we want to help entrepreneurs create sustainable businesses. We have adopted a tool called the Business Model Canvas, created by a fellow by the name of Alexander Osterwalder that encourages an entrepreneur to identify and define the key building blocks

of their business … to show how they will make a profit … and do it all on one piece of paper." "I like that," said Neubacher, "but if we begin this process with a pre-bid qualification process, isn't that a lot of work?"

"You're right," replied Mendoza, "but we could do with a simplified version for the pre-bid. We'd need the complete Business Model Canvas for the full bid. For the pre-bid, I'm thinking of just five areas of Canvas. First, and it sits in the very center of the Canvas, is the **value proposition**, the bundle of products and services that creates value for your customers. Next, we'd want to know about the **customer segments** they are targeting, the people or organizations who are targeted by the value proposition of the company." "Yeah, we'd like to know that too," said Neubacher, "and it would be important to know if the bidding company could do all the work or if they would have to partner with another company."

"Exactly," said Mendoza, "that's what's known as **key partners** on the Canvas and it shows who can help the entrepreneur leverage their business model. Finally, and most important is a clear description of the **revenue streams** and **cost structure**. The revenue streams make clear how and through which pricing structure the business model is capturing value and the cost structure is a description of the major costs involved in delivering value." "Seems like a great addition," replied Neubacher, "I'll summarize our conversation to Washington and we'll work the Business Model Canvas into the pre-bid requirements."

ENGR 057: Statics and Dynamics – UC-Merced

Bob Rice stood up to adjust the louver blinds in his office and he glanced out over the Central Valley plains to see the Sierra Mountains in the distance. Dr. Robert Rice works inthe Sierra Nevada Research Institute at UC-Merced where he researches the impact of climate change on mountain hydrology, water resources, and snow science using remote sensor networks. "Dr. Bob," as he is known to his students, enjoys teaching introductory statics and dynamics because it's often the first course a student will take in engineering, and if he can make it interesting to students, then it often sets the stage for a successful career in engineering.

snri.ucmerced.edu

There is a small knock on the office door, it opens, and in walk Janna and Brandi. They were students of Dr. Bob several years earlier and stayed in touch throughout their time at UC-Merced. Now, they needed his help. "Hi Dr. Bob!" said Janna, "good to see you again and thanks for agreeing to see us." "I had a feeling I might hear from you when I read about the Yosemite/SBA bridge project competition," said Bob, "it sounds like it's a perfect fit for your business." "We think so," said Brandi, "but we're a little worried about this bid process competition." "Yeah, I heard about that" replied Bob, "they're having the informational meeting on campus. I thought I might stop by and listen in."

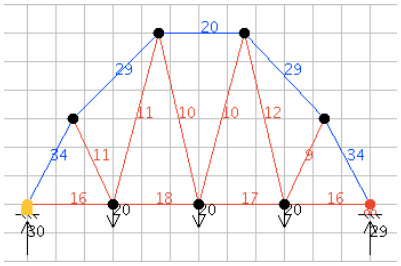
"We've heard that there will be a lot of emphasis placed on the engineering analysis," said Janna, "so we were hoping for a little refresher course on statics." "You're not telling me you've forgotten what I taught you!" laughed Bob. "Well, maybe a little," chuckled Brandi.

"OK then, the first step is to sketch out some designs," started Bob. "They want a truss bridge," said Janna, "it can be a Howe or Pratt design, but there are extra points for something different." "Great," replied Bob, "do several sketches so you can explore the possibilities. Remember, you will be solving for **maximum internal load** or the total force the structure can handle up to its failure point." "Since it's a competition, the winner will be the bridge that carries the greatest load," said Janna. "I doubt it," countered Bob, "typically there's a minimum load the structure must carry, then a **safety factor** that defines the range of load expectations beyond the minimum load, and this determines the maximum load the structure should carry before failure. The winner will probably be the prototype that fails beyond the minimum load and before maximum load." "I suppose we'll get all of this in the competition instructions," said Brandi.

"Next you'll have to decide on your **target maximum internal load**, the point where you want your bridge to fail," continued Bob, stepping up to the whiteboard in his office and picking up a pen. "You can probably assume an equally distributed load on the bridge road bed, so divide the target maximum internal load by two, because each side of the bridge will share the load through the road bed cross members. Then, divide the load carried by each side by the number of cross members in your road bed," continued Bob. "And that might be different for each design," said Janna. "Exactly," replied Bob, "that's the force at the joint of each cross member.

$$\circlearrowleft^{+} \Sigma M_A = 0$$
$$\rightarrow^{+} \Sigma F_x = 0$$
$$+\uparrow \Sigma F_y = 0$$

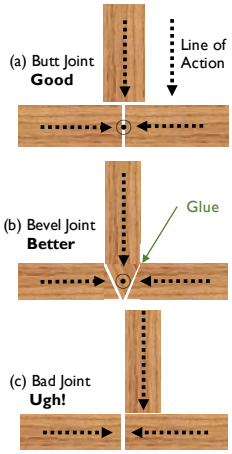
Then for analysis it's a matter of using the **method of joints**, remember that's solving the equilibrium equations for forces acting on each joint. Or you could use the **method of sections**, that's when you pass an imaginary line through the truss, cutting it into sections, and each imaginary section must be in equilibrium if the entire truss is in equilibrium." "Yikes, I've been out of school too long," thought Brandi.



Johns Hopkins Bridge Designer
pages.jh.edu/~virtlab/bridge/truss.htm

"The next step is to learn a little about the materials you will be using," said Bob. "They said in the announcement that the prototype bridges would be made out of balsa wood," said Janna. "They'll probably supply you with the materials they want you to use, just to make the competition fair, "said Bob, "if it's those thin strips of balsa wood used in model airplanes, you can find the material properties on matweb.com or in the competition instructions. You will want to note in your bridge design analysis which members have a **tensile load**, meaning they are in tension, and which members have a **compressive load**, meaning they are in compression." "We have that," said Brandi," and we plan to color code and number each member of the bridge for post failure analysis."

"Remember," continued Bob, "when you are analyzing compressive load, there are two types of failures – crushing and buckling." "Yes, I remember," said Janna, "**crushing** is a material failure that's a function of the area cross section times the rated material strength." "And **buckling** is more of a structural failure," continued Brandi, "where the member fails outward of the line of action. To calculate buckling failures you need to use the **area moment of inertia** and Young's modulus for balsa wood." "It will all come back to you when you see the formula," said Bob, "and it's helpful to remember that for any given member, the longer it is the more likely it is to buckle before it crushes."



"One last point," continued Bob, "Brandi, you mentioned line of action earlier. It's important to remember that as you construct your bridge, the **line of action** of each joint moves through a single point. If it doesn't, then all your calculations are meaningless. You are trying to model a pin joint with balsa wood and glue, so carefully shape your joints so that the line of action of each member moves through a single point."

Wednesday, 7:00pm - Lakireddy Auditorium on the campus of UC-Merced

Janna and Brandi arrived early for the presentation, met up with Dr. Bob and took seats near to the front. The auditorium was crowded; there were certainly more people than Janna and Brandi had expected. They could see that several of the big design firms from Sacramento and San Francisco were in attendance, which they also found a bit surprising. The program began with a welcome to the UC-Merced campus from the Dean of the School of Engineering, Mark Matsumoto, followed by an overview of the bridge project by Yosemite Park Superintendent, Don Neubacher. Don introduced Carlos Mendoza, Director of Small Business Administration, Fresno Office who explained the business requirements of the class.

Finally, Victor Knox, the Associate Director of Park Planning, Facilities and Lands of the National Park Service, took the stage to explain the rules and requirements of the design competition. About half way through the Knox presentation, Brandi turns to Janna and whispers … "what the heck is a *bake off*?"