Invention by Design:
How Engineers Get from Thought to Thing

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Process of Innovation

Process of Innovation

Nine Common Items

Paper Clips

Pencil Points

Zippers

Aluminum Cans

Facsimile

Airplanes

Water

Roads

Buildings

Nine Basic Concepts

- Paper Clips → Design
- Pencil Points → Analysis
- Zippers → Development
- Aluminum Cans → Failure
- Facsimile → Networks
- Airplanes → Computers
- Water → Society
- Roads → Politics
- Buildings → Systems

Paper Clips
&
Design

Paper Clips & Design

A paper clip is among the simplest of objects.

BUT

Sometimes the simplest objects can hold as much mystery and provide as many lessons about the engineering as the most complex.

Paper Clips & Design

Design Considerations – Tradeoff of Many Factors

1. Springiness of material.
   - Elastic enough to be opened easily.
   - Able to spring back into shape.
2. Cost of materials – Metal or Plastic
3. Manufacturing process – Make by hand or automated process.
4. Limitations of existing technologies – Pins & staples were existing technologies.

Paper Clips & Design

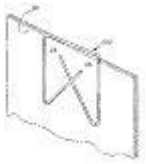
The Gem Clip – The "First" Paperclip

- 1899 – William Middlebrook of Waterbury, Connecticut made the "Gem Clip".
  - Made of metal wire.
  - Automated process via machine.
  - Good springiness.
  - Cost was competitive with pins & staples.
  - Very reliable.

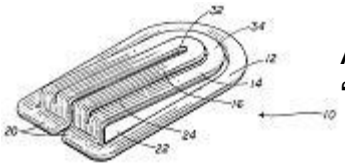
Paper Clips & Design

The Gem Clip – Opportunities for Improvement

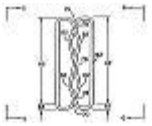
1. It goes on only one way.
2. It does not just slip on.
3. It does not always stay on.
4. It tears the papers.
5. It does not hold many papers well.
6. It bulks up stacks of paper.



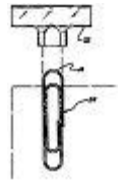
Aug. 21, 1990 – Dr. Gary K. Michelson
"New Paper Clip"



Apr. 30, 1991 – Suzy Chung Hirzel
"Paper Clip with Vertical Panel"



Nov. 12, 1991 – Charles Link
"Endless Filament Paper Clip"



Dec. 15, 1992 – Billie E. Strong
"Time Saving Paper Clip"

Paper Clips & Design

Section Summary

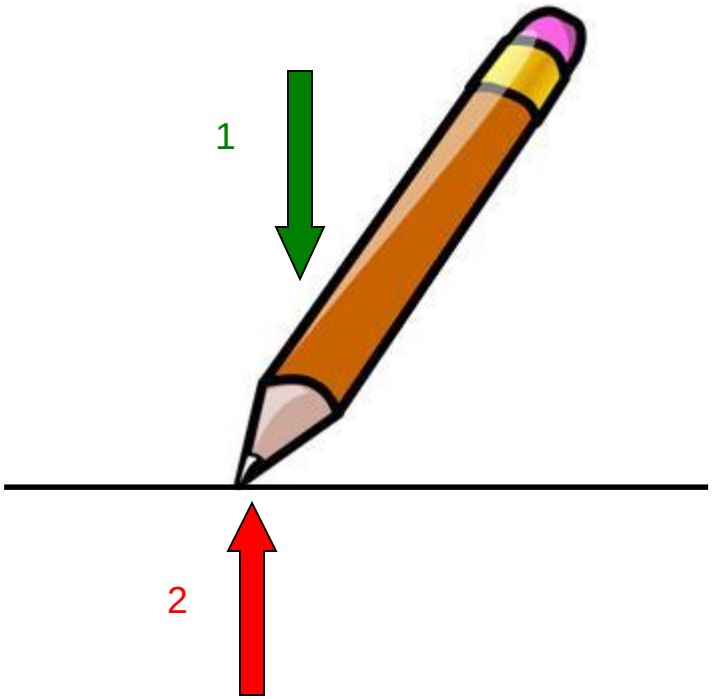
- Sometimes the simplest of things can hold as much mystery and provide as many lessons about the nature of engineering as the most complex.
- Design considerations often involve a tradeoff of many factors.
- A new technology will displace existing ones only if it offers a clear advantage over existing technologies.
- Limitations of a new technology can offer opportunities for continuous improvement.

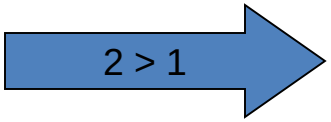
Pencil Points
&
Analysis

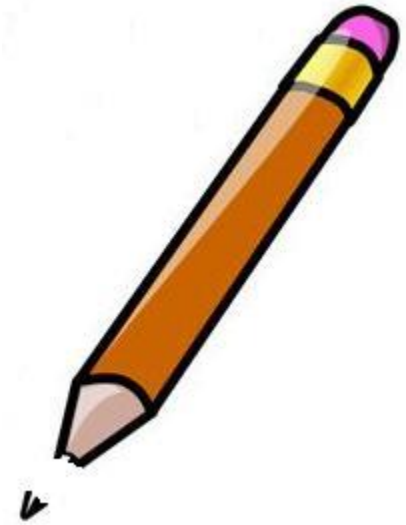
Pencil Points & Analysis

An Unanswered Question

Newton's Third Law





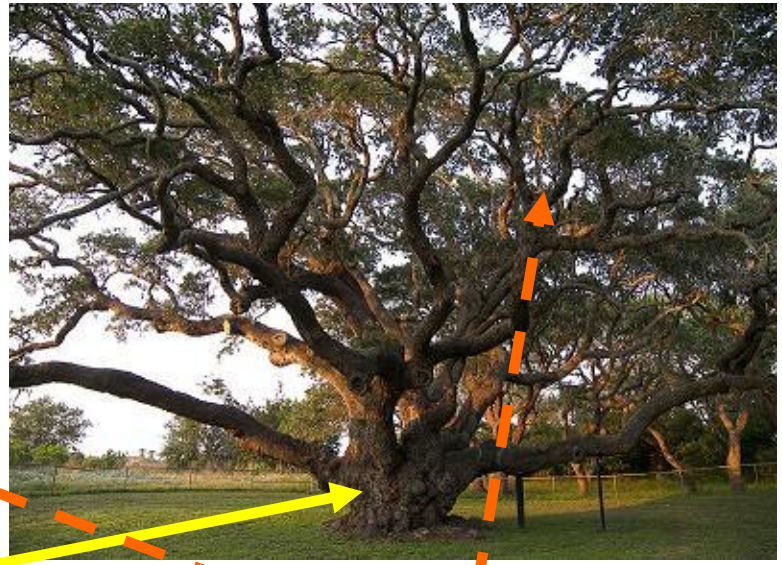


Broken Pencil Point!

Pencil Points & Analysis

Alertness in Analysis

A pencil is a cantilever beam.



A cantilever beam is a beam supported from one end.

Opposing force is applied at the other end.

Key is to ensure that the support exceeds the opposing force.

Pencil Points & Analysis

Two Types of Pencils

Mechanical Pencils

Wood-cased Pencils

Pencil Points & Analysis

Small Details & Analysis

Mechanical Pencils

Analysis

- Juncture between the lead & the metal or plastic sleeve.
- Nicks/imperfections in the lead.
- Thin-lead mechanical pencils vs. Polymer-based leads.
- Make the lead as thin as possible.
- Make the lead thick enough to give it sufficient strength.
- Comfortable size.
- Fine lines.

Pencil Points & Analysis

Small Details & Analysis

Wood-cased Pencils

Analysis

- When a pencil is sharpened, the wood is thinned where support is needed most.
- Complex geometry.
- Interaction between wood & lead.
- If the pencil is badly warped or dropped on a hard surface, then the lead inside wooden case becomes broken thereby weakening it.
- Presence of wax in wood interferes with glue between wood & lead.

Pencil Points & Analysis

Section Summary

- Nagging, unanswered questions often drive engineers and scientists to look further at problems.
- To ensure all factors are considered, it is important to be reflective and alert in analysis.
- Small details sometimes complicate analysis but do not make it impossible.

Zippers
&
Development

Zippers & Development

19th Century Clothing

- Clothing consisted of many buttons & hooks.
- Time-consuming.
- Frustrating.
  - Dressing quickly & inattentively.
  - Skip a button or hook.
- 1851 → Elias Howe, Jr., invents new type of fastening device.

Zippers & Development

The First Zipper

- 1891 → Whitcomb L. Judson, a Chicago mechanical engineer, awarded patent.
- 1902 → Patent on "chain-making machine".
  - Made zipper more reliable.
  - Made zipper more economical.
- Marketed as "C-curity".

Zippers & Development

Improvements to the Zipper

- 1940s → Plastic-toothed zippers
  - NO sticking & snagging.
  - NO rusting.
  - NO losing teeth.
- Cloth tape in many different colors.

Zippers & Development

Related Items

Ziploc Plastic Bags

Velcro

Zippers & Development

Section Summary

- The development of a product involves continual improvement.
- Some developments are evolutionary in nature. Others are revolutionary.
- Some developments may spawn related products.

Aluminum Cans
&
Failure

Aluminum Cans & Failure

- In order for an inventions to be successful, their creators must anticipate how they can fail to perform as intended.
  - Pencil Points → They could break.
  - Cantilever Beam → It could break or fail.
  - Bridges → They could buckle under their loads.
  - Computers → Computer bugs … need I say more!

Aluminum Cans & Failure

The First Aluminum Cans

- Earliest food & beverage cans were made of iron.
  - Heavy.
  - Opening was a major effort.
- Aluminum
  - Stiffness made a thinner (and cheaper) wall possible.
  - Must be strong enough to resist pressure inside of can.
  - Easy to calculate how thick the wall should be.
  - 1922 → First aluminum can.

Aluminum Cans & Failure

The Church Key

- First aluminum cans were opened with “church keys”.
  - A triangular hole was punched in the top.
  - Can was rotated 180 degrees.
  - Another triangular hole was punched in the top.
  - Beverage was enjoyed through one of the triangular holes.
- Problem …
  - What if a “church key” was nowhere to be found?
  - Ernal Fraze, of Dayton, Ohio, set out to devise a self-opening can.

Aluminum Cans & Failure

The Pull Tab

- Ermal Fraze invented the pull tab.
  - Tab was riveted to can top.
  - Didn't want can to open spontanously or too easily.
  - Didn't want undue force to be required to open.
- Issues
  - Leaks.
  - Rivet broke off the top → "Does anyone have a 'church key'?"
  - Rush of pressure.
  - Environmental issues → "What do I do with the tab?"

Aluminum Cans & Failure

The Stay Tab

- 1976 → Invented by Daniel F. Cudnik, of Richmond, Virginia.
- Benefits
  - Stay tab stays attached to the top of the can.
  - NO leaks.
  - Not as likely to break → No "church key" necessary.
- Issues
  - Scoring → Must enable easy opening but not fail under pressure.
  - Making the top as thin as possible.
  - Top diameter must be large enough to incorporate a tab opening.

Aluminum Cans & Failure

Section Summary

- In order for an inventions to be successful, their creators must anticipate how they can fail to perform as intended.
- Failure can come in many forms, such as aesthetically, environmentally, or ergonomically.

Facsimile
&
Networks

Facsimile & Networks

Many inventions are complicated by the fact that the marketplace was not prepared for them.

- Light bulbs & electricity.
- Automobile & road network.
- Airplanes & airports.
- Fax machines & phone networks.

Facsimile & Networks

Early History of Fax Machines

- 1843 → British patent to Alexander Bain for transmitting images electronically.
- 1902 → Arthur Korn, a German inventor, demonstrated transmission of photographic images.
- 1950s → Western Union sending & receiving telegrams.
- Infrastructure was not in place.
  - AT&T monopoly of phone network.
  - Differences in technical details.
  - Standards of communication.

Facsimile & Networks

Social and Cultural Factors

- 1980s → Dissatisfaction of postal services.
- Similar to copiers → Less intimidating to use.
- 1985 → Market @ 500,000.
- 1991 → Market @ 6,000,000.
- 1992 → Cost of digital fax machines dropped by a factor of 30.
- Mid 1990s → Computers equipped with fax boards.

Facsimile & Networks

Further Developments

- Transition from clumsy, slow analog device to compact, fast, user-friendly devices.
- High-quality images.
- Smaller size.
- 1984 → Development of ISDN standard.
- Now, fax machines are everywhere!

Facsimile & Networks

Section Summary

- Many inventions have difficult and uncertain gestation periods.
- Development of infrastructure to support an invention is important.
- Cultural, social, economic, and political developments can be as important as physical laws.

Airplanes
&
Computers

Airplanes & Computers

- Airplanes consists of many systems that must interact with each other.
- Systems are developed simultaneously and independently by different individuals in different parts of the world.

Airplanes & Computers

Traditional Aircraft Design

- Lots of engineers work individually & in teams on various parts & subsystems.
- Boeing 777 aircraft.
  - 130,000 unique individual parts.
  - 3 million total parts per plane (including rivets & fasteners).
  - 75,000 engineering drawings.
- Development was a slow, arduous, & frustrating process.
- Physical mockups were expensive, labor intensive, & time consuming.
- Not everything fit together exactly.
- Costly mistakes.

Airplanes & Computers

Computer-aided Aircraft Design

- For Boeing 777, computers were used in design, testing, & manufacturing process.
- Improved coordination
  - 238 teams.
  - As many as 40 engineers per team.
  - 7,000 workstations across over 17 time zones.
- Result
  - Design completed 3½ month ahead of allocated 24 month schedule.
  - Lower cost.

Airplanes & Computers

Computer-aided Aircraft Design

- Fly-by-wire
  - Flight control system operated electronically vs. mechanically.
- Economics
  - Designed to fly extended distances, even with one engine out.
- Human Factors
  - Location of dials, switches, lever, buttons, meters, & controls.
  - Higher ceilings & overhead bins.
  - Individual entertainment monitors.
- Involvement of airlines & passengers (the Customers).

Airplanes & Computers

Section Summary

- In many inventions, coordination among teams is essential to success.
- Computers can improve coordination among teams and can improve analysis of many factors.
- Computers can assist in involving the stakeholders in a project, especially customers.

Water
&
Society

Water & Society

- 70.9% of Earth's surface is covered by water.
- 3% of water is fresh water.
- <1/3 of fresh water is available for use.
  - Rivers.
  - Lakes.
  - Ponds.
  - Aquifers.

Water & Society

- Water is essential for life.
- Human body is 55-78% water.
- Water has driven the development of societies.
  - Ancient Egypt.
  - Coastal Areas.
  - Water Management in Inland Areas.

Water & Society

Water Supply and Removal

Roman Aqueducts

- Built in the 1st century A.D.
- 97 A.D. – Rome being supplied with 40 million gallons per day.
- Water loss.
- Unauthorized removal of water.
- Only the wealthiest citizens had water piped directly into homes.
- Disposal of waste water left to individuals.

Sanitary Conditions in London

- Early 19th century → Sanitary conditions were abominable.
  - Commission of Sewers for City of London covered 5% of houses & of total population of 2,500,000.
  - Regional sewer systems were poorly designed & ineffective.
  - 1847 → Houses without draining, overflowing cesspools, hundreds of streets without sewers.
  - Cholera outbreak → 25,000 deaths.
- Joseph W. Bazalgette appointed chief engineer of Metropolitan Commission of Sewers.
  - Addressed failures of existing systems.
  - Knighted in 1874.

Water & Society

Design Problems

- Logistics
  - Layout similar to laying out any transportation network.
- Transport of water
  - Pumps, tunnels, pipes.
- Balance of energy
  - Potential energy of reservoirs.
  - Losses through pipes due to friction.
- Computer models
  - Can help guide design & in decision making (rather than trial & error).
- Water Quality
  - Disease.
  - Pollutants.

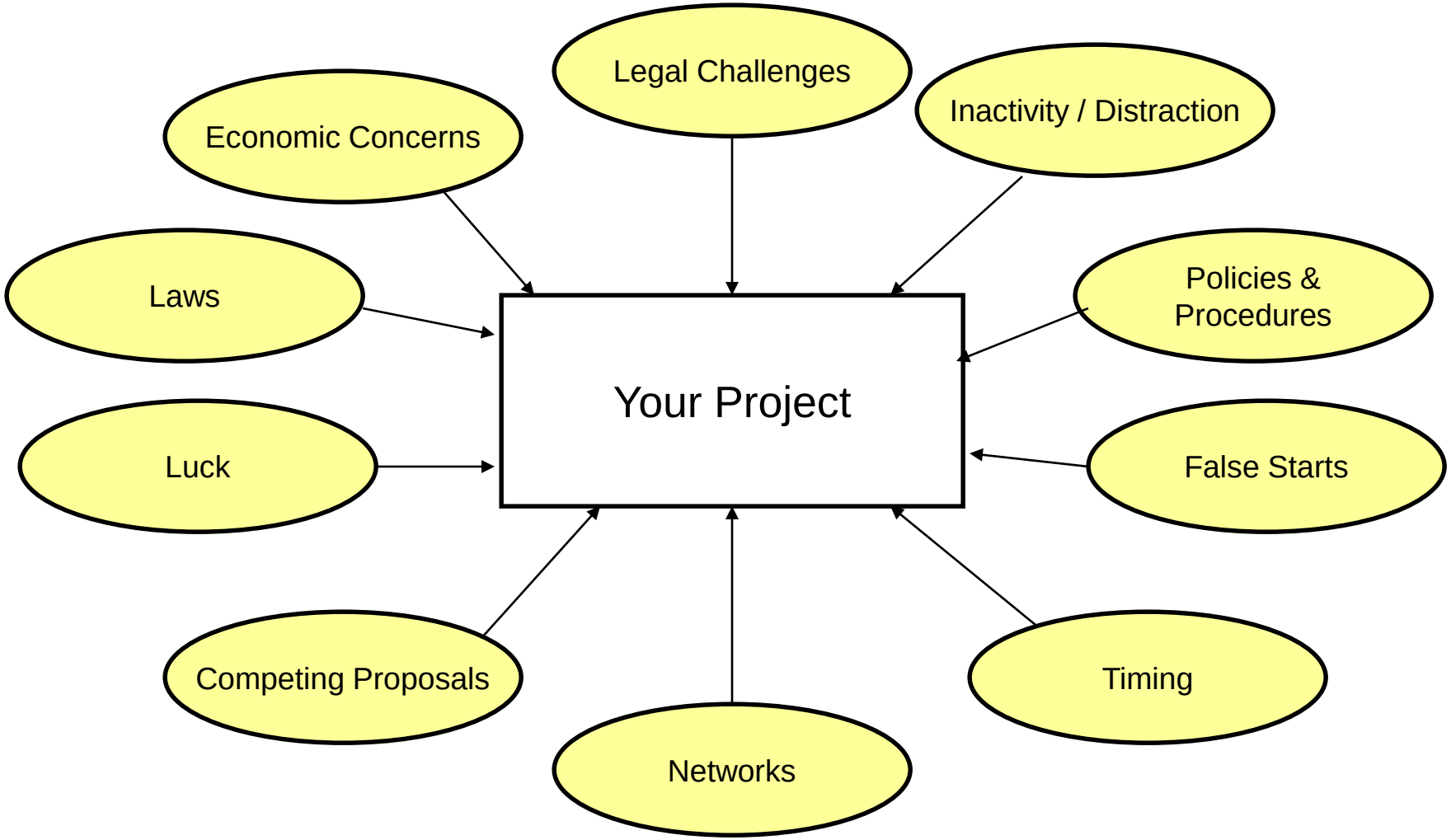
Water & Society

Section Summary

- Providing adequate water supply, disposing of waste water, and dealing with pollutants are among the most challenging problems facing society today.
- The solution to problems takes more than technical know-how. The societal resolve and financial means are necessary to solve problems.
- Some problems have no unique solution.
- Computer models can assist in making decisions, rather than by trial and error.

Roads
&
Politics

Roads & Politics



Roads & Politics

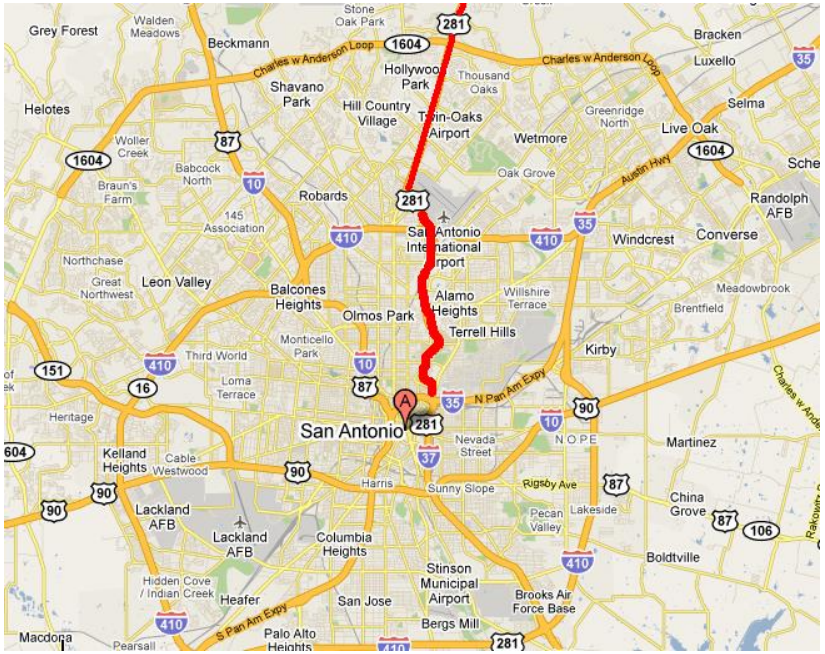
U.S. 281 Freeway – “McAllister Freeway”

San Antonio, Texas

1955 - 2010

Roads & Politics

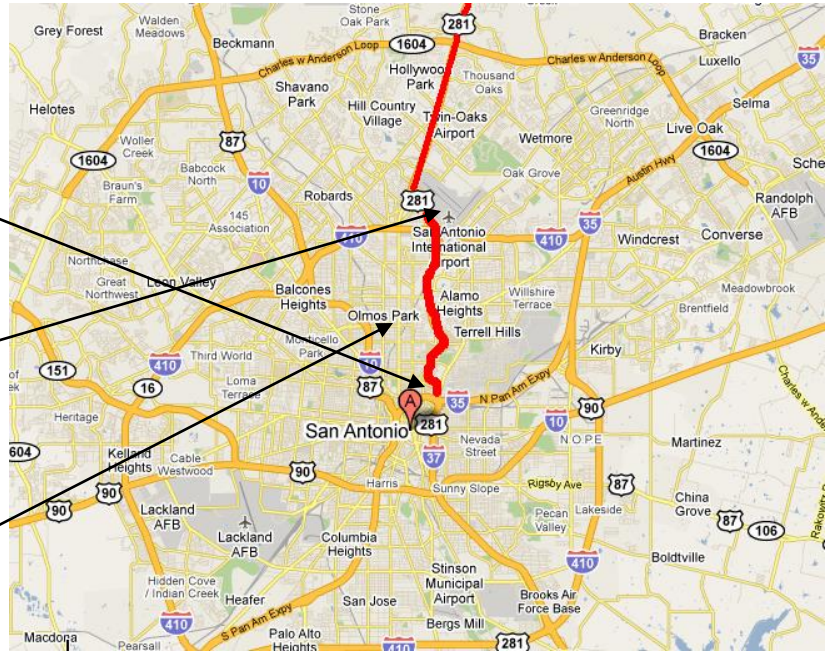
- Late 1940s – Early 1950s → San Antonio freeway system in early planning stages.
- Mid 1950s → Need for north central freeway identified.
- 1956 → Federal-aid Highway Act (Signed by President Eisenhower)



Roads & Politics

Early Design Considerations

1. Must start at I-35 & I-37 interchange in Downtown San Antonio.
2. Must provide connection with San Antonio International Airport.
3. Minimal commercial & residential displacement.



Roads & Politics

U.S. 281 Routes Considered in 1955.

Route #1 – San Pedro Ave.
- Original routing of U.S. 281 in San Antonio.
- Rejected because it did not connect with San Antonio Airport.

Route #2 – McCullough Ave.
- Local street that paralleled San Pedro Ave.
- Rejected due to expensive commercial & residential displacement required.

Route #3 – Broadway Ave.
- Local street that paralleled San Pedro Ave.
- Rejected due to expensive commercial & residential displacement required, AND lack of connection to San Antonio Airport.

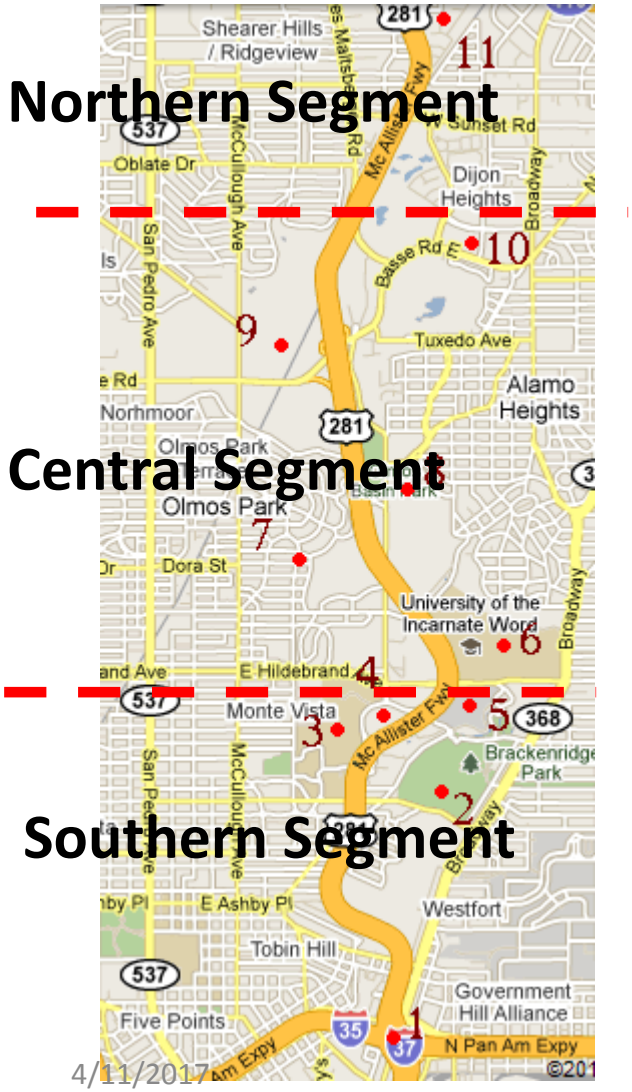
So, to meet original design considerations, a routing between Route #2 and Route #3 was considered.

Roads & Politics

U.S. 281 Final Routing in 1961

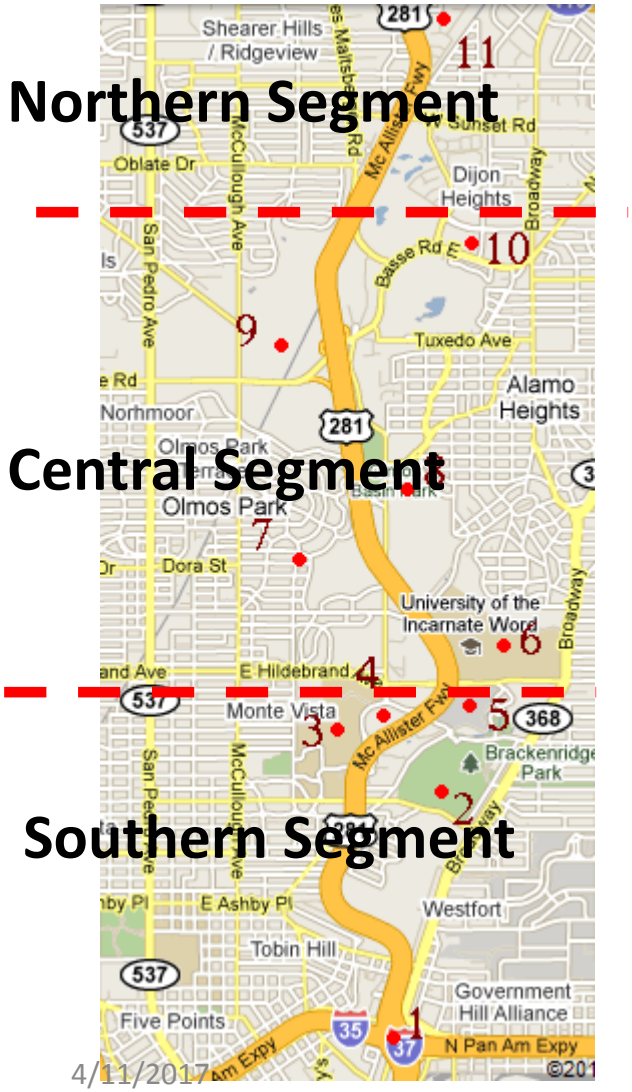
1. I-35 & I-37 Interchange.
2. Brackenridge Park.
3. Trinity University.
4. Alamo Stadium.
5. Sunken Gardens Amphitheatre.
6. The University of the Incarnate Word.
7. Olmos Park.
8. Olmos Basin Dam.
9. Olmos Basin Park.
10. Alamo Heights.
11. San Antonio International Airport.

Roads & Politics



- Jan. 10, 1961 – San Antonio residents approved bond issue to purchase strip of land through Olmos Basin Park.
- Sierra Club & San Antonio Conservation Society protest routing of freeway through the Olmos Basin Park.
- Project broken into three segments: a northern segment, a central segment, & a southern segment.
- 1969 – Construction on northern & southern segments begins. Central segment stalled due to debate about routing.
- Environmental groups file lawsuit.
- May 1971 – Federal court order halts the entire project.
- 1972 – U.S. Supreme Court upholds rulings from lower courts.
- All Federal funding for U.S. 281 project is revoked.
- Work on entire project is halted.

Roads & Politics

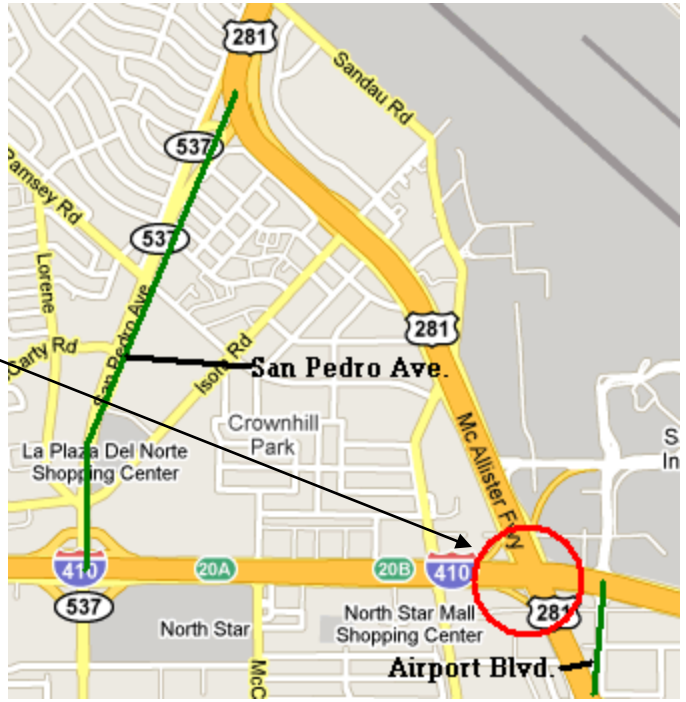


- 1973 – Senators John Tower & Lloyd Bentson, both from Texas, sponsored legislation in U.S. Congress to allow project to be built without Federal funds.
- Dec. 10, 1973 – Legislation passes both houses of Congress. Signed by President. Construction on U.S. 281 resumes on northern & southern segments.
- 1974 – Environmental groups sue state of Texas to halt the project.
- Entire project suspended again.
- July 1974 – Lawsuit dismissed.
- Nov. 13, 1974 – Work resumes on all segments of U.S. 281.
- Feb. 7, 1978 – U.S. 281 freeway opened to traffic.

Roads & Politics

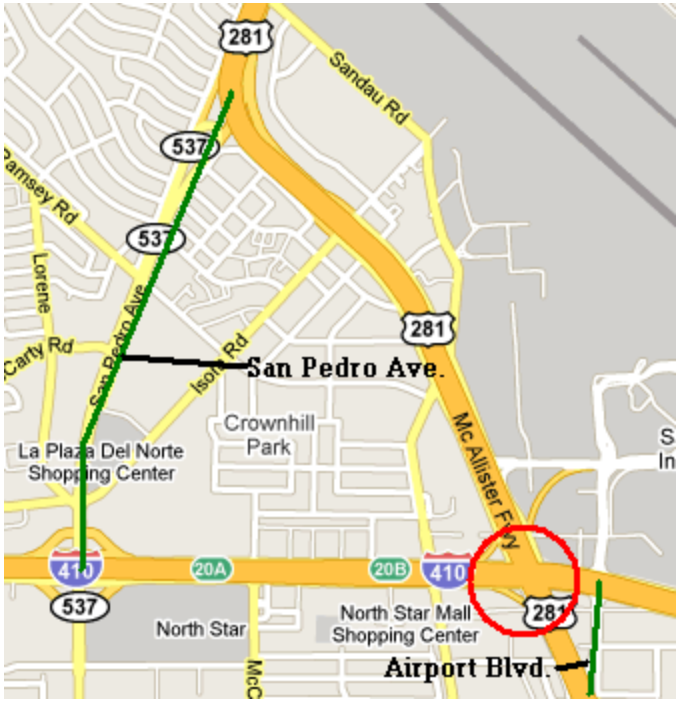
The project was not complete!

An interchange was needed between U.S. 281 and I-410 (Loop 410) at the San Antonio International Airport.



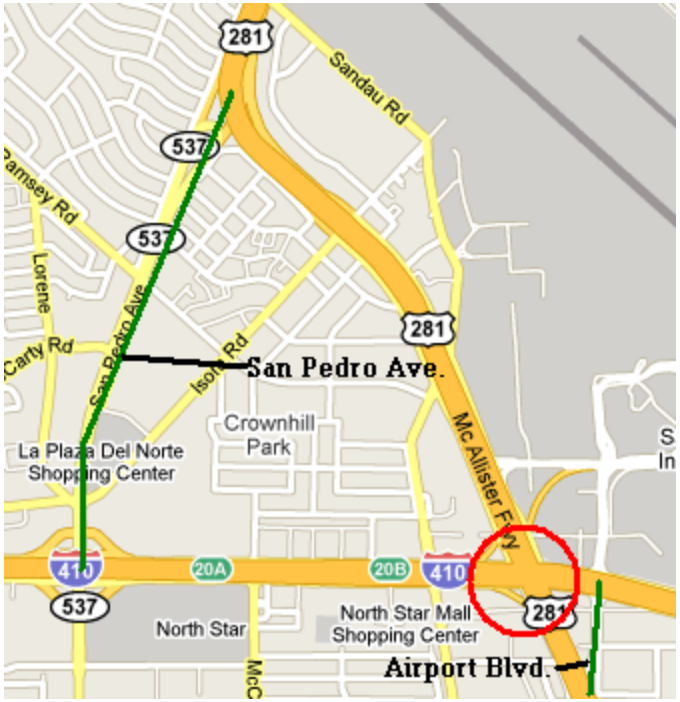
Roads & Politics

- 1964 – Interchange was planned between U.S. 281 & I-410.
- Early 1970s – San Antonio condemned land for interchange.
- Mid 1970s – U.S. 281 project appeared dead.
- Owners of land petition San Antonio.
  - Purchase land.
  - Release it for development.
- San Antonio chose to release the land.
  - Commercial development appears almost overnight.
- Late 1970s – U.S. 281 freeway is completed.
  - Land has risen in value and interchange is scrapped.
  - Local roads handle traffic between the freeways.



Roads & Politics

- 1990s – Local streets become overburdened with freeway traffic.
- 2005 – Construction on interchange begins.
- 2010 – Interchange between U.S. 281 & I-410 completed!



Roads & Politics

Section Summary

- Large engineering projects usually have a long history.
- Politics offers a lot of factors to consider. Some of these factors are tangible, and others are intangible.
- You must be flexible as you deal with politics.
- Dealing with politics often requires patience.
- Perseverance is the key to success.

Buildings
&
Systems

Buildings & Systems

Buildings are more than just “structures with facades”. They are systems of systems.

Many systems must fit together and work together to form a successful overall system.

- Structure.
- Electrical Systems.
- Plumbing.
- Transportation – External & Internal.
- Environmental Controls.
- Security.

Buildings & Systems

The Pyramids

Even older structures required some degree of systems thinking as they were designed and constructed.

- Materials.
- Labor.
- Passages & Chambers.
- Structure & Support.

Buildings & Systems

The Crystal Palace

- Built for first World's Fair in London in 1851.
- Initial Plan – Construct temporary building in London's Hyde Park.
- Joseph Paxton's Plan
  - Wood, iron, & glass structure.
  - Reusable columns, girders, & roof components.
  - Prefabricated parts.
  - Drainage system.
  - Air circulation & heat control.
  - Cleaning system.
- Successful 1851 Great Exhibition of the Works of Industry of All Nations

Buildings & Systems

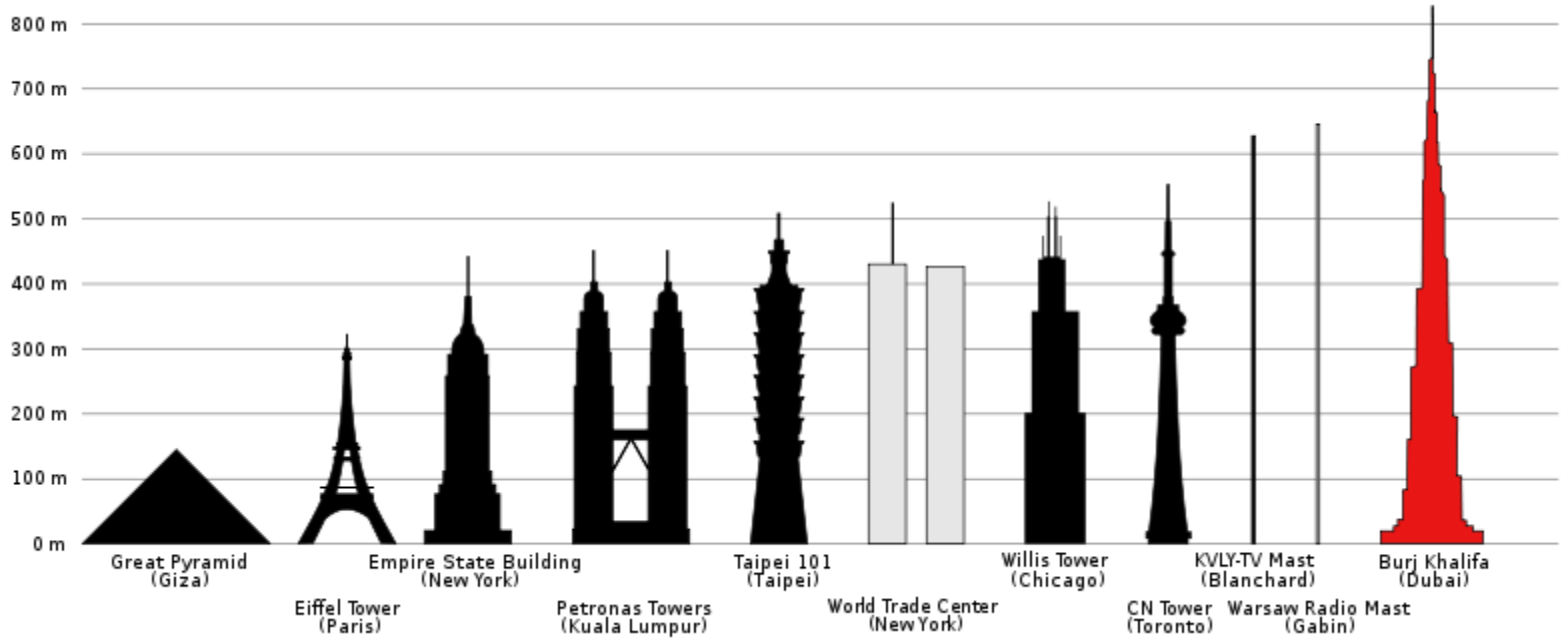
The Woolworth Building

- One of the more famous skyscrapers in New York City (and one of the oldest).
- Issues
  - Cost -- $13 million paid in cash by Frank W. Woolworth, owner.
  - Foundation – Excavated 110 feet below street level to bedrock.
  - Structure – Steel skeleton.
  - Electrical – 87 miles of wiring powered by generators.
  - Elevators – Could go from street level to 54th floor (700 feet) in < 1 minute.
- 1913 – Opened as world's tallest skyscraper (until 1930)

Buildings & Systems

“Supertall” Skyscrapers

Improvements to the underlying Systems within buildings have allowed them to grow taller and taller!



Buildings & Systems

Section Summary

- Systems are composed of many parts that must fit together and work together.
- Improvements to the parts of a system can result in huge improvements to the overall system.
- Systems are often more complex than initially realized.

Conclusion

Nine Common Items

Paper Clips

Pencil Points

Zippers

Aluminum Cans

Facsimile

Airplanes

Water

Roads

Buildings

Nine Common Concepts

Paper Clips

Design

Pencil Points

Analysis

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Development

Aluminum Cans

Failure

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Systems

Questions / Discussion

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