Intermodal Container System Solutions for the Chicago Area -- Crete Freight City

An IIT Interprofessional Project

Prepared by:
Fall 2010 IPRO 307 Project Team
The Interprofessional Projects Program
Illinois Institute of Technology

John Allen
Sasha Bajzek
Aaron Davis
Anca Gruita
Jeremy Levin
Aaron Pollack
Izydor Radzik
Jessica Roth
Gabriel Williams
Bryan Woods

Lawrence Rohter, IPRO Instructor

Prepared for:
Mi-Jack Products Inc.
Peter Mirabella

The Interprofessional Projects (IPRO®) Program at Illinois Institute of Technology

An emphasis on multidisciplinary education and cross-functional teams has become pervasive in education and the workplace. IIT offers an innovative and comprehensive approach to providing students with a real-world project-based experience—the integration of interprofessional perspectives in a student team environment. Developed at IIT in 1995, the IPRO Program consists of student teams from the sophomore through graduate levels, representing the breadth of the university's disciplines and professional programs. Projects crystallize over a one- or multisemester period through collaborations with sponsoring corporations, nonprofit groups, government agencies, and entrepreneurs. IPRO team projects reflect a panorama of workplace challenges, encompassing research, design and process improvement, service learning, the international realm, and entrepreneurship. (Refer to http://ipro.iit.edu for information.) The Crete team project represents one of more than 40 IPRO team projects for the Fall 2010 semester.

Table of Contents

List of Figures

Acknowledgements

We would like to thank Mi-Jack for their continuing support of this IPRO. We would also like to thank John Hillman for meeting with us to discuss his Hybrid Composite Beam.

Executive Summary

The aim of this project was to investigate the feasibility of a brand new intermodal shipping yard in Crete, Illinois with the ATMS system. Currently, tractor-trailer pickup and drop-off time suffers greatly due to poor yard layout. An overabundance of unclaimed containers and semi-chassis results in an average pickup/drop-off time of two hours or more. The new intermodal transfer system will not only greatly reduce this time, but will be a far more economical choice for customers in terms of product turnaround.

For the fall 2010 IPRO team, the intention is to develop an efficient urban center in Crete. Using the ATMS system, this site would allow much greater speed in unloading trains, and getting freight onto trucks far more efficiently than was ever before possible. The team also looked into the possibility of having the trains run at higher speeds, by upgrading the track to a high speed railway, and building a viaduct to separate the passenger and freight trains to prevent rail traffic interference from creating stalls and lowering profitability. Another goal at the forefront of our design was ensuring that the site was environmentally friendly and that the site did not create traffic problems from the increase in shipping traffic using the roadways.

Purpose and Objectives

Intermodal freight, the movement of containers and trailers by rail, truck, or water carriers, has been the fastest-growing major segment of the U.S. freight rail industry. Rising from 3.1 million trailers and containers in 1980, to 11.5 million trailers and containers in 2008, indications are that all-container shipments will continue to grow. At this point in time, Chicago is the third largest port in the world for such operations.

The purpose of this IPRO was to create a newer and more efficient mode of transporting and shipping using an ATMS system designed by Mi-Jack. The high speed rail group worked to integrate high speed rail and intermodal freight systems. The site team designed a space in Crete, Illinois that will support an intermodal freight rail yard that will undergo one million lifts per year. The viaduct team designed a viaduct system that includes three different modes of transportation (high speed passenger rail, freight rail, and automobile highway).

Using a high speed rail system, combined with the ATMS, the newly designed Crete site is expected to make upwards of one million container lifts per year. This is highly advantageous because it allows rapid movement of products from Chicago to anywhere in the Midwest in less than a day. Additionally, it allows for less lag time between container drop off and pick up by trucks, and less time for drivers to wait for pick up, reducing fuel costs.

Analysis and Findings Summary

The teams were divided into three separate groups tasked with working on a portion of the project. The high speed rail team investigated the current state of high speed rail in the United States, the funding currently allocated for high speed transportation provided as part of the initiative laid out by president Obama, the most effective method of stacking the containers on the freight trains, and the mechanics of high speed rail transportation. The site redesign team set out to make the ATMS system work on the site given to us. They looked into adding infrastructure to support the increase in traffic to the area, and investigated various methods of increasing the profitability of the site. The final team, the Viaduct team, was assigned the task of designing a system capable of handling the entire intermodal system at high-speed capacity, incorporated into a single structure, which saves space, as well as calculating the cost of constructing a factory to handle the production of concrete columns and steel beams for the viaduct.

High Speed Rail System

Overview

In April of this year, the Obama administration unveiled its ambitious plan to revitalize the transportation system in America. As part of the stimulus plan, $8 billion dollars were set aside to construct or improve high speed rail lines across the country. The Midwest Regional Rail System won a considerable piece of the funding to improve rail lines between Michigan, Wisconsin, Illinois, and Indiana. Chicago was chosen to be the hub of such a project, as it is already a major hub for passenger as well as freight traffic moving across the country. In addition to the funding set aside for high speed rail, Amtrak received $1.3 billion to improve its own infrastructure and repair aging railway lines.

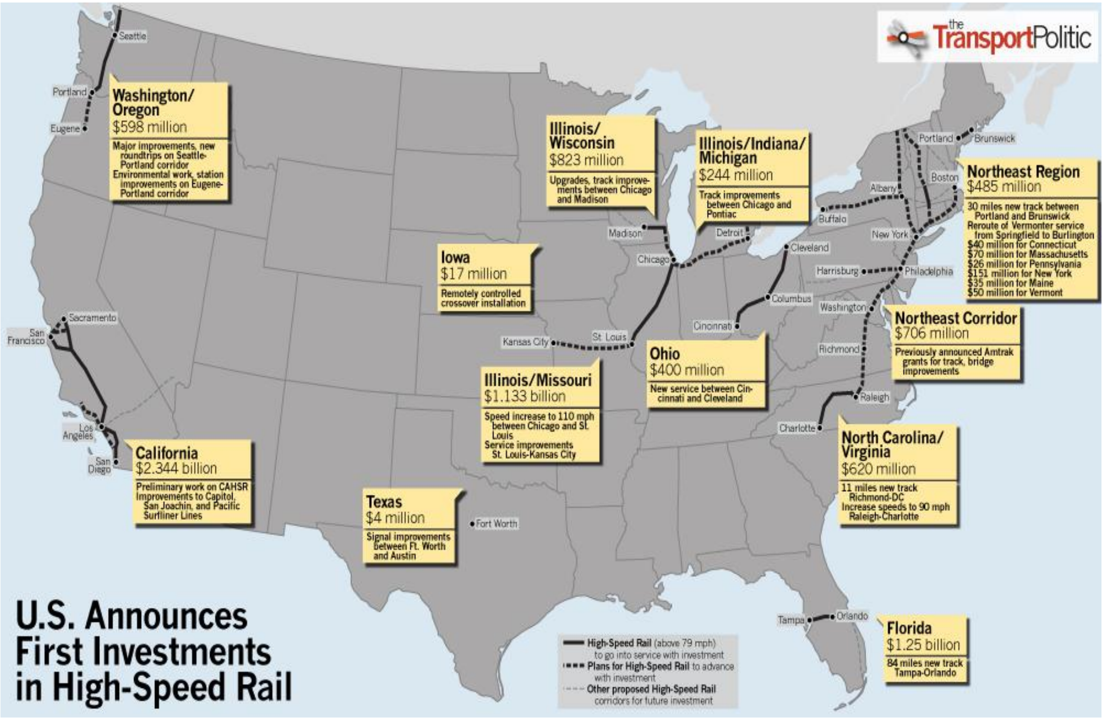


Figure 1: Distribution of funding for high speed transportation

Team Goals

Given the considerable amount of funding directed towards high speed rail systems, the logical step was to investigate the feasibility of incorporating a high speed rail system, for passenger as well as freight trains, into the design of the intermodal yard. In order to accomplish this, the task was divided into components, each of which helped with the overall assessment of the project. The first task was to find out what the standards are for high speed trains, and compare the different specifications to those already in use. The aerodynamics of the trains had to be calculated, which depended on the configuration of the containers, as well as the viaduct shape. Another investigated aspect was determining if the existing Amtrak schedule allowed for extra trains to be run during off hours in a way that would not interfere with their operation.

Standards for High Speed

The standards for high speed rail tracks are differ between countries. Generally, the desired track spacing is such that it reduces turbulence and friction, so the locomotives have lower forces resisting their movement. Unfortunately, high speed rail systems are currently very scarce in the United States, and codes for standard track spacing have not yet been written. In order to get an approximation for the high speed specifications which are expected, the standards for a number of European countries, notably France, were used.

Davis Equation/Number of Engines

Using the European high speed rail standards, attention was turned to simulating the high speed trains in order to optimize the configurations of the trains and shipping containers. Typically in long freight trains, a number of locomotives are used in the front to pull the freight cars, and a number of locomotives are used in the rear to push the freight. The governing equation determining the number of engines required is called the Davis equation, which is a summation of the resistive forces acting on the train. Sources of the resistance include drag, friction from the track, and the percent grade of the track. Unfortunately, the equation was designed for a train going at only 30mph, and although it had been extrapolated out to 50mph, it was not valid for trains going upwards of 110mph as the high speed freight was planned to run. A set of new equations was derived that was valid for the high speeds that were planned:

$$F = ma \qquad a = \frac{d}{t^2} \qquad v = \frac{d}{t} \qquad nP = Fv$$

So,

$$n = \frac{d^2 m}{t^3 P}$$

Where

- N =number of engines (#)
- P = Effective power of engine (Watts)
- m = Mass of train (kilograms)
- d = Distance traveled (meters)
- t = Time to travel (seconds)
- F = Force exerted by the train (Newtons)
- a = Acceleration of train (meters/seconds^2)
- v = Velocity of train (meters/seconds)

It was found that four trains were required for the high speed intermodal freight.

Aerodynamic Modeling of Train

A computational fluid dynamics (CFD) analysis was then performed on the proposed train in order to determine the aerodynamic drag forces that the engines would have to overcome while traveling at high velocities. For this analysis, CFDesign 10.0 a finite element CFD program was used. A representative model of a typical 8000 ft long double stacked intermodal train configuration was made using the Autodesk Inventor 3D solid modeling program with the double stack case being chosen to represent the maximum possible drag case. For the boundary conditions, an oncoming flow velocity of 90 mph was chosen with the exit boundary condition being unknown. The surrounding boundary conditions were set to ambient pressure (0 gage) and 90 mph tangential velocity in the z-direction. The train volume was given a material property of steel (for skin friction drag) and a surface boundary condition was chosen for the bottom to act as the ground. Once the analysis was performed, the forces acting in the z-axis (direction of flow) were summed up using the wall force calculation feature of CFDesign. These wall forces are by definition equal to the drag force imparted on the train, including skin friction drag. Finally, the power required to counteract the drag force was determined using the definition of power given above. In order to verify the results, a visual depiction of the velocity flow field was made and is shown below (Figure 2) for the case of the standard double stacked configuration. The above process was then repeated for an aerodynamic train model complete with streamlined engine and fairing covered cars. The two results were then compared to see the difference in drag and therefore power required. The end result was that, for the large length involved in the intermodal trains the aerodynamic shell, it might not be worth the cost because the drag reduction was not incredibly significant.

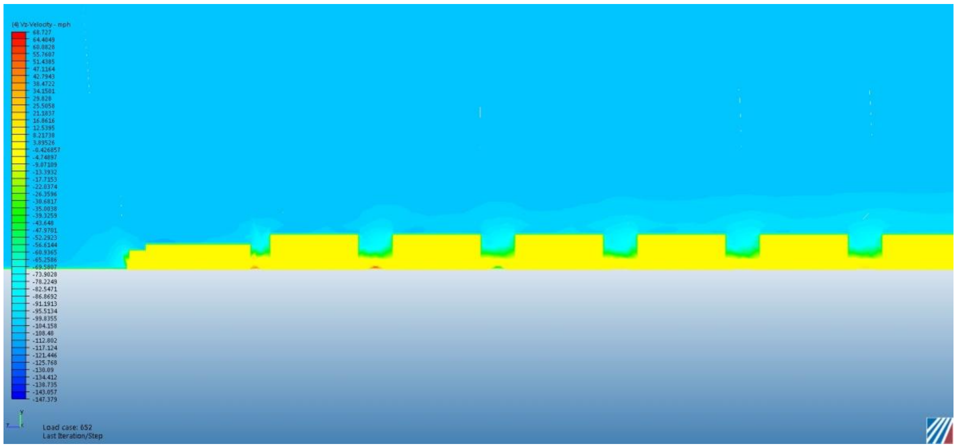


Figure 2: Aerodynamic simulation of double stacked freight

Schedule Optimization

Another possibility that was investigated was the optimization of the current rail system used by Amtrak, which would allow intermodal freight trains to use the Amtrak lines during hours of low traffic. Currently, there are a number of wide gaps in the Amtrak schedule with little to no rail traffic, which could be better utilized. In order to get an idea of when these times are, a time-space diagram was constructed that shows the positions of each train at various times of the day. It was seen that four different times of the day had the greatest region of low traffic.

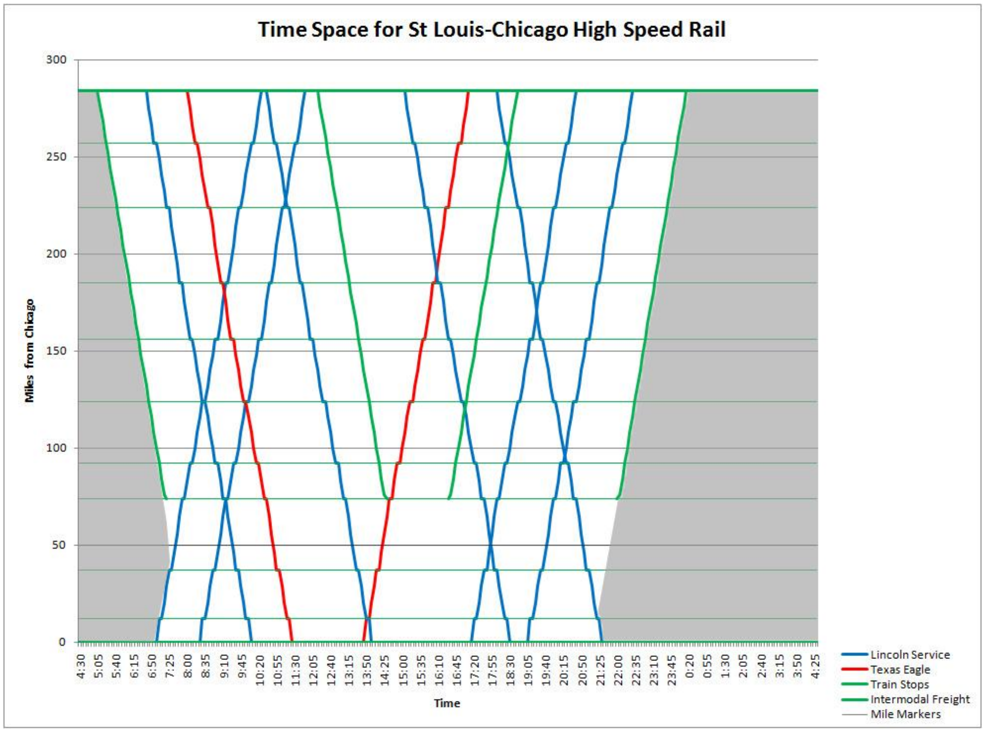


Figure 3: Time-Space diagram of Metra schedule

Site Design Team

Overview

The CenterPoint intermodal yard was redesigned to include the ATMS for the client Mi-Jack. In addition to adapting the site to include ATMS, several other improvements were made based on a number of factors. First, plans were laid out regarding how to allocate the additional space provided by the ATMS. Other considerations were based on traffic surrounding our site, and anticipation of future increases to traffic at the site, which are expected following the SES Metra expansion and the Illiana Tollway.

ATMS Description

ATMS stands for Automated Transfer Management System. It consists of a fly over crane that spans over four rails. On either side of the rail group is a row of double stacked storage for containers to be dropped off or picked up by truck drivers. Additionally, the system includes a quicker sign in system for drivers that alert them to the exact location of their container with use of RFIDs.

Figure 4: A conceptual rendering of the ATMS

Comparison to Old Design

ATMS reduces the area required for intermodal transfer and storage of containers. We looked at other sites and compared their intermodal area to other land uses. The original design maintained the ratios we found. Since the use of land for industrial buildings is the most profitable, that is how most of the space freed by using the ATMS was allocated. This design allowed for a 5.5 times increase in industrial space.

CRETE SITE CHARACTERISTIC COMPARISONS	**Old Site Design**	**New Site Design**
Site Size in Acres	1000 Acres	1000 Acres
Site Size in Million SqFt	43.5 Million SqFt	43.5 Million SqFt
Intermodal Area in Acres	300 Acres	86.8 Acres
Intermodal Area in Million SqFt	13 Million SqFt	3.75 Million SqFt
Total Building in Acres	137.75 Acres	220.5 Acres
Total Building in Million SqFt	6 Million SqFt	9.6 Million SqFt
Acres of Intermodal to one Acre of Building	2.17 Acres per building Acre	.39 Acres per building Acre

Notes:
The capacity of the intermodal area (in lifts per day) stays the same in both designs
The original designs has no room for future alterations
The original design had no room for trucks on site to alleviate traffic issues
The ratio of intermodal to building acres was made 5.5 times better

Figure 5: Comparison of old site design to the updated design

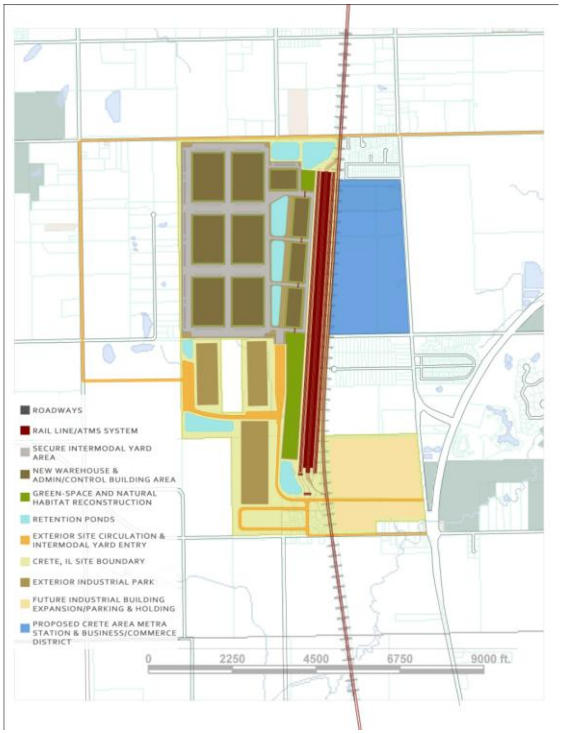


Figure 6: The redesigned Crete intermodal yard

Site Improvements

Redesigning the site also included taking into account traffic issues that were present in the site both in 2010 and those which are predicted to occur as early as 2020. Most importantly, the entrance to the site would have created a bottle neck if the design did not add either a new entrance or alleviate the congestion at the current entrance of the site. Both approaches were eventually taken. A new area was created for trucks to park and wait before going through the ATMS login, and a west entrance was created that looped across the top of the site.

Metra Station

The Metra SES expansion is going to be located directly east of the site on the northern end. This expansion actually lessened our site's size. The Illiana, when constructed, goes south of Crete. However, the increased traffic could head north and increase traffic to Crete and the Centerpoint intermodal yard.

Difficulties Encountered

When the project was started, the plans for the Metra station were not known. Had they been, the direction of the design for the site would have been far different. As it stands, the Metra station is going to take up the space that is required in order to have an ATMS type intermodal facility built on the Crete site. Given more time, attempts would have been made to find alternative sites. This will have to be the responsibility of the next semester's group.

Highway and Double Decker Viaduct

Overview

In a 2003 report of our nation's infrastructure, it was found that 27.1% of our bridges (160,570) were structurally deficient or functionally obsolete.[1] With barely passing scores on the 2005 Report Card for America's Infrastructure,[2] now is the time for America to revitalize itself using new and revolutionary construction methods. Our client, John Lanigan Sr., founder and chairman of Mi-Jack Product, hopes to accomplish this task. During the course of this IPRO, we have finished the preliminary designs for his innovative Combo Highway and Double Decker Viaduct System.

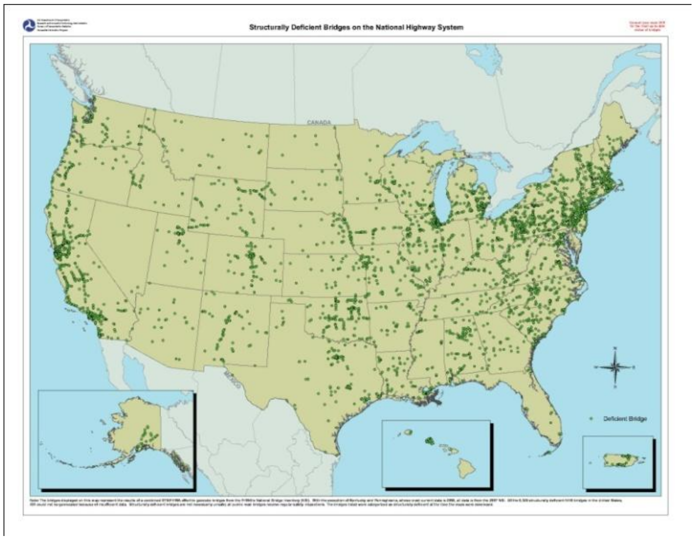
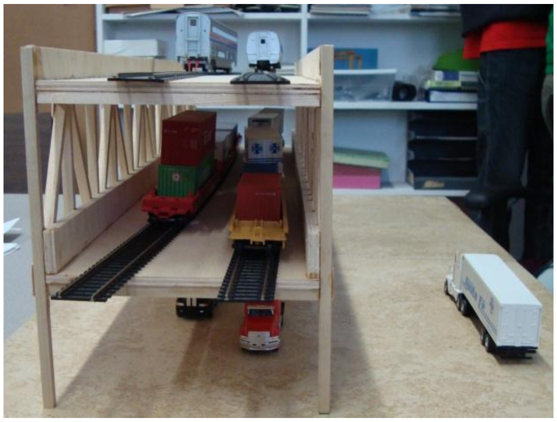
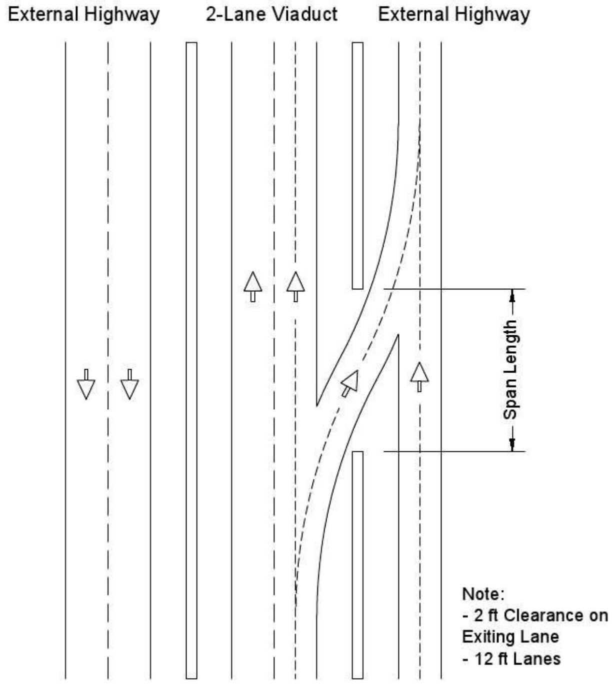


Figure 7 Structurally Deficient Bridges on the National Highway System 2007

Viaduct Design Features

The Combo Highway and Double Decker Viaduct System helps to conserve space by building up instead of out. It provides ease of transport for the complete intermodal process by including both freight trains and truck traffic. The top level of the viaduct consists of two High Speed Passenger rail lines with an open view of the surrounding area. The middle level includes two freight train lines. Finally, the ground level has two lanes of highway traffic under the viaduct system travelling one direction, and two more lanes of traffic next to the viaduct, travelling in the opposite direction.





Note:
- 2 ft Clearance on Exiting Lane
- 12 ft Lanes

Figure 8: Top-down view of roadway

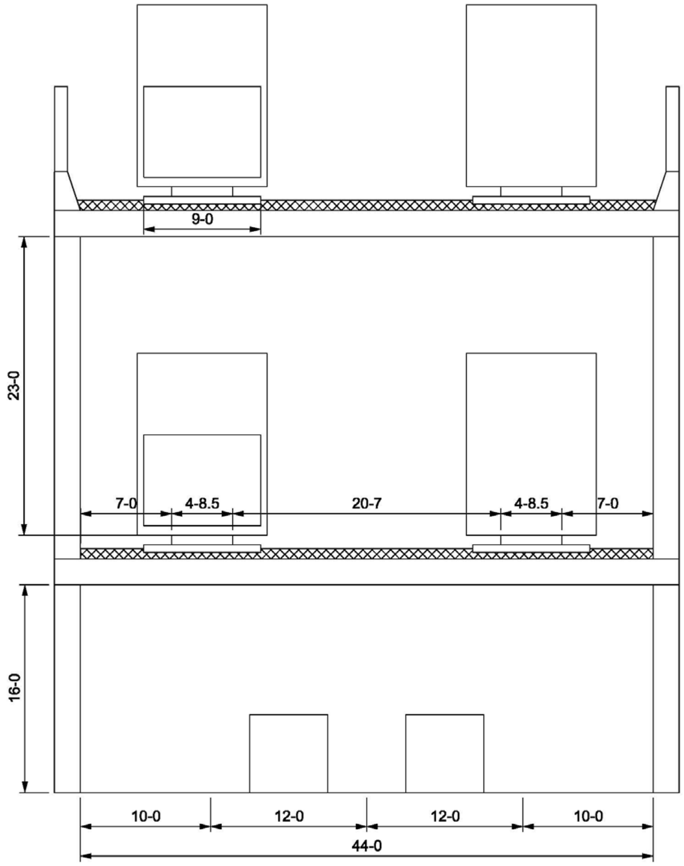


Figure 9: Cross section of viaduct

Soil Properties

The first task that was done was to assess the soil quality on the Crete site. The soil properties would ultimately determine how the viaduct was engineered. Various GIS maps, water tables, and elevations were found for the area. Because the viaduct route was not known exactly, planning was done under the assumption that soil between Crete and the final destination was approximately the same, and any differences in the soil properties could be dealt with individually. It was found that the bedrock was very shallow, which allowed the foundation to be designed easily.

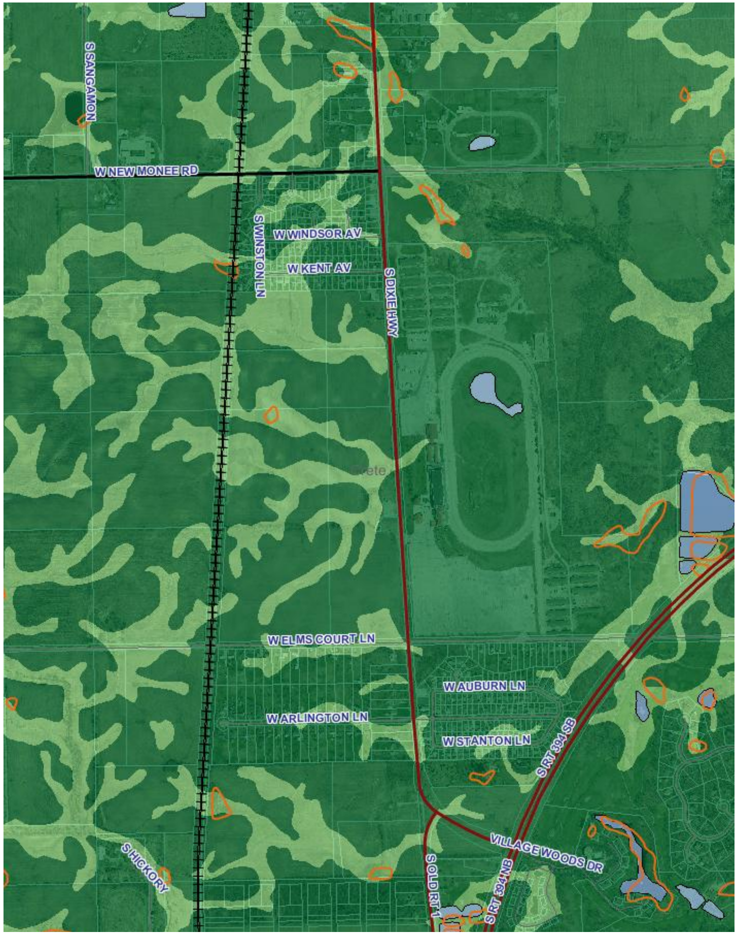
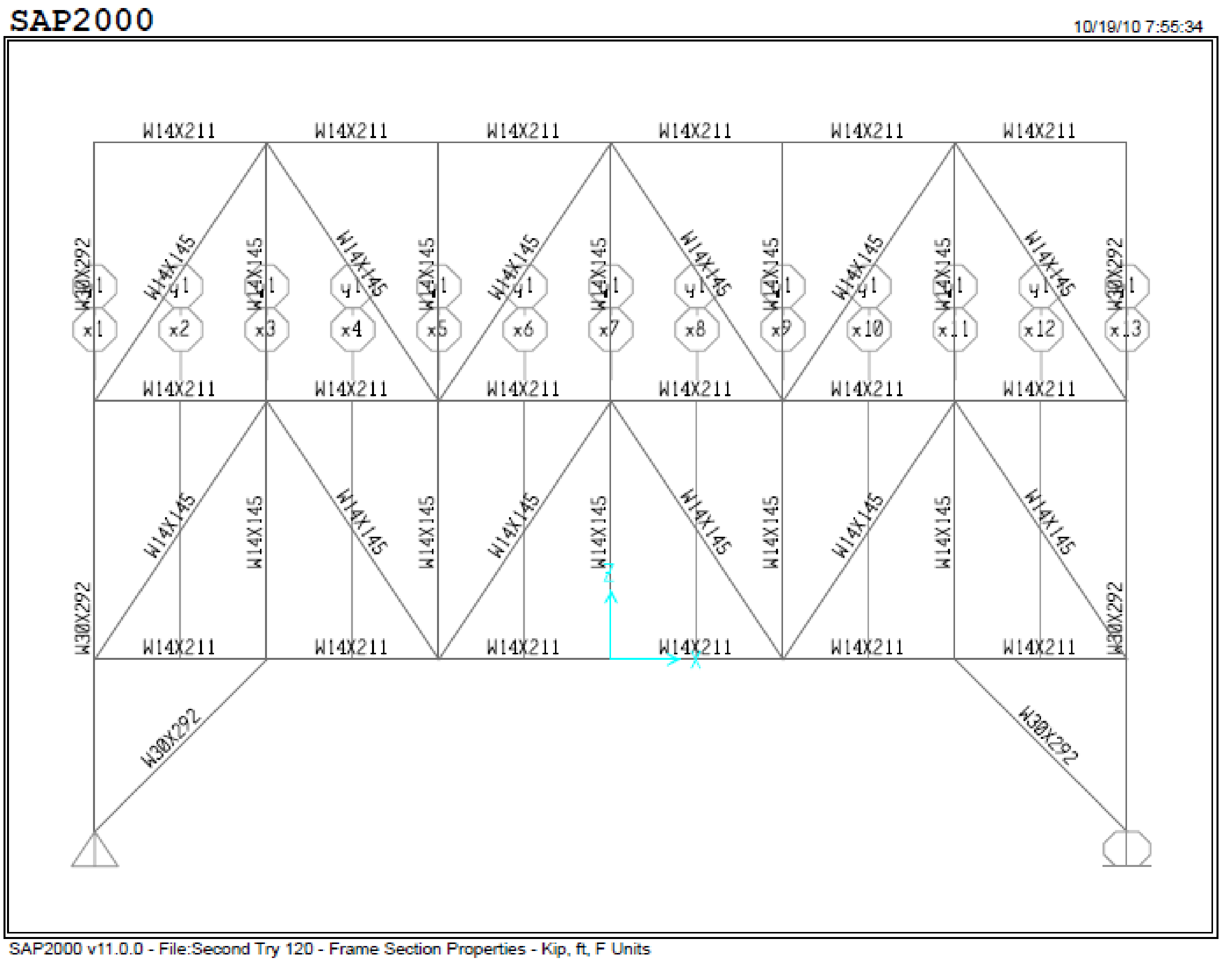


Figure 10: Soil map of Crete site

Analysis and Design

The viaduct was designed using a truss configuration with 120 foot spans using the AREMA code for the loads. The span length was chosen to allow for trucks to turn in and out from under the viaduct safely. The height of the underpass was 20 feet for clearance for the trucks, and the height of the inside level of the viaduct was 30 feet to provide room for double stacked freight trains. The viaduct is constructed with both steel and concrete. The deck, columns, and foundations are made with 4,000 psi concrete. The truss, floor beams, and lateral bracing are made with 60 ksi steel. A SAP 2000 analysis was used in the design of the truss to make sure that the deflections did not exceed 0.5 inches when fully loaded.



SAP2000 10/19/10 7:55:34

SAP2000 v11.0.0 - File:Second Try 120 - Frame Section Properties - Kip, ft, F Units

Figure 11: Beam configuration of viaduct

Figure 12: 3D rendering of viaduct, showing all decks and the roadway below

Cost Estimate

A cost analysis was done on the viaduct with a total cost per mile of $17,500,000, including both the cost of materials and the cost of construction. The deck was $6,000,000 per mile, the beams were $5,000,000 per mile, and the columns were $600,000 per mile. This included 28% for contractor fees, 10% for architectural fees, and 15% for miscellaneous items.

Decks	$ 6,000,000.00
Beams	$ 5,000,000.00
Columns	$ 600,000.00
Contractor fees	28%
Architectural fees	10%
Misc.	15%
Total per mile:	$ 17,500,000

Figure 13: Cost estimate of viaduct

Construction Facility

In order to facilitate the production of the materials for the viaduct, an idea was presented for the construction of a new factory designed to produce the concrete columns and beams that were required for the viaduct. A cost estimate was done of the factory using a 45,000 square foot factory as a reference. The estimated cost of building such a factory was $4,800,000 for the structure, and an additional $1,000,000 for equipment to pour the concrete columns and roll steel I-Beams. The factory was designed with portability in mind. However, many of the elements that were cost estimated were intended for permanent structures, so the actual cost of building a mobile factory could be much lower.

Factory Cost Breakdown	% of Total	Cost Per S.F.	Cost
A Substructure	12.00%	$9.60	$432,000
B Shell	36.80%	$29.54	$1,329,500
C Interiors	14.80%	$11.83	$532,500
D Services	31.60%	$25.37	$1,141,500
E Equipment & Furnishings	4.80%	$3.84	$173,000
SubTotal	100%	$80.19	$3,608,500
Contractor Fees (General Conditions,Overhead,Profit)	25.00%	$20.04	$902,000
Architectural Fees	7.00%	$7.01	$315,500
User Fees	0.00%	$0.00	$0
Total Building Cost		$107.24	$4,826,000

Figure 14: Cost estimate of factory

Hybrid Composite Beam

One idea that we considered in the design of the viaduct was the use of John Hillman's Hybrid Composite Beam (HCB). "The HCB is a revolutionary, sustainable technology that combines the strength and stiffness of conventional concrete and steel with the lightweight and corrosion resistant advantages of fiber reinforced polymers."[4] In order to finish the design in the allotted time, however, we were unable to incorporate it in the design. The HCB would have been used for the floor beams.

Obstacles Encountered

Some obstacles that were encountered during the design of the viaduct relate to the availability and breadth of code. The codes for bridge design in the United States have not yet been developed to account for high speed trains. The difference in forces between passenger and freight trains at high speeds has yet to be studied and accounted for with the codes. Also, no one in our IPRO group has taken any bridge design classes, so every step of the design was a learning experience.

Conclusion and Recommendations

After much investigation, it has become exceedingly clear that the intermodal yard at the Crete site will not work. One explanation relates to the progressing standards of freight train length, as attempts are being made to standardize a 10,000-foot train, rather than an 8,000-foot train. The longest portion of the Crete site barely allows for the current train length, let alone an extension in the future. Another explanation relates to the proposed Metra station, which will remove even more space from the proposed site. While the current site cannot be pursued for the intermodal yard, the knowledge gained in designing the site layout will be beneficial in determining the potential of future sites.

As the current site must either be expanded or ignored, the design process should be continued for other potential sites. It would be beneficial for future groups to also grow in the experience of choosing the site based on the knowledge gained in this study. Future studies should also pursue the development of code relating to high-speed train, both freight and passenger. Two areas of focus will be the use of codes in designing any bridge structure for these trains, as well as designing the complete feasibility standards for the movement of such trains.

References

1. http://apps.asce.org/reportcard/2005/page.cfm?id=22
2. http://apps.asce.org/reportcard/2005/index2005.cfm
3. Figure 7: http://www.dot.state.ri.us/documents/bridges/US_Deficient_Bridge_Map_no_counties%5B1%5D.pdf
4. www.hcbridge.com
5. http://www.engr.psu.edu/ae/steelstuff/economy.htm
6. http://www.willcogis.org/
7. http://metrarail.com/metra/en/home.html
8. http://rsmeans.reedconstructiondata.com/