IPRO 307- Automated Shipping Container Transportation System Design
Final Report
Fall 2004

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Introduction

The goal of this IPRO is to design and make a financial analysis of an automated container transport system for the Chicago region. The project is sponsored by Bruce Dahnke the founder of Skytech Transportation. Mr. Dahnke's vision is a completely automated system that would transport containers from one rail yard to another. His system if created could reduce the number of trucks on the road which would reduce traffic congestion, transport containers faster and more efficient, and help handle the increased intermodal container traffic that is being predicted for the Untied States over the next 20 years. If the system works in Chicago, he plans to expand his system to connect other cities and sea ports.

The problem that this IPRO is addressing is both a real problem and a local problem. In figure 1 there is a picture of a container being lifted off of a train flat car by an overhead crane. These containers are interesting in that they can be stacked on top each other and be transported by ship, truck, or train and can carry anything from computers to clothing. Currently Chicago handles over 7 million containers a year making it the third largest port in the world behind Hong Kong and Singapore. Believe it or not, Chicago has over 26 rail yards in and around the Chicago area and one of their primary jobs is to take containers off rail cars and onto a trucks or vica-versa.

Figure 1

The problem is that many containers are being held up in Chicago for two to three days. The reasons for the delays are many. First, the old rail infrastructure in and around Chicago makes it difficult for trains to move from one rail yard to another (called steel wheel transfer). The result is that some containers have to be moved by road from one rail yard to another and this is done by truck (which is called rubber tire transfer). As an example, between the Corwith Rail Yard and the 47th Street Rail Yard there are about 48 thousand truck transfers a month. Considering that this is just 2 out of 24 other rail yards in Chicago this equals a lot of truck traffic around the city which causes lost time, pollution, and heavy congestions on Chicago streets and highways. Second, most of rail yards in Chicago are at or near capacity and are unable to expand because of the shortage of available land in Chicago. The problem will to continue to get worse because modest projections tell that container transportation in the United States will double by 2020.

So, this is a very real problem and much work has been done in the past two semesters to work to solve the problem. This paper will first talk about the work that was done last semester, and then how the IPRO moved forward by this semester's work.

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Project Background

This IPRO started at IIT in the spring 2004 semester. The students in the spring accomplished a lot, so before going into this semesters work I need to explain what was accomplished last semester. The primary goal last semester was to design an automated system that would transfer a container from the 47th Street Rail Yard to the Corwith Rail Yard and visa-versa. To accomplish the goal they first defined the problem which has been discussed in the introduction of this paper. Second, when the team was researching possible design solutions to the problems they discovered the GRAIL System. The GRAIL System was designed in the late 1970's for a company called SeaLand as a means of completely automating there container sea port, but it never was built. Last semester's group decided to implement the ideas of the GRAIL system to there design.

The GRAIL consists of a steel overhead lattice structure that covers over the top of a rail yard. Connected to the overhead structure are steel rails and riding on these rails are automated vehicles called Shuttles (figure 2). On these Shuttles is a spreader bar that is used to pick up containers. To give an example of its functionality, a train first pulls into a rail yard. Under the command of a central computer a Shuttle is commanded to move over the container on a flat bed rail car. Once the Shuttle is over the container it stops and lowers the Shuttle's spreader bar down. Once the spreader bar drops down on top of the container it locks onto it and raises it up. Then, the Shuttle takes the container either to another flat rail car, to a container storage area, to a buffer (which is a mechanical structure that puts a container on a truck), or on a Chassis.

Figure 2

Along with work done on the GRAIL yard design, the spring 2004 team also started the design of the Inter-Yard Structure (which is the structure to the left of the Interface in figure 3). The Inter-Yard Structure is an elevated concrete bridge like structure that has two sets of rails on it. Riding on top of the Inter-Yard structure are automated linear induction motor driving vehicles called Chassis. The interesting thing about the Inter-Yard structure is that it is designed to fit over the top of ground level railroad tracks. This will allow the structure to be placed over land that is already being used by a railroad company, which could avoid having to buy and improve land around Chicago. Riding on the top of the Inter-Yard structure are automated linear induction motor driven vehicles called Chassis. What these Chassis do is drive containers from

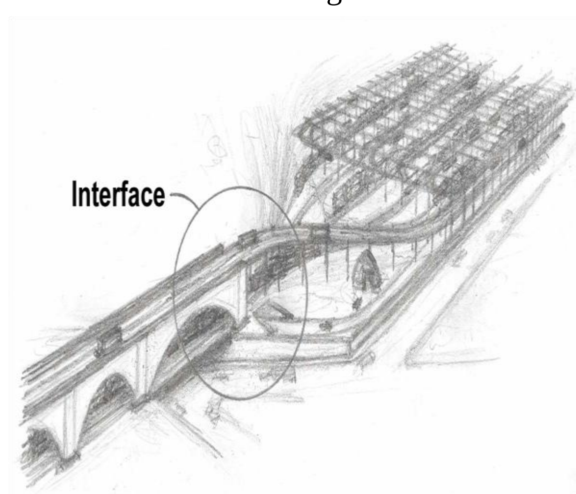

Figure 3

one rail yard to another rail yard (which was Corwith Rail Yard to the 47th Street Rail Yard). So, just to summarize how a container would be transferred from one rail yard to another: A Shuttle would get an order from the rail yard's central computer informing it that it had to pick up a container and the computer will tell it were to go to get it. The Shuttle would then travel to the container and stop over the top of it. Then, the Shuttle's built in computer would adjust the Shuttle's spreader bar to line up correctly to the container. Next, it would lower the spreader bar down and land on the top of the container. The spreader bar would then lock onto the container and then bring it up into the air. After the container is up and locked the Shuttle would then drive to a section in the yard called the Shuttle/Inter-Yard Interface. At this point, the Shuttle places the container on a Chassis. Once the container is on the Chassis, the Chassis would then drive it on the Inter-Yard Structure to the other rail yard.

The spring 2004 IPRO team also started design of the control system for the Shuttle. They documented all the different scenarios that the Shuttle might encounter and researched different kinds of ways that a container could be tracked within the system. Another thing the previous IPRO team researched was using linear induction motor technology to move the Chassis, which is the vehicle that drives from one rail yard to the next on the Inter-Yard structure. They concluded from there research that the permanent magnet LIM (Linear Induction Motor) would best suit there needs.

The last thing that the spring IPRO team did was make an Excel program financial analysis of what the cost of the IPRO GRAIL System and figured out an IRR (internal rate of return) of the IPRO GRAIL System. In the table below, shows a summary of there work.

Inter-Yard Structure (cost per mile)	**$5,000,000.00**
Shuttle Cost	**$450,000.00**
Chassis Cost	**$500,000.00**
Total GRAIL Construction Cost	**$162,270,000.00**
Variable Cost (per year)	**$7,445,999.64**
IRR over 20 years (with lift cost $50.00 and transfer cost $50.00)	**38.68%**

For the details of the GRAIL System financial analysis and all the rest of the spring 2004 semester's work could be found in the spring 2004 IPRO 307 Final Report.

Project Purpose

This semester our IPRO team made several goals to help move the project forward. The first goal was to make a detailed Shuttle Design. This includes detailed CAD Drawings of the Shuttle and a description of different parts of the Shuttle. The second goal was to analyze the Inter-Yard Structure further. The purpose of this was to revisit the work of the last semester to check the structure design and the cost of construction of the Inter-Yard Structure. The third goal for this semester was to take the Shuttle Control System a step further from last semester. The fourth goal was to design a

Regional Connector Network for the for the Chicago area. In other words, we wanted to connect all 26 rail yards in Chicago together by the Inter-Yard Structure and figure out what the network would look like. The final goal of this semester was to update the financial analysis for the GRAIL system. This goal has two parts to it. We wanted to first update the financial analysis of the 47th Street Rail Yard and the Corwith Rail Yard connected GRAIL System, and second we wanted to make a financial analysis of the Regional Connector Network.

Research Methodology

Because there were so many goals for this semester and each goal was not exactly related to each other, it was necessary to divide the IPRO team up to accomplish all the goals that we set. There ended up being four sub-teams; the Shuttle Design Team, the Control System Team, the Regional Connector Network Team, and the Feasibility Team. Here is the roster for each sub-team:

Shuttle Design Team
*** Alec Frost**
Graham Stephen Hodgson
Abhinav Pamulaparthy

Control Team
*** Rafiu Amolegbe**
Chris Brewster

Regional Connector Network
*** Paul Hamernick**
Keegan Adcock
Abhinav Pamulaparthy
Venkata Chintaluri

Financial Analysis Team
*** Venkata Chintaluri**
Paul Hamernick

* Sub-Team leader

The sub-team leader assigned work to there team and was responsible for there teams deliverables. All the sub-teams meet on Tuesdays and Thursdays during the IPRO scheduled class time to keep everyone up to date on what each sub-team is doing and to discuss important IPRO issues. On the next pages are the results of each teams work starting with the Shuttles Design Team, then Control Team, Inter-Yard Structure final analysis, Regional Connector Network Team, and finally the Financial Analysis Team.

Shuttle Design Team: Final Report

IPRO 307 Fall 2004

Alexander Frost
Graham Stephen Hodgson
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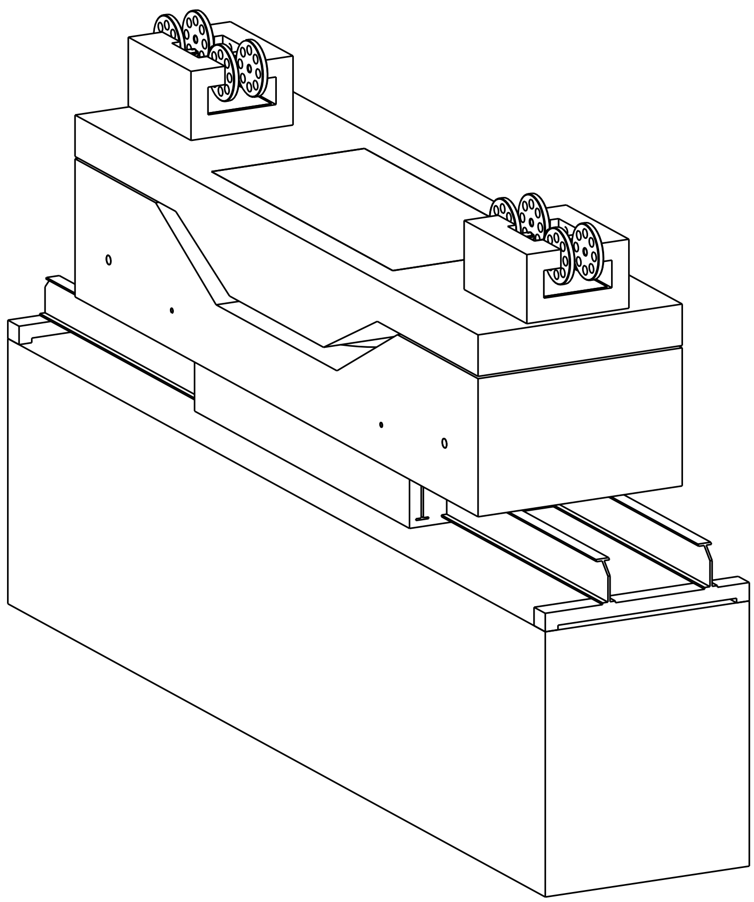

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Introduction

With the discovery of the Grid Rail, or GRAIL, system during the spring of 2004 IPRO 307, there was now a means of automating the rail yards to greatly increase the number of lifts that could be performed. This GRAIL system was a step in the right direction, but certainly did not have all the answers. Questions still requiring resolution include: 1) What is the vehicle which will be the workhorse of this automated GRAIL system and, 2) Has this vehicle ever been designed or built? In response to question 1, the Shuttle will be the workhorse vehicle for moving containers within the GRAIL. However, in response to question 2, there is no Shuttle design known to exist for purposes of working with the GRAIL system. The GRAIL patent, issued to SEA-LAND Corporation in 1990, details requirements of the Shuttle vehicle, yet no detailed designs were provided or are known to exist. The work of the Shuttle sub-team for the fall 2004 IPRO 307 was to develop a detailed Shuttle design as a means to get closer to a Shuttle design capable of manufacture and also obtaining a more accurate cost estimate of the vehicle.

Shuttle Requirements

Before jumping head first into the problem of designing a vehicle from scratch to work with the GRAIL system, it was necessary to first outline the requirements of the vehicle. Ranging from general to specific, these requirements detailed various parts of the Shuttle as well as its operation. For example, one such requirement is the speed with which the Shuttle travels. This requirement is in place for various reasons such as safety and system efficiencies.

The Shuttle requirements are provided below:

Requirements:

1. Lock onto, Lift, and Lower a container weighing no more then 82,000lb (41 tons)
2. Shuttle weight should not exceed 100,000 lbs (50 tons)
3. Lower/Lock/Lift container in one minute’s time (70ft/min hoist rate)
4. Use spreader bar (identical to gantry crane spreader bar) to accommodate 20’, 40’, 45’ container lengths and to accommodate container widths of 8ft (96”).
    a. Spreader is lowered by a type of reeved cable to minimize container sway
    b. BROMMA YSX-45E Spreader bar recommended

5. Use “safety arms” to ensure container does not fall in the event of a collision or faulty container hold
6. Able to rotate container a full 360 degrees to accommodate train loading and high-density stacking for storage
7. Precisely move container within yard such that the location of Shuttle/container is known within half an inch (0.5”).
8. Maximum speed of 10mph with a slower speed of 5mph through switches
9. Safety braking mechanism to avoid collisions in loss of power situations
10. Perform switching operations throughout the GRAIL structure
11. Completely interfaced with control system
12. Use Linear Induction Motors (LIM) for propulsion purposes
13. Use on-board sensing technology to prevent collisions
14. Use on-board computer system to execute orders from main computer (smart Shuttle

Assumptions:

1. Shuttles adhere to a maintenance schedule which incorporates the use of on-board sensors to direct maintenance personnel to the exact nature of the maintenance.
2. Shuttles will be powered through the use on a inductive rail.

Detailed Shuttle Design

With the requirements of the Shuttle vehicle known, it was time to progress into the Shuttle design stage. In industry, the most common tool for designing is computer aided design (CAD) software. Using hand drawn sketches of the Shuttle from the previous and current semesters as a foundation of what the vehicle would look like, the Shuttle was modeled in a three-dimensional CAD package called Unigraphics v18.

CAD software, such as Unigraphics, is constantly improving and allowing parts or components to be modeled easier and faster then ever before possible. Most, if not all, three-dimensional CAD packages use parameters which are just values assigned to various dimensions of the component (part). An example of this would be the diameter of a hole. A parameter value is assigned to the diameter of the hole and if the diameter is ever required to be changed then the only number that needs to be changed is the parameter value assigned to that holes diameter. This is much faster then erasing the hole and re-creating a new one with the new diameter.

In terms of Shuttle design, each component (part) of the Shuttle was modeled separately in its own model file. Assemblies and sub-assemblies of the components were then created and the Shuttle began to take shape. An assembly is the bringing together of various different components in one file. For example, the Shuttle bogie (truck) assembly file is a sub-assembly consisting of the Shuttle bogie body, load wheels, and various other components assembled to look as it would on the actual Shuttle.

The CAD packaged used, Unigraphics, is also capable of producing a more traditional two-dimensional (2D) engineering drawing. Such drawings, which look like blue-prints, are typically used to call-out dimensions of parts as well as other features such as a component's surface finish, material type, etc. Also, most industry still uses these types of drawings as the means of communicating between engineering and manufacturing. In other words, if a part or even an entire vehicle is to go from something in a computer to something in real life, engineering drawings are involved. Unigraphics creates these engineering drawings by allowing the user to pick various views of the 3D model, such as a front or top view, and then attach dimensions where necessary. Section views can also be made by cutting the model in order to see the inside of the component. Assembly drawings can also be created which show how various components of the Shuttle fit together. Most of the components of the Shuttle, which were modeled in 3D, also have 2D engineering drawings and are discussed in the next section.

Shuttle Parts List & Descriptions

With all of the various components of the Shuttle modeled and engineering drawings produced, it is necessary to describe just what these components are and what role they play in the Shuttle's operation. Table 1 lists the various components (parts) of the Shuttle and their quantities, followed by their descriptions.

#	Part	Quantity
1	Shuttle truck(bogie) body	2
2	Shuttle truck (bogie) guide pin	2
3	Shuttle truck load wheel	8
4	Shuttle truck side wheel	8
5	Shuttle truck slider bar	8
6	Linear Induction Motor	2
7	Shuttle Body: Upper	1
8	Shuttle Spur Gear	1
9	Shuttle Pinion Gear	1
10	Shuttle Body: Lower	1
11	Motor Bay Cover (Lower)	2
12	Cable Spool	4
13	Cable Spool Support Rod	2
14	Cable Pulley	4
15	Cable Pulley Support Rod	2
16	Bromma YSX-45E Spreader Bar Assembly	1
a	Spreader Bar Arms	2
b	Spreader Bar Body	1
17	Shuttle Retention Plate	1
18	Shuttle Truck Retention Plate	2
19	Motor Bay Cover (Upper)	1
20	Hoisting Motor	2
21	Rotation Motor	1
22	Computer/Location Device	1?
23	Storage Batteries	1?
24	Transformer/Power Converter	2-4?

Table 1: Component list for the GRAIL Shuttle

1) <u>Shuttle Truck (Bogie) Body:</u>

The Shuttle bogie body is most closely related to the “truck” of a railroad car. The “truck” supports the wheels which contact the track and also holds the weight of the railcars chassis. The bogie of the Shuttle acts in the same manner except that in this case the Shuttle is hanging from an overhead track rather then sitting on top of a track like a railcar. The bogie has provisions to rotate in such a manner as to be able to go around curved sections of track with a fifty foot (50 ft) radius. There are two bogies on each Shuttle

2) <u>Shuttle Truck (Bogie) Guide Pin:</u>

The Shuttle bogie guide pin is a support device designed to help support the load from the weight of the Shuttle when making switches from one track to another. The Shuttle will have to bridge gaps in the track while switching and the bogie guide pin provides support to the Shuttle bogie so as to minimize deflection. The guide pin fits through the upper Shuttle body into the Shuttle bogie and uses the upper body as a rigid support.

3) Shuttle Bogie Load Wheel:

The Shuttle bogie load wheel is, as the name suggests, a wheel supporting the load of the weight of the Shuttle. In other words, the load wheels contact the track and support the weight of the entire Shuttle. The Shuttle has a total of eight load wheels with four on each bogie body (similar to a railroad car).

4) Shuttle Bogie Slider Bar:

The slider bar holds the bogie side wheel and is attached to the bogie body in such a manner so that it can move in a linear motion. The purpose of this linear motion is to allow the slider bar to move and allow contact of the side wheel with the overhead track structure.

5) Shuttle Bogie Side Wheel:

The bogie side wheel attaches to the bogie slider bar and makes a small assembly which attaches to the bogie body (see #3). When the Shuttle is negotiating a curve, the slider bar will move and allow the side wheel to contact the track as a means to keep the Shuttle properly positioned on the track. This operation is essential in order for the Shuttle to work properly because without the slider bar/side wheel assembly, the Shuttle could derail from the track and fall. There are a total of four (4) slider assemblies on each Shuttle bogie.

6) Linear Induction Motor:

The proposed propulsion for the Shuttle is Linear Induction Motor (LIM). There are many different variations of this technology, but for the purposes of the Shuttle, the LIM would be of the most traditional type. This type of LIM is where the active coils (or electromagnet) as well as the appropriate power conversion and control devices reside on the vehicle (Shuttle) itself. In this type of arrangement, the track supporting the Shuttle will also act as the “reaction rail” or something for the LIM to push against and propel the vehicle. There are provisions for the LIM’s to be located in each bogie of the Shuttle but the total number of LIM’s is still undetermined.

7) Shuttle Body (Upper):

The upper Shuttle body is an important component of the Shuttle for it connects with the two Shuttle bogies as well as with the entire lower half of the Shuttle. The upper body has an open cavity (motor bay) in its center to allow for such components as the computer, storage batteries, power converters/transformers, and the electric motor required to rotate the lower part of the Shuttle. The Shuttle bogies attach to the upper body via retention plates as does the lower body of the Shuttle.

8) <u>Shuttle Drive Gear (Spur):</u>

The Shuttle spur gear is attached to the lower body of the Shuttle and is driven by the pinion gear to allow for 360 degrees of rotation of the lower half of the Shuttle. This gear would be similar to the large gear found in a "Front Shovel" which is a piece of construction equipment most recognizable by its large front mounted arm and tank-like tracks.

9) <u>Shuttle Drive Gear (Pinion):</u>

The Shuttle Pinion Gear is attached to the motor which will be inside the open cavity of the upper shuttle body. This gear makes up one half of the gear system which is used to rotate the entire lower half of the Shuttle. Although the exact type of teeth on this gear has not been determined, it will most likely be a straight-cut gear designed to fit the requirements of the Shuttle.

10) <u>Shuttle Body (Lower):</u>

The lower shuttle body resides just below the upper Shuttle body and is attached via a retention plate in the same manner as the Shuttle bogies. As stated before, the Shuttle spur gear is attached to the lower Shuttle body for the purposes of rotating itself as well as the spreader bar assembly. There are two matching cavities in either end of the lower Shuttle body which hold the mechanisms for winching the spreader bar assembly vertically through cables, cable spools, cable pulleys, and electric motors. These cavities are called electric motor bays 1 and 2.

11) <u>Motor Bay Cover (Lower):</u>

This is simply a cover for the two motor bays (cavities) of the lower Shuttle body. Their purpose is to cover the openings and protect the contents as well as provide easy access for maintenance and repair.

12) <u>Cable Spool:</u>

The cable spool is a spool for storing and managing the cable to lift and lower the spreader bar assembly. There four different cables connecting the spreader bar to the Shuttle (one at each corner of the spreader), thus there are four cable spools with two at each end of the Shuttle (two in each motor bay). The spools sit on a supporting shaft which is turned by an electric motor to provide winching power.

13) <u>Cable Spool Support Rod:</u>

This rod holds the cable spool in position and is supported by the lower Shuttle body itself. The cable spool support rod also has provisions to be driven by the winching motor, which turns the spools and either winds or un-winds the cable (lift or lower the spreader bar and attached container). Each cable spool support rod holds up two cable spools for a total of two on each Shuttle.

14) <u>Cable Pulley:</u>

The cable pulley is a guide for the cable so that it can come through the bottom of the lower Shuttle body without interference. As the cable comes off of the cable spool, it wraps around the cable pulley so that the cable will drop straight down and not rub the lower Shuttle body and become damaged. There is one cable pulley for every cable spool for a total of four on the Shuttle.

15) <u>Cable Pulley Support Rod:</u>

Very similar to the cable spool support rod (#12), the cable pulley support rod supports the cable pulleys and is supported by the lower Shuttle body itself. There is one rod for every two pulleys, for a total of two on the Shuttle.

16) <u>Bromma YSX-45E Spreader Bar Assembly:</u>

As stated before, the Shuttle vehicle is designed for the purposes of moving intermodal containers of varying sizes throughout a rail yard in an automated manner. A majority of machinery found in shipping and rail yards today work by using some type of crane or overhead device to lift the container from their four top corners and moving them on/off the train or ship. The actual piece of equipment which locks onto the container and lifts is called a spreader bar and it is the device controlled by the crane operator. The Shuttle vehicle will require such a device and rather then re-engineer one it is better thought that a commercially available device which fits the needs of this application will be obtained. Research has lead to a Swedish company by the name of Bromma which is the world's largest manufacture of spreader bars. One model called the YSX-45E suits the application for the Shuttle well and so it will be purchased for use on the Shuttle. Nonetheless it is still valid to explain the major parts of the spreader bar to further understanding.

a. <u>Spreader Bar Arm:</u>

The spreader bar assembly has two spreader bar arms and these are the parts of the spreader which actually move in a liner motion to increase/decrease the length of the spreader bar assembly to accommodate different length containers. The spreader bar arms also have the twisting-lock devices which physically lock the spreader bar assembly to the container for lifting/lowering purposes.

b. <u>Spreader Bar Body:</u>

The spreader bar body is the part of the spreader bar assembly which holds both of the spreader bar arms and contains the machinery to move the arms in and out for accommodation of different length containers. The winching cables which lift/lower the spreader bar assembly attach to the spreader bar body as well.

17) Shuttle Retention Plate:

The Shuttle retention plate a steel disk which bolts to the upper Shuttle body and holds the lower Shuttle body (and essentially the entire Shuttle) together. Essentially there is a large peg on the upper Shuttle body which fits through a hole on the lower Shuttle body and the Shuttle retention plate bolts to the upper Shuttle body to prevent the two bodies from coming apart yet allows rotation of the upper and lower bodies independent of one another.

18) Shuttle Truck (Bogie) Retention Plate:

The Shuttle bogie retention plates work in the same manner as the Shuttle retention plate (#16) by affixing the Shuttle bogies to the upper Shuttle body, but still allowing the bogies to rotate. There is one retention plate per bogie for a total of two on the Shuttle.

19) Upper Motor Bay Cover:

This component is similar to the lower motor bay cover (#10) which covers the open cavity of the upper Shuttle body to protect such items as the rotation motor, Shuttle computer, storage batteries. The cover also allows access for maintenance and repair.

20) Hoisting Motor:

The hoisting motor (located in the lower Shuttle body) is an electric powered motor which turns the cable spools (#11) through the cable spool support rod (#12) for purposes of lifting the spreader bar assembly. When lowering the spreader, the motor would serve as a generator and send power to the storage batteries for future use thus recharging itself continuously. There are two hoisting motors per Shuttle.

21) Rotation Motor:

This electric motor (located in the upper Shuttle body) is responsible for rotating the lower Shuttle body (and attached spreader bar assembly) for the purposes of achieving maximum container storage in the storage facility.

22) Computer/Location Device:

The Shuttle is automated, requiring on-board computer to perform various routine operations. Also, a location/tracking device will be required and would be part of the computer or be a separate entity. The upper Shuttle body has provisions to hold the computer and any locating devices.

23) Storage Batteries:

The Shuttle is powered entirely by electric power which is transferred to the Shuttle by an inductive “third rail”. Power outages are bound to happen and in this case, the on-board storage batteries will be required to operate the Shuttle in some kind of “limp” mode to assure safety in the yard. When the Shuttle switches from one track to another, such as during a turn, the batteries will also be required to power the Shuttle. The Storage Batteries can be located in the upper Shuttle body.

24) Transformer/Power Converter:

The Shuttle is powered by linear induction motor (LIM) and this type of technology requires on-board transformers/converters to correctly change the electrical power from the inductive rail into electrical energy which can be used by the LIM. Again, these devices can be located in the upper Shuttle body.

Cost Estimate

The Shuttle will serve as a machine to lift intermodal containers to/from a train and to/from a storage facility in a fully automated manner. During last semester’s IPRO (spring 2004), it was estimated that the shuttle vehicle (not the interyard chassis) would cost approximately one half million ($500,000) dollars. One goal for the current semester (fall 2004) was to determine if this cost of $500,000 was a reasonable guess or not. In an effort to get a more accurate estimate, a detailed Shuttle was first designed and modeled in a CAD software package such that engineering drawings (similar to blueprints) could be produced and shown to possible manufactures. With a manufacture’s input, a fairly accurate cost estimate could be attained. Due to time constraints and the end of the semester rapidly approaching, a manufacture’s input has not been attained but a more accurate cost has still been determined.

The Shuttle will require a device much like a ship-to-shore crane uses to lower to the container, latch onto it, and lift it up. These devices, called spreader bars, are already manufactured by several companies, so rather then make a new design it is the consensus of the group to buy a spreader bar from a current manufacture. Research has shown that a company by the name of Bromma is a predominant manufacture of spreader bars for all over the world. One particular model, named the YSX-45E, would work particularly well with the Shuttle and the YSX-45E costs approximately $70,000 US.

Preliminary engineering and design work expects the Shuttle to weigh 100,000lbs or more and steel will be the major raw material used in production. High demands for steel in the world market today dictate a price of roughly $5 (this is on the high end of the scale) per pound of steel. At 100,000 lbs, there will be at least $500,000 in just the cost of steel for the Shuttle.

Before the shuttle can be manufactured, though, there are still other items which will need to be purchased to complete it. For example, the Shuttle is to be powered by linear induction motor (LIM) and be computer controlled, so these items will need to be costed-out. A non-comprehensive list of the components which will need to be purchased to complete the shuttle and their approximate costs is included in the table below.

#	Purchased Items	Quantity	Estimated Cost Each ($)	Total Cost ($)
1	Hoisting Motor	2	10,000	20,000
2	Rotation Motor	1	10,000	10,000
3	Computer	1	20,000	20,000
4	Storage Batteries	1	20,000	20,000
5	Transformer/Power Electronics	2	30,000	60,000
			Total,$	**130,000**

Table 2: Cost Estimate for Purchased Items

Without a manufacture's input for what it might cost to manufacture the Shuttle, a few assumptions must be made. The Shuttle will *not* be manufactured in high volumes like automobiles, so it will be safe to assume that manufacturing cost will be generally higher. Also, due to the size and weight of the Shuttle, there is not going to be a large number of manufactures willing or able to make such a vehicle and this also will add to the cost. Speaking with IIT professors from the MMAE department, a multiplying factor of 3 was chosen as a way to get an estimated cost for the steel in the Shuttle, which means is that the raw material cost can be multiplied by a factor of 3 to get an estimate for what the final cost of the steel in fabricated, joined and assembled form. For example, if the steel cost is $5 per pound, then the cost of the steel in its final, desired form (fabricated, joined, and assembled) is $15 per pound. A spreadsheet indicating this multiplying factor and thus giving the total Shuttle cost estimate is provided in Table 3 below.

Shuttle Cost Estimation Sheet			
#	**Item**	**Value**	**Total, $**
1	Raw Material (steel)	100,000 lbs	
	Multiplying factor	3	
	Steel price per pound	$5/lb	
	Finished material price		1,500,000
2	Purchashed Items	$130,000	130,000
		TOTAL	**1,630,000**

Table 3: Shuttle Cost Estimation Table

Thus, it is evident that the cost of the Shuttle is sensitive to the cost of the raw steel. Rough estimates for the cost of the shuttle indicate that the original value of $500,000 was in error and the current values indicate a cost of approximately $1.5-2.0 million per Shuttle. Without contacting a manufacture the current estimate will still be in error but certainly not as much as last semester's figure.

Conclusion

In terms of the progress of the second semester of IPRO 307 with respect to the Shuttle vehicle, it can be said that the question of what the Shuttle is and what its requirements are have been answered. There now exists a detailed Shuttle design including engineering drawings, and an updated estimate for the cost of the Shuttle. Although there has been a great deal of progress made, there is still quite a bit of work before this area of study is complete. The following is a short but not entirely complete list of what still needs to be accomplished.

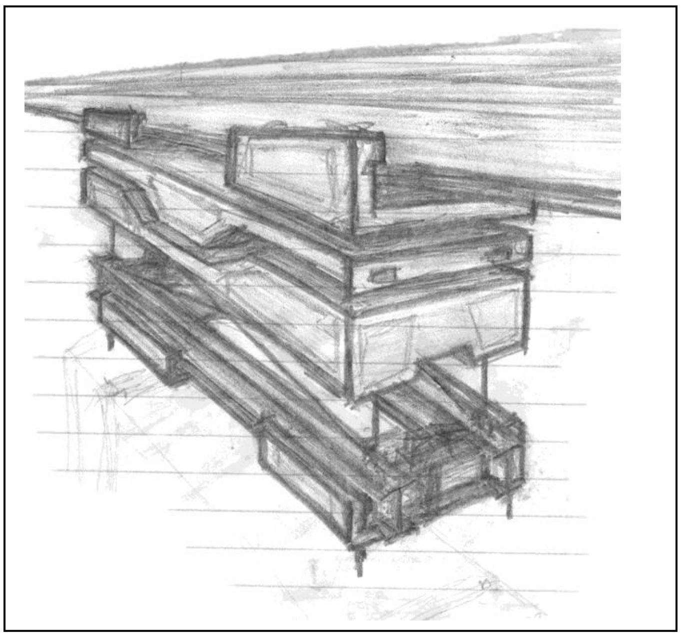
Although a detailed Shuttle design has been provided, this project is far from complete. Structural analysis of the Shuttle vehicle is required to ensure that the design chosen is not only feasible but practical as well. Input from a manufacture such as Caterpillar or Mi-Jack would go a long way to help with this task. Finite Element Analysis (FEA) software is available for use at the university and this would be an invaluable tool for performing structural analysis. This software allows for structural analysis to be performed on much more complicated problems and in less time then possible by hand calculations. Also, the Shuttle is to work with the GRAIL structure and FEA analysis of this structure should be performed to make certain that it can simultaneously support the weight of multiple Shuttles. It should be noted that FEA is a sophisticated tool and requires a person with a background in solid mechanics as well as design specifics in order to accomplish the design tasks.

The Shuttle is to be powered by a linear induction motor (LIM) but even after extensive research this semester, there are no specific details as to exactly what type of LIM the Shuttle would need or the LIM's specifications. LIM technology for this application is not known to currently exist so detailed information will be required to either prove or disprove LIM's use on the shuttle. If LIM technology is proven to work, then detailed drawings and exact specifications such as the type, location, size, number, power source, efficiency, etc. is <u>required</u>. Also, if LIM is found to be impractical, then a suitable propulsion system would need to be determined and proven to the same level as stated earlier (to the same detail that the LIM would need to be documented). Also, if an alternate propulsion is specified, then appropriate modification to the shuttle design would be required. This information will be able to further the cost estimate of the shuttle and should be done.

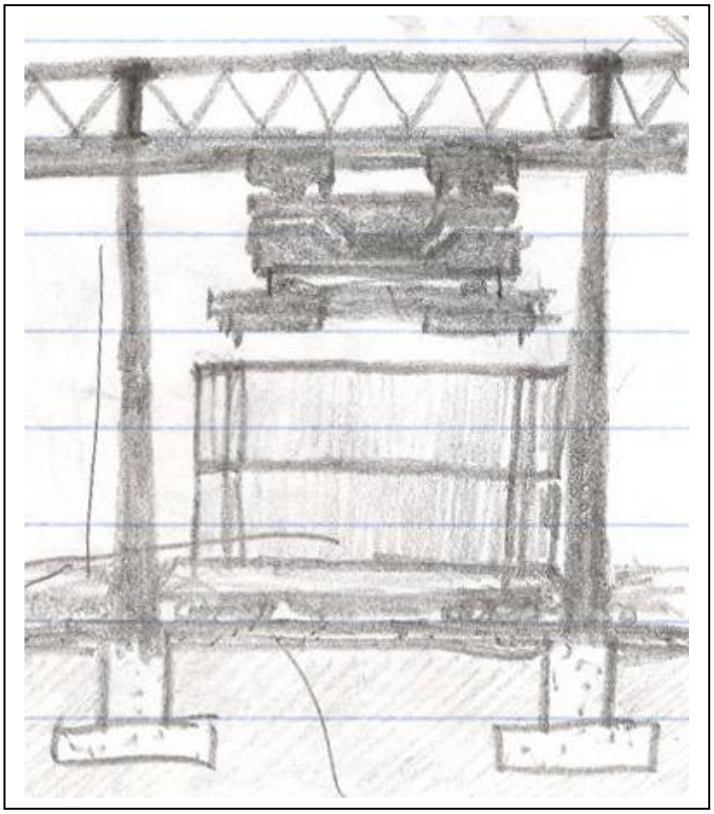
Appendix

Appendix A:

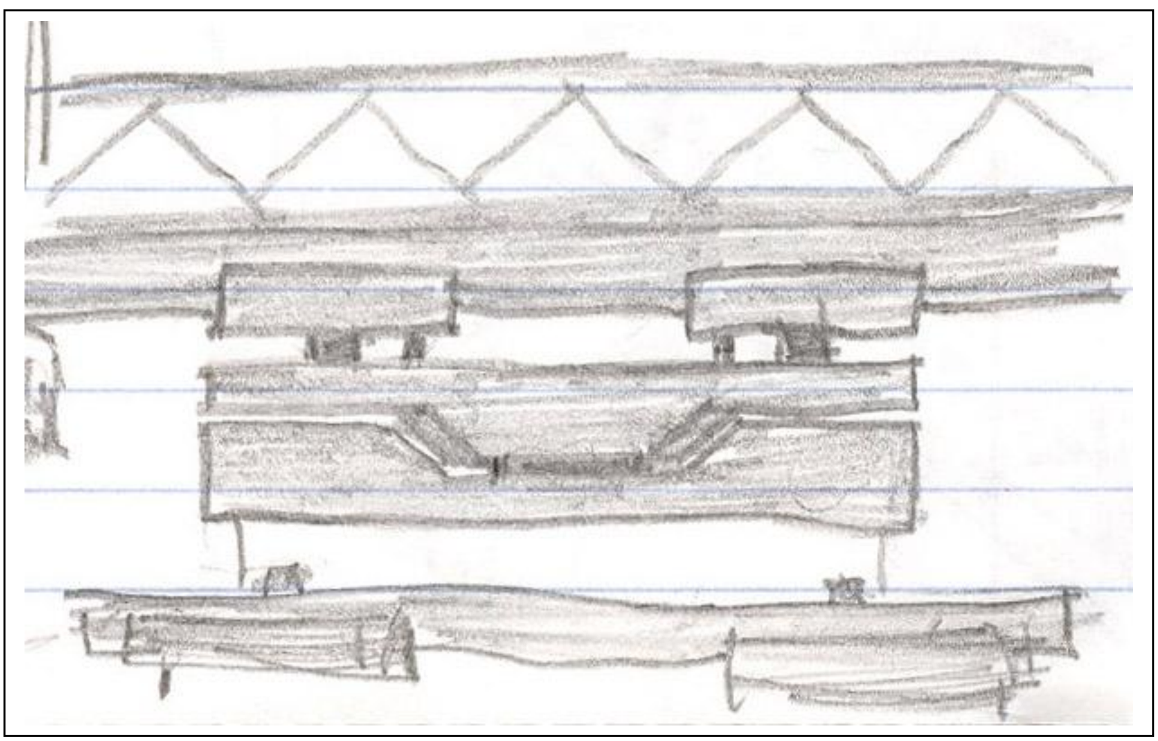
Ideas for what the Shuttle should look like came from many different preliminary sketches. Some of the sketches used are provided below.



Sketch 1: Preliminary sketch of Shuttle



Sketch 2: Shuttle lifting container



Sketch 3: Side view of Shuttle

Appendix B:

As stated in section 3, several parts of the Shuttle were modeled with CAD software and 2D engineering drawings were produced. For those parts with such an engineering drawing, a copy is provided in this section. Table 4 lists the various parts with drawings.

#	Part	Size	Part Number	Drawing Number
1	Shuttle truck(bogie) body	B	1	18
2	Shuttle Truck Guide Pin	A	20	19
3	Shuttle truck load wheel	A	2	17
4	Shuttle truck side wheel	A	3	16
5	Shuttle truck slider bar	A	4	15
6	LIM	A	5	14
7	Shuttle Body: Upper	B	6	13
8	Shuttle Spur Gear	A	7	12
9	Shuttle Pinion Gear	A	8	11
10	Shuttle Body: Lower	B	9	10
12	Cable Spool	A	11	9
14	Cable Pulley	A	13	8
17	Shuttle Retention Plate	A	17	7
18	Shuttle Truck Retention Plate	A	18	6

Table 4: Engineering Drawing List

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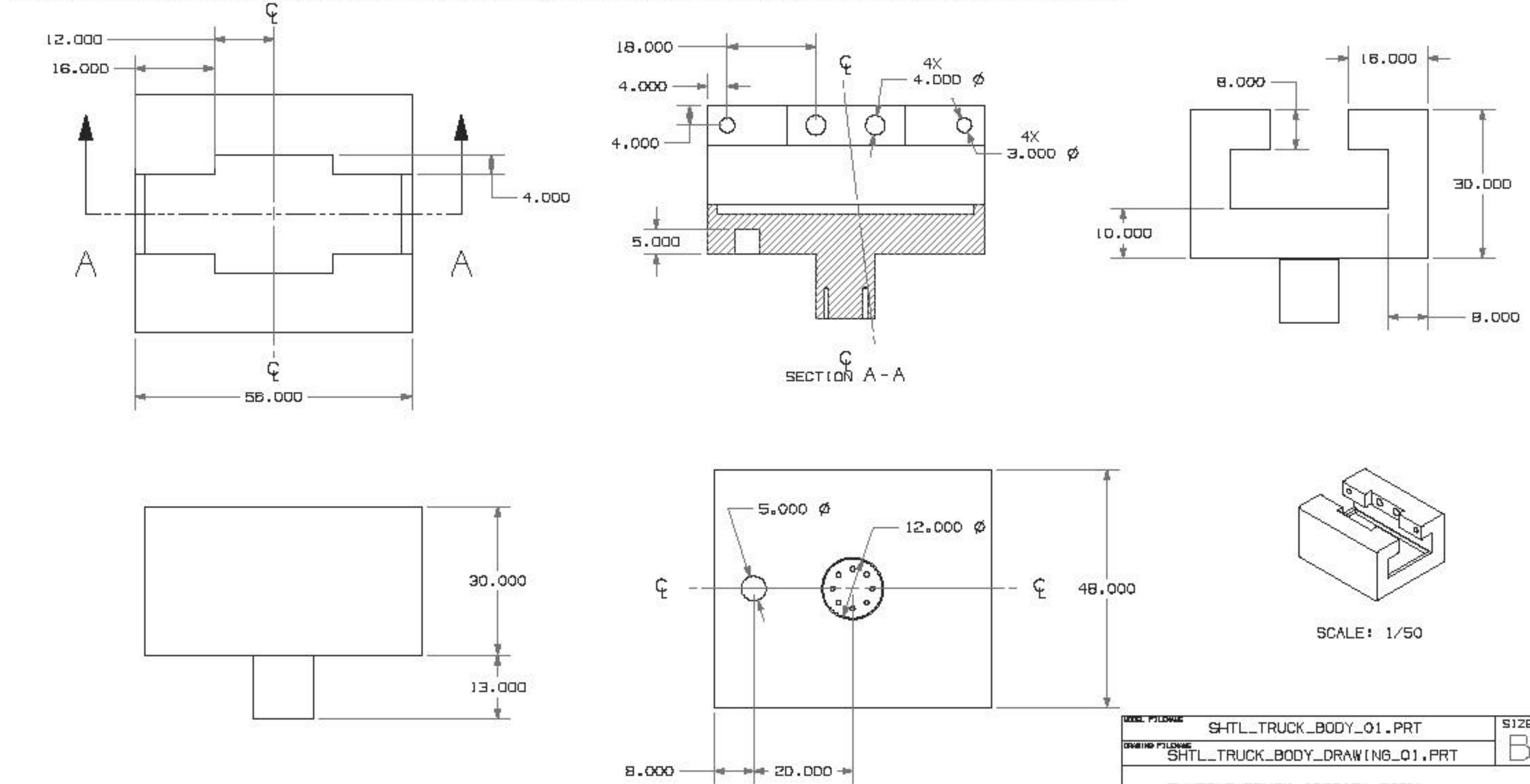

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MODEL FILENAME: SHTL_TRUCK_BODY_01.PRT

DRAWING FILENAME: SHTL_TRUCK_BODY_DRAWING_01.PRT

SIZE: B

SHUTTLE TRUCK (BOGIE) BODY

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THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
(.X) ±.03 (.XXX) ±.005
(.XX) ±.01 ANGLES ± 1°

DRAWN BY: AGF

DATE: 11/23/2004

CHK'D:

REVISED DRAWING NUMBERS

MAT'L:

I.J. NUMBER: NS-XXXX

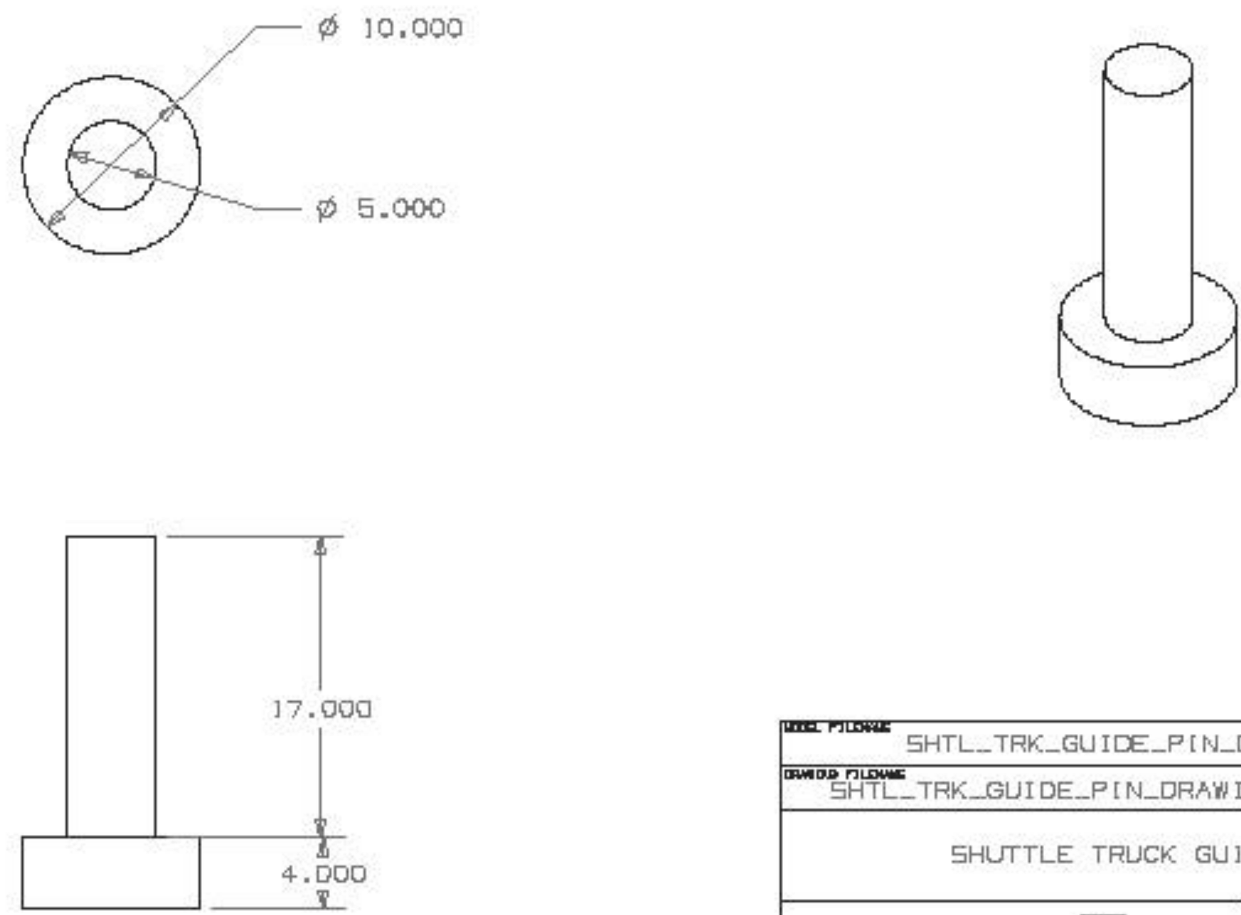
PRODUCT SPEC/ PKG SPEC: XXX

ASSY METHOD/ TEST METHOD: XXX

SCALE: 1/20

PART NO.: 001

DRAWING NO.: 018



X	=	X		X	X			
REV	DATE	BY	CHK	DESCRIPTION	ECN - R	CUST	SUP	OTH

MODEL FILENAME: SHTL_TRK_GUIDE_PIN_DD.PRT

DRAWING FILENAME: SHTL_TRK_GUIDE_PIN_DRAWING_DD.PRT

SIZE: A

SHUTTLE TRUCK GUIDE PIN

ILLINOIS INSTITUTE OF TECHNOLOGY

THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.

DIMENSIONAL TOLERANCES ARE:
[.X] ±.03 [.XXX] ±.006
[.XX] ±.01 ANGLES ± 1°

I.J. NUMBER: NS-XXXX

PRODUCT SPEC/ PKG SPEC: XXX

ASSY METHOD/ TEST METHOD: XXX

SCALE: 1/10

DRAWN BY: AGF

DATE: 11/28/2004

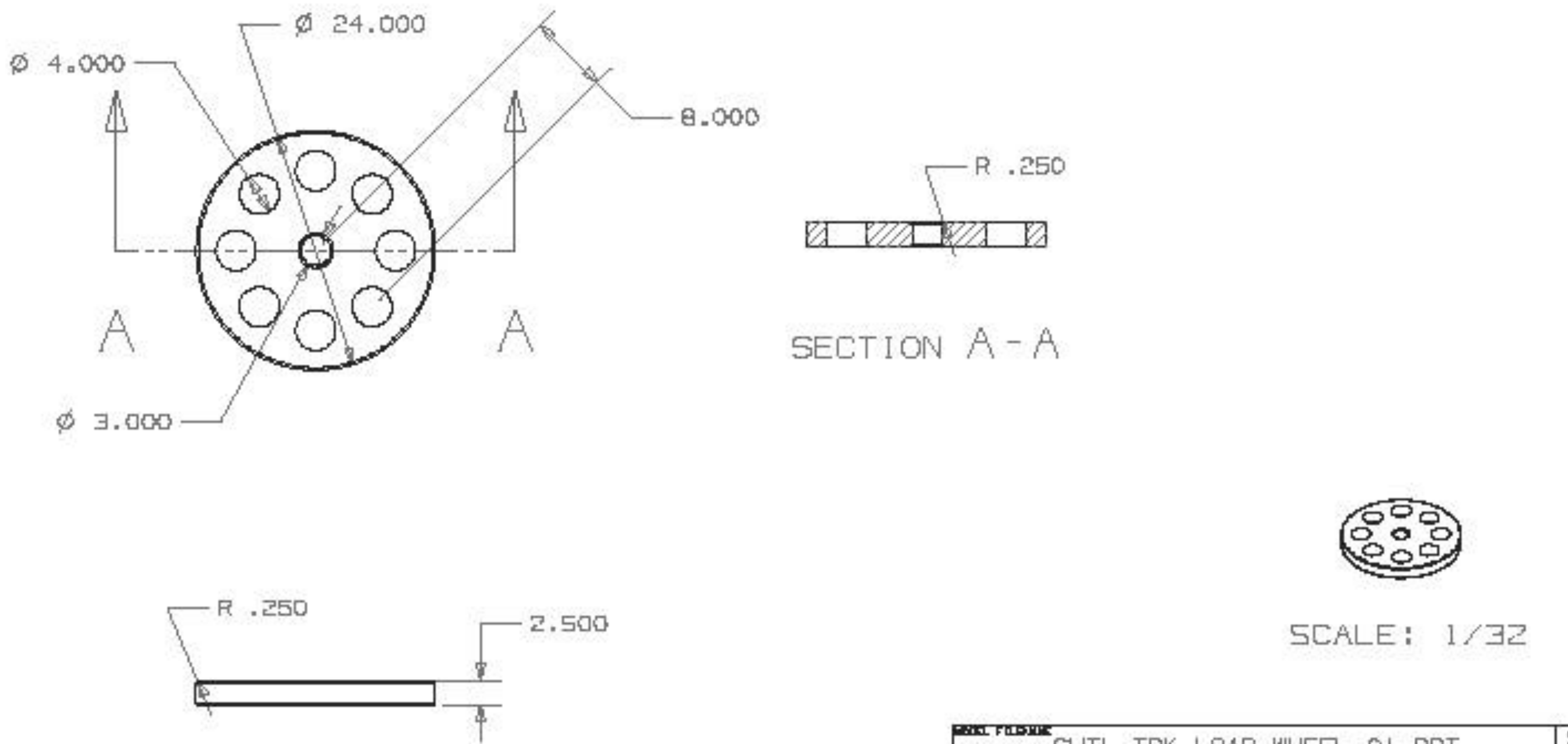
CHK'D:

REVISION DRAWING NUMBERS

MAT'L

PART NO.: XXXXX-XX

DRAWING NO.: XXXXX-XX



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DRAWING FILENAME	SHTL_TRK_LOAD_WHEEL_DRAWING_00.PRT
SIZE	A

SHUTTLE TRUCK LOAD WHEEL

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THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE SHOWN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
[.X] ±.03 [.XXX] ±.005
[.XX] ±.01 ANGLES ± 1°

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DRAWING NO.	017
DRAWN BY	AGF
DATE	11/25/2004
CHK'D	
REVIEW DRAWING NUMBERS	
MAT'L	

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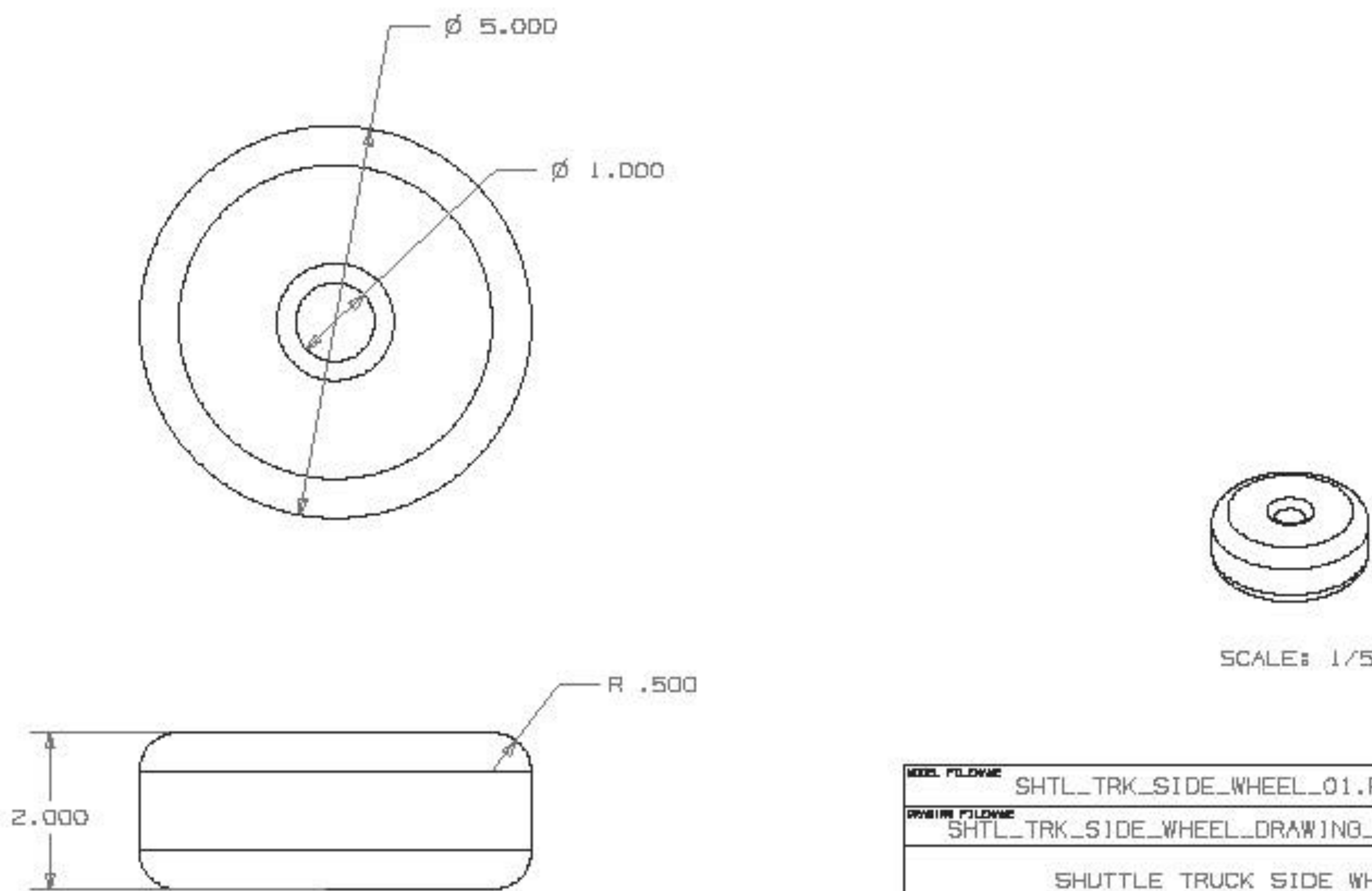

SCALE: 1/5

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DRAWING FILENAME: SHTL_TRK_SIDE_WHEEL_DRAWING_00.PRT

SIZE: A

SHUTTLE TRUCK SIDE WHEEL

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THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
(.X) ±.03 (.XXX) ±.005
(.XX) ±.01 ANGLES ± 1°

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PRODUCT SPEC/ PRG SPEC: XXX

ASSY METHOD/ TEST METHOD: XXX

SCALE: 1/2

DRAWN BY: AGF

DATE: 11/25/2004

CHK'D:

REVISED DRAWING NUMBERS:

MAT'L:

PART NO.: 003

DRAWING NO.: 016

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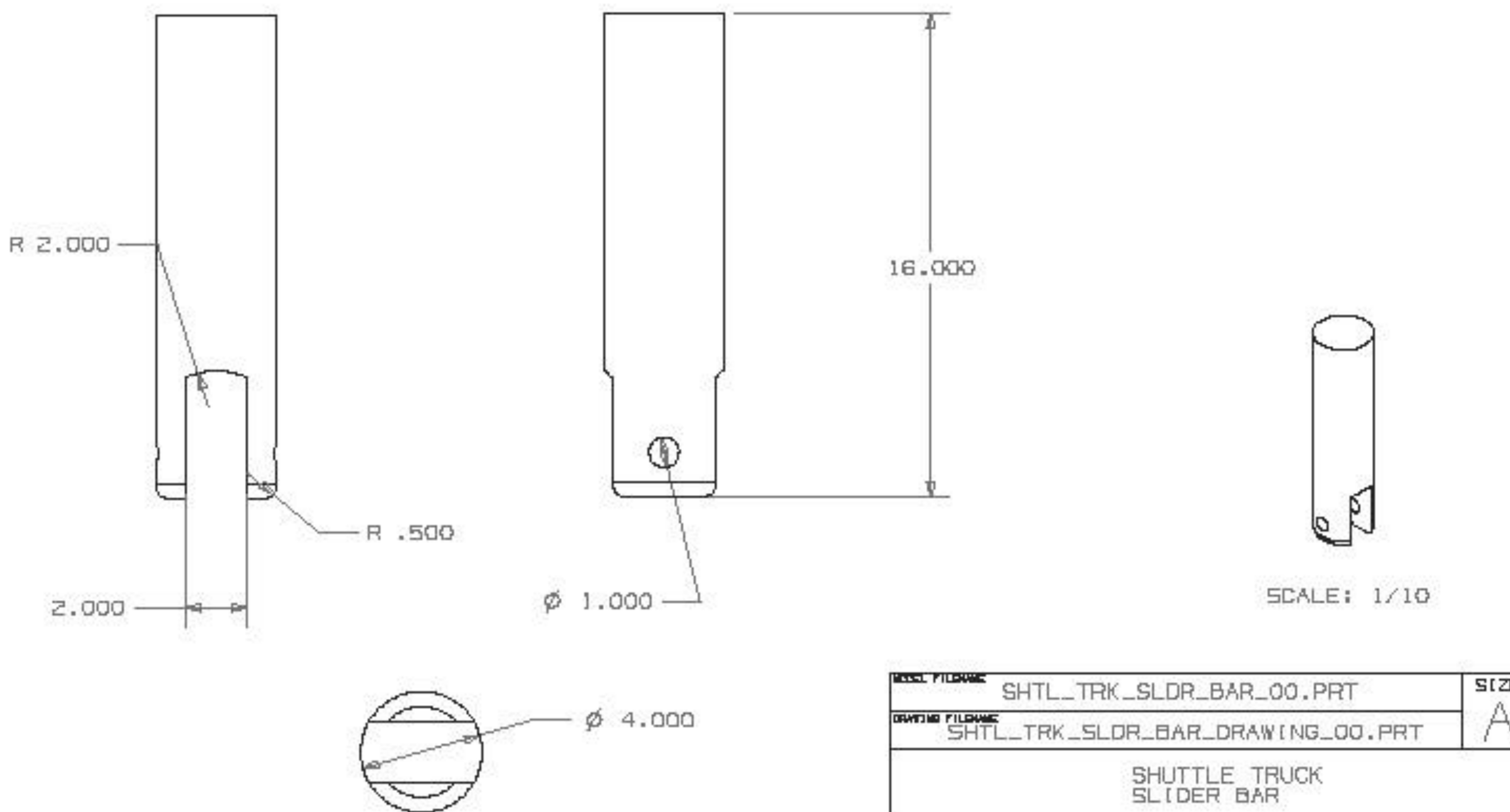

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	ILLINOIS INSTITUTE OF TECHNOLOGY
I.I. NUMBER	NS-XXXX
PRODUCT SPEC/ PUB SPEC	XXX
ASST METHOD/ TEST METHOD	XXX
SCALE	1/5
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DRAWING NO.	015
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DRAWN BY	AGF
DATE	11/25/2004
CHK'D	
REVISE DRAWING NUMBERS	
MAT'L	

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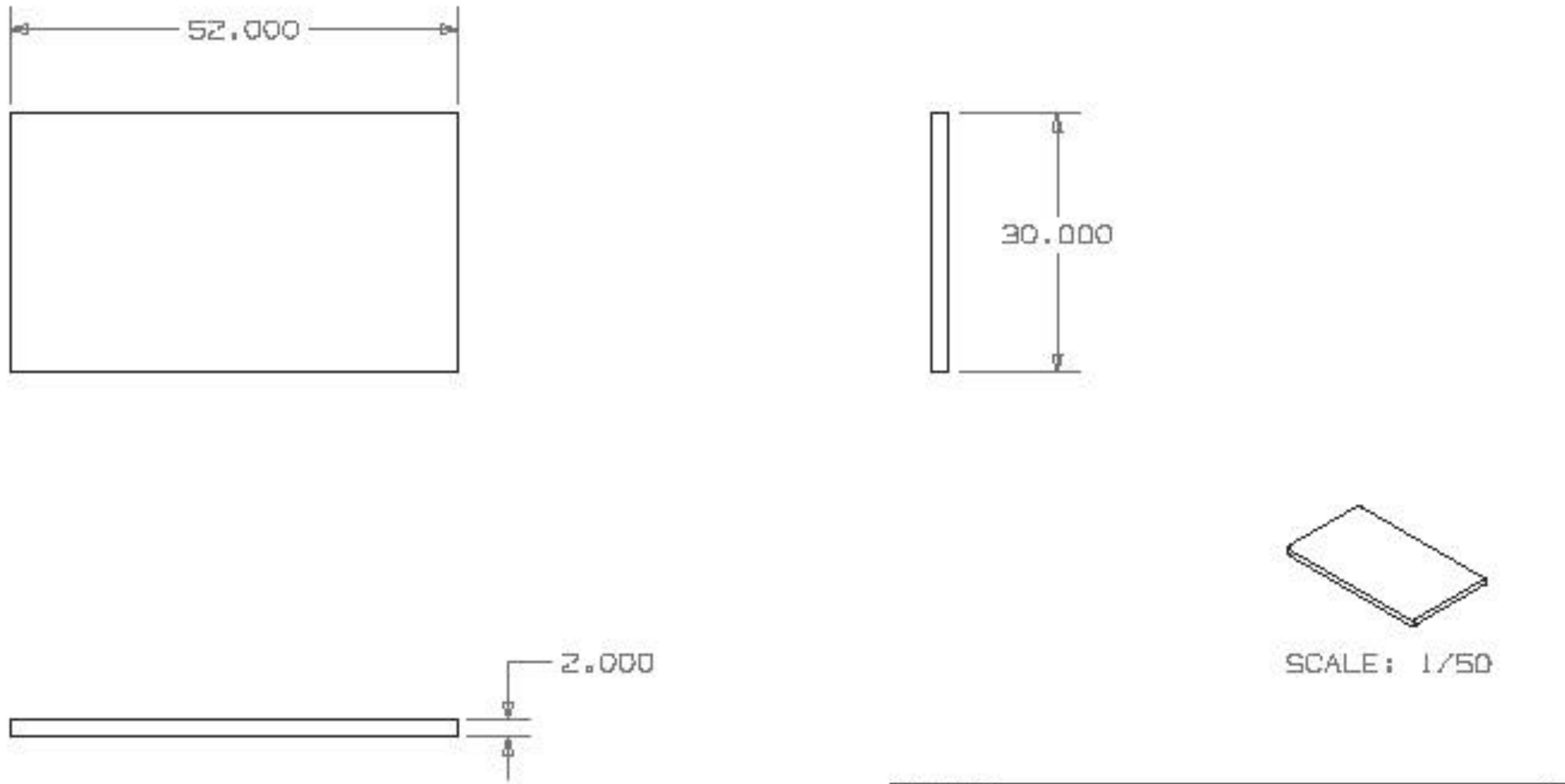

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SIZE	A

SHUTTLE LINEAR INDUCTION MOTOR

ILLINOIS INSTITUTE OF TECHNOLOGY

THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
(.X) ±.03 (.XXX) ±.005
(.XX) ±.01 ANGLES ± 1°

I.C. NUMBER	NS-XXXX
PRODUCT SPEC/ PRG SPEC	XXX
ASSY METHOD/ TEST METHOD	XXX
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DRAWING NO.	014
DRAWN BY	AGF
DATE	11/27/2004
CHK'D	
REVIEW DRAWING NUMBERS	
MAT'L	

REV	DATE	BY	CHK	DESCRIPTION	ECN - R	CUST	SUP	OTH
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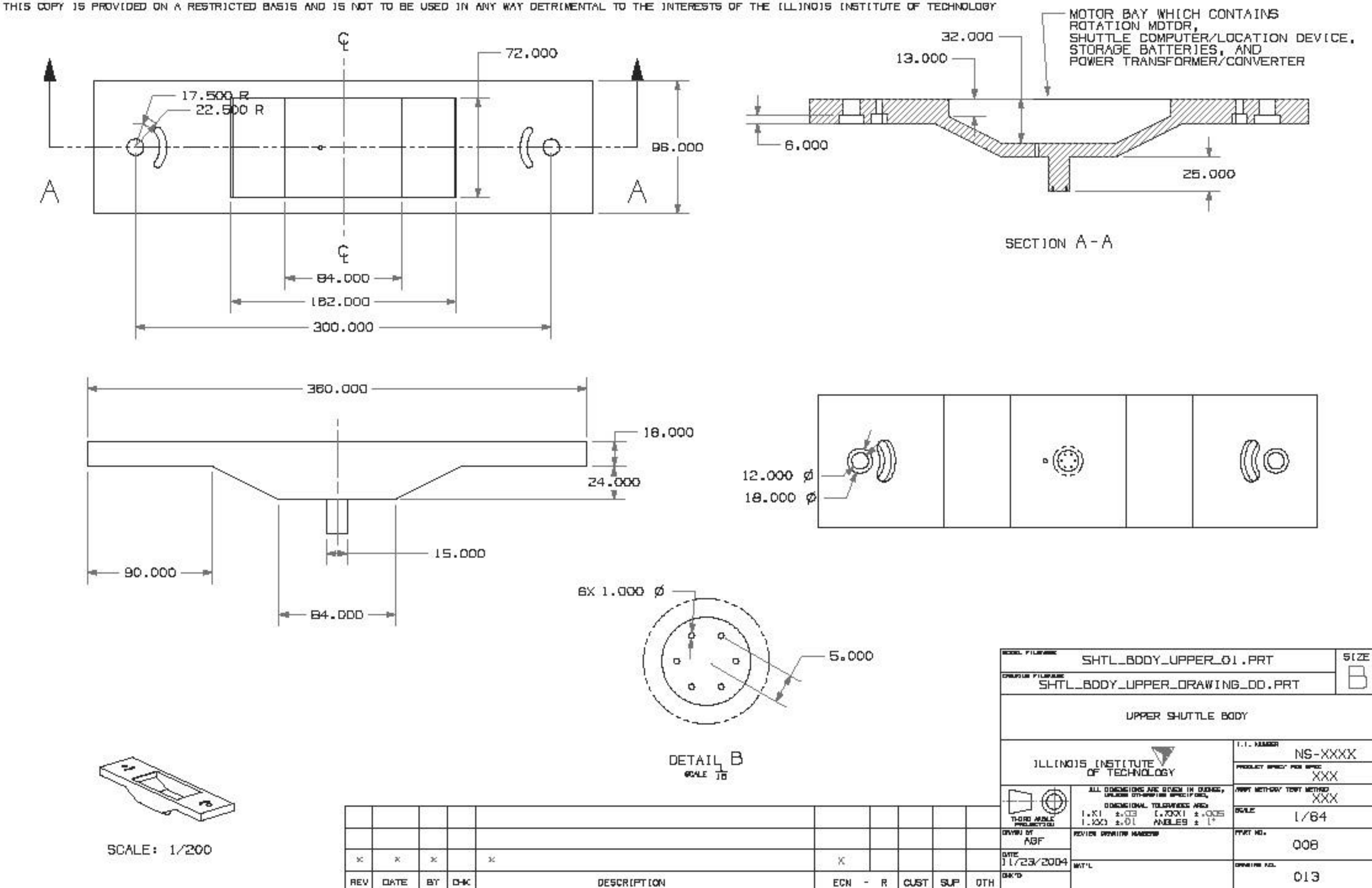
MOTOR BAY WHICH CONTAINS
ROTATION MOTOR,
SHUTTLE COMPUTER/LOCATION DEVICE,
STORAGE BATTERIES, AND
POWER TRANSFORMER/CONVERTER
72.000
17.500 R
22.500 R
96.000
84.000
182.000
300.000
32.000
13.000
6.000
25.000
SECTION A-A
360.000
18.000
24.000
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90.000
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6X 1.000 Ø
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DETAIL B
SCALE 1/16
SCALE: 1/200
SHTL_BODY_UPPER_01.PRT
SHTL_BODY_UPPER_DRAWING_00.PRT
SIZE B
UPPER SHUTTLE BODY
ILLINOIS INSTITUTE OF TECHNOLOGY
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1/64
008
013
THIRD ANGLE PROJECTION
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DATE 11/23/2004
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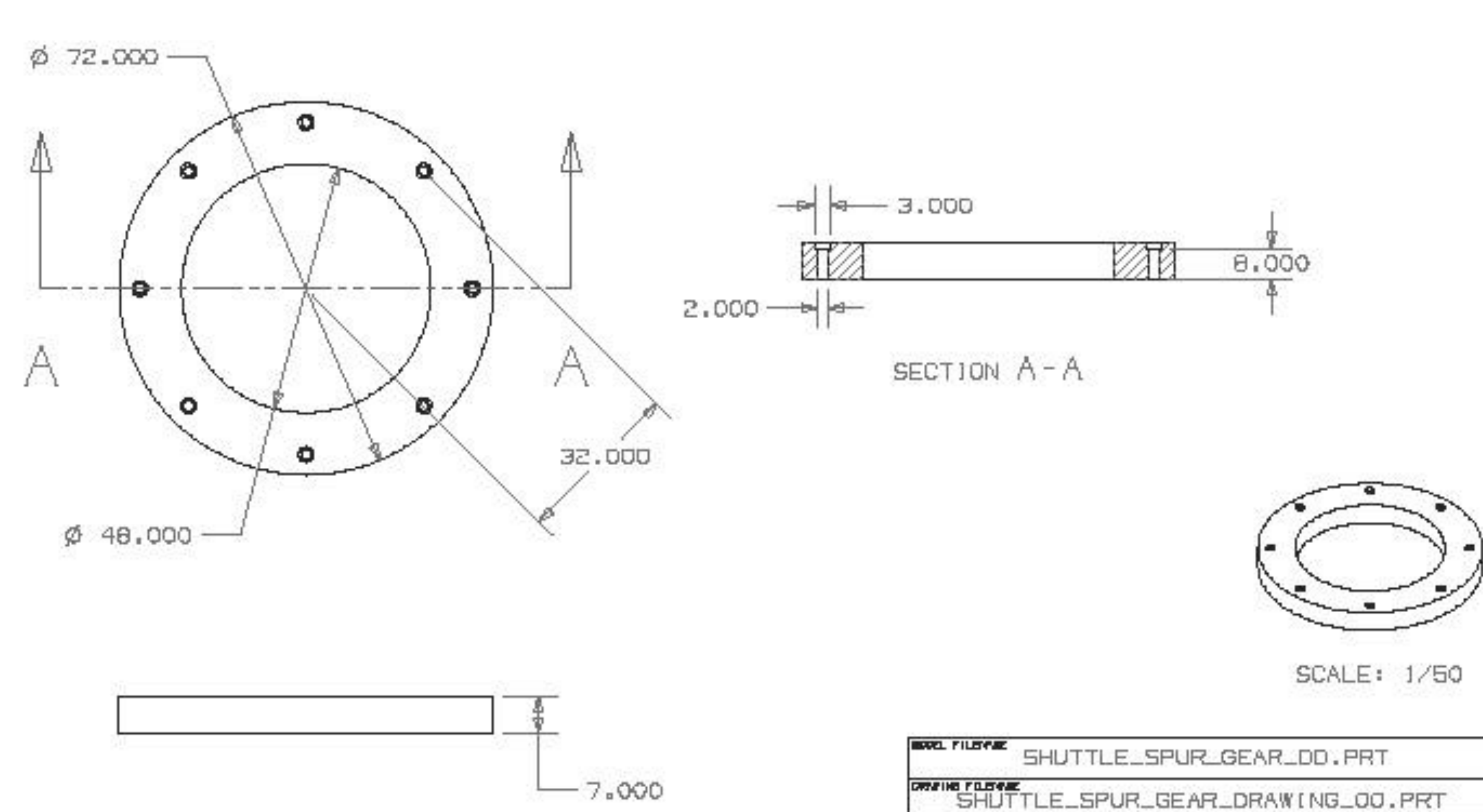

NOTES:
1) THIS IS A REPRESENTATION OF A GEAR
2) ACTUAL SIZE AND TYPE OF TEETH OF THIS GEAR
IS TO BE DETERMINED

MODEL FILENAME: SHUTTLE_SPUR_GEAR_00.PRT
DRAWING FILENAME: SHUTTLE_SPUR_GEAR_DRAWING_00.PRT
SIZE: A

SHUTTLE DRIVE GEAR (SPUR)

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DIMENSIONAL TOLERANCES ARE:
(.X) ±.03 (.XXX) ±.005
(.XX) ±.01 ANGLES ± 1°

THIRD ANGLE PROJECTION

I.C. NUMBER	NS-XXXX
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TEST METHOD/ TEST METHOD	XXX
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DRAWING NO.	012

DRAWN BY: ABF
DATE: 11/28/2004
CHK'D:
REVIEW DRAWING NUMBERS
MAT'L

REV	DATE	BY	CHK	DESCRIPTION	ECN - R		CUST	SUP	OTH
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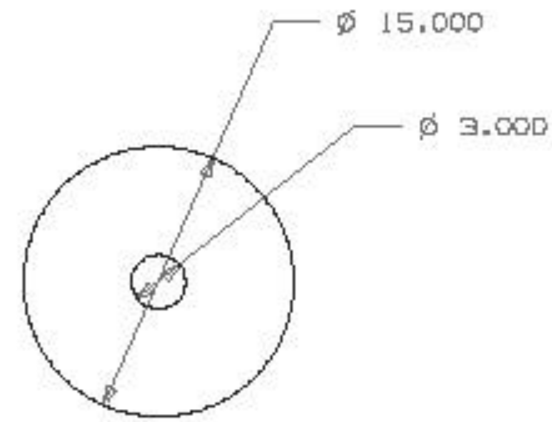

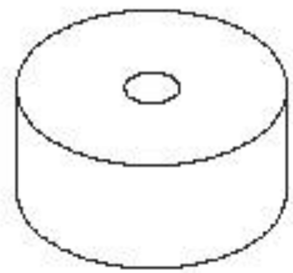

NOTES:
1) THIS IS A REPRESENTATION OF A GEAR
2) ACTUAL SIZE AND TYPE OF TEETH OF THIS GEAR IS TO BE DETERMINED

MODEL FILENAME: PINION_GEAR_00.PRT

DRAWING FILENAME: PINION_GEAR_DRAWING_00.PRT

SIZE: A

SHUTTLE DRIVE GEAR (PINION)

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THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
(.X) ±.03 (.XXX) ±.005
(.XX) ±.01 ANGLES ± 1°

C.I. NUMBER: NS-XXXX
PRODUCT SPEC/ PKG SPEC: XXX
ASSY METHOD/ TEST METHOD: XXX
SCALE: SCALE: 1/10
DRAWN BY: AGF
DATE: 11/28/2004
REVISED DRAWING NUMBERS:
MAT'L:
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PART NO.: 008
DRAWING NO.: 011

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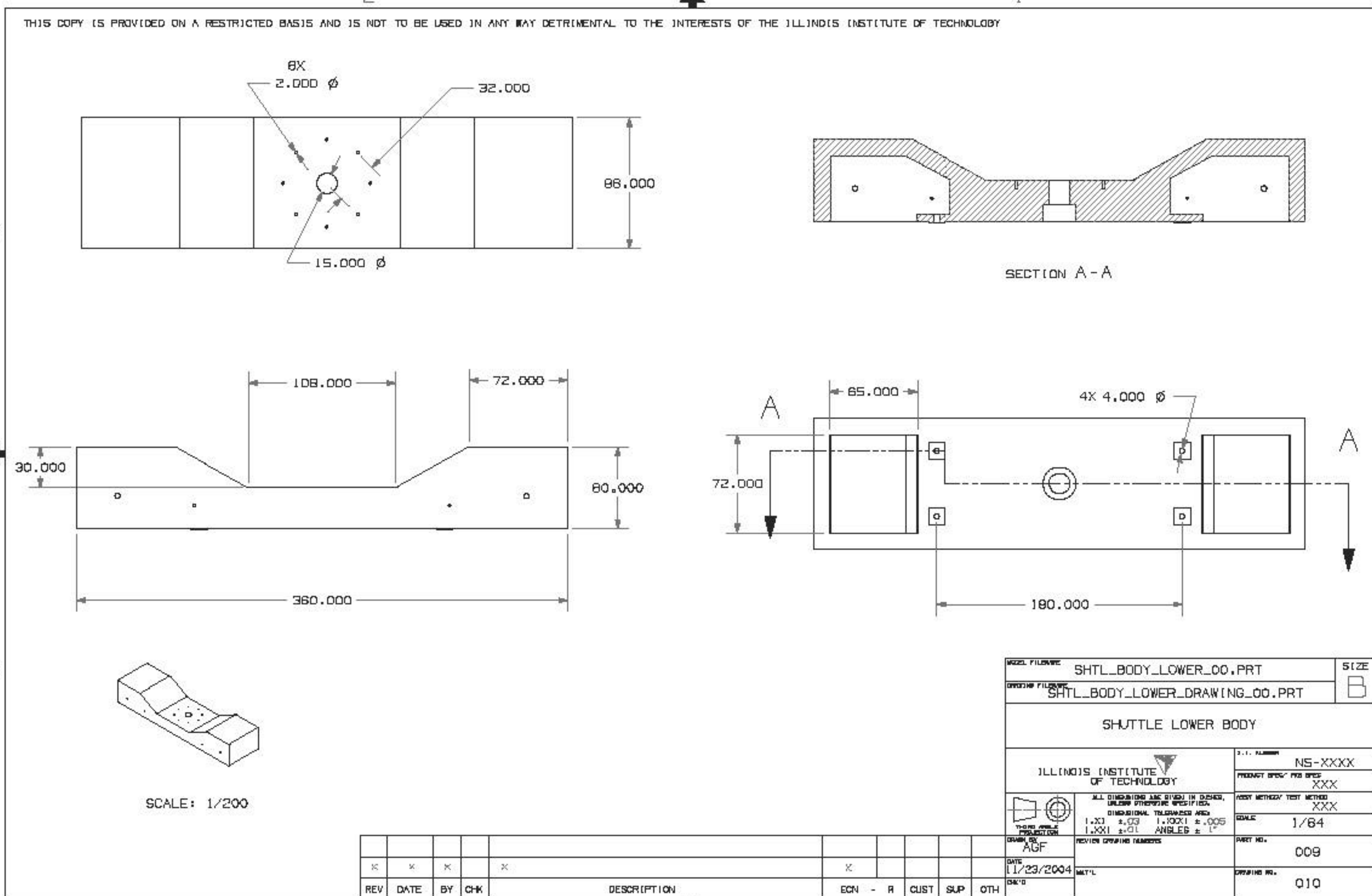

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8X
2.000 Ø
32.000
88.000
15.000 Ø
SECTION A-A
108.000
72.000
30.000
80.000
360.000
A
65.000
4X 4.000 Ø
72.000
A
180.000
SCALE: 1/200
SHTL_BODY_LOWER_00.PRT
SHTL_BODY_LOWER_DRAWING_00.PRT
SIZE
B
SHUTTLE LOWER BODY
ILLINOIS INSTITUTE OF TECHNOLOGY
NS-XXXX
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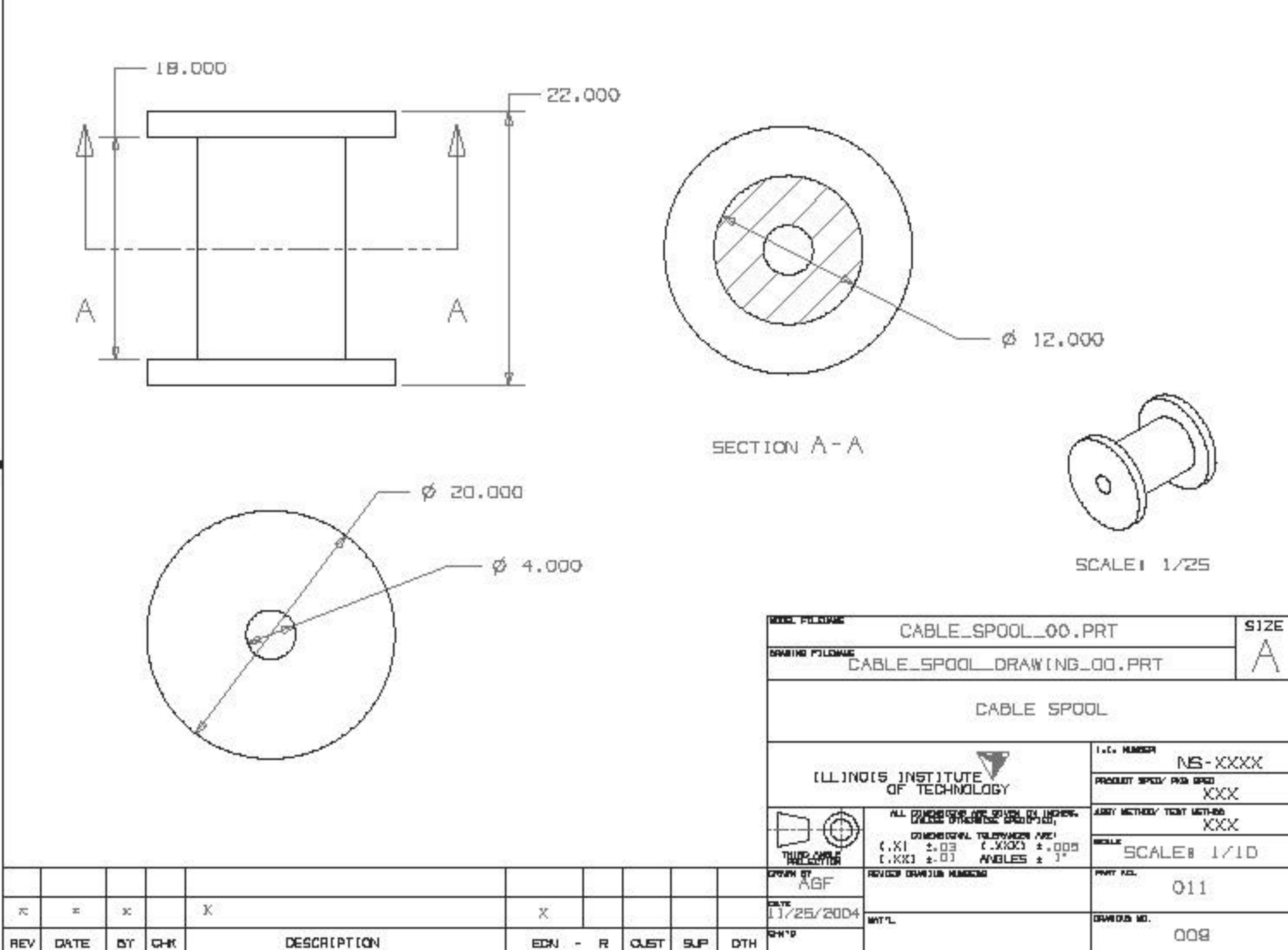
18.000
22.000
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Ø 20.000
Ø 4.000
SCALE: 1/25
MODEL FILENAME
CABLE_SPOOL_00.PRT
DRAWING FILENAME
CABLE_SPOOL_DRAWING_00.PRT
SIZE
A
CABLE SPOOL
ILLINOIS INSTITUTE OF TECHNOLOGY
I.C. NUMBER
NS-XXXX
PRODUCT SPEC/ PKG SPEC
XXX
ASSY METHOD/ TEST METHOD
XXX
SCALE
SCALE: 1/10
THIRD ANGLE PROJECTION
DIMENSIONAL TOLERANCES ARE:
[.X] ±.03 [.XXX] ±.005
[.XX] ±.01 ANGLES ± 1°
DRAWN BY
AGF
DATE
11/25/2004
CHK'D
REVISED DRAWING NUMBERING
MAT'L
PART NO.
011
DRAWING NO.
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REV
DATE
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DESCRIPTION
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X

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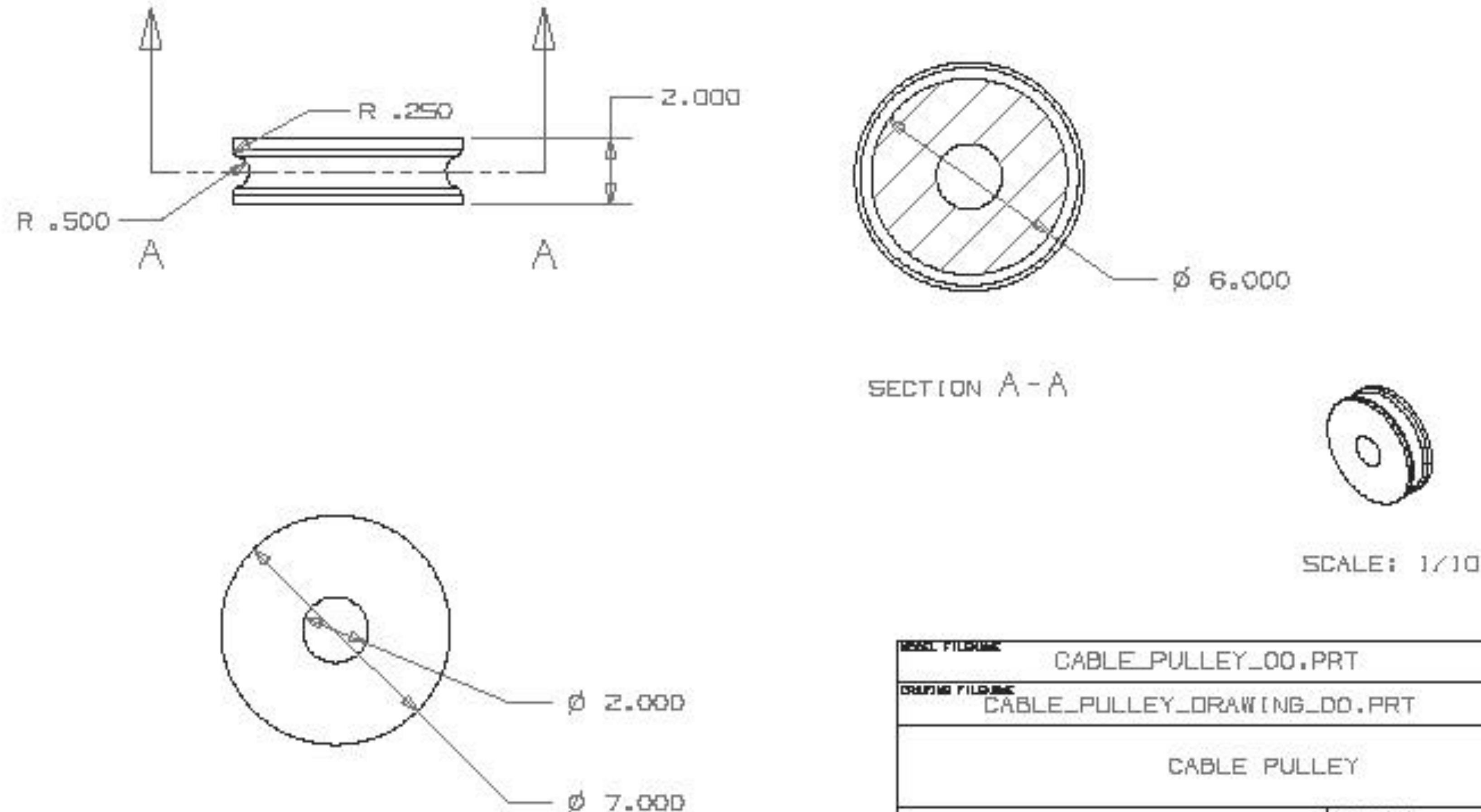

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DRAWING FILENAME: CABLE_PULLEY_DRAWING_00.PRT

SIZE: A

CABLE PULLEY

ILLINOIS INSTITUTE OF TECHNOLOGY

THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE SHOWN IN INCHES, UNLESS OTHERWISE SPECIFIED.
DIMENSIONAL TOLERANCES ARE:
[.X] ±.03 [.XXX] ±.005
[.XX] ±.01 ANGLES ± 1°

I.I. NUMBER: NS-XXXX

PRODUCT SPEC/ PER SPEC: XXX

ASSY METHOD/ TEST METHOD: XXX

SCALE: SCALE: 1/5

DRAWN BY: AGF

DATE: 11/25/2004

CHK'D:

DEVICE DRAWING NUMBERS:

MAT'L:

PART NO.: 013

DRAWING NO.: 008

REV	DATE	BY	CHK	DESCRIPTION	ECN - R	CUST	SUP	OTH
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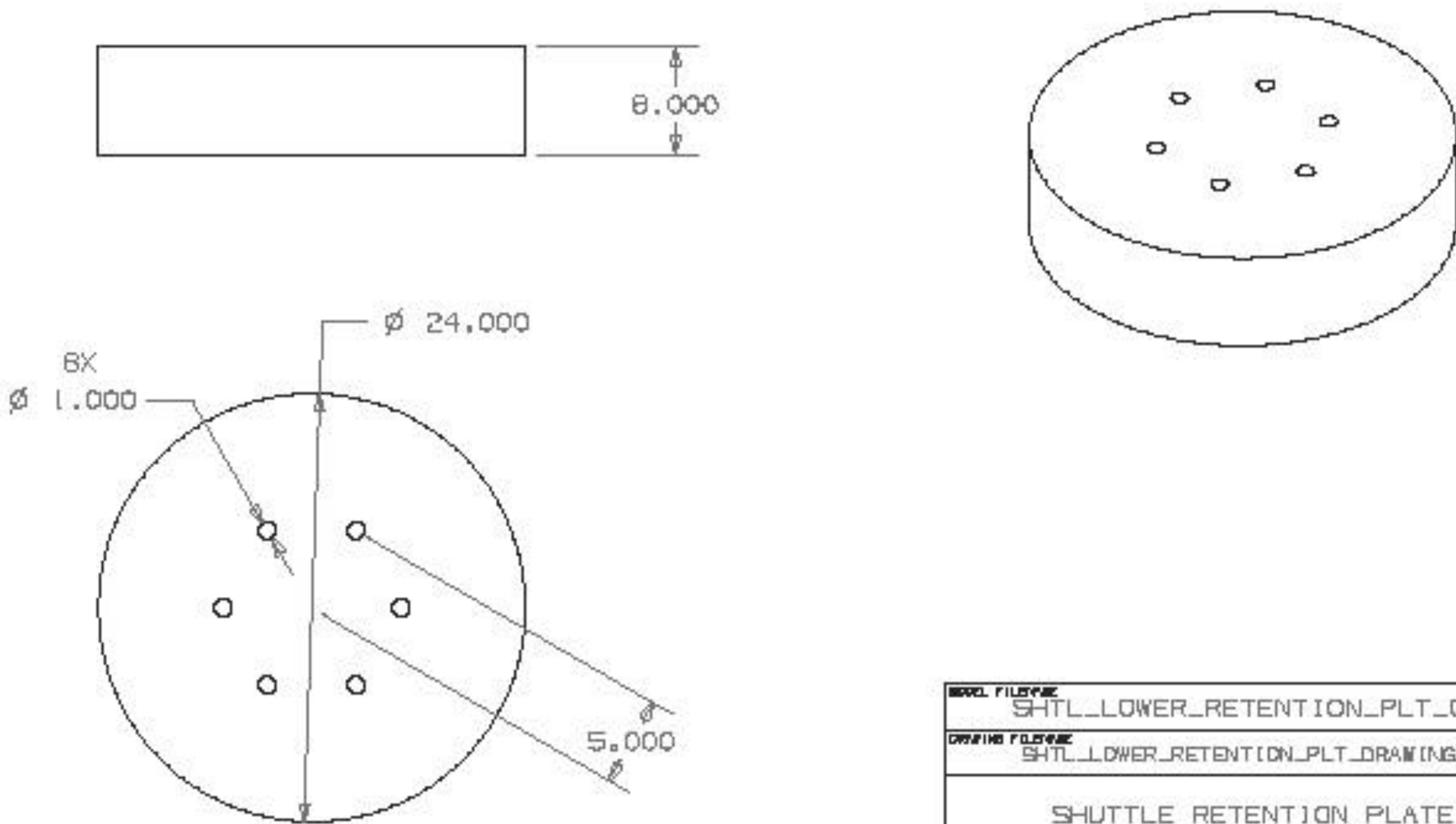

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DRAWING FILENAME: SHTL_LOWER_RETENTION_PLT_DRAWING_00.PRT

SIZE: A

SHUTTLE RETENTION PLATE (LOWER)

ILLINOIS INSTITUTE OF TECHNOLOGY

I.I. NUMBER: NS-XXXX

PRODUCT SPEC/ PUR SPEC: XXX

ASSY METHOD/ TEST METHOD: XXX

THIRD ANGLE PROJECTION

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED,

DIMENSIONAL TOLERANCES ARE:

[.X] ±.03 [.XXX] ±.005

[.XX] ±.01 ANGLES ± 1°

SCALE: SCALE: 1/10

DRAWN BY: AGF

REVIEW DRAWING NUMBERS

PART NO.: 017

DATE: 11/25/2004

MAT'L

DRAWING NO.: 007

CHK'D

x	x	x		X	X			
REV	DATE	BY	CHK	DESCRIPTION	ECN - A	CUST	SUP	OTH

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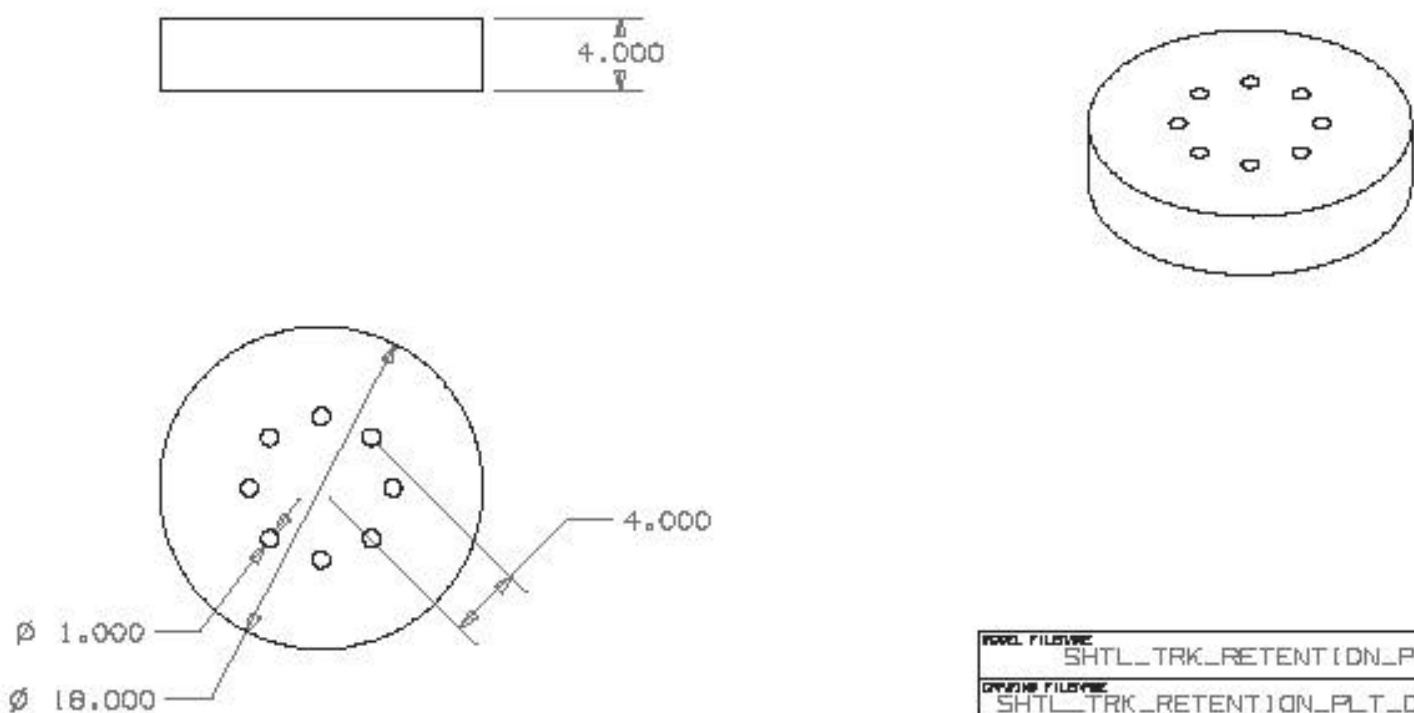


MODEL FILENAME: SHTL_TRK_RETENTION_PLT_00.PRT

DRAWING FILENAME: SHTL_TRK_RETENTION_PLT_DRAWING_00.PRT

SIZE: A

SHUTTLE TRUCK RETENTION PLATE

ILLINOIS INSTITUTE OF TECHNOLOGY

NS-XXXX

PRODUCT SPEC/ PKG SPEC: XXX

TEST METHOD: XXX

ALL DIMENSIONS ARE GIVEN IN INCHES, UNLESS OTHERWISE SPECIFIED.

DIMENSIONAL TOLERANCES ARE:

[.X] ±.03 [.XXX] ±.005

[.XX] ±.01 ANGLES ± 1°

THIRD ANGLE PROJECTION

DRAWN BY: AGF

DATE: 11/25/2004

CHK'D

REVIEW DRAWING NUMBERS

MAT'L

SCALE: 1/10

PART NO.: 018

DRAWING NO.: 006

REV	DATE	BY	CHK	DESCRIPTION	ECN - R		CUST	SUP	OTH
x	x	x		X	X				

Appendix C:

A copy of the "Physics of Seraphim" paper can be found at

http://www.monorails.org/webpix%202/Seraphim101401.pdf

Control Team:
Final Report

Rafiu Amolegbe

Abstract

This paper describes the control system for a high productivity and high-density overhead Grid rail or GRAIL system adjacent to a rail line. The facility will be designed to move containers to and from storage areas and interconnected rail yards. The vehicles of conveyance for the GRAIL system are shuttles. In this design, container-carrying shuttles are routed within the GRAIL: by a master control system. The control system subgroup has been charged with the design of such a network and the acquisition of its software.

The GRAIL system:

The GRAIL proper is the interconnection of overhead monorails for shuttle conveyance of containers. It uses linear induction motors (LIM) to propel shuttles along these monorails. It connects the trains and trucks' loading and unloading terminals, container storage area, repair and maintenance yard and other associated yards.

System Requirements

Our first order of business is to delineate the requirements of our control system. To better understand our goals and the tasks before us, we looked at last semester's requirements for the control system and studied the GRAIL report. We also studied actual control systems at the O'Hare airport transit system and Crate & Barrel automated warehouse in Naperville. And some of our issues were resolved at these facilities. Thereafter, we decided that our control system must meet the following requirements:

Locate shuttles anywhere in the system
Get shuttles to buffer areas, storage locations, and repair and maintenance yard along least traveled routes
Prevent collision by maintaining safe proximity between shuttles
Precisely position shuttles above containers for easy access
Choose container storage locations and direct shuttles accordingly
Interface with other computers in the system including interconnected yards
Schedule maintenance and repair
Bill and notify customers

Shuttles:

The shuttles are the workhorses of the system and are used to move, stack, lift, lower and rotate containers. They are computer controlled and they store and retrieve containers anywhere in the yard in accordance with the tasks assigned them. They are equipped with spreaders with which to pick up the containers and because of the imposing weight of the containers, shuttles may also be equipped with side clamps. All shuttles also carry RFID readers that work in conjunction with the tags on the containers. The shuttle computer initiates all communications between the readers and the tags, both of which are equipped with antennas that receive and emit electromagnetic waves. Data exchange between readers and tags are immediately transmitted to the master control unit. The RFID tag is an integrated electronic circuit and antenna system. They contain memory cells for data storage. These cells may either be read only or read and write. The tags in our design would be a passive as opposed to active, since they will be transmitting information over relatively short ranges. In the course of completing each task, shuttles must avoid collisions and other unsafe situations. The collision detection device on the shuttles are photographic range finders that detect and measure the distance of any object in the path of a shuttle and alerts the shuttles of hazards. The shuttles' transfer of containers within the GRAIL system could be divided into the following tasks:

Transfer of containers between the train and the storage area.
Transfer of containers between trucks and train.
Transfer of containers between trucks and storage area.
Transfer of shuttles to repair and maintenance yard.
Each of these tasks requires a set of commands from the master control unit to the GRAIL components. The issues that arise under such a configuration are numerous and will be resolved in the scenarios.

Scenarios:

The scenarios below illustrate the operations of the control system in conjunction with other components of the GRAIL network. A simplified illustration is presented in FIG. 2 of the appendix.

• Container pick-up
• Train will pull into the yard and stop at loading buffer
• Buffer will notify the yard computer that there is a train waiting to be unloaded
• Yard computer will reference traffic management program and direct shuttle to loading area.
• Shuttle will align itself with the first container on the first car of the train
• Sensor will size container and determine height above container
• Spreader bar will set itself based on the optical scan
• Shuttle will release and lower spreader bar
• Spreader bar will use optical sensors to realign spreader bar over container as lowering
• Once container is clamped, Radio Frequency Identification (RFID) scanner will scan contents of container

• Origin, destination, weight, contents, whether labeled for immediate shipment or storage, serial number, and hazmat label are scanned and sent to yard computer

If labeled for storage

• Yard computer uses Expert program to assign location in the yard for container
• Yard computer then references traffic management program for route to location
• Shuttle raises container and locks spreader bar into place
• Shuttle is directed to determined location and lowers container
• Yard computer confirms container placement and stores location in database

1. If labeled for immediate shipment, Yard computer determines if container requires rubber tire transfer, steel wheel transfer, or inter-yard transfer

1i. If rubber tire transfer
• Truck pulls up to rubber tire transfer buffer[13]
• Buffer aligns truck for shuttle
• Buffer tells yard computer that there is a truck available
• Yard computer instructs shuttle to go to buffer
• Shuttle aligns itself above truck and lowers container
• Container is secured to truck and is transferred

1ii. If Steel Wheel transfer
• Train pulls onto steel wheel transfer buffer[14]
• Buffer tells yard computer that there is a train available
• Yard computer instructs shuttle to go to buffer
• Shuttle aligns itself above train and lowers container
• Container is secured to train and transferred once train is full

1iii. If inter-yard transfer
• Yard computer will communicate with the other yard and notify it of an incoming shipment
• Inter-yard chassis will arrive at inter-yard transfer buffer[16]
• Buffer will tell yard computer that there is a chassis waiting
• Yard computer will direct shuttle to inter-yard buffer
• Shuttle will align itself above chassis and lower container
• Once container is secured to chassis, yard computer will direct chassis to its destination yard
• Chassis will execute transfer

1iv. If container is ready to be transferred
• Yard will reference that database to find container
• Yard computer will direct shuttle to location

1v. If container is buried

a. Yard computer will instruct shuttle to pickup top container and reference expert program to place in new area and send another shuttle to pick up lower container
• Optical sensor will size container
• Spreader bar will set itself based on the attached sensors
• Shuttle will release and lower spreader bar
• As lowering spreader bar will use sensors to realign it's self above container
• Spreader bar will clamp onto container
• Container will be raised and locked
• Yard computer will direct shuttle to steel wheel buffer, rubber tire transfer buffer, or inter-yard transfer buffer

Appendix.

Glossary

1. Loading Buffer – Sensor under rail track to detect whether there is a train present and to line up train with loading points.

2. Yard computer – Main computer in the train yard. The Yard computer utilizes many programs to perform various tasks.

3. Traffic Management Program – A program in the yard computer that keeps track of shuttles and shuttle routes and issues most efficient route when asked how to get from one point to another.

4. Shuttle – A vehicle suspended from the GRAIL that retrieves, lowers, and moves containers to various destinations.

5. Container – A large steel box that is fairly standard for shipping many items. Containers come in sizes ranging from 20ft to 80ft.

6. Sensor – Many spreader bars have available options for sensors for determining the size of a container, and the distance to a container.

7. Spreader Bar – A device commonly used with cranes for grabbing containers.

8. Radio Frequency Identification (RFID) – A device that can communicate encrypted programmed information to an RFID interrogator. The containers will be fitted with a passive RFID tag (Passive meaning non-powered, power is provided through the interrogator) and the shuttles will have active RFID interrogators to read information about the container.

9. Expert Program – Program spoken of in the GRAIL report that has several techniques of storing containers in it. The Techniques were compiled from interviewing many yard managers (in non- automated yards), to efficiently place containers in the yard.

10. Rubber Tire Transfer – Refers to transferring a container to a location through use of trucks with trailers.

11. Steel Wheel Transfer – Refers to transferring a container to a location through use of trains.

12. Inter-Yard Transfer – Refers to utilizing the Inter Yard Structure (Structure that connects various train yards in Chicago designed by IPRO 307) to transfer between yards

13. Rubber Tire Transfer Buffer – A Platform that a truck and trailer park on that arranges the truck to align under shuttle drop point.

14. Steel wheel transfer buffer - Sensor under rail track to detect whether there is a train present and to line up train with drop points.

15. Inter-Yard Chassis – A vehicle that moves along the Inter-Yard Network to transfer containers to various yards.

16. Inter-Yard Transfer Buffer – marker for inter-yard chassis to stop in order to be aligned with shuttle drop point.

Network Configuration

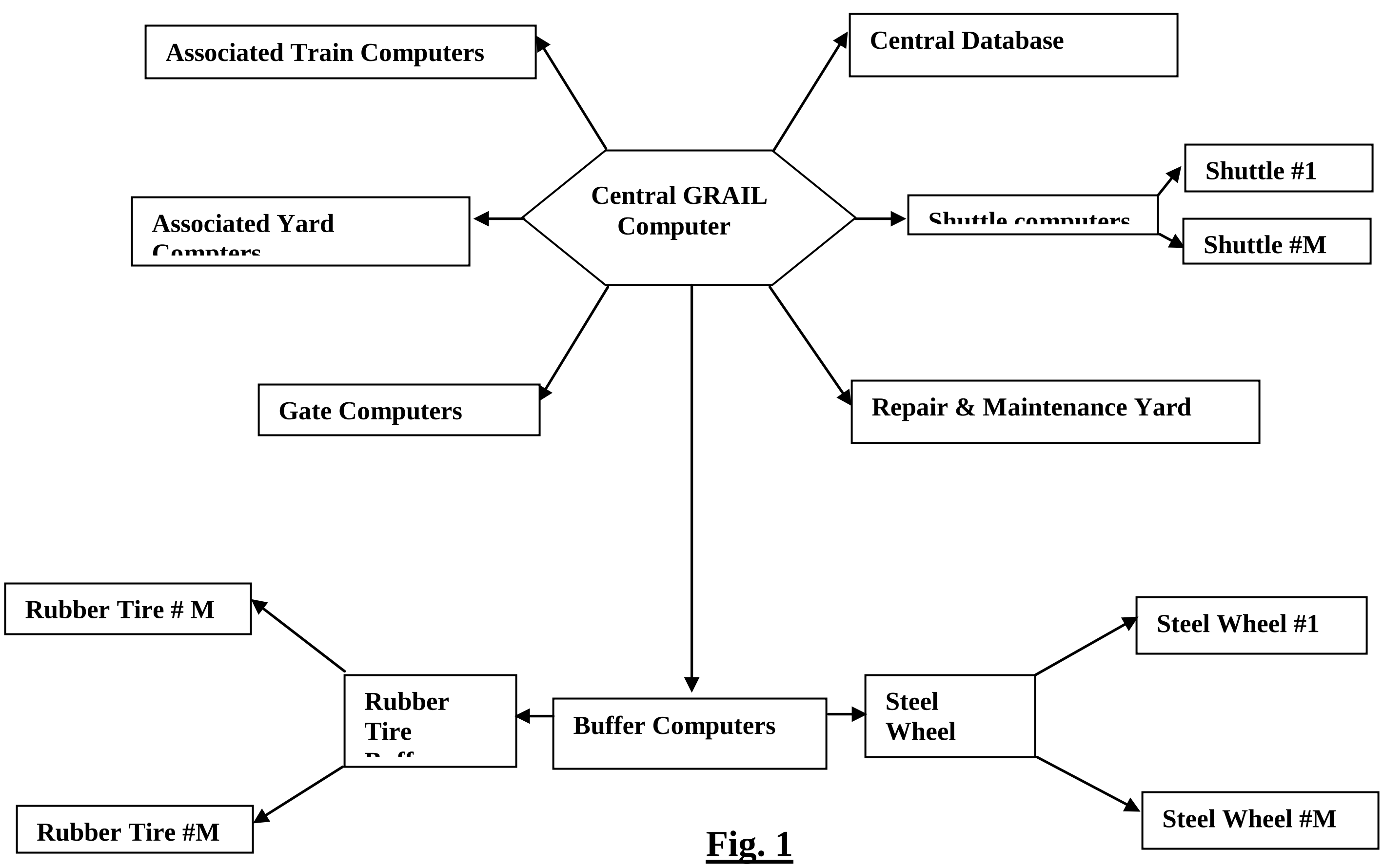


Fig. 1

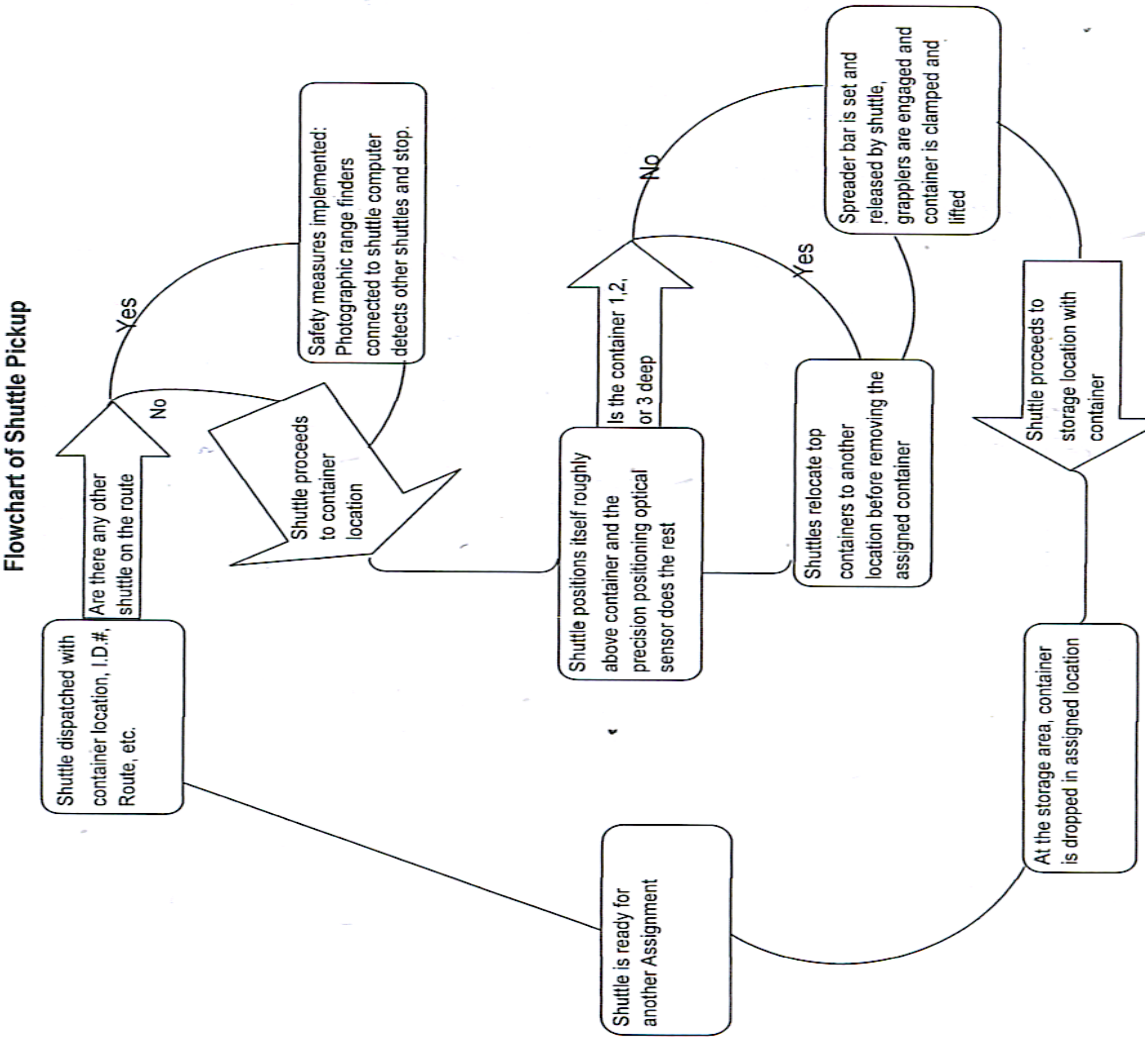

Flowchart of Shuttle Pickup
Shuttle dispatched with container location, I.D.#, Route, etc.
Are there any other shuttle on the route
Yes
No
Safety measures implemented: Photographic range finders connected to shuttle computer detects other shuttles and stop.
Shuttle proceeds to container location
Shuttle positions itself roughly above container and the precision positioning optical sensor does the rest
Is the container 1,2, or 3 deep
No
Yes
Shuttles relocate top containers to another location before removing the assigned container
Spreader bar is set and released by shuttle, grapplers are engaged and container is clamped and lifted
Shuttle proceeds to storage location with container
At the storage area, container is dropped in assigned location
Shuttle is ready for another Assignment

FIG. 2

THE INTER-YARD STRUCTURE:
Final Report

Abhinav Pamulaparthy

Table of contents:

INTRODUCTION

After automating the Rail Yard's around the Chicago area, the biggest problem that needed to be addressed was How to connect the Rail Yards and automation of the vehicles that run on them? The connector network team in spring 2004 came up with the concept of connecting the rail yards by means of a structure that would be independent of existing rail road. In accomplishing this goal the main constraint was the space, it was decided that an elevated structure above the existing the rail road would be the most optimum thing to do. This design was made under the assumption that the air space was readily available to use with out any constraints from any source. The following report discusses the structural analysis of the structure designed and also gives the financial estimate for the structure.

DESIGN REQUIREMENTS

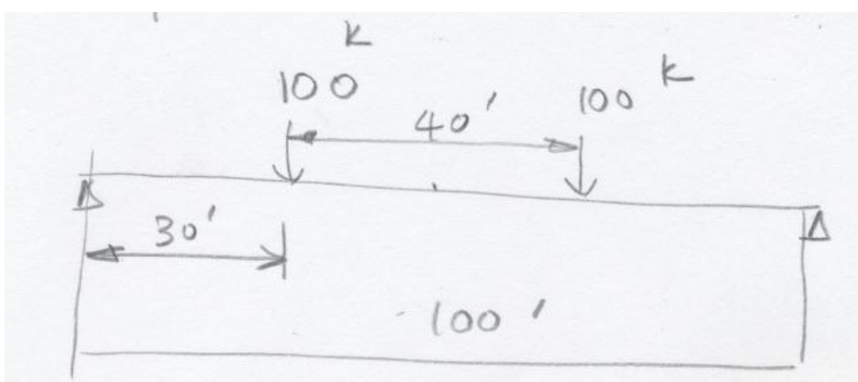
The structure has got to meet the following requirements:

- Loads of the containers : Max 80,000 lbs for the 40 ft container
- Loads of the chassis : Max 20,000 lbs per Chasse
- Compatible with the LIM (Linear Induction Motor) Technology used in propelling the chassis.
- Has got to withstand any sudden shocks produced by the braking of the chassis.
- At any given point of time there could be 4 containers (320,000 lbs) with in the 100 ft span.

STRUCTURAL ANALYSIS

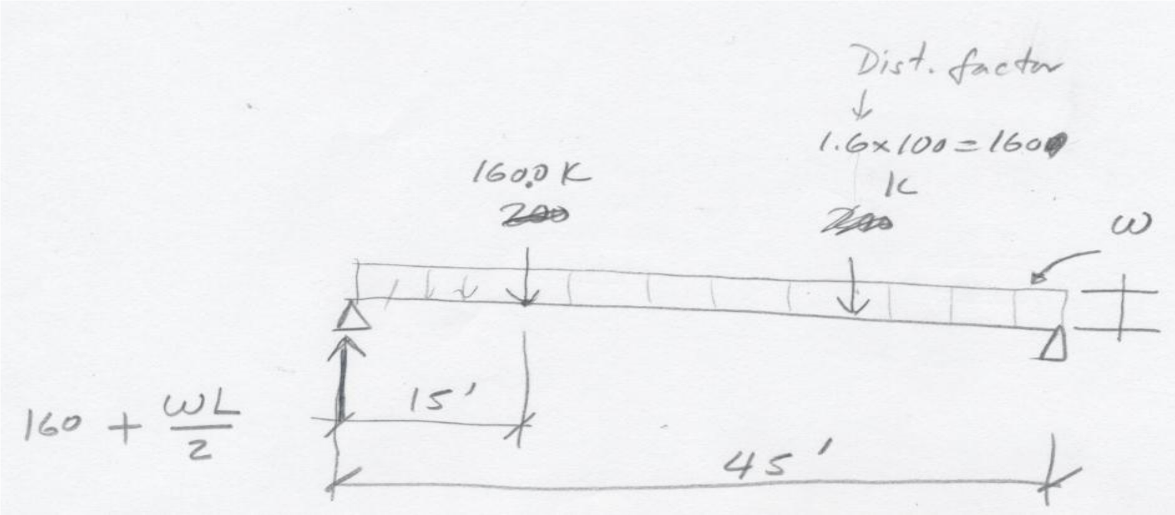
Using the design requirements mentioned a structural analysis was performed for the structure.

Steel Girder:



$$M = \frac{30}{2} \times 100 = 1500\, ft.K$$

W 40 by 167 I beam can be used.



Load factor: 1.6

$$M_L = 1.6 \times 160 \times 15' = 3840\, ft.K$$

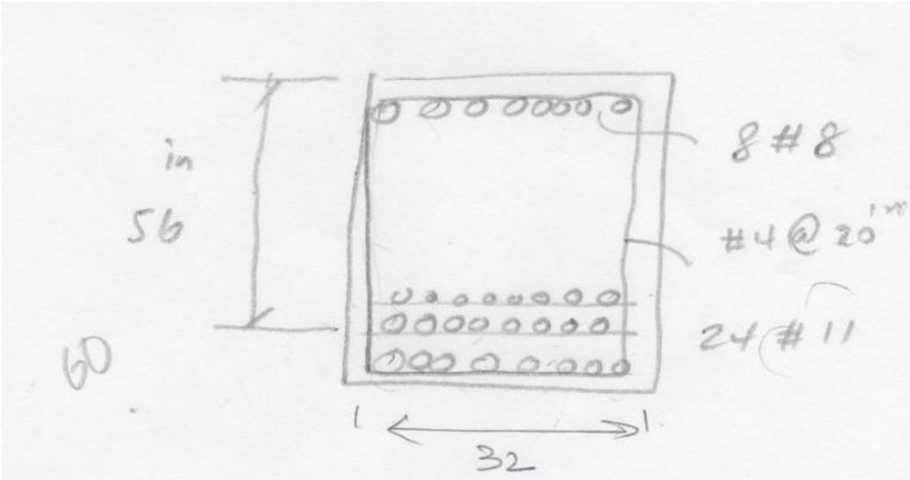
Dead Load factor: 1.3

$$w = \frac{32 \times 48}{144} \times 0.150 = 1.6\, {}^{k}\!/\!_{ft}$$

$$P_{wtofsteelbeam} = 2 \times 167 lbs / ft \times \frac{100}{2} ft = 16{,}700 lbs$$

$$M_D = (160 + \frac{wl}{2}) \times 1.3 \times 15' - w \times 15 \times \frac{15}{2} \times 1.3 = 3588\, ft.K$$

$$M_u = M_L + M_D = 3840 + 3588 = 7428\, ft.K$$



$$R = \frac{M_U / 0.9}{b \times d^2}$$

Where 0.9 is the Capacity Reduction Factor.

For the considered slab dimensions R= 1061

Steel ratio is given by the formula

$$\rho = \frac{1}{m}[1 - \sqrt{1 - \frac{2 \times R \times m}{f_y}}$$

Where f_y is the yield cap of steel = 60 Ksi

$$m = \frac{f_y}{0.85 \times f_c^{'}}$$

Where $f_c^{'}$ is the compressive strength of concrete = 5 Ksi.

$$m = 14.1$$

$$\rho = 0.021 < \rho_{\max} \approx 0.03$$

$$(A_s)_{total} = \rho \times b \times d = 36.2 in^2$$

There fore required # 10 bars = 30

11 bars = 24

<u>FINANCIAL ESTIMATE:</u>

To estimate the cost of the structure for 1 mile the costs used for the materials are as follows:

<u>Material:</u>

Concrete: $ 50 / Cubic ft

Steel: $ 5/ lb

<u>Labor:</u>

Concrete: $ 25/ Cubic ft^2

Steel: $3/ lb

These costs were taken to get the high end estimate of the structure.

<u>Material Cost per mile:</u>

Steel: $ 19,473,960.00

Concrete: $39,160,672.00

Total Cost per Mile: $ 58,634,632.00

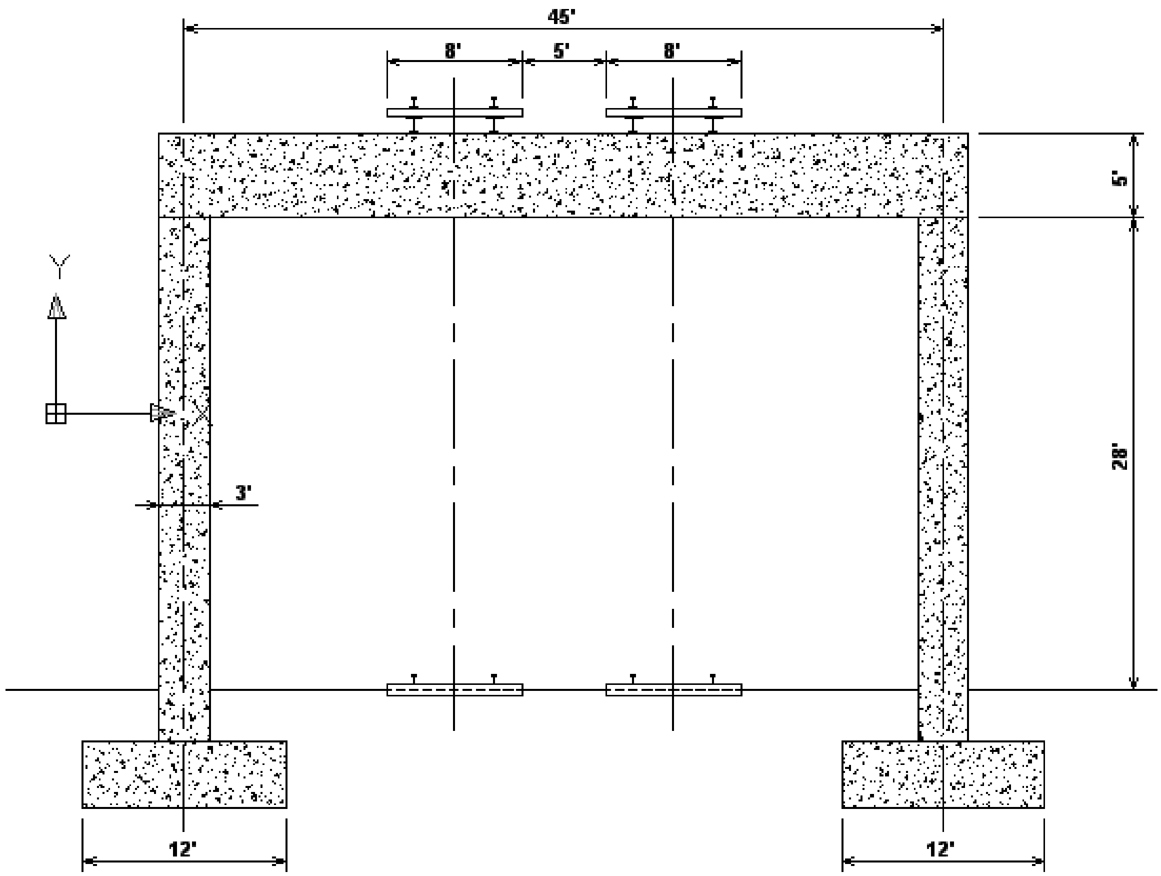
<u>Labor Cost per Mile:</u>

Steel: $11,685,960.00

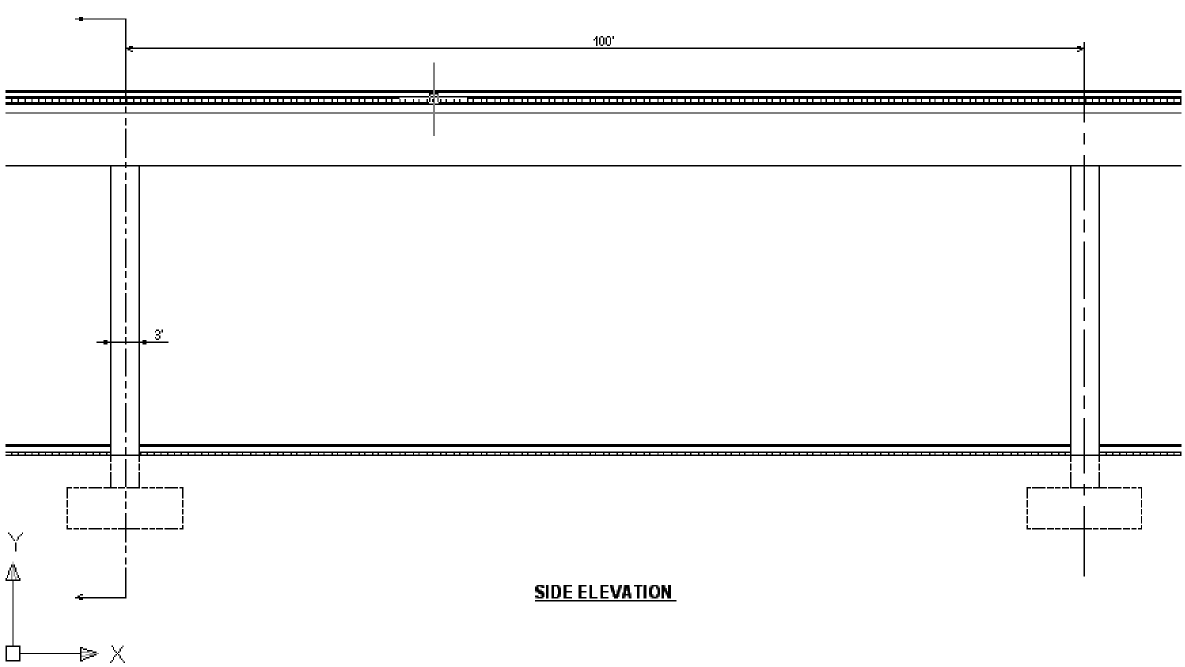
Concrete: $19,580,336.00

Total Cost Per Mile: $31,266.296.00

DRAWINGS:



SECTION THROUGH COLUMNS



SIDE ELEVATION

Inter-yard Connector Network Subteam:
Final Report
Regional Network Design Maps

Keegan Adcock

The regional network design maps were created using ArcView 9.0. The two versions represent the shortest total distance network connecting all yards and an alternate network that avoids a potential zoning conflict with downtown Chicago. Coincidentally, the alternate network directly connects Corwith to 47th, the two yards with the most direct transfers.

The design began with a core network sketch by professional advisor Gerald Rawlings. This was a subjective estimation for one possible network. The first step towards the final maps was recreating this sketch electronically. GIS shapefiles containing the entire city's rail lines and yard placements were acquired, and the core network was traced along existing right of way connections between the yards (ie, the actual train route between the yards). At this point it became clear that there were several yards left off this core network, so another map (in a separate shapefile) was created extending the network to include every yard still in operation. In the future, some of the new yards will likely be cut, but for the purpose of this semester's analysis, all yards were considered. After extending the network to include every yard, several additional connections were put in to be considered in the Linear Programming analysis.

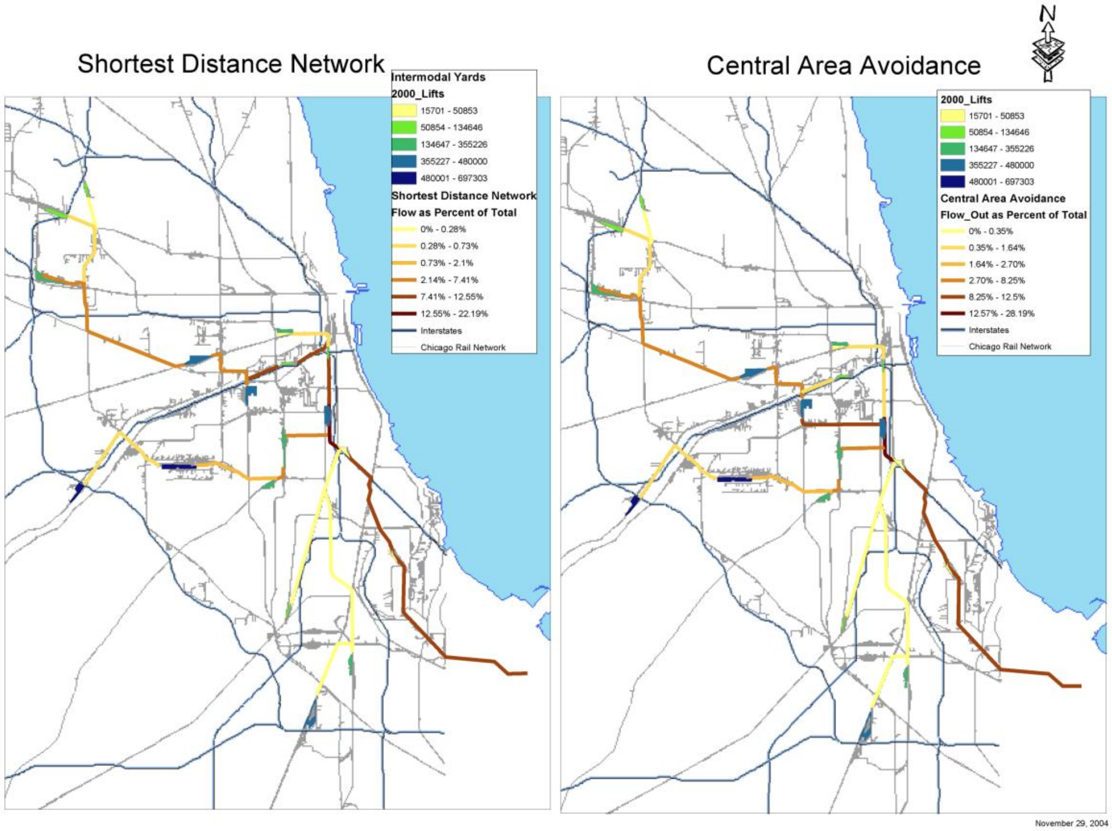
Recreation of Original Network Sketch

The Linear Programming analysis was designed to create a network of shortest total distance. For this semester's research a Minimum Spanning Tree algorithm was decided upon for its simplicity and availability. This algorithm would consider only distance in determining the final network as saving as much track from the $60 million per mile cost would greatly outweigh any benefits from ease of traffic flow. In order to set up the algorithm, each connection's distance would be needed to weight the edge between the source and destination nodes. Fortunately, the exact distance for each connection is easily calculated over the rail lines using ArcView. In short, the Core Network map with the alternate connections was recreated (again) in a minimum spanning tree program, and the result was then retranslated back into GIS.

The resulting map from the minimum spanning tree algorithm was presented for review, and a potential zoning conflict was brought to attention. A total distance (61.7 miles) was now available for the purpose of financial analysis. However, numbers for extending the network to include Indiana truck transfers were acquired, so the network had to be extended again. Several problems arose here. For one, the network would have to be extended to an non-existant Indiana rail yard. Also, the original rail maps stopped at the Illinois border.

To solve the first problem, a set of criteria for picking a new truck depot site was determined. These criteria were general and really for the purpose of initial analysis. The criteria were: to be near a major highway heading into Chicago, near the Illinois-Indiana border, near a rail line leading into Chicago, and having a suitable amount of undeveloped land. Naturally, these criteria can be improved upon. In any event, a site was located using the USGS Seamless Urban Area Mosaic Viewer (available free online), and the rail connections leading out to it were closely approximated past the Illinois border.

With the Indiana connection added, the last major change to the design of the network was in creating the Downtown Avoidance map, which changed one connection from the Shortest Total Distance map. Undirected traffic numbers were calculated for each segment of track for each map to illustrate the importance of certain connections. Thus, each ArcView shapefile for the final maps contains distance and traffic values for each segment of track.



Calculating the traffic values for each segment of track was not trivial. A good example of the process is if you look at the middle corridor from Willow Springs to 47th. Starting from the outside, the first piece of track (from Willow Springs to Bedford Park) is simply all of the traffic going to and from Willow Springs. The next piece of track (from Bedford Park to Landers/Hanjin) is all of Bedford Park's traffic, plus all of the previous track's traffic, minus the traffic from Willow Springs to Landers (because those numbers should only show up in the first piece of track). The next piece of track's traffic (Landers to 59th) included all of Lander's traffic, plus all of the previous track's traffic, minus the traffic from Landers to Bedford Park <u>and</u> the traffic from Landers to Willow Springs. Clearly, the calculations get significantly more complicated further in. To simplify the calculations, each branch was calculated separately, then combined (with the appropriate subtractions) for the central segments.

The first chart on the following page was the transfer data used to calculate each map's traffic, recorded in the following 2 charts.

	Rails -->	R1	R3	R4	R5+6	R8	R9	R10	R14	R15	R16	R18	R19	R20	R22	R92	R25	R26	R9
R1	Schiller																		
R3	Bensenville			133				25	49	78	78	46	302	14	53	17	25	14	3
R4	Global II		87					1	3	1111	265	391	381			100	3		4
R5+6	Cicero									1661	333	1329	1360			431			76
R8	Global I							1					9						
R9	Western												5						
R10	26th/Canal		11	2						218	73	46	207		12	79		11	6
R14	Corwith									2312	463	1848	741			384			44
R15	47/51/55		184	1394	879	17		345	1702			1	6	953	159	58	287		1
R16	63rd		4	79	335	8		211	98			1	3	959	8	31	48		
R18	Landers		37	547	733			76	725	41	1	1	8	183	43	89	17		1
R19	Bedford Pk		209	245	255	312		106	369			7	1	1258	67	80	22		22
R20	WillSprings									3	2	1	6			1			
R22	Dolton		57	1				7		248	128	35	152			114			
R25	IMX		71	3						278	85	11	66		1	54		5	1
R26	Calumet																		
R91	59th		66	108	49	152	5	19	160	1	1	6	209	181	21	41	5		
C1	Borman	25 1	8	2458	1136	499	352	188	1678	78	24	740	713	33	92	26	683	7	11
C2	Tollway	49 9	16	4885	2257	997	699	375	3331	155	46	1463	1415	65	180	51	1362	13	23

Connection_	Length (ft)	Flow
Corwith to IMX	9019.77	61248
IMX to Canal	9821.17	65517
Canal to 47th	12317.83	71986
59th to 63rd	11802.1	24638
63rd to Yard Center	55992.84	1632
Yard Center to Moyers	18532.42	0
63rd to Blue Island	30870.64	0
63rd to Calumet	29798.56	54045
Calumet to Indiana	54695.23	54059
Shiller Park to Bensenville	9294.58	1584
Bensenville to Global 2	24638.31	3187
Global 2 to Cicero	49344.38	22728
Bedford Park to Willow Springs	30047.1	3759
Bedford Park to Landers	18870.74	12320
59th to Landers	4005.41	22675
Global/Western to Canal	13262	4215
Cicero to Corwith	16474.38	42518
47th to 63rd	12694.53	127263

connection_	Length (ft)	Flow
47th to 63rd	12650.26	128520
63rd to Blue Island	30695.87	0
63rd to Yard Center	55864.86	1632
Yard Center to Moyers	18419.96	0
Bedford Park to Willow Springs	29438.97	3759
Corwith to Cicero	16298.16	37633
Cicero to Global 2	48882.04	22728
Global 2 to Bensenville	24463.98	3187
Bensenville to Shiller Park	9096.49	1584
Corwith to IMX	9000.98	4437
59th to Landers	4409.27	22670
Bedford Park to Landers	18705.69	12314
Canal to 47th	12301.49	7513
Canal to Global 1	13112.62	5181

59th to 63rd	11745.79	24633
63rd to Calumet	29923.44	57325
Calumet to Indiana	54208.2	54058
Corwith to 47th	21515.59	56297

Financial Analysis Team:
Final Report

Team Members:
Paul Hammernick
Venkata B. Chintaluri

Table of Contents

1. Introduction:

This being the second semester for this IPRO the financial analysis team had bits and pieces of information available from the last semester's work; at this point the costs outlined for all the different parameters were not very accurate as a result putting feasibility of this whole project under question.
The Goal for the team this semester:

- Decision Rule for GRAIL system
- Update the Corwith to 47th Street analysis based on the new numbers obtained from the Shuttle Design team and the Connector Network Team.
- Extend the Analysis to both the Scenarios of the Complete Network.

To accomplish the goals outlined the team worked on creating financial models, which could simplify the process of analysis. The models were created using Microsoft Excel. The models are designed to take in a few specified inputs based on the analysis, and output the Capital Costs, Operational Costs and the range of Internal Rate of Returns that could be expected over a 20 year period.

The Models gave the team a chance to break down the analysis into many different levels. The team defined the yards as being the basic units in the network. These yards formed the vertices of the graph for the Network design. First the individual yards were analyzed which was followed by the analysis of all the different connections in the scenarios followed by the complete analysis of the two proposed network scenarios.

2. Individual Yard Analysis (Decision Rule)

The Decision Rule is an algorithm that is used to determine which of the Yards in the network would have the Grail System installed in them. This task was accomplished by first collecting information about the individual yards, like acreage and the number of lifts within the yard[1]. After acquiring this information the team created the Excel Model to simulate the Internal Rate of Returns based on the inputs and the base costs for the basic parameters.

Assumed Base Costs (Part of Capital Cost):

Yard Cost	Unit	Unit Cost
Grail Foudation. Track, and supports	acre	$164,141.00
Switching Area of grid		
Shuttle Vehicles	per	$2,000,000.00
Power Distribution Center	per	
Buffer for Truck Loading (14 at Corwith; 11 at 47th)	per	$500,000.00
Maintenance Vehicle	per	$2,000,000.00

Table 1

Control Systems	Unit	Unit Cost
Software for Grail system	Per	$1,150,000
Computer systems	Per	$3,350,000

Table 2

The parameters like the Grail Foundation, Power Distribution center, Buffers and maintenance Vehicles were based on the acreage of the Yard(automatically calculated by the model), other entities like number of Shuttles was based on the lift volumes within the yard.

Assumed Base Costs (Part of Operating Costs):

Labor	Average Salary in Illinois per year*
Janitor	$39,316.80
Security Guard	$43,993.60
Business Office Manager	$108,616.00
Data Entry	$56,744.00
Data Control Clerk	$50,760.00
Accountants	$66,611.20
Maintenance Labor	
General Maintence Worker	$70,206.40
PC Maintence Technicans	$72,120.00
Electrical Engineering Technicians	$75,873.60

Table 3

	Cost of Power per kilowatt hour (KWHR)	Power kilowatt using linear induction (KW)**
Shuttle	$0.15	70
Chasses	$0.15	70

Table 4

Assumptions were also made about the salaries of the employees and the power consumption by the system on an annual basis. The number of employees needed by a particular yard is calculated by the model based on the acreage of the yard and the power consumption is calculated based on the number of shuttles in operation at the yard.

Once all the assumption and the input values were clearly stated the model calculates the IRR values over a period of 20 years. The results obtained from the analysis of the individual yards are as follows:

IRR for Each Yard with $50/lift

Change in Lift Volumes -->	**1%**	**3%**	**5%**	**-1%**	**-3%**	**-5%**	Fully Automate
Corwith	20.83	23.22	25.61	18.43	16.04	13.65	Yes
47th/51st	15.76	18.05	20.35	13.47	11.18	8.89	Yes
59th Street	12.54	14.77	16.99	10.31	8.08	5.85	Yes
Cicero	13.35	15.59	17.84	11.1	8.86	6.62	Yes
Willow Springs	32.05	34.66	37.28	29.43	26.82	24.2	Yes

Bedford Park	20.6	22.98	25.37	18.21	15.82	13.43	Yes
Global II	8.87	11.02	13.18	6.71	4.55	2.4	No
Moyers/CNIC	17.39	19.72	22.04	15.07	12.74	10.42	Yes
63rd Street	11.14	13.34	15.54	8.94	6.74	4.54	Yes
IMX($73-$88)*	0	0	0	0	0	0	No
Canal Street($61-$70)*	0	0	0	0	0	0	No
Global I	16.61%	18.92	21.23	14.3	12	9.69	Yes
Western Ave.($175 - $205)*	0	0	0	0	0	0	No
Schiller Park ($91 - $102)*	0	0	0	0	0	0	No
Bensenville($111-$147)*	0	0	0	0	0	0	No
Yard Center	9.63%	11.8	13.98	7.46	5.29	3.12	No
Blue Island($70-$85)*	0	0	0	0	0	0	No
Calumet($275 - $330)*	0	0	0	0	0	0	No

Table 5

The team also suggested having a smaller version of the Grail in the yards that do not have a good return on investment to accommodate them into the overall Network Design.

3. <u>Yard Connectivity Analysis:</u>

The first step for the team was to update the Corwith to 47th analysis done by the team in spring '04. This included the new numbers received from the shuttle design team and the Connector Network Team. The next step was to create a model which should have the capability to take into account information about any two nodes in the network and the details about the connection, and then generate the Internal Rates of Return over a 20 year period assuming changes in the volumes(-5% to 5%) and the variable costs(-5% to 5%).

All the assumptions made in the first part remained the same. The new model had to take into account the assumption made earlier that the Yards with low lift volumes would have a partially automated Grail system installed. The other factors to be included in this analysis were the distance between the yards and the volume flows between the yards.

Factor affecting the different costs:

Capital Costs

1. Acreage of the two yards
2. Level of Grail Automation for both yards
3. Distance between the yards

Container Variables

1. Lift volume per year for Yard 1

2. Lift volume per year for Yard 2
3. Transfer volume between the two yards

Assumptions:

1. All the yards that yielded less than 10% IRR when Lift Cost and Transfer Cost are $50 have a partially automated GRAIL system (covering 20% of the yard).
2. The number of chassis operating between any two yards depends just on the number of transfers.
3. All assumptions about the Capital costs and operating costs were maintained same as those mentioned above in **Tables 1-4**.

4. Scenario Analysis:

The last step of the analysis was to extend the Corwith and 47th street analysis to the two proposed network scenarios. For the purpose of this analysis all the yards and the connections between them had to be considered.

The values of the Capital costs obtained for the Individual yards are:

Yard	Total Cost
Corwith	$107,148,934.00
47th Street	$90,862,951.00
59th Street	$72,900,215.00
Cicero	$105,052,169.00
Willow Springs	$86,989,541.00
Bedford Park	$111,879,613.00
Global II	$78,031,673.00
Moyers/CNIC	$94,278,145.00
63rd Street	$51,584,079.00
IMX	$25,005,106.00
Canal Street	$24,601,730.00
Global I	$56,908,886.00
Western Ave.	$24,250,383.00
Schiller Park	$25,229,779.00
Bensenville	$29,795,279.00
Yard Center	$32,258,201.00
Blue Island	$24,629,759.00
Calumet	$22,534,113.00
Total Cost for GRAIL	$1,063,940,556.00

Table 6

The values of the Operating Costs obtained for the Individual yards are:

Operating Costs for Each yard	
Corwith	$9,337,804.54
47th Street	$8,737,106.44
59th Street	$8,242,494.56
Cicero	$9,087,225.36
Willow Springs	$8,811,164.88
Bedford Park	$9,363,571.58
Global II	$8,311,873.42
Moyers/CNIC	$8,846,444.30
63rd Street	$7,315,578.60
IMX*	$6,914,030.57
Canal Street*	$6,918,275.55
Global I	$7,838,918.24
Western Ave.*	$6,854,671.86
Schiller Park*	$6,905,391.07
Bensenville*	$7,013,279.23
Yard Center*	$7,190,120.62
Blue Island*	$6,906,135.85
Calumet*	$6,798,655.41
Total Operational Costs	$141,392,742.08

Table 7

The values obtained were then input into another model which calculated the total investment required and the IRR's over a 20 year period. For the purpose of analysis the team assumed a 10% return on investment to be reasonable and based on that calculated the costs/lift and the cost/transfer.

The Lift volumes and the Transfer volumes were obtained from the CATS staff. Using the Capital and Operational costs obtained from the Excel Models, and the Lift and transfer numbers obtained from the CATS office, IRR's could be calculated for this scenario. The final results obtained were:

a. Minimum Distance Network Analysis(Scenario 1)

The Total Investment Required: $5.73 Billion
Range for Cost/Lift : $50 - $100
Range for Cost/Transfer: $50 - $90

b. Analysis of Central Area Avoidance Network(Scenario 2)

The Total Investment Required: $5.84 Billion
Range for Cost/Lift : $55 - $100
Range for Cost/Transfer: $50 - $95

All the assumptions that were made earlier were maintained constant throughout the process. This is just a preliminary stage of the analysis, and we believe that the team next semester can expand on this by using the Excel models to do an analysis of the two network scenarios one connection at a time to come up with an optimal network design that is cost effective and more up-to-date.

Results and Conclusions

Here is a brief summary of what each team has accomplished for the semester. The Shuttle Design Team has created a functional requirement list for the Shuttle. They have also started the design of the Shuttle. This includes 13 CAD drawings of the Shuttle and parts of the Shuttle. Along with that there is now a parts list of the Shuttle including the description of each part. The Control Team has taken the GRAIL control system farther by breaking down the decisions that the computer has to make to accomplish a goal. For instance, for the Shuttle to travel from one point to another on the GRAIL System is not as easy as just moving itself, it has to maneuver around other Shuttles, know where to turn, and determine if the container is secure this all has to be decided by the control computer. The Control Team has moved forward the IPRO by making a list of the decisions a control system has to make for three different operations that the Shuttle has to make. Abhinav Pamulaparthy from the Shuttle Team took it upon himself to reanalyze the Inter-Yard Structure. What he did was design a better structure then last semester using less concrete. To back up his design, he had meetings with Dr. Muhamadi of IIT's engineering department to figure out the structure's load limits and cost of construction. One of the most import things that Abhinav discovered was the cost of construction of the Inter-Yard Structure for one mile is around 58 million dollars, which is very different from the cost per mile from the spring 2004 team which was only 5 million.

The Regional Connector Network Team with the much appreciated help from Ariel Iris, who is from CATS (Chicago Area Transportation Survey), made groundbreaking work in the design of the Inter-Yard Network. Keegan Adcock of the Regional Connector Network Team used GIS software and data given to him from CATS to make two very informative maps of the layout of the Inter-Yard Structure and the container flow volumes. Finally, the Feasibility Team had a pleasant surprise when they made the financial analysis of the system. When the team found out that the Shuttle cost is roughly 2 million dollars a difference of 1.5 million from last semester's research and the cost per mile of the Inter-Yard Structure was 58 million dollars a difference of 53 million from last semester's research, and that the capital and variable calculations from last semester needed to be reworked, it seemed that this project could never be profitable to do. But to the surprise of everyone the numbers worked out in such a way that assuming that a 10% IRR was an acceptable value we came out with the cost for a lift and the cost of a transfer to be the same as what the current system charges. This is very promising discovery!

Recommended Next Steps

As of right now several things have been explored for this IPRO project. We have discovered the GRAIL System, which has become the central system for this IPRO to solve the container problem. We have made a design and an accurate cost analysis of an Inter-yard Structure, which is the structure that we are going to use to connect the yards. We have started the design of our Regional Connector Network to map the connections of our complete system for Chicago. We have professional CAD drawings of the Shuttle and a 24 item parts list of the Shuttle components. Also, we have an overview of all the decisions that will have to go into the programming of the central computer to control the Shuttle, and a way to track containers. What should be worked on next is analysis of the GRAIL structure itself, try to get more accurate container transfer numbers, and continue to improve the Excel programs to new data that is discovered. The GRAIL Report is very general about some things like the computer software that controls the Shuttle, detailed drawings of the GRAIL structure and supports, and technical information like how the LIM is positioned on the Shuttle to move it. I think some time needs to be devoted to work on making detailed drawings of the GRAIL structure and the rails that would be used for the Shuttle to ride on. This would not only help in the steps for yard design it would also make a more accurate construction cost for the GRAIL structure, which is a major question mark as of right now and that number could possible sink the project. As far as the container transfer numbers are concerned, they have proved, in the financial analysis, to play an important role in the revenue of our system, especially the traffic from Indiana. The rubber tire transfer matrix data that CATS has so graciously provided us is out of date and is missing many numbers. I feel that some time should divide to check the numbers and try to fill in the blank values. So, both GRAIL Structure design and researching rubber tire transfer numbers is a good place to start for next semester, because enough work has been done to make an overview of the GRAIL System now it is time to use our brains and design the unknown.

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