Kitchen Reliability

Design of a Containerized Kitchen

A Major Qualifying Project Report

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By

Nicholas Gilligan

Laura Rosato

Approved By:

WPI Project Advisor

Frank D. DeFalco

WPI Project Advisor

Mustapha S. Fofana

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Abstract

The army desires a portable kitchen that will fit inside a standard 20 foot shipping container. The kitchen should be usable in any condition that the army would travel to. It should feed 800 soldiers three meals a day for three days without being restocked. All appliances needed to achieve this will be fixed within the container. Seven layout designs were created and analyzed for weight distribution, ease of access and use, and potential hazards. Transportation of the kitchen will occur by truck, helicopter or forklift. Shipping containers are designed to withstand the dead weight and wind loads that it will face, however modifications need to be made for doors and windows. A vibration analysis was also performed for the case when the container was dropped from a height of 30 feet. A maximum deflection of 0.001 inches and maximum stress of 550 pounds per square inch was found. Much more design work is needed for this to be a complete, working kitchen.

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Chapter 1: Introduction

Success on the battlefield requires, among many other things, plentiful supplies, speed and coordination of movement, and efficiency in every endeavor. Soldiers in the battlefield are submitted to strenuous labor each day in harsh terrains and through unforgiving elements. It is essential to keep soldiers supplied with proper meal rations to ensure the efficient operation of any army. The subject of this project is to improve the method by which basic sustenance is supplied to the battlefield and then to the troops.

The US army wants to use a standard shipping container as a portable kitchen. The final design must feed 800 soldiers three full hot meals a day for three days without resupplying. In 2004, the army completed testing their containerized kitchen. Because of its weight, setup and take down times, complexity and structural failures, it was determined to be a failure. The objective of this MQP was to create a new design would reduce the total weight of the system, reduce setup time, and increase the structural stability of the container during transportation as well as the overall reliability.

To gain a better understanding of what was involved with a portable army kitchen, background research was done on current food distribution methods, shipping containers, and appliances was done. To create an effective design, the previous design must be understood, and the design needs considered. Design criteria are taken from this understanding and preliminary designs made. Iterating these designs led to seven possible solutions. Analyzing with respect to the design goals will show the benefits and disadvantages of each design. Because the original army design failed structurally, it was important to make sure this container design would withstand the conditions and stresses it was put under. Lastly, there is a small chance of the container being dropped from a low height when being transported by helicopter. This fall would result in an impact force and vibrations which create stress in the container.

Chapter 2: Background Research

Before the kitchen could be designed it was important to understand how and why the previous design failed. Other methods of delivering food to soldiers, the container, lighting, anchors, suspension, and appliances also needed to be researched thoroughly. Detailed knowledge of the design of each individual component was necessary for a successful design. Each component would be looked at for their safety, efficiency, durability, reliability, and cost.

Safety is a major factor when choosing equipment. The kitchen would be used in a battlefield, and as such would need to protect the soldiers using it so that they could focus their efforts on cooking. There would also be the possibility of an attack, and if this was to occur, the components must not be harmful if broken. Because the kitchen would be used for three days without being restocked, it was important to minimize the amount of fuel consumed by each appliance. It was also important to ensure that all components could run continuously and would not break easily or break down often. If a failure was to occur, the soldiers could be left without food.

2.1 Food Delivery Methods

Currently, the army uses Meals Ready to Eat (MRE's) to feed soldiers. They were first used in 1981. Each MRE is a meal that generally contains an entrée, side dish, bread or cracker, spread, desert, candy, drink and seasonings for an average total calorie content of 1,200. They are heated using a flameless radiation system. Each MRE can be stored for up to three years. However, many soldiers do not find these meals unpalatable, and desire a home cooked meal.

MRE's are also less nutritious then freshly made foods. However advances have been made recently to improve the nutritionally quality.

Late 2008, the Air Force tested their Single Pallet Expeditionary Kitchen (SPEK). This kitchen is capable of feeding 300 people, two meals a day for 30 days. Each meal is prepared in less than two hours. It is delivered to a site using a helicopter. All of the materials come on a wooden pallet (Figure 1) and must be set up upon arrival. Set up takes a minimum of eight people, two hours to set up and requires four people to operate it. The final result is a 20'x24' tent with full kitchen and serving area inside. It can come with a TEMPER tent (soft shell) that weighs 3,655 pounds or an ESAMS shelter (hard exterior) that weighs 7,330 pounds. The operating conditions range from -20°F to 120°F and 20-80% humidity. A 2kW military generator powers everything. The SPEK is still in the testing and revision stage of design.

Figure 1: SPEK Ready for Delivery [26]

2.2 Previous Design

The army completed a containerized kitchen design in 2004. However, this design was determined to be unsuccessful due to major pitfalls in the design, as well as key failures. The containers weighed 14,000 pounds, could be stacked nine high, and be transported by a CH-47D helicopter. The design could feed 800 soldiers three meals a day for three days. Each meal could be prepared in three hours or less. There would be a 10kW generator, sink, warming cabinet, two refrigerators, griddle, two air conditioners, two ovens, two storage cabinets, and steam table in each. Stored within the container would be four tables, four roasting pans, two cook pots and five insulated food containers. The configuration of the kitchen for transportation and storage is shown in Figures 2 and 3. The kitchen would be staffed by 4 crew people plus a supervisor.

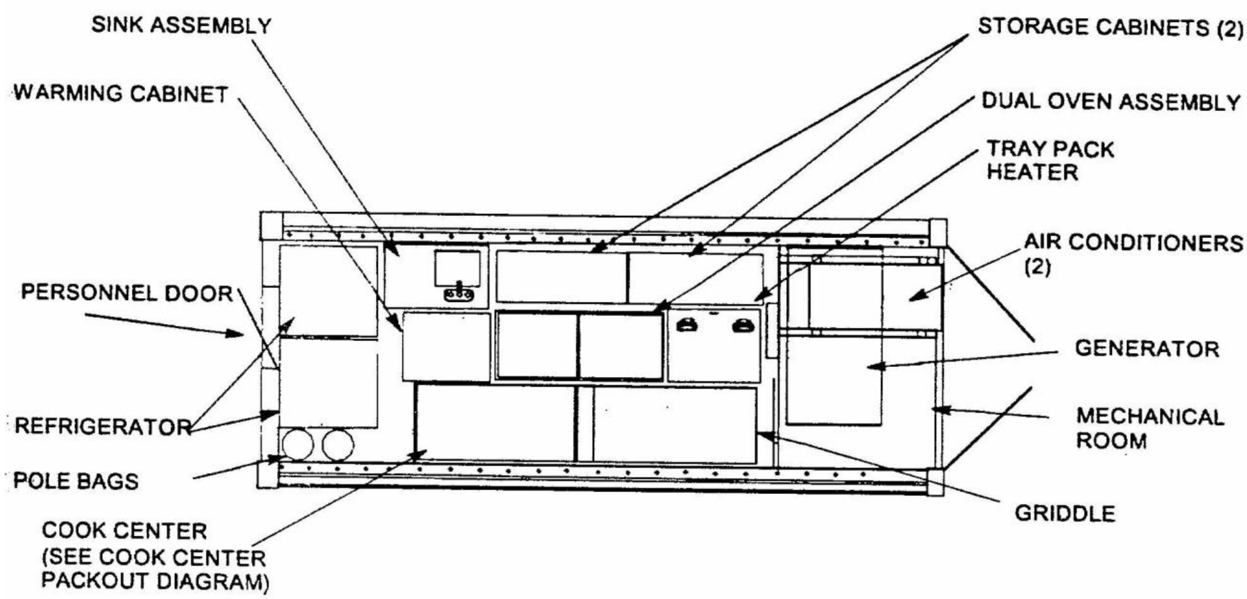

Figure 2: Army Design Storage/Transportation Configuration (view 1) [A.1]

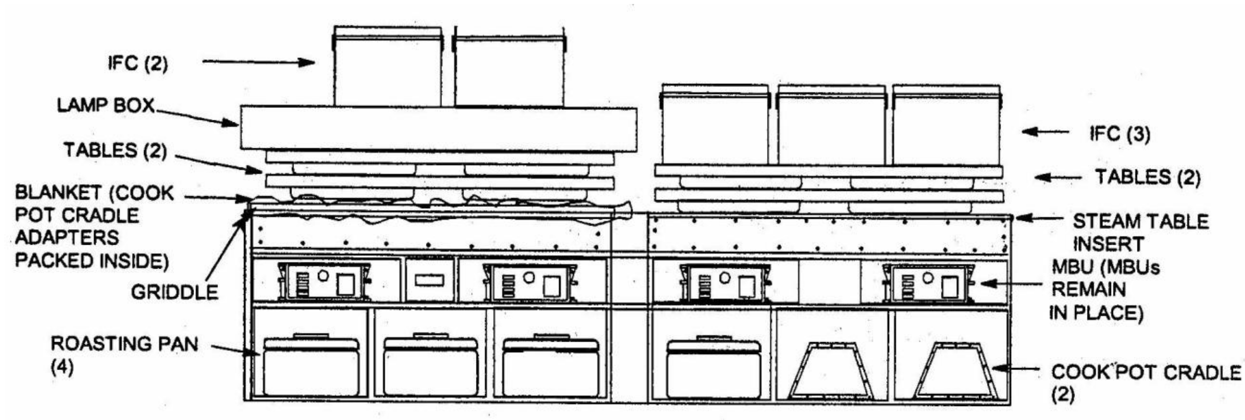

Figure 3: Army Design Storage/Transportation Configuration (view 2) [A.1]

The container was modified to fold out creating approximately 360 square feet of covered floor space. Setting up the kitchen would involve unlatching camlocks to allow for the side to drop down creating more floor space. The sides would be manually dropped using a hand crank attached to a wench. Steel supports are then raised under expandable vinyl fabric and attached from the bottom outside edges to the top outside edge of the original container. This creates a completely sheltered working space. If the container is on a trailer, the stairs are also attached along with a platform by the entrances. The appliances are then unstrapped from their storage places and moved to their working locations where they will be hooked up. Lighting is installed on the roof supports in the container and extended area. The complete extended kitchen can be seen in Figures 4 and 5. Set up and take down of the kitchen would take between 30 and 45 minutes.

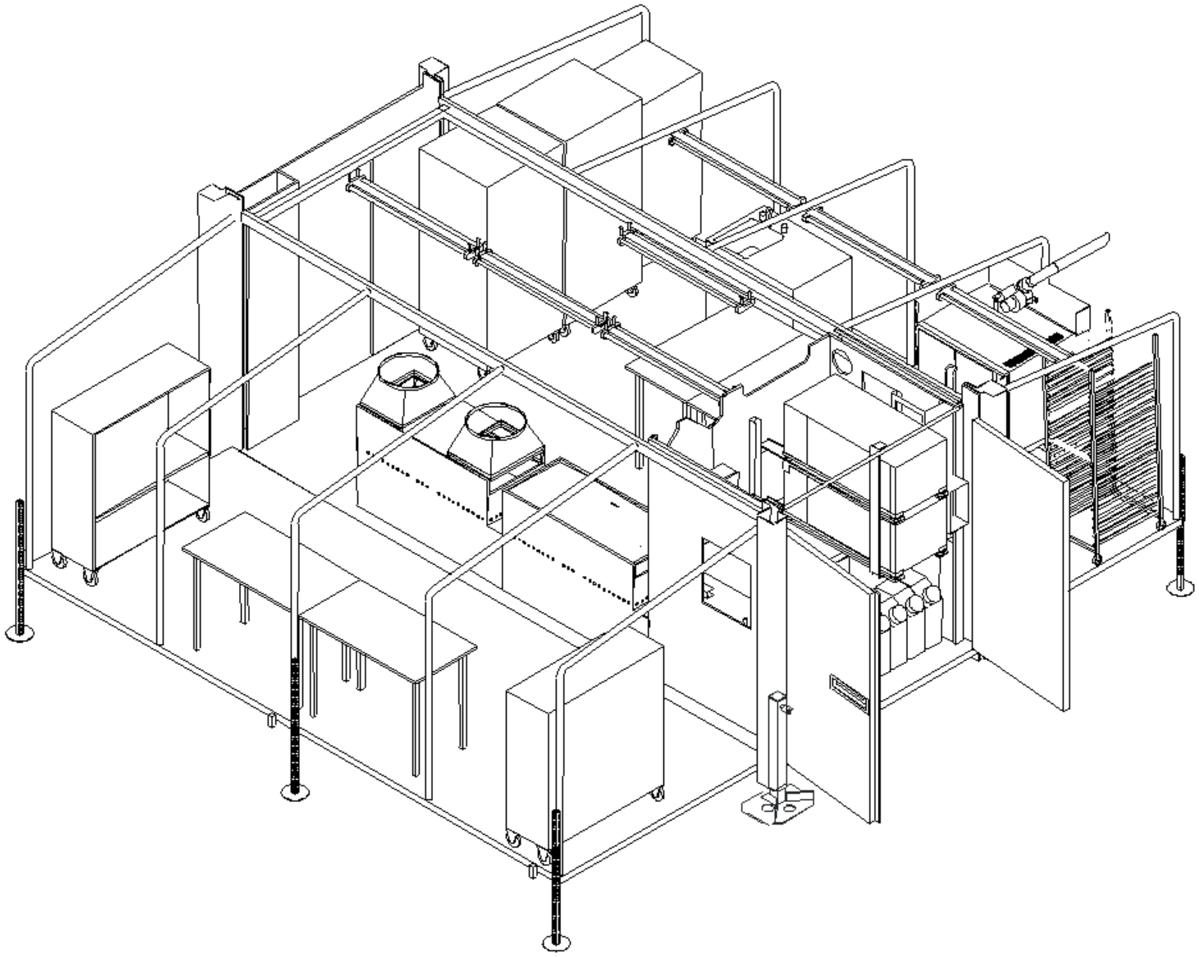

Figure 4: Expanded Army Design (view 1) [A.1]

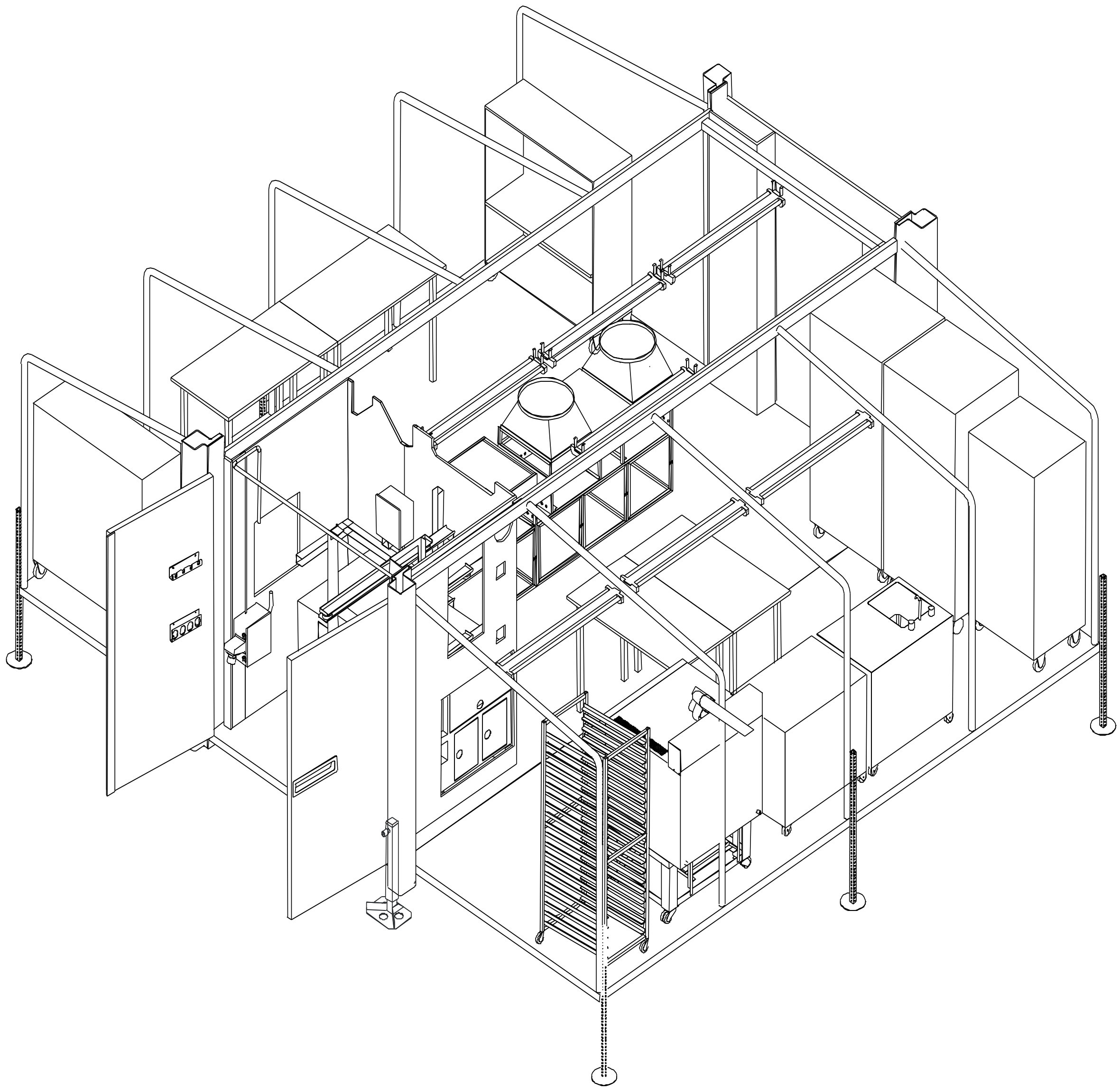

Figure 5: Expanded Army Design (view 2) [A.1]

This design was determined to be a failure because of the set up and take down times and complexity, structural failure, and inefficiencies. In the battlefield, time away from the task is time wasted. The time it takes to set up and take down the kitchen could be used more effectively elsewhere. Also, with so many parts that need to be built, moved or set up, there is a high probability of mistakes being made or something being broken. When this kitchen was moved using a forklift, there was damage made to the container. Hookups for water, bolts, and other exterior components were damaged beyond repair (Figure 6).

Figure 6: Failure of Exterior Connections [A.1]

This could cause structural failure in the long run if damage occurred in key locations. The appliances in the kitchen are also older designs and have been improved over time. It is important to keep the kitchen modern and up to date so repairs can be made easier, and the resources are used as efficiently as possible. It is also important because newer technology tends to be easier to use and more ergonomic. This design also requires that a water truck follow the container. Without water, there can be no food cooked. Therefore, it would be a beneficial component of the design to have a water tank. This design was also very heavy making it difficult to transport.

2.3 Containers

2.3.1 Development/Early Use

Businesses always have and always will have a need to safely transport raw materials to manufacturing plants, parts to assembly factories, and finished products to customers. In the past this was a difficult proposition as there was no standard method for packaging items of an immense variety of sizes, shapes, weights, materials, and other specifications to be transported on standard sized railroad cars or ships. Wood and iron boxes have been used since the earliest goods were shipped to distant locations. The irregularity in size of these containers made it difficult for third party carriers to efficiently load their trucks, trains, and ships. This inefficiency led to a demand for a standardized system for shipping containers.

Containers became more and more popular as businesses grew larger and reached markets more spread out than ever before. However, industry standards for these containers were not developed until the late 1960's and early 1970's. International Organization for Standardization (ISO) Containers has revolutionized the way freight businesses, and their customers, operate. Today, a single ship can contain a variety of types of cargo which are packed in ISO containers to be stacked and arranged for maximum density and efficiency. This development has drastically reduced the amount of time required to load and unload a ship, train, or truck with cargo, and in turn has greatly reduced the overall cost of shipping. Standardized containers save everyone time and money. An example of a standard shipping container can be seen in Figure 7.

Figure 7: Standard 20x8x8 Shipping Container [23]

2.3.2 Standard Specifications

Today, containers are designed for a variety of functions. There are shipping, freight, storage, and even portable office containers to name a few. All ISO certified containers follow a standard set of dimensions which dictate their size and shape. All containers are rectangular shaped so that they can stack on top of other containers during transport. There are two primary standard sizes, twenty and forty foot long containers. The height of both of these container standards is eight feet six inches, and the width is eight feet. The interior dimensions of a twenty foot container are 19’4” x 7’9” x 7’ 8” (L x H x W). The interior dimensions of a forty foot container are 39’6” x 7’10” x 7’8” (L x H x W). These dimensions yield total storage volumes of 1,166 cubic feet and 2,360 cubic feet for the twenty and forty foot containers respectively. Other sizes exist for standardized containers, but are far less common than the twenty and forty footers.

Depending on the material of construction used, the weight and maximum payload of a container varies. The most commonly used material in container construction is steel, although fiberglass and aluminum are used for some specialty containers. The standard specifications for weight and load requirements are not as constant as those for size and shape. The following specifications are approximate and are for containers manufactured by Chassis King. Twenty foot steel containers weigh 5,000 pounds and have a maximum payload rating of 47,900 pounds. Forty foot steel containers weigh 8,900 pounds and have a maximum payload of 58,300 pounds.

2.3.3 Applications

Although rectangular box containers are the most commonly used type, there are several other common designs used. To accommodate a variety of loads, open top, platform, liquid tank, and other modified freight containers exist. There are even containers designed specifically to handle dangerous radioactive waste. All of these types of containers are built using the standard external dimensions so that they can be shipped with containers carrying different types of loads.

Open top containers are essentially the same as the standard rectangular freight containers. The primary difference is that there is no steel roof on these containers. Instead numerous tie-down points exist on the top of the sides and faces of the container, to which tarps can be fastened to protect the contents for shipping. Open top containers are used to carry cargo which is too large or awkwardly shaped to load through doors on the side of the container. These contents are loaded by cranes from above, although, additional access doors on the container sides usually exist.

Flat rack and platform containers are used for oversized and very heavy loads. Both have the same base dimension as a standard freight container, approximately twenty feet by eight feet, but have lack the surround walls and roof structure. Flat rack containers have flat or collapsible end walls and platform containers have no walls whatsoever. Although these containers are useful for train and truck transport of extremely heavy or oversized loads, they cannot be stacked and therefore cannot be transported by container ships.

Liquid tank containers are extremely common in a range of applications and industries. They consist of an ISO container frame with a cylindrical tank suspended within, usually constructed of stainless steel to avoid contamination of the contents and prevent corrosion. The sides of the container box are optional as the only cargo is contained within the tank. Sometimes the tank itself serves as the structural component on the long side and only square frames on each end are required. Cargo can consist of a range of liquids including drinkable liquids, and hazmat materials such as fuels or other hazardous chemicals.

IP2 containers are ISO shaped and sized containers designed specifically for the transportation of low level radioactive waste. These containers can be found in various standard shapes and sizes. All of these containers are held to higher standards in strength and durability than their normal cargo counterparts. These containers also include shielding to prevent contamination of anything external to the container when sealed.

Reefer containers are refrigerated containers found in many ISO shapes and sizes. These containers are similar in construction to rectangular freight containers and include insulation and refrigeration equipment so that the contents can be maintained at a constant temperature. Power can obtained from an internal diesel generator, internal batteries, or an external electrical source.

Reefer containers are used primarily in food or perishable item transport but are useful anytime cargo needs to be kept cool during shipping.

Numerous custom modifications are available from many different container manufacturers. Some of the most common modifications are custom doors and windows, interior accents such as paneling, lighting, paint and shelving, ventilation, and custom locking mechanisms. Another common modification is to have containers fit to operate as transportable offices or workshops with all items necessary for optimal operation.

2.3.4 Transportation

The frames of ISO containers include four eyelets on the top and bottom corners. These holes are used to lift the container using four hooks. These built in attachment points help to distribute the load evenly for a crane lifting from a single point. These eyelets can also be used to attach stacked containers to each other to prevent the containers from deviating from the stacked configuration until desired. These attachment points are critical in the transportation of containers.

Containers are transported by various types of vehicles. For long journeys, the most cost effective method of transportation is container ships wherever large waterways separate the origin and destination. When only land must be traversed, train transportation is the most efficient method. Trucks are used to distribute containers once they have reached a distribution center such as a shipping container yard or train yard. Airplanes and helicopters (Figure 8) can be used in certain situations but because of the great weight of containers, these methods are used only when no other option will suffice.

Figure 8: Helicopter Transporting Shipping Container [28]

2.3.5 Failures

Container failures (Figure 9) occur for a variety of reasons. Failures can be caused by fatigue, human error, extreme or unexpected environmental conditions, and overloading. These problems can cause a container to fail by any number of the following modes: Buckling, corrosion, creep, fracture, impact, melting, mechanical overload, thermal shock, wear and tear, and yielding. Of these failure modes, buckling, fracture, impact, wear and tear and yielding are the most likely to cause failure in shipping containers.

Fatigue is the most common reason why a container will fail. Containers are shipped around the world, carrying various types of cargo. Containers are constantly stressed by various types of forces which weaken them over time. Corrosion due to constant exposure to the atmosphere assists in weakening materials by corroding the interior of cracks caused by repetitive loading.

Extreme environmental conditions, as experienced on the deck of a container ship, cause a great deal of corrosion to occur in containers. Strong winds provide extreme and constantly varying loads on all exposed sides of a container during shipping. Extreme heat and cold stress various parts of the container, especially when different materials are used (which have different thermal expansion coefficients).

Human error has been the cause of numerous container failures. If a container is not placed on a flat surface from a prescribed height, a number of unexpected forces can cause the container to buckle, create cracks, puncture a surface, and cause many other types of problems. The effects of these human errors are only exacerbated when fatigue has taken already place as in an older container. Human error can also cause a container to be insecurely fastened during shipping which can lead to the loss of the entire container. Containers are regularly inspected and repaired. Overlooking problems or improperly repairing problems are examples of human error.

Overloading can occur due to human error. It can also be the result of loading a container to its rated payload when it hasn’t been properly inspected and contains cracks which threaten the integrity of the structure. Regardless of the cause, overloading can cause buckling, yielding, and at the very least increases the rate of wear the container experiences.

It is critical to maintain containers properly to protect their contents, those who work around them, and the ships and other containers they are transported on and with. Although stringent regulation and inspection can prevent some accidents, extreme conditions will always cause some problems. This fact, as in the design of any structure, leads designers to include safety factors in all of the ratings applied to a specific type of container.

Figure 9: Container Failure [29]

2.3.6 Custom Box Options

Standard steel containers are perfectly suitable for most shipping needs. For our purpose, other lightweight materials must be considered to maximize the internal storage capacity.

Materials which compose the exterior of a container must be structurally strong and rigid but not brittle, have thermal properties suitable to withstand a variety of climates, and be able to resist various types of corrosion from a number of weather conditions.

Fourteen material properties considered as critical in choosing materials for the exterior of the container are listed below in order of their importance. A desirable range is listed next to each property.

Table 1: Container Material Properties

Yield Strength	High
Tensile Strength	High
Compressive Strength	High
Price	Under $50,000
Maximum Service Temperature	200°F
Minimum Service Temperature	-100°F
Density	Low
Resistance to corrosion from fresh water	Good
Resistance to corrosion from salt water	Good
Resistance to corrosion from sunlight (UV radiation)	Good
Resistance to corrosion from oxidation	Good
Hardness	High but not brittle
Fatigue Strength	High
Flexural Strength	High
Melting point	High
Flammability	Non-flammable

Upon reviewing desired properties and their values, three metals were chosen as suitable ingredients for a container exterior alloy. These metals are steel, titanium, and nickel. Steel would require a coating to satisfy some of the requirements listed above. Because of the high cost of nickel and titanium alloys, steel could be used to form the frame of the container while lighter materials make up the walls supported by this frame.

2.4 Lighting

Light emitting diodes which produce white light are constructed from a blue indium gallium chip with a phosphor coating. Light emitting diodes are extremely efficient at converting electricity into light. A nine watt light emitting diode can put out as much light as a seventy watt incandescent bulb. This is partly because most of the energy input to a light emitting diode produces light, not heat. Light emitting diodes are also much better than other types of lights at directing their output in one direction. Light emitting diodes are also more durable than any other types of bulbs because they utilize a solid chip rather than a fine filament or compressed gas to produce light. Their life cycles are very long (approximately 50,000 hours until seventy percent brightness occurs), and they are resistant to thermal and vibration effects as well as power switching.

2.5 Anchors: Magnets

Magnets have replaced vices and clamps in many applications. Magnetic tables and vices used in machining metals pose several benefits over their mechanical counterparts. Magnetic clamps can save time, labor, and money when used to replace mechanical clamps. With magnetic clamps a simple switch, usually a lever, is all that is necessary to fix the piece to be machined in place whereas careful adjustment of the clamp is required in a mechanical setup. Much more effort is required to properly fix something in a mechanical clamp whereas with magnetic clamps, all that is necessary is to turn the lever to the on position. Mechanical clamps can cause damage to the piece being machined, or other than ideal securing of the piece. With magnetic clamps this problem is nearly entirely alleviated because the clamping force is much more evenly distributed.

Most magnetic chucks and vices use Electro-permanent magnets. These are powerful permanent magnets which use electricity to change the pole of the magnet effectively turning the chuck or vice on and off. These powerful permanent magnets are capable of producing forces in the area of twelve tons per square foot. In other words, these clamps should be more than sufficient for securing materials against great loads. The most commonly used material for these permanent magnets is neodymium iron boron (Figure 10).

Figure 10: Neodymium Iron Boron Magnetic Clamp [16]

2.6 Suspension

The suspension system for the container must be strong enough to withstand the impact of the container falling from a height of 20 feet and landing on any side. It also should add a minimal thickness to the sides of the container. Two types of suspension were looked into for this application: leaf springs and coils. The benefits and disadvantages of each of these were compared and leaf springs were determined to be the best option.

Leaf springs (Figure 11) are the oldest form of suspension. It consists of a curved piece of metal (or other material) connected at the end to a load. When an impact force is applied, the metal will absorb it through straightening. They can come in any size, and the strength can be tailored by changing the dimensions, radius of curvature, or material. Newer leaf springs have layers of curved plates decreasing in size, increasing the strength for the size.

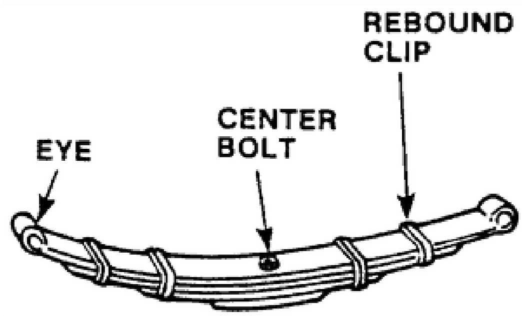

Figure 11: Leaf Spring [30]

Coils are like big springs. They absorb impact forces by compressing. They can also come in any size and strength which varies with dimensions, number of coils per length, and material. Some new technology allows the stiffness to be varied within a coil suspension through magnetic forces. The suspension of higher end Cadillac cars places the coil in a magneto-rheological fluid which changes viscosity when a magnetic force is applied to it. The viscosity will govern the stiffness. Bose Corporation also made a coil suspension that changes stiffness through the use of an electromagnetic force. However, in this case, the coil is providing this force which is then applied to a piston or strut.

2.7 Appliances

Commercial refrigerators (Figure 12) and freezers come in a multitude of shapes, sizes and designs. Traditionally they come with one, two and three doors, each with a standard range of sizes. A one door vertical refrigeration unit ranges from 23 cubic feet (78"x27"x31") for a standard type and 37 cubic feet (84"x35"x35") for a roll-in. A roll in type refrigerator can fit a baking tray and a tray rack. For the two and three door refrigerator, these dimensions are approximately doubled and tripled respectively. Horizontal refrigerators come in one, two or three doors, and also with drawers. These have a larger range of designs, with a mix of drawer and door arrangements available. Some can also be used as a countertop or workspace. Refrigerators and freezers also come as walk-ins which range from 85 (78"x59"x47")-100 (90"x59"x47") cubic feet.

Refrigeration units all come with a different set of features. Refrigerators have a temperature range of about 33-38 Fahrenheit and freezers are about -10 Fahrenheit. However, the temperature can be adjustable using a dial or digitally. Some units can have adjustable shelving, automatic lighting, or a ramp to roll in a tray rack. Each one of these features must be thought about when choosing appropriate refrigeration units.

Figure 12: Beverage Air 66" Roll-in Refrigerator [8]

An electric stove for a commercial or industrial kitchen can as a flat plate griddle and a coil hotplate. All of these can come in different sizes with the number of heating zones varying. A flat plate griddle is a flat metal surface usually made of stainless steel. This surface is heated from below creating an evenly hot cooking surface. There is a food trap at the front of the griddle to trap grease and excess food. A hotplate has metal coils that heat up and transfer heat to a pot or pan. These can come with multiple elements per unit that can be used independently. Ranges are a mix of these two types with an oven underneath.

There is a newer technology for stove tops called induction. With these types, a current is created in the pot or pan, which then heats the food to be cooked. This saves energy and runs colder than other types.

An all in one solution to cooking is to use a range. These units include several burners, griddle surfaces, and ovens contained within one unit. This allows for maximum space and energy efficiency, as well as a convenient centrally located cooking area. Like their separate counterparts, they can come in gas or electric and vary greatly in size. A range is the most likely candidate for use in cooking in the containerized kitchen.

Water purification can be done in many ways, each of which reduces the amount of certain contaminates. These contaminates include suspended solids, chemicals, bacteria, viruses, and other organisms. Activated carbon, chemicals, ultra violet rays, reverse osmosis, distillation and deionization are methods of filtration. Each method has different power requirements, dimensions, maintenance procedures, and can produce a different amount of water per hour.

Activated carbon filters remove some chemicals, such as chlorine, suspended solids, and some organic compounds. They vary in size depending on the amount of time it needs to run, and the quality of the water to be cleaned. Additives, such as silver, can also be used in the filter to get rid of other contaminates. The silver, for example can cut through bacteria making them inactive. These filters need to be replaced once the pores in the carbon cannot collect any more contaminate so they need to be monitored.

Ultra violet (UV) filters use shot wave UV rays to inactivate bacteria, mold, viruses and other living organisms. These rays are not naturally occurring in the environment so they need to be artificially produced. Suspended solids in the water can interfere with the UV rays and make the method less effective. Because of this, another form of filtration should be used before to remove the suspended solids. UV filters are very low maintenance and does not need to be monitored like other methods, to be discussed later.

Reverse osmosis is used to remove solids from water. It requires that the water be pushed through the system at a very high pressure, so that it can break through a semi permeable membrane. Contaminate will stay on the other side of this membrane and out of the water. This process I very slow and requires a lot of power to pressurize the water.

Distillation removes close to all contaminates from the water. Water is boiled producing steam and leaving the impurities in the original container. The steam is collected as clean drinking water. This process needs a lot of power to boil the water, and the container needs to be cleaned frequently.

Mesh filters removes suspended solids by forcing water through a fine metal mesh. Some filters can remove particles as small as 5 microns. Most of these types of filters are cleaned easily by running water backwards through the system. Some even have a self cleaning system where they do this automatically and internally. The power and pressure requirements for this are low.

Convection, conveyer, toaster and standard are all types of ovens that can be used in an industrial kitchen. A convection oven uses fans to blow hot air over food. They cook food faster and more evenly then other types of ovens. However, they draw more power as they need to heat the air and also circulate it. All other types of ovens use heated coils placed within the cooking area. In a conveyer type oven, food will go in one side of the oven, pass through the cooking area, and exit fully cooked. Some ovens also require a hood or vent to blow the air and heat away. Many newer ovens have a built in computer or RS232 port, to plug into a computer, to control the cooking process or programmable cooking modes. Some can double as a heater, to heat the area around the oven. There are also some ovens that double as a steam cooker.

A microwave (Figure 13) uses radiation to excite water molecules in food to cook it. Many microwaves have programmable modes to cook different meats at specific weights, to reheat food, or defrost them as well as custom power ratings. Generally, they have viewing window in the door which is made out of special material to block the radiation from escaping. The general dimensions are approximately 13.5x16.75x22, and 14.25x21.75x20.25 with interior dimensions of 6.75x13x12 and 9x14.25.16.38 respectively. The can have a voltage of 120 or 210, and a wattage of 1,200 or 1,800.

Figure 13: Amana 21-3/4" Heavy Duty Microwave [8]

Chapter 3: Development of the Containerized Kitchen

Each component included in the kitchen was modeled in computer aided design (CAD) software. These were inserted into an assembly to create different layout designs and perform a mass properties analysis. This analysis gave the total mass of the system, center of gravity, and mass moments of inertia. Each design was then be evaluated for its positive and negative features.

3.1 Design Criteria

The kitchen must stay within set standards given by the US Army as well as some created by the design team. The army states that the kitchen must fit within a standard 20 foot shipping container, feed 800 troops three meals a day for three days. Ideally, the cost would remain under $200,000, but the price has not been calculated as of the end of this project. The goal of this project is to improve upon the design created by the army.

The most important design consideration was making significant improvements over the army design. First, the setup and take down times must be reduced. This was done by limiting the amount of moving parts. Every appliance would be fixed in a location for transportation and use. This cuts back on setup time because not only do they not have to be moved into place, they come already hooked up and ready to use. Also, the only changes made to the container upon arrival are to open vents, doors and windows; no time is needed to expand the container and set up a tent, stairs or platforms. Also, an internal water tank will be designed so that a water truck will not have to be hooked up to the container. The weight of the container will be reduced by using more compact, efficient appliances and removing unnecessary items. These include air conditioning, tables, heating cabinets, etc.

The weight of the appliances is being transferred through the walls or floor into the four corners. Because of this, it is important for the design to have an even weight distribution. It is also important under the circumstance that the container is transported by helicopter. If this were to occur, the kitchen would be lifted by four hooks attached to the top. If the weight is not evenly distributed, the container may start to sway. This swaying could cause the helicopter to lose control, the hooks to fail thus dropping the container, or any other disastrous consequences. This will be evaluated in the CAD software through a mass properties analysis. The closer the center of gravity is to the middle of the container, the more evenly distributed the weight.

It is important to take into account that there is limited space for the men preparing the food to move around in and as such, as much usable open space should be left as possible. This open space should be near working stations so the soldiers have a comfortable amount of room. There also needs to be an appropriate amount of space in front of exterior doors as well as appliance doors for them to open without interfering with other appliances or activities in the kitchen. The walking area in the kitchen should be large enough for a person to walk through carrying a tray of food. This would not be completely necessary depending on the location of the serving window.

Serving windows and doors must be added to the container. Room along the exterior walls must be left open to provide space for this. Traditional doors are approximately 36 inches wide. A person could fit through a smaller opening. However, it may be difficult to go through a smaller door while carrying something. The serving window must provide enough space for multiple containers of food to be placed out. There should also be room for beverages and utensils near here. Both the doors and serving window need to be placed in a location that is out of the way while also convenient to access. Serving windows should be as close to the cooking area as possible as to limit the distance the food will need to travel before being served.

The accessibility and location of the appliances is another important design factor. A person must be able to use an appliance without difficulty. This means there should be enough room surrounding it for a person to move around comfortably while holding anything necessary for use of that appliance. A person must also be able to take the food or dishes out of an appliance without difficulty. It also means that it should be at a comfortable height for use. For example, the fryer basket should be at about arm level, or 36 inches off the ground. It is also important to consider the movement of the appliance doors. There must be room in the front of the appliance for the door to open and a person to access the contents. The door cannot block anything else in the kitchen.

The sanitation issues in this kitchen arise mostly from the location of the toilet and sink in respect to the other appliances. The toilet cannot be placed near any cooking appliances because of the risk of contaminating food with human waste. It is also important to place the sink in close proximity to the toilet to personnel can wash their hands before returning to work. Sanitation concerns can be lessened by changing the barrier around the toilet. If a full height wall with a door is built around the toilet then there is minimal chance of contamination. However, if a curtain is used around the toilet, then there is a much higher risk, and it must be placed far away. If a curtain is used instead of a wall, slightly more floor space is available.

Depending on how many people there will be cooking, the location of the cooking appliances differs. However, in all circumstances, it is important to keep the cooking appliances in close proximity to each other. With everything close together, there will be less movement through the kitchen with ingredients and prepared foods. Less movement through the kitchen lowers the chance of an accident. It is also important to keep these close together for easier cooking. If all parts of a meal are cooked close together, they can be combined and served the same way.

The location of the water using appliances relative to other appliances also needs to be taken into account. If there was a leak or spill from one of those appliances, then it may cause damage to an appliance that was not made to be near water. It could also pose a potential fire hazard. For example, if water was to get into the fryers, it could cause a fire, or burn someone easily. There could also be a short it water was to get on the generator.

The flow of movement through the kitchen can affect ergonomics, efficiency and safety. Appliances must be placed far enough apart that a person can walk between them while carrying a tray of food. If an appliance is low to the ground, like the freezer, there must be enough room around the door opening for a person to crouch down and reach food in the back of the compartment. Open appliance doors must not prevent movement through the kitchen. Door openings must be placed in a location where there is easy access in case of emergency exits. In general, movement through the kitchen should remain unrestricted no matter what appliances are in use. Also appliances should be places so that movement is kept at a minimum.

The water, waste, electrical and fuel system designs have not been designed yet. However, they still must be taken into account when designing the floor plan. Having all appliances that use the water or waste systems close together will make the respective systems less complicated to design, install and repair. All of the appliances in the kitchen are electric and as such, the electrical system has a lot of options in their design. The location of water, waste and fuel tanks will change the weight distribution of each design significantly. When they are designed on must consider this.

3.2 Appliance Models

The container, seen in figure 14, as discussed in the background section, is 20 feet long, 8 feet wide, and 8.5 feet tall.

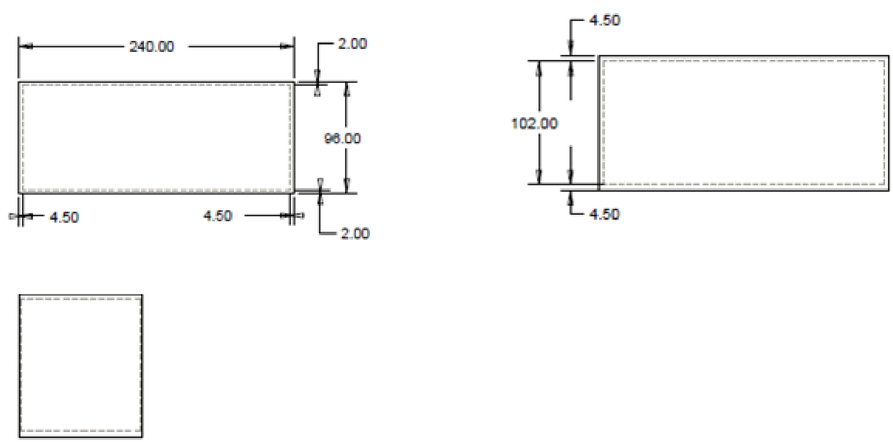

Figure 14: Top, Front and Side Views of Container (from left to right)

The dishwasher model shown in Figure 15 is 71.125 inches tall, 36 inches deep and 50 inches wide. This model was chosen because of its large capacity, quick cycle times, and low water and power usage. The wash chamber is 38.75 inches wide, 26.375 inches deep and 28.5 inches high. Because of the large volume, this area could be used as storage for cooking utensils during transport. Each 27 second cycle uses 5 gallons of water. The design is very sturdy; all connections are either MIG or TIG welded. Every component is made of stainless steel.

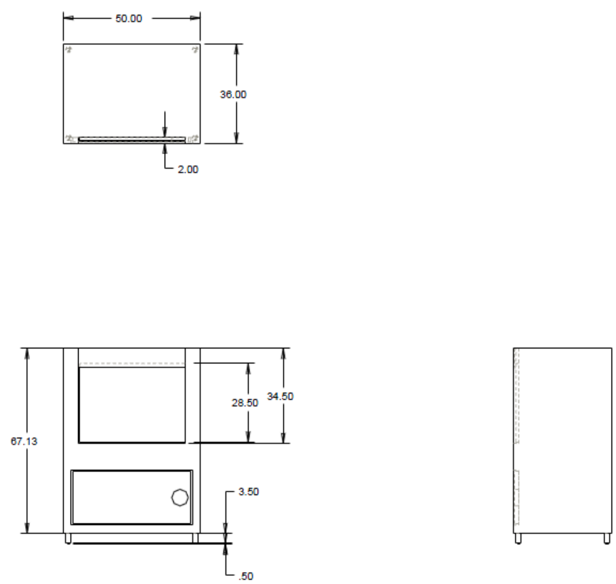

Figure 15: Top, Front, and Side Views of Dishwasher (from left to right)

The freezer, shown in figure 16, is 36 inches tall, 31.5 inches deep and 32 inches wide with an internal volume of 6.9 cubic feet. This is a standard size, small refrigerator. However, the top surface on this model can be used as a preparation surface. The freezer is made of stainless steel, weighs 280 pounds

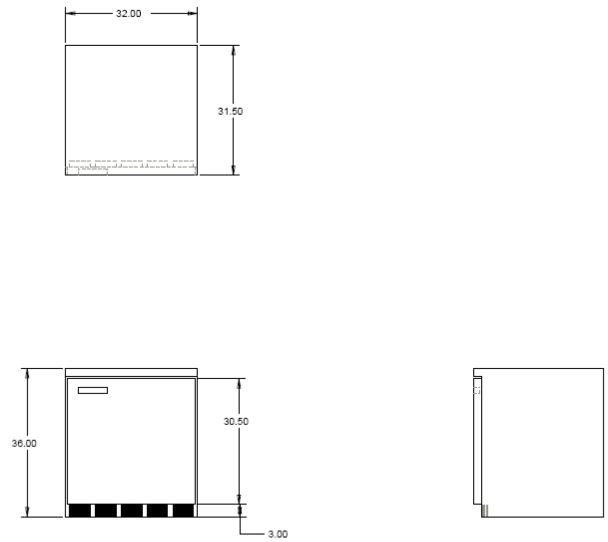

Figure 16: Top, Front and Side Views of Freezer (from left to right)

The fryer, shown in Figure 17, is 11 inches high, 7 inches wide and 15.5 inches long. It can fry 22 pounds per hour and can hold 10 pounds of oil. It is made out of stainless steel and weighs 12 pounds. This was chosen because it is a standard, one basket fryer size and runs off a 12 volt power source.

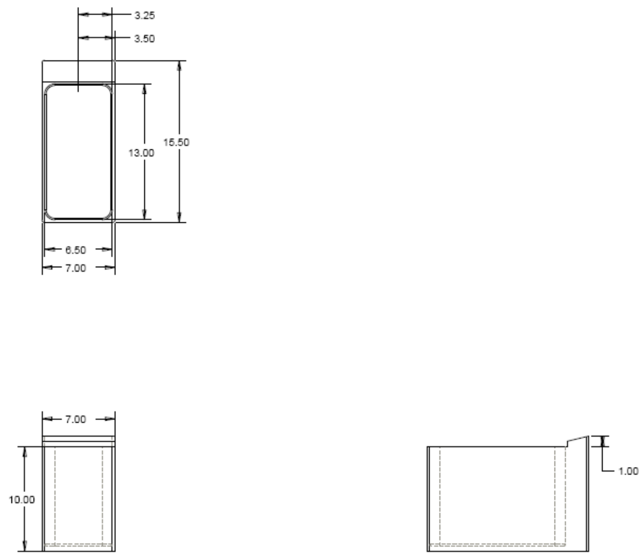

Figure 17: Top, Front and Side Views of Fryer

A 30kW Guardian Elite generator, shown in Figure 18) was chosen for this kitchen because of its compact design, low noise level and safety features. This generator is a 4 cylinder in-line engine that runs off natural gas or propane. It is 62.2 inches long, 29 inches wide and 33.5 inches tall and weighs 935 pounds. There is a 0.75 inch fuel line connection 30.7 inches from the edge on one long side. There is also a control panel on this side that may need to be accessed. This will be taken into account when placing the generator. This generator is a significant improvement in size and power over the original design by the army.

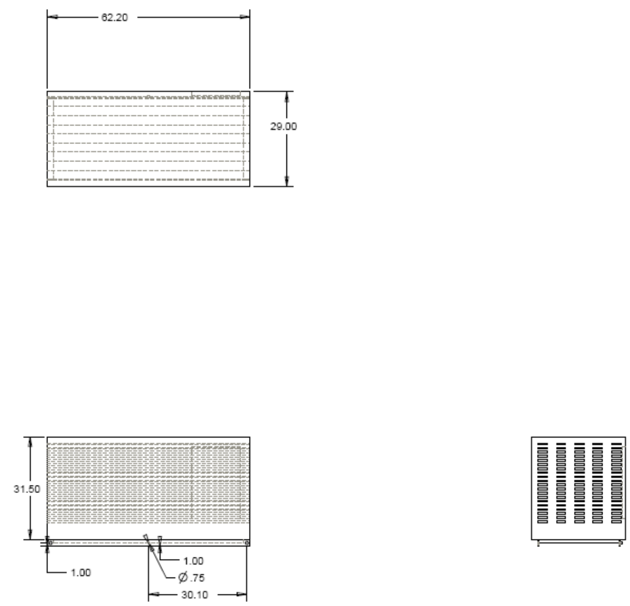

Figure 18: Top, Front, and Side Views of Generator

The microwave (Figure 19) chosen is a standard design made by Amana. It is 14.25 inches tall, 21.75 inches wide and 20.25 inches deep. It has an internal volume of 1.22 cubic feet and weighs 142 pounds. The design can be wall mounted or placed on a surface.

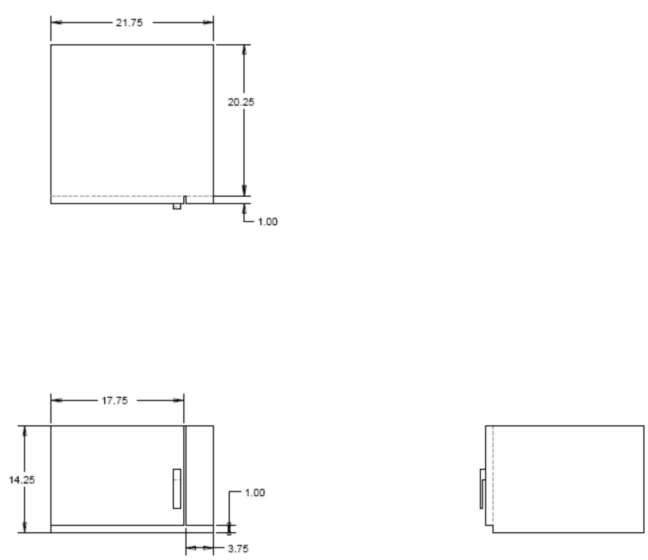

Figure 19: Top, Front and Side Views of Microwave

The range chosen is a Vulcan Hart brand (Figure 20). There are two convection ovens that can reach temperatures of 500 degrees Fahrenheit. Convection ovens were chosen because they cook food faster and more evenly. Two were needed to prepare the appropriate quantity of food. There are six, 9.5 inch hotplates that can be controlled separately. There are also two independent griddle sections. This is much more space and energy efficient then having separate griddles, hotplates and ovens, like was used in the initial army design. Also having separate heating zones for the griddle and hotplates adds energy efficiency.

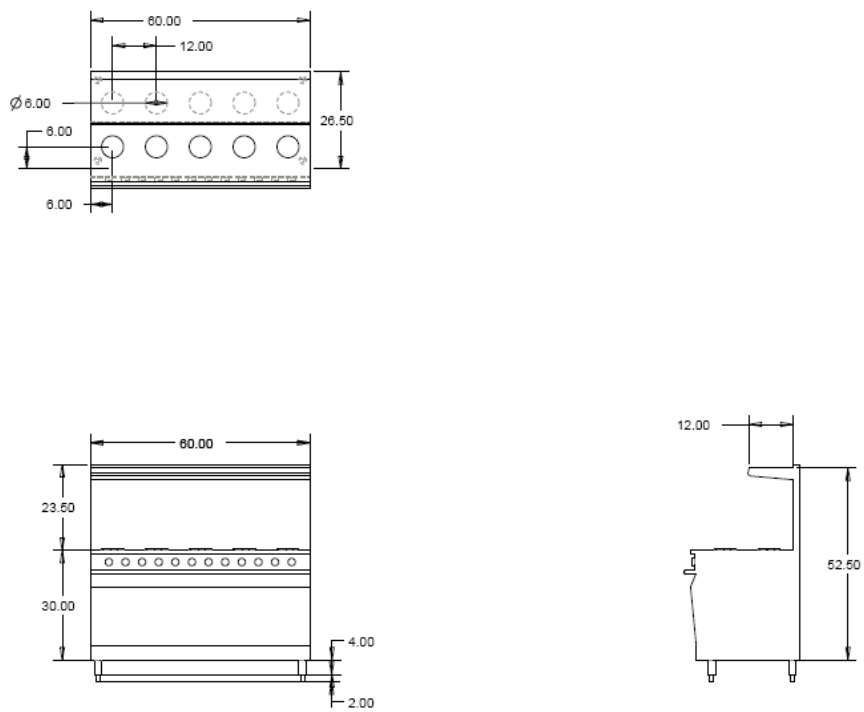

Figure 20: Top, Front, and Side Views of Range

The refrigerator (Figure 21) chosen is a standard size, duel section made by Beverage Air. The total internal capacity is 73.4 cubic feet. It is 66 inches wide, 33 inches deep and 84.5 inches tall and weighs 777 pounds. This refrigerator is taller than most because the mechanical/cooling system is on top rather than in back. It was determined that having a design like this would allow for greater and more efficient use of floor space. Also, having one, two section refrigerator saves space and energy compared to having two, one sections. However the large size and weight of the appliance could limit the layout design options.

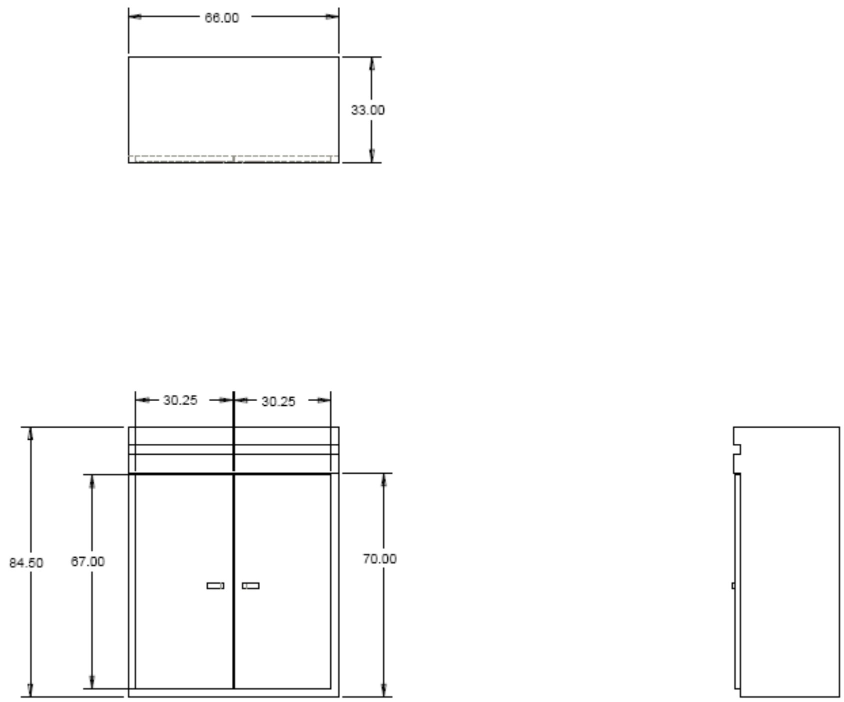

Figure 21: Top, Front and Side Views of Refrigerator

A single sink (Figure 22) with no connecting surface was chosen. The total height of the sink is 42.25 inches which includes a 9.5 inch splash guard behind the basin, 13 inch deep basin and 22.75 inch tall legs. It is 20.5 inches wide and 21.25 inches long. The basin measures 18 inches in length and width. The construction is all stainless steel. This sink was chosen because of the simple, space saving design and the low weight of 33 pounds.

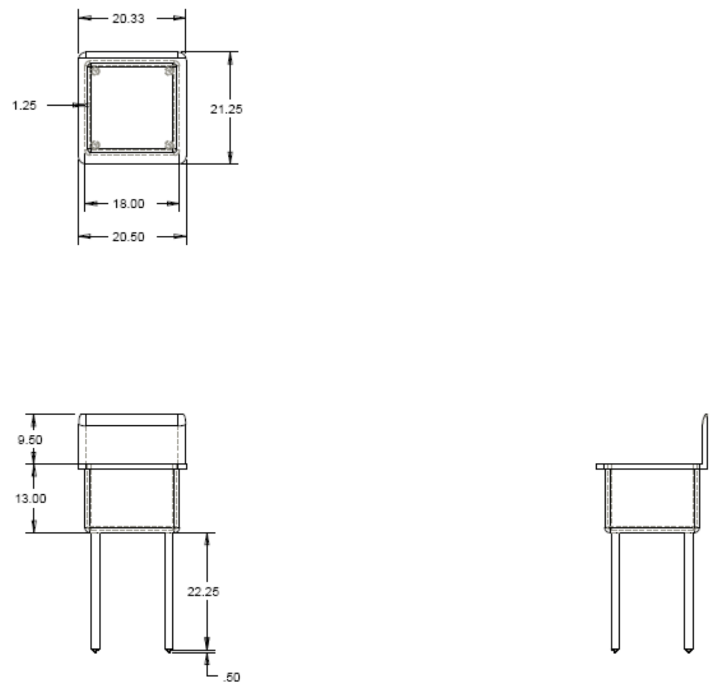

Figure 22: Top, Front and Side Views of Sink

The toilet (Figure 23) that was decided upon was designed to be used in marine applications. It was chosen because it is manually operated by a hand pump. This means that there is less likelihood of failure. Because it was designed to be used on a boat, there is minimal water used; one gallon per flush. It is also a very compact design, measuring only 24.21 inches tall while open, 17.72 inches wide and 19.09 inches deep while open, for the compact design.

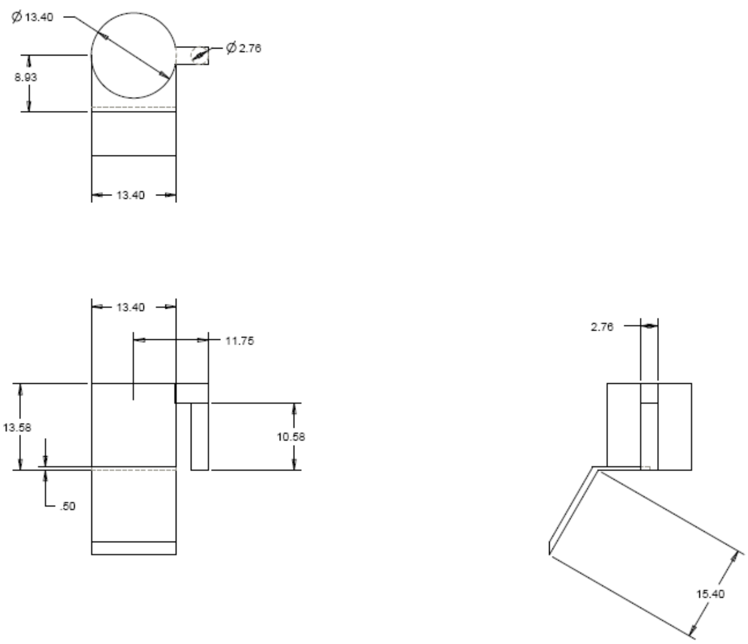

Figure 23: Top, Front, and Side Views of Toilet

If an appliance fails in the field, it will be replaced instead of repaired. The methods of connecting the appliances to the container have taken this into account. The appliance will either be removed through an opening in the ceiling, or pulled out through the door. By doing this, less time is lost due to a broken appliance.

3.3 Water Usage/Systems

The total water in the system takes into account the water needed for drinking, shower, toiler, dishwasher, sink, cooking and cleaning. Each person will drink 12, 8 ounce glasses of water per day for a total of 67,200 oz (525 gallons) per day, and 201,600 oz (1575 gallons) total. The shower is used for emergency purposes only. Seven 10 minute showers were allotted for over the course of the week. At 3 gallons per minute, this means 30 gallons are used. The toilet uses one gallon per use and with ten uses per day, 10 gallons are used each day and 30 total. Each load of dishes washed uses five gallons, with six cycles per day, 30 gallons are used each day and 90 total. It was assumed that the sink would only be used for one hour during each meal (not including the water to fill cooking pots). At a flow rate of 1.6 gallons per minute, this equals 288 gallons per day and 864 gallons total. To keep the kitchen clean, it was assumed that 10 gallons of water was needed every day for sanitary purposes for a total of 30 gallons.

The total amount of water needed cannot be stored in the container because of the volume and weight. However, some of the water can be filtered and reused. The drinking, toilet, cooking and cleaning water cannot be reused, while the rest can. The reusable water totals 528 gallons of water per day. The total 210 gallons for the shower was used as it cannot be predicted when the showers would occur. The maximum flow rate that the water could run through a filter occurs when the shower and sink are running, and the dishwasher is emptying. This would result in a flow rate of 9.6 gallons per minute.

A combination of a mesh and an ultraviolet light (UV) filters were selected. A mesh filter will remove solid particles down to a size of 10 microns. It will also kill some organisms because when they impact the mesh they die. This filter can operate at a maximum filtration rate of 65 gallons per minute and at low pressures. A UV filter will kill living organisms such as bacteria or viruses including some possible bio weapons. It can operate at a maximum filtration rate of 52 gallons per minute, also at low pressures. Additional pressure may be needed depending on the location of the filters. This could be done using an appropriately sized pump.

With a total of 528 gallons of reusable water needed daily, a minimum storage tank capacity could be found. It is assumed that water is used evenly at each one hour meal (cooking time may be longer but would only require a smaller tank). If a 15 minute complete recycle time is assumed (far longer than actually needed), the minimum tank size is approximately 45 gallons.

A 45 gallon tank is slightly larger than 6 cubic feet and would weigh 375.4 pounds. A larger storage container may be used for water to be used for non-reusable purposes.

3.4 Preliminary Designs

Two preliminary designs were created to help gain a better understanding of how the weight, ergonomics and open space would be affected.

The first preliminary design is shown in Figure 24 below:

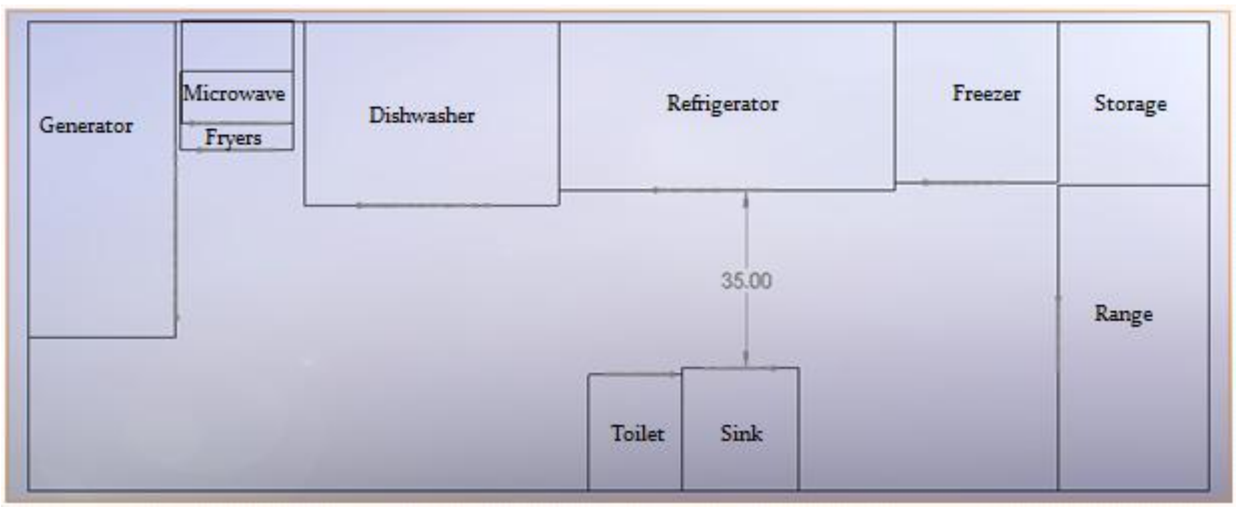

Figure 24: Preliminary Design 1

This design incorporates a U-shape. There is ample open space for movement within the kitchen, as well as wall space for doors and serving windows. The freezer, with preparation surface on top, is located near the range and refrigerator for convenience. The toilet is well removed from cooking areas for sanitation. However, the microwave and fryers are located on the opposite side of the kitchen as the rest of the cooking appliances. This could create an inefficient system. However, if the generator can run off bio-fuels, having the waste oil from the fryers next to it could be beneficial.

Preliminary design 2, shown in Figure 25, has a long hallway design. This leaves even more open wall space for a door on the short side and a serving window on the long. In this design, all of the cooking appliances are positioned close together. This could either be beneficial or detrimental. Having them close together will create an efficient space for one cook to multi-task. However, if there is more than one cook there may not be enough space to move around. This could cause accidents or injuries. Once again, the freezer is located next to the range for convenient surface working space. However, the toilet is not well isolated from the cooking area causing a sanitary concern.

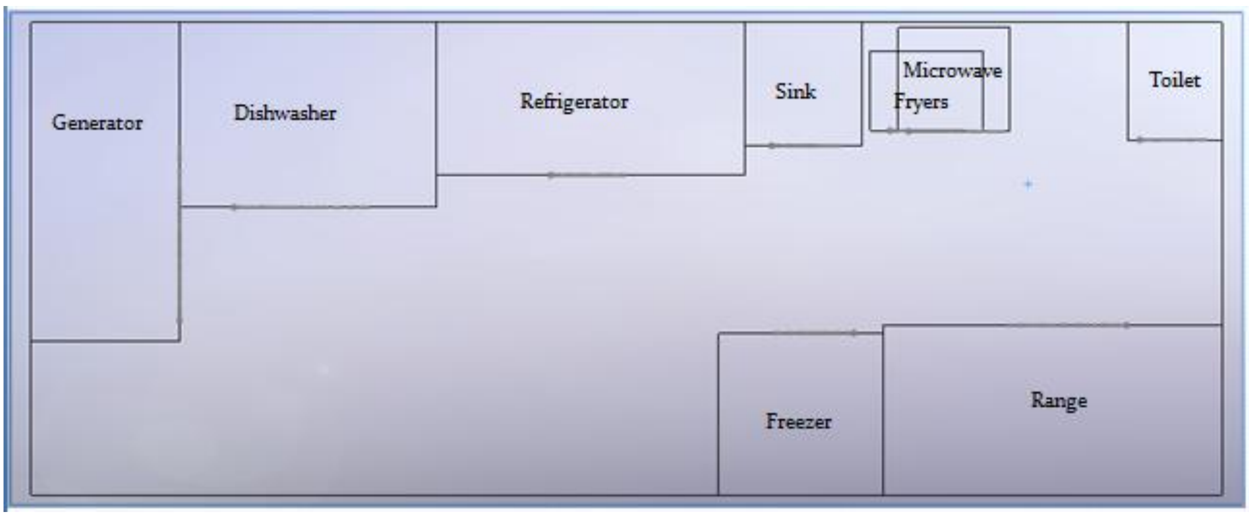

Figure 25: Preliminary Design 2

3.5 Design Iterations

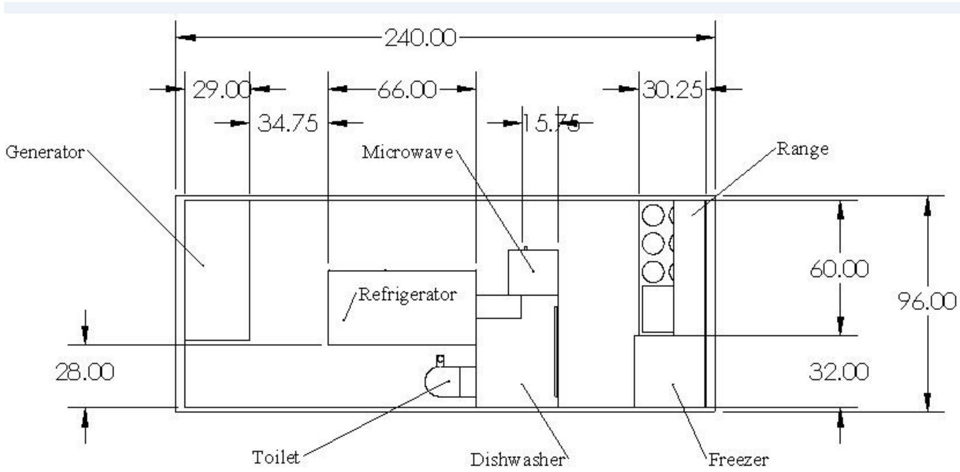

Figure 26: Design 1 Top View

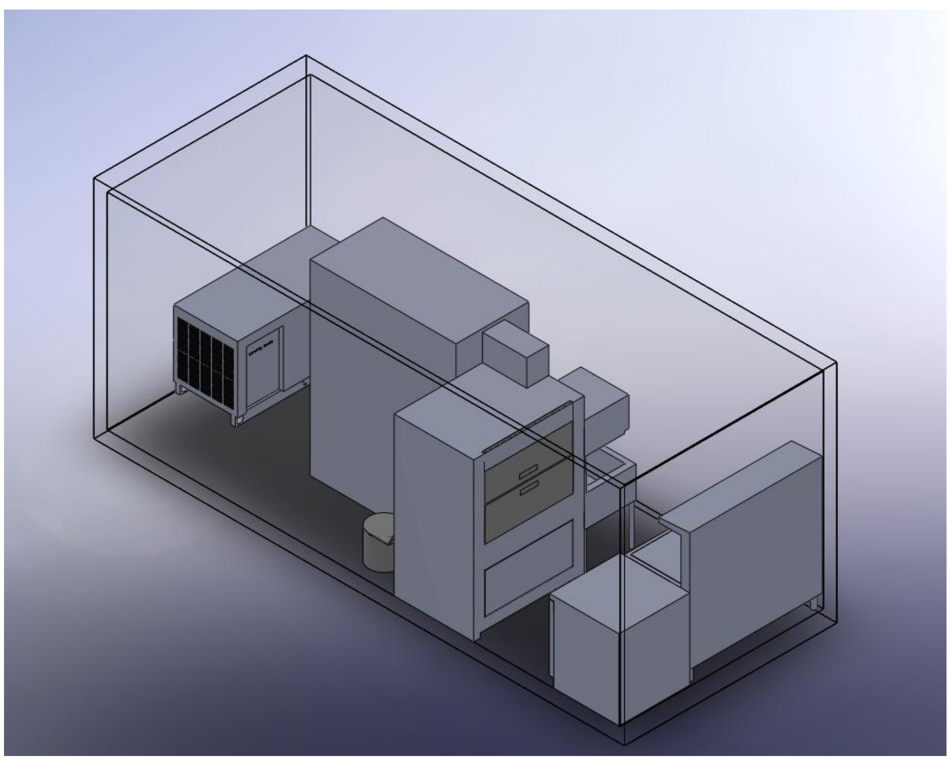

Figure 27: Design 1 3-D View

Design one (Figures 26 and 27), positions the refrigerator and dishwasher in an L shape around the bathroom area. This design efficiently isolates the bathroom area from the cooking area while providing a protected space from intruders in case of an attack by the enemy. The orientation of the various components results in a fairly balanced distribution of weight which leaves the center of gravity near the geometric center of the container.

The ergonomics of this design have suffered as a result of the improved efficiency of the design. Although all appliances will be function properly and be usable, this design will most likely be uncomfortable for the end users. There may be issues in transferring foods from storage to cooking and to serving. These issues could pose problems such as inefficient food production, serving, and safety. The cramped configuration also poses a problem in determining the best location for a serving window. There is limited wall space available for an egress and serving window, and high foot traffic in any area of this design would only create more congestion to the kitchen staff.

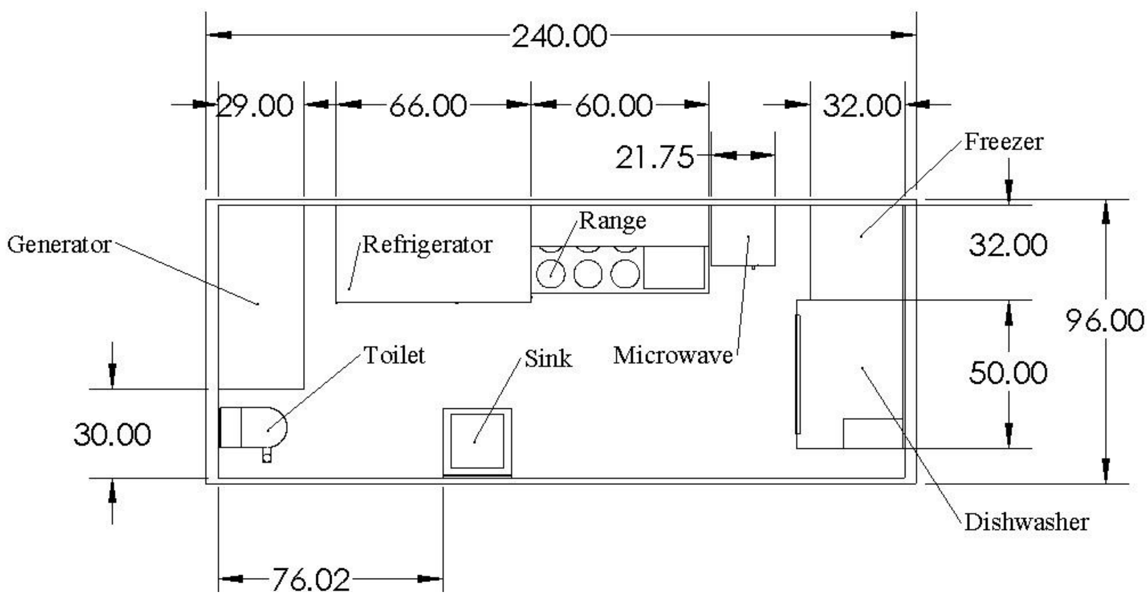

Figure 28: Design 2 Top View

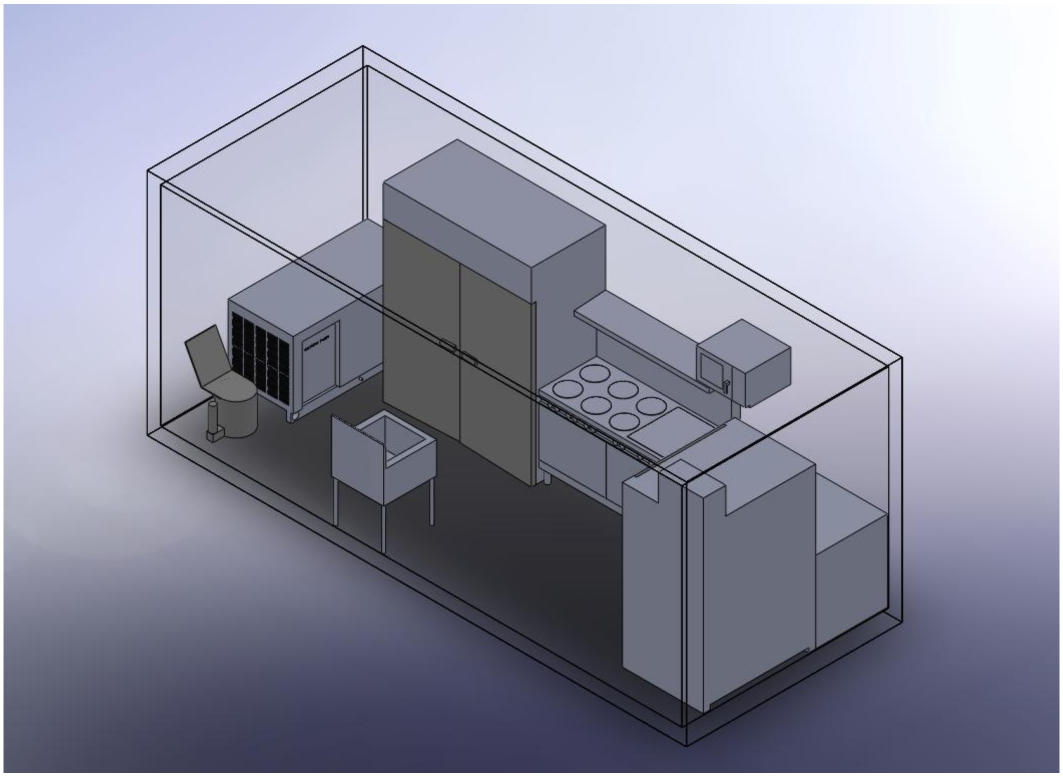

Figure 29: Design 2

Design two (Figure 28 and 29), positions the appliances in a U shape along a single wall of the container. This open design allows for free movement of users of the kitchen to allow maximum cooking efficiency. The bathroom area is separated from the cooking space in a corner near the generator. The sink is centrally located to allow for easy use by all members of the kitchen staff. This design provides ample wall space for egresses and ventilation/serving windows. The ergonomics of this design are good; this configuration should be comfortable for the staff of the kitchen.

By positioning the bulk of the appliances along a single wall of the container, the center of gravity has shifted away from the geometric center. This weight imbalance could be a problem during transportation of the container to and from the battlefield. The open layout of this design could pose a problem if the container were ever breached by the enemy. There are no good hiding places or shields for use in a firefight.

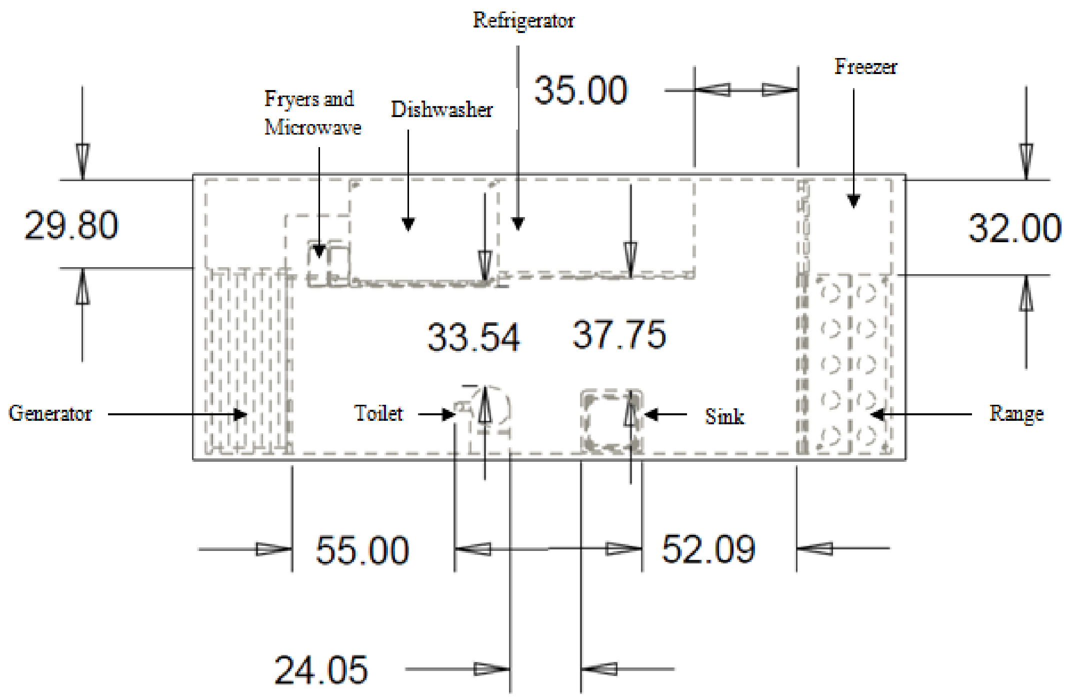

Figure 30: Design 3, Iteration 1

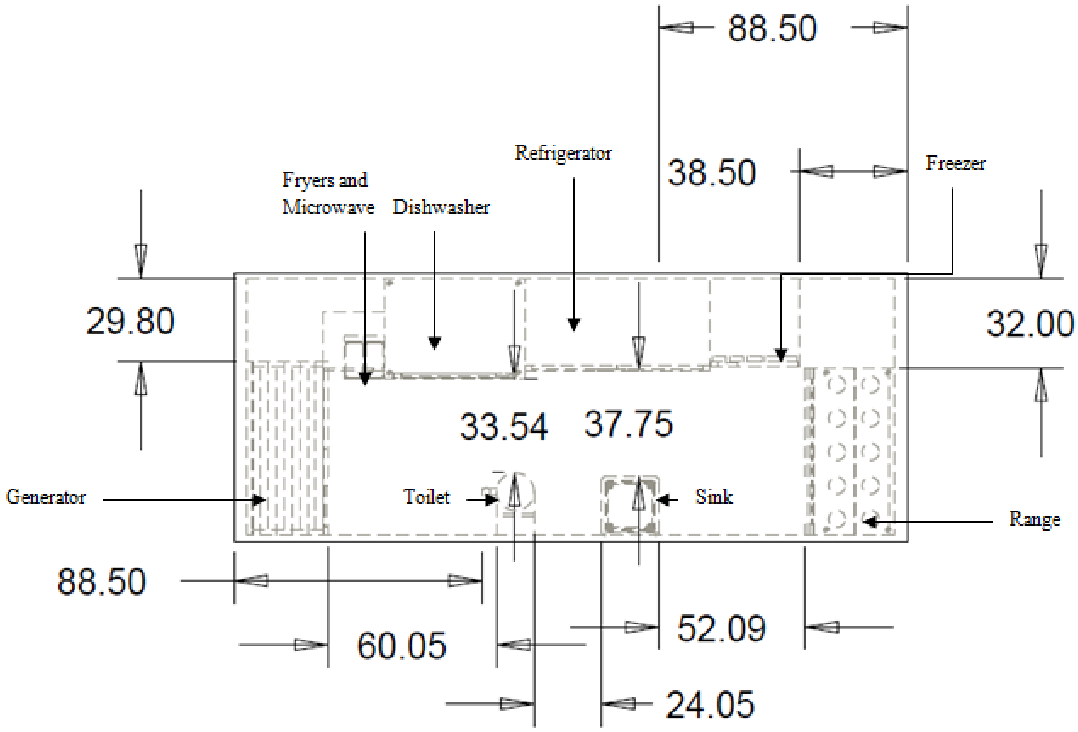

Figure 31: Design 3, Iteration 2

Design three (Figures 30 and 31), is similar to the U-shaped preliminary design. This design is good because it has lots of open space, there is working surfaces near the cooking areas, and the toilet is removed from any food preparation areas. However, the toilet is near a possible serving window location, which could cause sanitation concerns. The fryer and microwave are also far removed from the rest of the cooking area, which would mean that food may have to travel farther through the kitchen then necessary.

The difference between iteration one and two is the location and direction of the freezer. It was rotated 90 degrees and moved adjacent to the refrigerator. This makes the freezer door and top surface more easily accessible. However, it creates a corner of unusable space. As shown in the figures 60 inches and 52 inches of open space are on one edge of the container. These could be used as serving window or doors. The sink and/or toilet can be moved to change these dimensions as needed. However, the space between the sink and range needs to remain large enough for a person to work, as well as the ovens underneath to open. The open space next to the generator could be used as an access area or fuel storage. The walking area has 33.5-37.75 inches of walking room. This is plenty of space for a person to walk through, even if they are carrying a tray of food.

The approximate center of gravity for iteration two is approximately 1.83 inches to the left of the midline in the long direction, 9.43 inches below the midline height, and 2.87 inches towards the back in the short direction. This means that there is room for improvement in terms of weight balance.

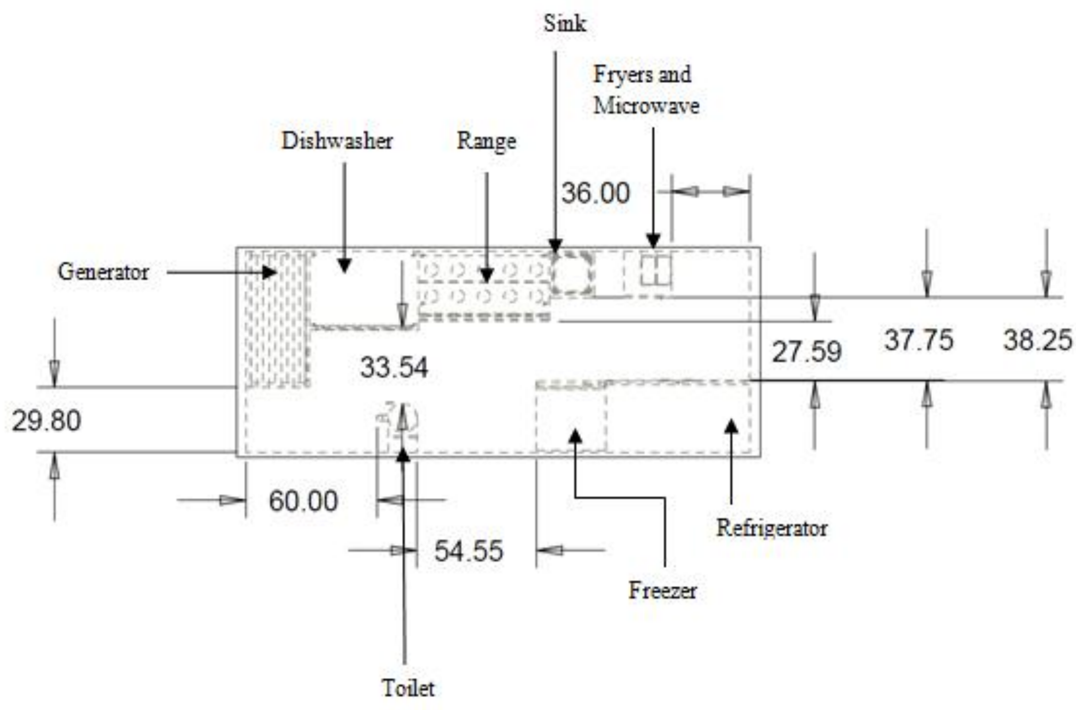

Figure 32: Design 4

Design four (Figure 32) is like the second preliminary design. All of the cooking appliances are located close together so that only one chef would be needed. However, given the amount of food being made in a short amount of time one person might have a difficult time. The sink, dishwasher and toilet are also not located near each other, which makes the water system harder to design. The toilet has been moved from its location in the preliminary design. In the new location, it is away from any food, except a possible serving window. The toilet could also be rotated and placed in the corner by the generator. This would reduce the space around it making it more awkward to use. However it would open up the long edge for a serving window. As it stands now, there is a 60 inch opening and a 54.55 inch opening. Along the short side, there is also a 59.5 inch opening that could be used. The walking space within the kitchen never goes below 27 inches. This is large enough for a person to walk through, though it might be difficult with a tray of food.

The center of gravity is located 7.47 inches to the right of the centerline along the long side, 9.43 inches below the height midline, and 3.76 inches towards the back in the short direction. This shows that design four has a more uneven weight distribution then design three.

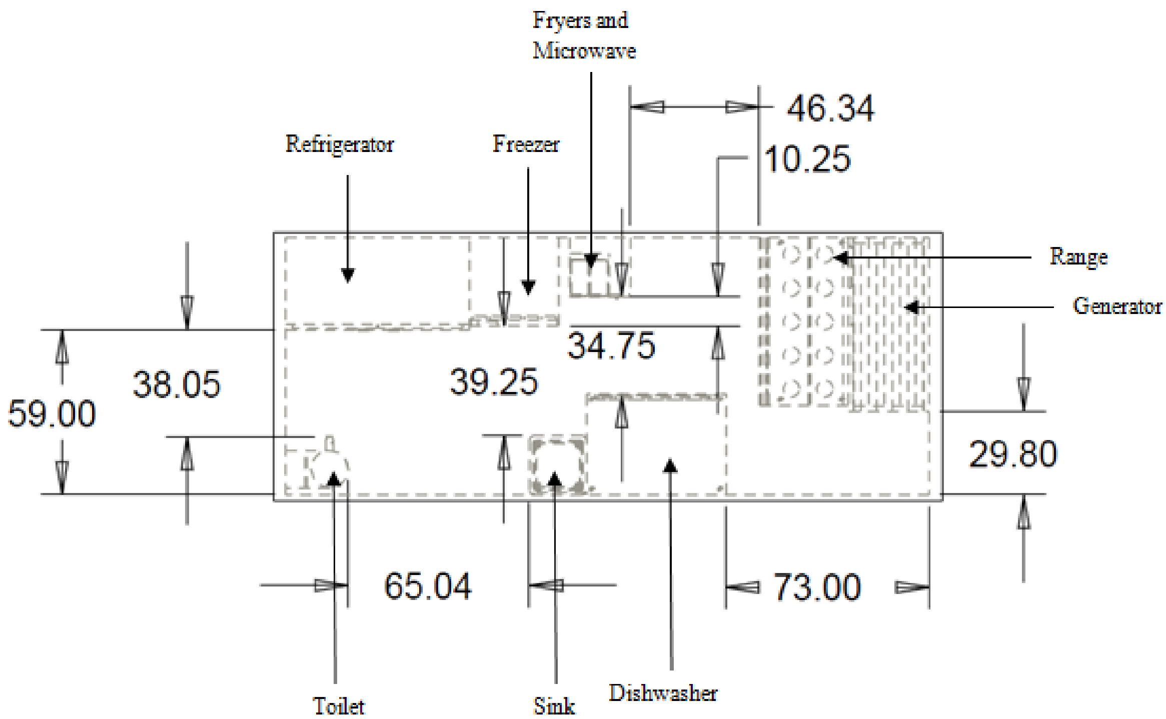

Figure 33: Design 5

Design five (Figure 33) is not like the other designs. There is no hallway or clear path for movement. The cooking appliances are all located in the same area. However, there is room on more than one side of the microwave and fryers to allow for more than one person to cook. Also, the freezer is near the cooking area so that there is preparation surface near. The toilet is on the opposite end of the kitchen from the cooking, so sanitation will not be an issue. Also, all of the water using appliances are located along the same wall so the water distribution system will be easier to design. However, with the dishwasher where it is, it would be impossible to load or unload dishes while someone was using the microwave or fryers. There is also no way to access the control panel of the generator from the inside as the generator is blocking one side.

However, if the control panel was located against the exterior wall, an opening could be made to access it.

In the 73 inch by 29.8 inch area next to the generator and range, there could be fuel storage. The 38 inches on the short side of the container could be a door, while the 65 inch opening could be a serving window. However, this creates a sanitation issue having the toilet directly next to the serving window. Movement through the kitchen should be easy with the hallway getting no narrower than 34.75 inches.

The center of gravity is located 10.3 inches to the left of the centerline along the long side, 9.40 inches below the height midline, and 4.51 inches towards the back in the short direction. This shows that design four has a more uneven weight distribution than the previous designs.

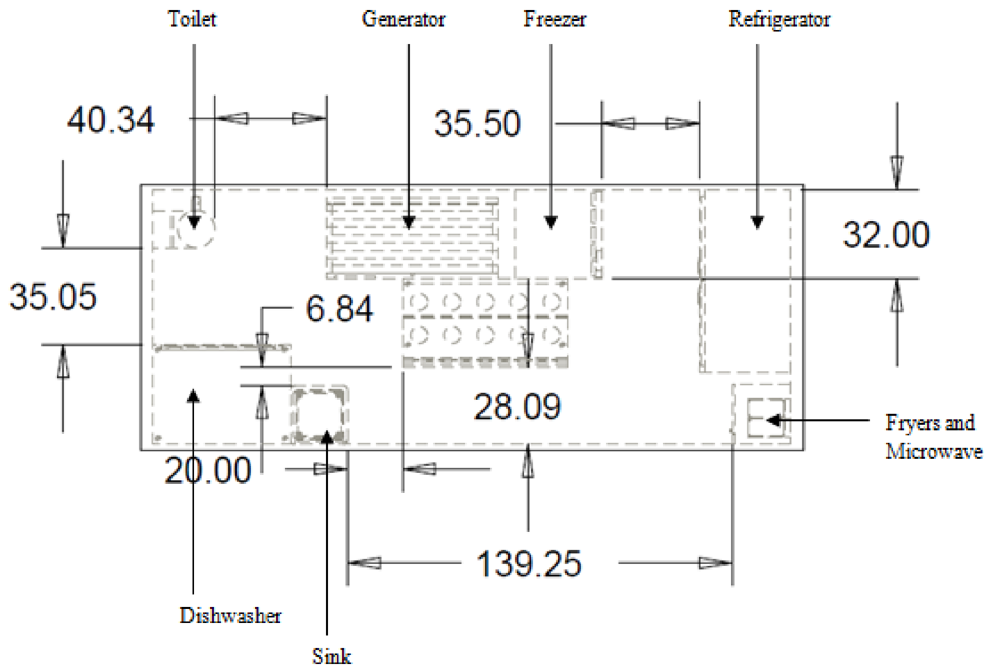

Figure 34: Design 6, Iteration 1

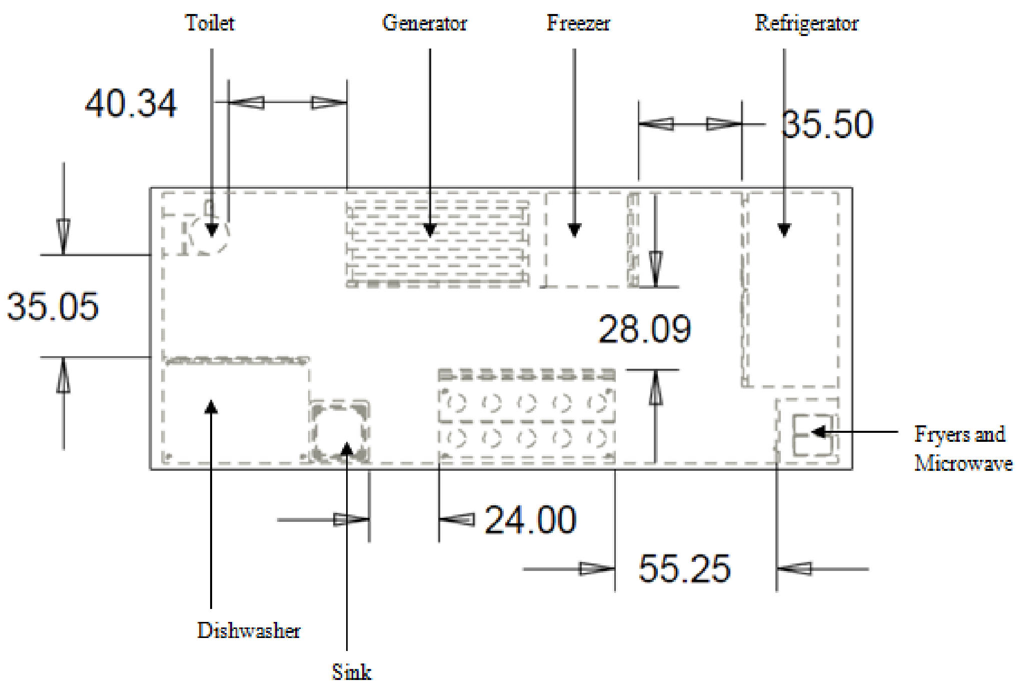

Figure 35: Design 6, Iteration 2

The first iteration of design 6 (Figure 34) creates a U-shaped walking area. Some of the walking space is narrow, reducing to 20 inches in an area, but it will only be necessary to walk through those areas with dishes. All cooking appliances are located in the same region. However, there is room for more than one cook to be working. The space between the refrigerator and freezer is also very constricting (35.5 inches), only leaving a few inches after a door is opened. The freezer and generator can be moved slightly is more room is desired. Each door will open toward the wall so access is still available from the more open area. All water using appliances are located in the same corner, away from other appliances, minimizing the possibility of a spill damaging other equipment.

This design does not leave much open wall area for doors and serving windows. A door could fit on either side of the toilet, but it would limit the space within the restroom area. The 139.25 inch space across from the range could fit both a door and a serving window. This is a good place for a serving window because it is in very close proximity to where the food is cooked. This means that the food does not have to be moved through the kitchen before being served.

The second design iteration (Figure 35) rotates the range 180 degrees and places it against the exterior wall. This creates a long, narrow hallway through the kitchen. Because there is a straighter, less constricting path through the kitchen, there will be a lessened chance of an accident. However, this design reduces the available locations for doors and serving windows, as well as their respective sizes. The space between the range and sink is 24 inches, just wide enough for a small door to be placed there (the range could be moved to the right slightly for a wider door). Once again, a door could be placed near the toilet as well. The 55.25

inch space between the range and the fryers is the best place for a serving window because it is located in close proximity to the food and is the longest open space.

The center of gravity for the first design iteration is located 1.10 inches to the right of the centerline of the long side, 9.47 inches below the vertical centerline, and 2.55 inches to the front of the short side centerline. The second design iteration is very similar to this. There is a 1.48 difference in the long direction, 9.47 again in the vertical direction and 5.14 in the short direction. This shows that the first design has the better weight distribution.

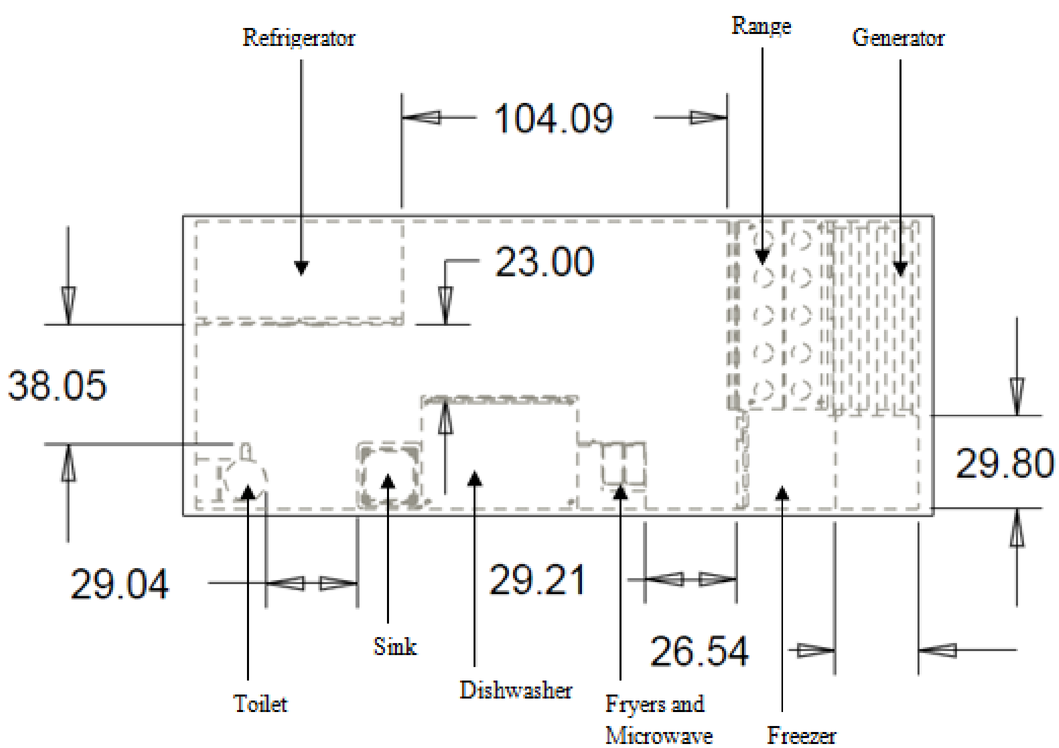

Figure 36: Design 7, Iteration 1

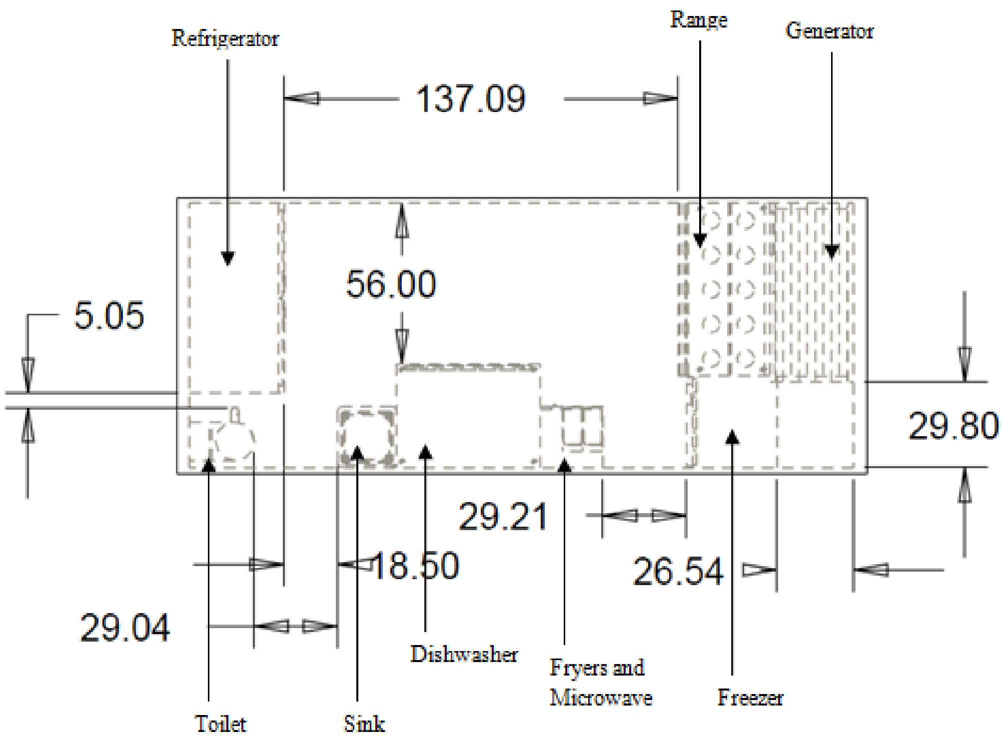

Figure 37: Design 7, Iteration 2

Design seven is based off design five in that the generator and range are abutting each other. In this design, the cooking appliances are once again all placed in close proximity to one another. The freezer is next to the range for a convenient preparation surface. There is a greater amount of open space in this design. Once again, all of the water using appliances are located close to each other. The space next to the generator could be used for fuel storage. The freezer in these designs is given just enough space to fully open the door. It is also in a hard to access corner which could make it difficult to reach foods in the back.

In the first iteration (Figure 36), there is a narrow (23 inch) walkway to get to the sink, toilet and front of the refrigerator. This opening is at an angle though and should not cause a problem when walking through with food from the refrigerator. There is a 104 inch opening between the refrigerator and range that could be used as a serving window. This would be the ideal location because it is close to cooking, which would therefore minimize the movement within the kitchen. There would also be enough room to add a door in this area. Another location for a door would be next to the toilet along the short wall. This would be just wide enough, but would make the restroom area cramped.

The second design iteration (Figure 37) rotates the refrigerator 90 degrees and places it against the short exterior wall. This will make it easier to access the front of the refrigerator as well as open up space along the long exterior wall. The 137 inches along the long wall could once again be used as a door and serving window. This is recommended as there is no other location for a door in this design. By rotating the refrigerator, the open space surrounding the toilet is significantly reduced. However, an entranceway could still be made between the sink and refrigerator.

The center of gravity of the first iteration is located 10.9 inches to the right of the long axis centerline, 9.4 inches down from the vertical centerline and 1.91 inches to the front of the short axes centerline. The second iteration is slightly better in the long axes with 9.39 inches, the same vertically and worse in the short axes with 4.01 inches.

3.6 Prototype

A half size prototype to be build out of plywood and 2x4's was designed. The container and appliances would be built with a 2x4 frame and then covered with 0.5 inch plywood. This prototype would be used to help determine the most ergonomic layout to use. It would also help visualize the best location for storage, lighting, and openings. Since it was not essential to have the appliances in the proper shape, each would be created as a box of the largest dimension. See Appendix A.3 for design.

To build the prototype, a total of 16 sheets of 4’x8’x0.5” plywood, 16 2x4’s, 2 boxes of 3” nails and wood glue would be needed. The final design created from this would then be made in an actual shipping container with functional appliances and systems. This could then be tested.

Chapter 4: Structural Analysis

A standard shipping container of the size used in this design can hold over 60,000 pounds. For our purposes, a payload capacity of 60,000 pounds will be assumed. The appliances in the kitchen will weigh less than 9,000 pounds, far under the maximum. No modifications are needed to the container for this purpose. Additional reinforcement would be needed near any windows, doors, ventilation or other modifications. When an opening is added to the side of the container, the stiffness of that area is removed. Standard structural design methods can be used to design supports above and next to the opening to transfer the loads.

Each container can have eight other containers stacked on top of it. This means that it has a capacity of 480,000lb (8 containers * 60,000lb/container), over the top area of the container. This weight is evenly distributed down the four corner support columns. Each of these columns can support 120,000lb (480,000/4) vertically, without a safety factor. This will not change with any modifications to the container. This will be sufficient support for our purposes.

With the addition of doors, windows, serving windows, and ventilation, the structural integrity of the lateral supports is removed in that area. The sides of a container are designed to withstand the ocean wind speeds of at least 11 meters per second (24.6 miles per hour). However, for the kitchen to be used in extreme conditions, additional support will be needed. There will also be supports added near any openings made that will provide stiffness. These will need to be designed after the location of these modifications is decided.

There are many possible ways of adding lateral support. One is adding cross bracing on sides where no modifications are made. Holding containers for overhangs, appliances, utensils, or other permanent fixtures could be attached to the container. Also, where modifications are made, supports will be added above and to the sides. These could be made stronger to add lateral stability.

4.1 Vibration

However, the shipping container may be transported in a way where it will be off the ground and therefore have the potential of being dropped from a low elevation. The vibration of each side was analyzed. The resulting vibration is of the form:

$$x(t) = \frac{F_0}{K}[1 - \cos\omega_n(t - t_0)]$$

and

$$x(t) = \frac{F_0}{K}[\cos\omega_n(t - t_0) - \cos\omega_n t]$$

Where ω_n is the natural frequency, t is time, $t_0$is the time of impact, F_0 (790,967.9 lb) is the force of impact, and k is the system stiffness. The force of impact was found using a drop height of 30 feet and the acceleration of gravity.

The equivalent stiffness is found by the equation $k=192EI/l^3$ where E (30,000,000 lb/in^2) is Young's modulus, I (40,000,000 in^4) is the moment of inertia and l is the length of that side. The natural frequency is found by $\omega_n=\sqrt{(k/m)}$ where m is the mass. The resulting stiffness is

1.68×10^{15} lb/in and the natural frequency is 440550.8 (1/s). The graph in Figure 38 show the resulting vibration. There is a maximum deflection of approximately 0.001 inches.

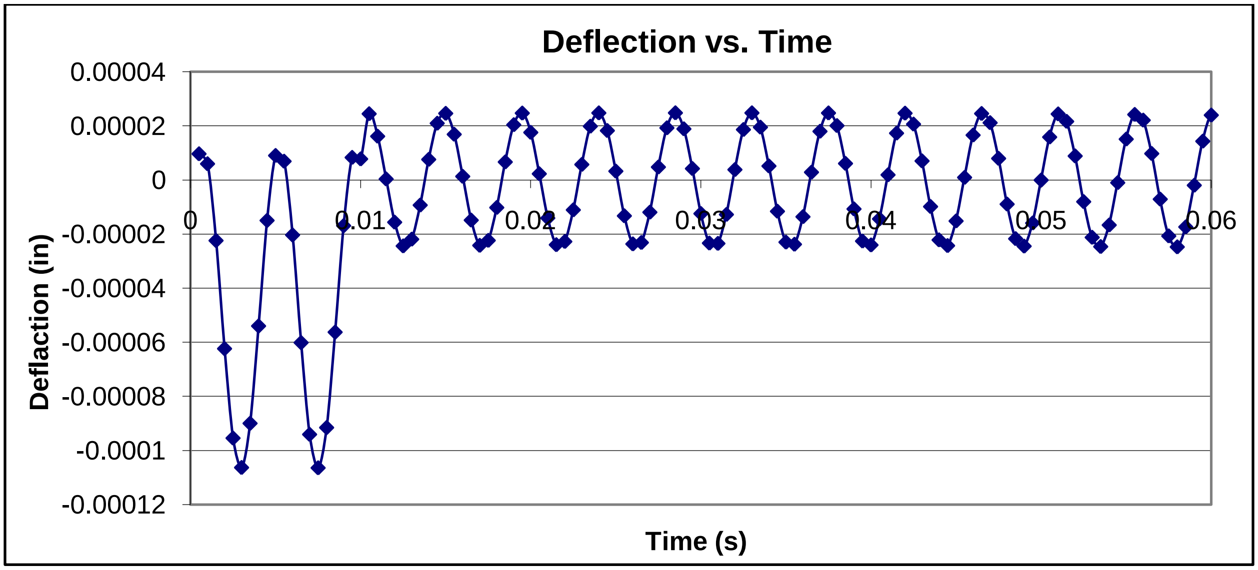

Figure 38: Deflection over Time

The stress was found using the equation σ=Mc/I, where M is the moment, c is the distance from the neutral axis and I is the moment of inertia. The moment was calculated as the force (stiffness x deflection) multiplied by the distance. This resulted in a maximum stress of about 550 pounds per square inch. The stress over time is shown in Figure 39 below.

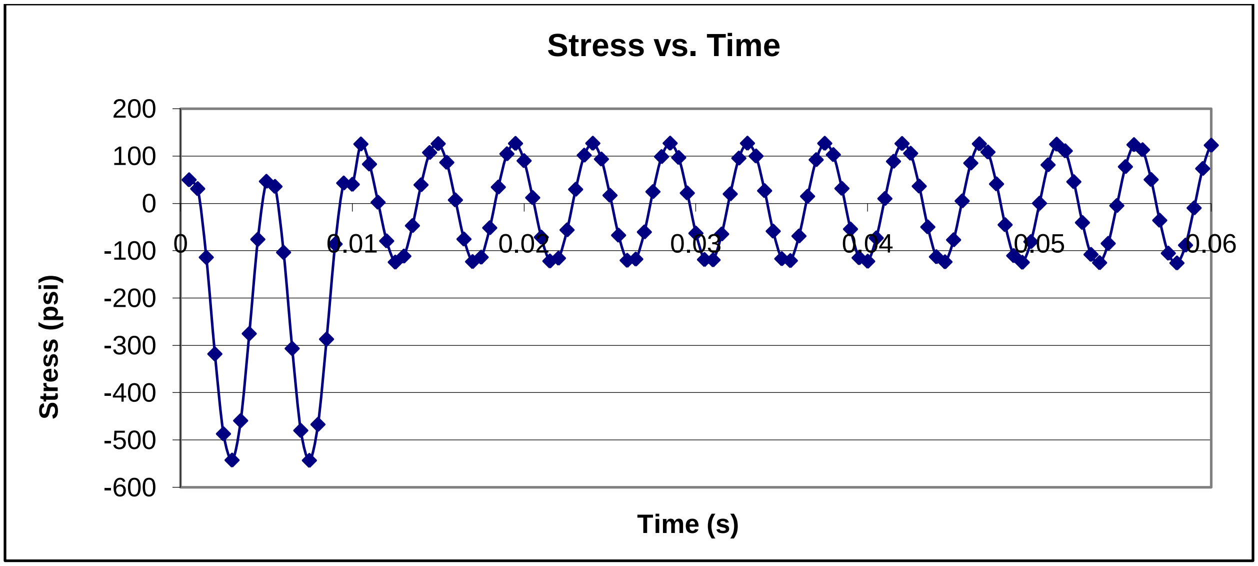

Figure 39: Stress over Time

The calculations and formula derivations can be found in the appendix.

Chapter 5: Conclusions

Any of the designs detailed above will have over a 25% reduction in weight (12,000 pounds to less than 9,000 pounds). This weight reduction will increase the safety factor in the design which means a safer, more reliable design. It will also reduce the stress on the joints that failed in the army design. This weight reduction was achieved by using a smaller, more efficient generator, a range instead of separate ovens and griddle, and removing unnecessary components. However, it is important to note that with the addition of water and fuel, the weight will increase substantially.

The designs also require a greatly shortened setup and take down times, estimated at 5-10 minutes. This is because none of the components need to be moved, and they come ready for use. The only preparation that may be required is cleaning and switching/ turning on the power supply, and opening doors, vents, and windows.

Each designs center of gravity was found to determine if the weight distribution was even. None of the designs had center of gravity in the long direction that was more than 11 inches (4.58%) from the center. The center of gravity in the short direction did not exceed 5.14 (5.35%) inches. Vertically, all of the designs were about the same: 9.4 inches (9.22%). This was expected as the only appliances that could move up or down are the fryers and microwave, which do not contribute much weight. This shows that the designs are balanced well as a 5% difference in weight to one side or the other is less than 200 pounds. Vertically, as the design stands now, not much can be done to change the center of gravity. However, the water, waste and fuel tanks and electrical system could be designed to offset the weight on the bottom of the container.

All of the final designs leave enough room for a person to walk around comfortably. Designs 6 and 7, first iterations, do not have appropriate room, which is why the designs were re-done. In design 6, there is not enough room for two people to pass between the range and wall or generator. Ample room is left for movement around the doors and serving window areas. As long as a serving window is less than 55 inches, there is room left in every design for one along with at least one door.

Many of the designs have potential problems with ease of access to the appliances. Design 3 iteration 1 has the freezer in the back corner. At this angle, it may be difficult for a person to gain access to food stored in the back of the freezer. Design 5 may not have enough room between the dishwasher and the microwave and fryers. However, the dishwasher has a vertically sliding door, which allows for less room to be needed. Both iterations of design 6 have multiple flaws. There is not enough room between the range and the generator or wall, depending, to open the oven while still being able to get the food inside it. It will also be difficult to use the refrigerator and freezer in their respective locations. Design 7 has similar problems as the others; the freezer is located such that when opened, access to the back will be limited.

Any design will have the potential for accidents. However, these are reduced in the designs. With the amount of open space increased, and open pathways through the kitchen made, accidents should be reduced.

Sanitation issues were addressed with each design. When the toilet is within a range where it can be a potential contamination hazard, walls can be built around it. However, if a curtain could be used instead, the amount of space devoted to the toilet is reduced. In each design, except 4, the sink is located near the toilet so proper washing procedures can be followed.

In all of the designs, except 3, the cooking appliances are located close to each other. In the third design, the microwave and fryers are located at on the opposite end of the kitchen as the range. However, some of the designs do not allow ample room if two cooks were working at the same time.

Water using appliances were kept away from other appliances, especially the generator, as much as possible. Only in design 4 was the dishwasher placed next to the generator. If there was a leak this could cause a short, spark or fire. However, depending on how the electrical system is designed, this may be an appropriate location. The design of the electrical system, along with the water, waste and fuel system still need to be designed. The location and size of these will need to be thought out thoroughly.

The vibrations that occur when the container is dropped from a height of 30 feet result in minimal deflections, around 0.0001 inches. This results in maximum stresses of 550 pounds per square inch. These are both incredibly small and the container should remain intact with minimal damage.

Chapter 6: Future Recommendations

If this project is going to continue as a Major Qualifying Project, this group has some recommendations. First, this project is too large for a group to complete in one year. We recommend focusing on one design component, such as the structural analysis, the water system, ergonomics, model building and testing, security, etc. This would allow for a more in depth analysis of the respective area, and for the section to be completed in the year.

The water system design in this project is a preliminary estimate. To complete this design, a more in depth analysis of the water needs will need to be done. Also, the size and location of the water tank will need to be determined. Once this is done, the plumbing can be designed along with the location of the filters. The location of the filters will determine the size and location of the pumps. It was also considered during this project, and a rainwater catch system could be designed to supplement the water supply.

A more in depth structural analysis needs to be done. Once the location of doors, windows and ventilation is known, supports around those locations will need to be designed. Also, if a suspension system is added to the container, further impact analysis will need to be done. This will determine if the suspension system will work if the container is dropped in some or all directions, as well as the damage that may be caused. Once the water, waste, and fuel systems are added, the vibration analysis will need to be redone. These fluid filled tanks could be used as dampers if placed in the right locations. They could also negatively impact the container as well.

How the container is lit is a very important design consideration that has not been discussed in detail yet. The lights need to be places so that only the inside of the kitchen is illuminated. This is partially for security purposes; if the container is in the field, and the enemy sees light coming from the container, they will know it is something of interest. It is important to design the lights so they use as little energy as possible. Safety is another concern when designing lighting. If a glass bulb were to break in the container, the pieces would scatter causing a safety issue.

A preliminary idea for anchoring the appliances to the container has been discussed previously. However, individual anchors for each appliance will need to be designed. Each appliance will need to be anchored in a different location and by a different amount of force. The way each appliance is anchored also affects the structure of the container. Also, the way each appliance can be removed from the anchors needs to be considered.

The container is going to need to store water, fuel, waste, food and other items. The water system design has already been discussed. The fuel system is very similar to the water system. The amount of fuel needed to run all of the appliances for three days will need to be determined. Once this is done, the dimensions and location can be determined. A fuel pump will be needed. Having gravity feed the fuel was considered, however if there was ever a spill or leak in the storage container, it would be disastrous. A possible other design would be to use waste oil from the fryers as biofuel to run the generator. However, this will require a filtration system for the oil. Storage and disposal of waste is going to be a key design. Waste is the scrap food, as well as human waste. Food scrap could be disposed of in a trash compactor and then stored, or it could put down a garbage disposal and into a storage container. If a garbage disposal is decided upon, it will need to be placed in an appropriate location in the floor plan. An appropriately sized storage container will need to be designed for human waste and any food waste that will be added to it.

Food will be stored within the container during transport. The refrigerator and freezer should have enough room to store three days of food in them. Dry food can be stored in containers and strapped down in various places within the container. Seasonings will be stored on the range. Because food is stored in the container during transport, there will need to be an auxiliary power supply designed to keep the refrigerator and freezer running. One possibility is having an external plug so that the container could be connected to the power supply of the vehicle moving it.

When a soldier is in the field, he carries a lot of equipment with him. In the kitchen this is not needed and must be stored in an easy to access location. Boots can be stored near the door. They will not be worn in the kitchen as to not track in dirt. Weapons need to be stored within the container so that they can be easily and quickly reached in case of an emergency. One idea was to have a trap door in the floor where they can be placed. They will be out of sight, and in a safe location and locked away so only authorized soldiers could get it.

The security system in the kitchen can be as simplistic or sophisticated as needed. Cameras could be installed on the inside and outside of the container and monitored by the cook, or another designated person. They could also come with night vision in case the kitchen was ever used in the dark. Odor sensors could be installed outside the container in case there was an attack and there was a chemical agent in the air. The water storage tank could also have an automatic tester to make sure that the water has not been contaminated. The final idea was to have a telecommunication system installed. This way the soldiers inside and outside could communicate through a headset. There could also be a way to send all the security information back to a base camp for monitoring.

Finally, once all of the theoretical and computational design work is complete, a working prototype needs to be build and sent to the army. This prototype can be tested for functionality as well as durability. As the design process continues, other design considerations will arise.

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Appendix

A: PowerPoint Presentations

A.1 USARC Containerized Kitchen

Project Manager, Force Projection Team

Containerized Kitchen (CK)

Acquisition Excellence

PEO CS CSS 1 -

Project Manager, Force Projection Team

Credit Given to

EARL MARSHALL - NET CHIEF / NET/TPF GROUP
DSN: 256-6072 / (508) 233-6072
***Earl.Marshall*@natick.army**

Acquisition Excellence

PEO CS CSS 1 -

CONTAINERIZED KITCHEN TRAILER MOUNTED

Mobile, Self-Contained, Rapidly Deployable Kitchen configured in an 8-ft by 8-ft by 20-ft container

Stored and shipped in Fully Packed-out configuration

CK Dry weight – 14,000-lbs (Trailer not included)

Can be stacked 9 high (Un-mounted)

Capable of being, sling loaded, by a CH-47D rotary wing aircraft

CONTAINERIZED KITCHEN TRAILER MOUNTED

Mobile, Self-Contained, Rapidly Deployable Kitchen has Approx 360 square feet of food preparation and serving areas

Can serve up to 800 meals 3 times a day

Meals can be prepared in 3 hours or less

SHELTER FLOOR AREA EXPANDED TO PROVIDE 360 SQUARE FT OF SHELTERED FLOOR SPACE

Project Manager, Force Projection Team

CONTAINERIZED KITCHEN UN-MOUNTED

Mobile, Self-Contained, Rapidly Deployable Kitchen has Approx 360 square feet of food preparation and serving areas

SHELTER FLOOR AREA EXPANDED TO PROVIDE 360 SQUARE FT OF SHELTERED FLOOR SPACE

PEO CS CSS

Acquisition Excellence

1 -

Project Manager, Force Projection Team

CONTAINERIZED KITCHEN SET-UP CONFIGURATION

CK SYSTEMS

WATER TRAILER

PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN

PREPARATION FOR INSTALLATION

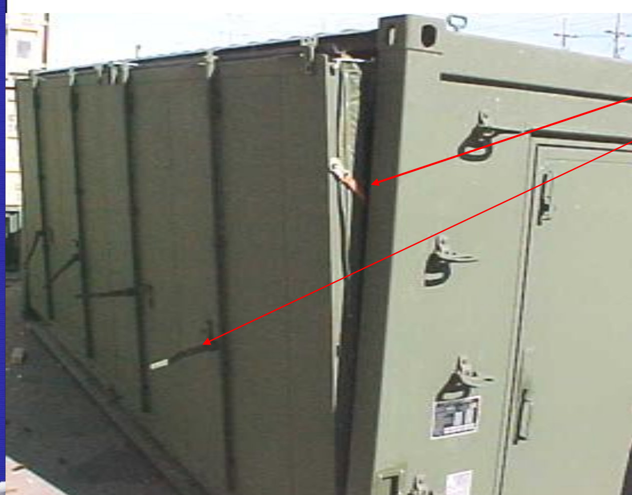
Project Manager, Force Projection Team

Acquisition Excellence

PEO CS CSS 1 -

CONTAINERIZED KITCHEN SET-UP

CREW OF 4 PLUS A SUPERVISOR CAN SET-UP OR TEAR-DOWN CK IN LESS THAN 45 MINUTES



Project Manager, Force Projection Team

Acquisition Excellence

PEO CS CSS 1 -


CONTAINERIZED KITCHEN
SET-UP
CRANKING DOWN
EXPANSION SIDES
HAND CRANK FOR
MECH WINCH
Project Manager, Force Projection Team
PEO
CS CSS
Acquisition Excellence
1 -


CONTAINERIZED KITCHEN
SET-UP
HINGED EXPANDABLE INSULATED
SIDEWALL PROVIDES FLOOR, ROOF
SIDES AND END WALLS
ADVANCED VINYL EXPANDABLE
FABRIC
STEEL ARCH SUPPORTERS
Project Manager, Force Projection Team
PEO
CS CSS
Acquisition Excellence
1 -

CONTAINERIZED KITCHEN

Bag containing Shelter Arch Frame Components (Arch Roof, Arch Spacers, Curved Spacers, Adjustable Spacers, Vertical Spacers and Vertical "T" Spacers)

OPENED DOOR OF FULLY PACKED CONTAINER

MACHINE ROOM OF FULLY PACKED CONTAINER

Project Manager, Force Projection Team

Acquisition Excellence

PEO CS CSS

1 -

CONTAINERIZED KITCHEN COMPONENTS SETTING UP MECHANICAL ROOM

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1 -

Project Manager, Force Projection Team

CONTAINERIZED KITCHEN SET-UP

PEO CS CSS

Acquisition Excellence

1 -

Project Manager, Force Projection Team

CONTAINERIZED KITCHEN SET-UP

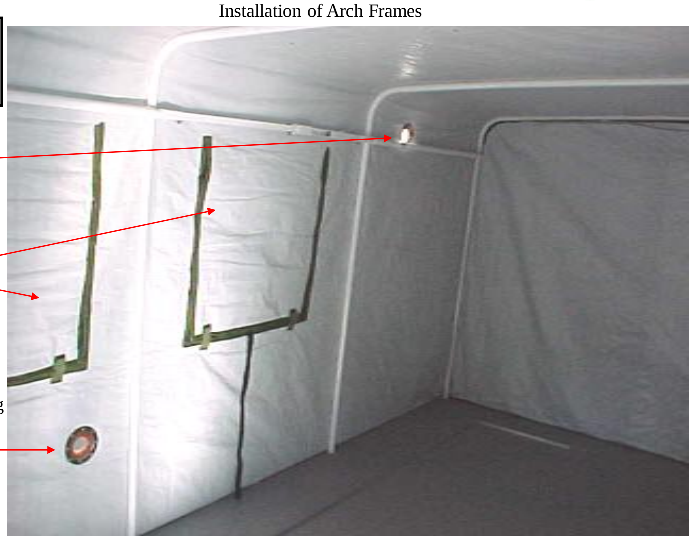
Installation of Arch Frames

“DO NOT FORCE CORNER FRAMES IN EXTREME COLD”

Opening for Oven Assy Chimney Pipe

Windows

Opening for Hose to bring Water from water source To Hand Sink Assy

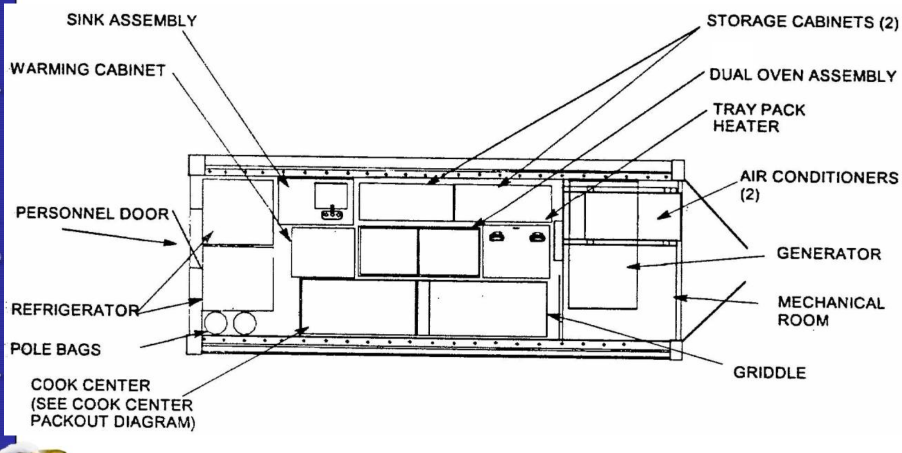


PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN PACKED FOR SHIPMENT TOP VIEW



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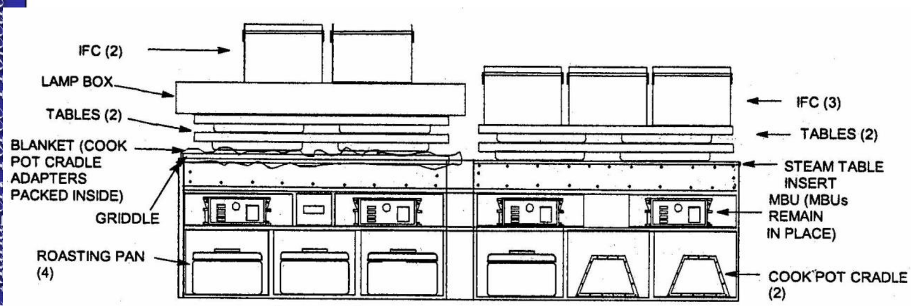
1 -

CONTAINERIZED KITCHEN PACKED FOR SHIPMENT SIDE VIEW



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Acquisition Excellence

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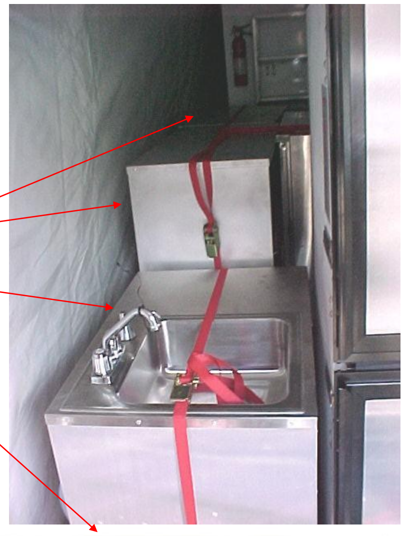
Project Manager, Force Projection Team

CONTAINERIZED KITCHEN PACKED FOR SHIPMENT



Storage Cabinets

Sink Assembly

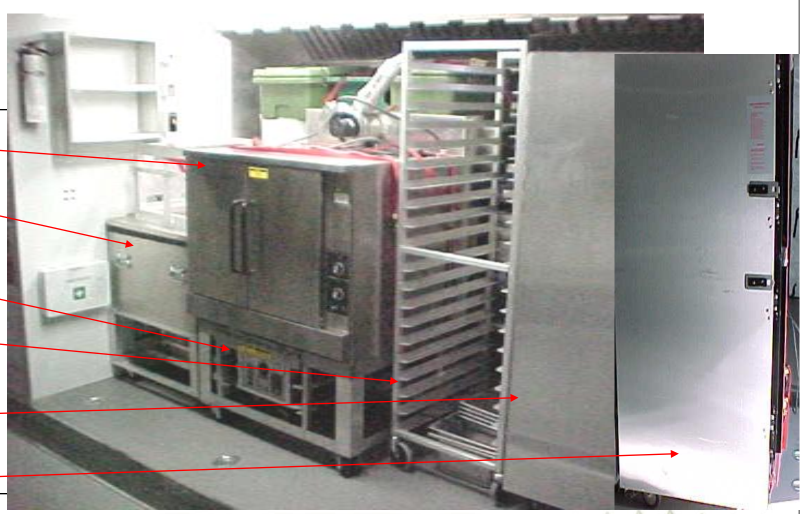
Refrigerator

Acquisition Excellence

PEO CS CSS 1 -

CONTAINERIZED KITCHEN PACKED FOR SHIPMENT

...ction Team



Single Oven Assy

Tray Pack Heater

MBU

Cooling Rack

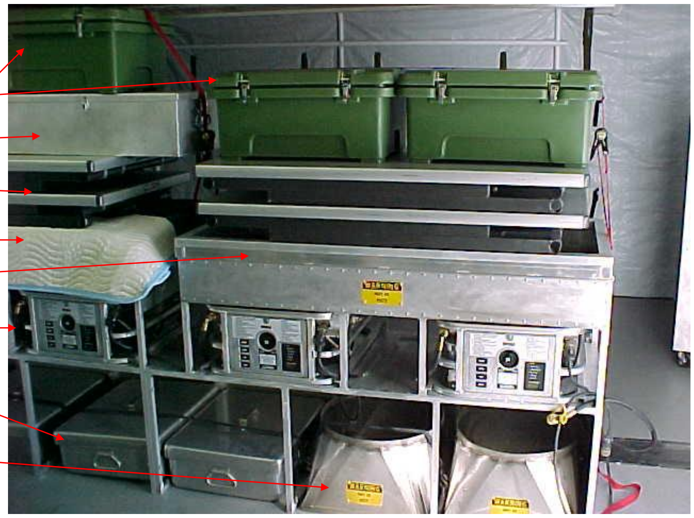
Refrigerators

Warming Cabinet

Acquisition Excellence

PEO CS CSS 1 -

CONTAINERIZED KITCHEN PACKED FOR SHIPMENT



Acquisition Excellence

1 -

CONTAINERIZED KITCHEN

Access to 10KW Generator Controls

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN
INSTALL LIGHTING

Project Manager, Force Projection Team

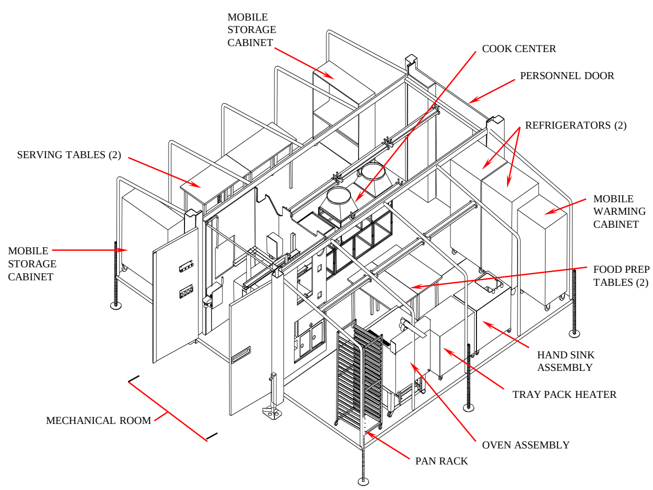
PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN

FOOD PREPARATION SIDE VIEW



Project Manager, Force Projection Team

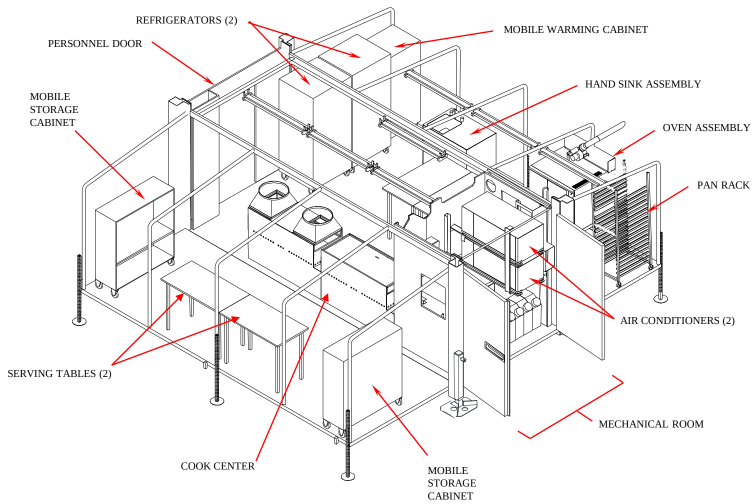
PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN

Serving Side View.



Project Manager, Force Projection Team

CONTAINERIZED KITCHEN

Single Oven Assembly

Doors Open

Doors Closed

Oven Fan

Cooling Rack

CONTAINERIZED KITCHEN COMPONENTS
TRAY PACK HEATER

Top Open

CONTAINERIZED KITCHEN COMPONENTS
COOK AREA

Fire Extinguisher

Refrigerators

Mobile Warming cabinet

Hand Sink Assy

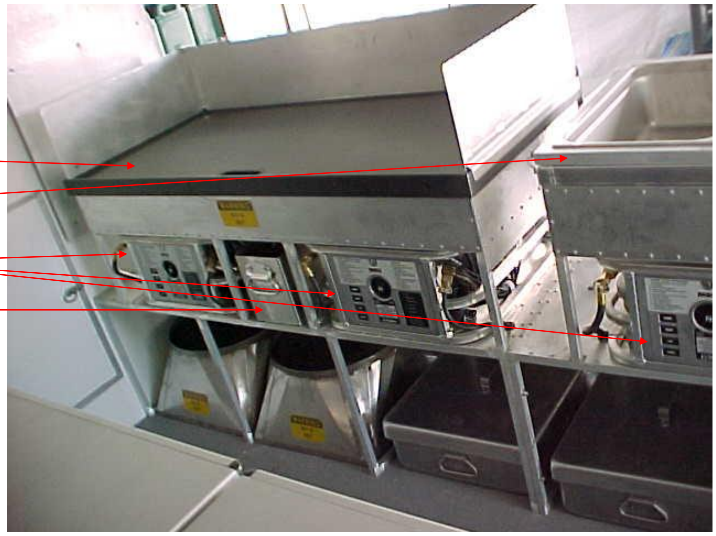
Appliance Control Box (Water Pump, Water Heater, Oven Fan, Heater Fan)

Tables for Food Preparation

Drawer to Store Utensils

Food Storage Containers

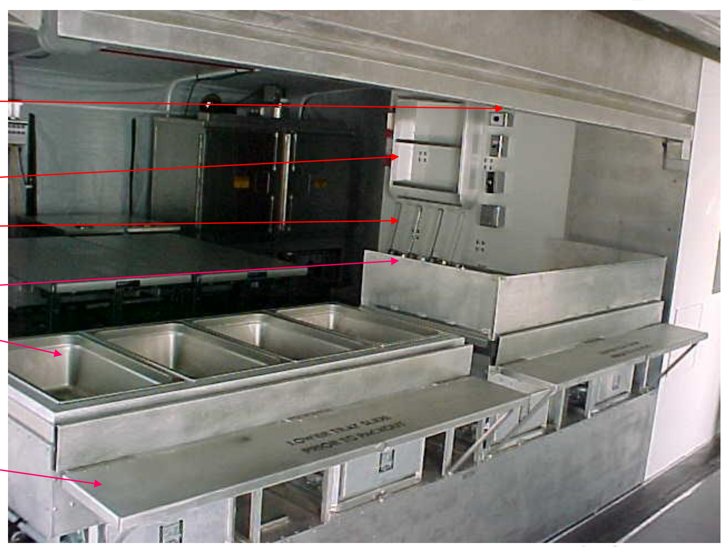
CONTAINERIZED KITCHEN COMPONENTS
COOK STATION



Project Manager, Force Projection Team

Acquisition Excellence

CONTAINERIZED KITCHEN COMPONENTS
COOK STATION



Project Manager, Force Projection Team

Acquisition Excellence

CONTAINERIZED KITCHEN COMPONENTS
SERVING SIDE

Project Manager, Force Projection Team

PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN COMPONENTS
LIGHTING, VENTS, CONTROL PANEL

Project Manager, Force Projection Team

Exhaust Hood

Environmental Control & Vent Blowers

Vent Duct

Reg and Black-out Lights

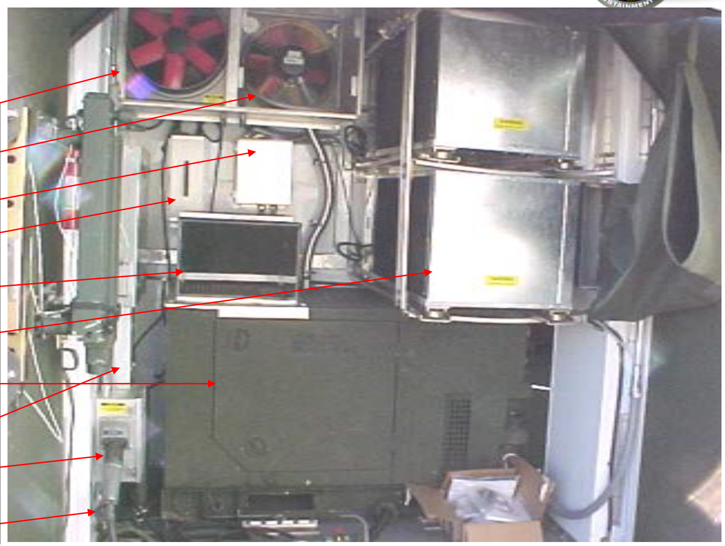
Main Control Panel

PEO CS CSS

Acquisition Excellence

1 -

CONTAINERIZED KITCHEN COMPONENTS
SETTING UP MECHANICAL ROOM



- Exhaust Fan Outlet
- Vent Fan Air Inlet
- ECU Controller
- MBU Converter
- Gen cooling air outlet
- Air Conditioners
- 10KW Generator
- Power Distribution Panel
- Power Entrance Panel
- Multi Fuel Connection

CONTAINERIZED KITCHEN COMPONENTS
MECHANICAL ROOM

Fuel Adaptors to fuel 10KW and MBUs

Power and Fuel Connectors

Ladder and Can storage for shipment

CONTAINERIZED KITCHEN FAST SET-UP TEAMS

2-4 PERSON TEAMS

TEAM-1 37 Min

TEAM – 2 45 Min

(CK Setup requires 4 People plus a supervisor)

Project Manager, Force Projection Team

PEO CS CSS   Acquisition Excellence   1 -

CONTAINERIZED KITCHEN FAST SET-UP TEAMS

Team - 2, CSSC2, IBCT1, Ft Lewis: (6 MAN TEAM)

SETUP CK – 30 Min. 32 Sec

PACKUP - 39 Min. 4 Sec

Project Manager, Force Projection Team

PEO CS CSS   Acquisition Excellence   1 -

SITE REQUIREMENTS
FOR

CK DEPROCESSING & TRAINING

- CLASSROOM WITH TABLES AND CHAIRS FOR 21 STUDENTS
- CLASSROOM IN A QUIET AND COMFORTABLE AREA
- WHITEBOARD OR BLACKBOARD
- OVERHEAD PROJECTOR AND SCREEN
- FUEL FOR MBUs AND GENERATORS (20 GAL per CK, JP8)
- WATER, 200- GAL MINIMUM (POTABLE)
- Grounding Device
- SPACE TO OPERATE 3 CKs (50' X 30' ea) SOLID FLAT SURFACE
- FACILITY TO DRAIN WATER (NOT POLLUTANT)
- DRIVERS TO MOVE CKs FROM RECEIVING SITE TO TNG AREA

Project Manager, Force Projection Team

PEO CS CSS

Acquisition Excellence

1 -

LOAD CK CONTAINER ON TRAILER

FORKLIFT

RTCH

Project Manager, Force Projection Team

PEO CS CSS

Acquisition Excellence

1 -


FORKLIFT DAMAGE LOAD/OFF-LOADING CK
Project Manager, Force Projection Team
PEO
CS CSS
Acquisition Excellence
1 -


WATER SUPPLY FOR CK SINK
Project Manager, Force Projection Team
PEO
CS CSS
Acquisition Excellence
1 -

A.2 Containerized Kitchen

Basic Requirements

- Feed 700 troops 3 times each day
- Contain fuel and supplies for 3 days of isolated operation
- Room for 5 to 6 kitchen staff
- Transported by all standard ISO container methods & CH-47D Helicopter
- Preparation for use and transport complete in under 25 minutes
- No open flame

Setup & Takedown Requirements

- To be completed in under 25 minutes
- All powered controls to have manual backups
- All parts and supplies to be contained within shipping container
- No more than kitchen staff required for setup and takedown in allotted time

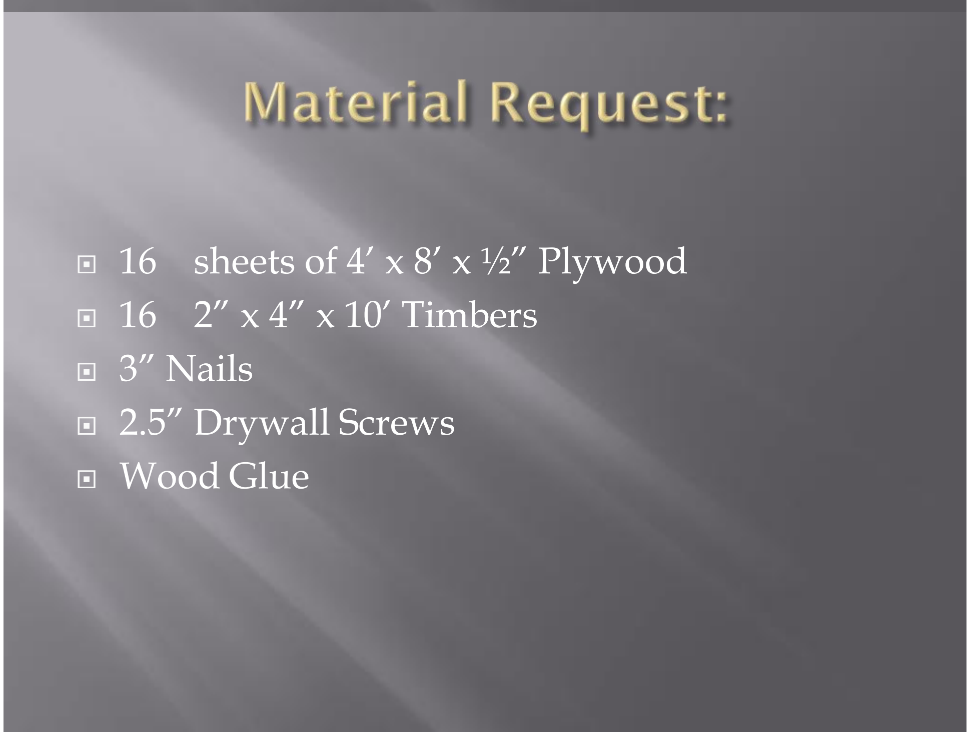
Our Goals

- Develop background research
- Develop Prototype Design
- Revise and Finalize Design
- Build a working prototype
- Notify Army to proceed with testing

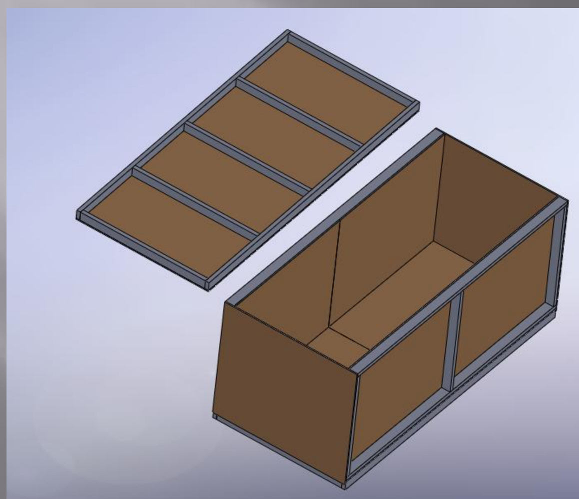
Timeline

- Complete Background Research by end of September
- Complete design by Thanksgiving
- Parts/materials order by end of B term (December 19)
- Working prototype built and fitted with appliances (ready to test) by end of D term (May 6)

A.3 Kitchen Reliability Half-Size Prototype

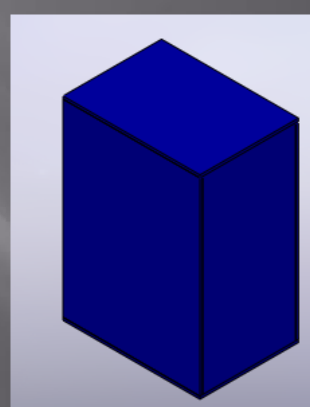


Container



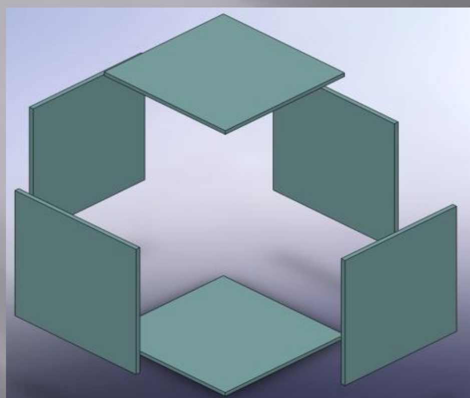
Internal Dimensions:
(HxWxD)
(45.5”x46”x115.5”)

Dishwasher

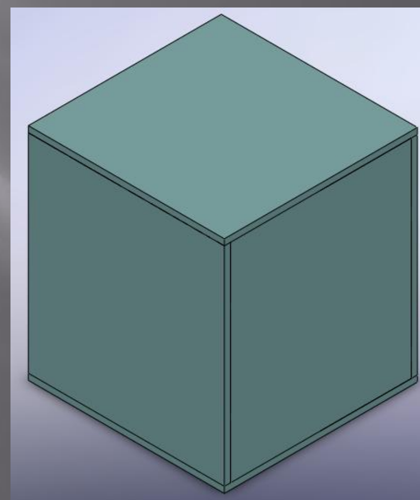


Dimensions: (HxWxD)
(35.5625”x25”x18”)
Pot, pan, utensil storage

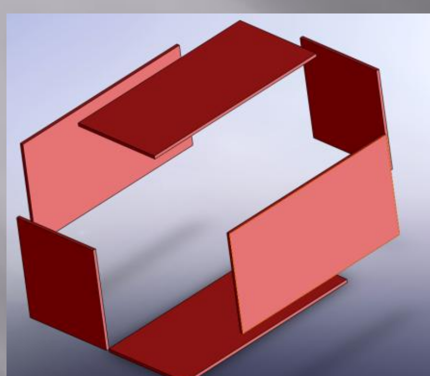
Freezer



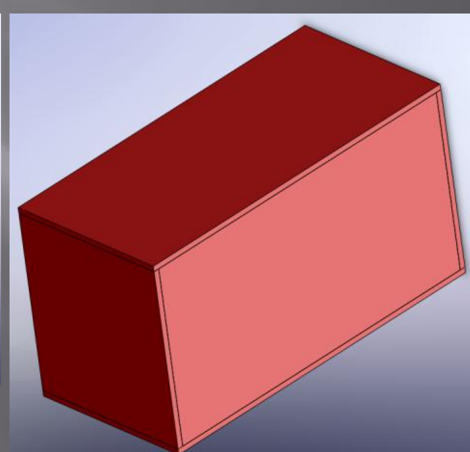
Dimensions: (HxWxD)
(18″x16″x15.75″)



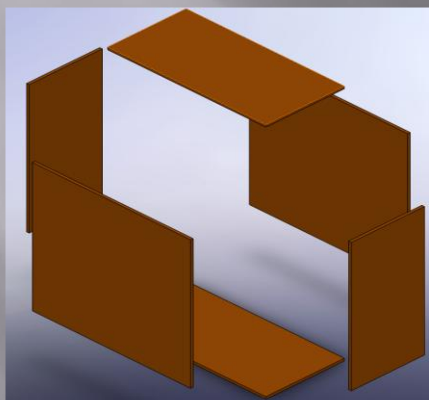
Generator

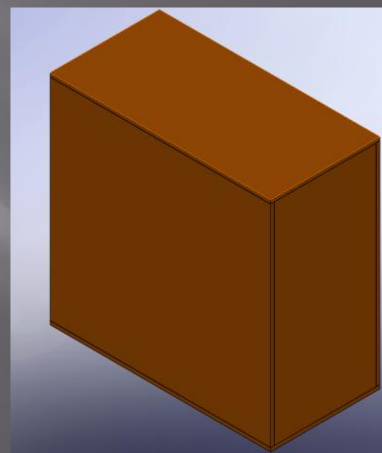


Dimensions: (HxWxD)
(17″x14.5″x31″)



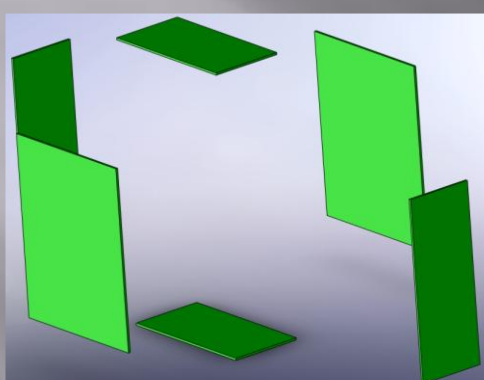
Range

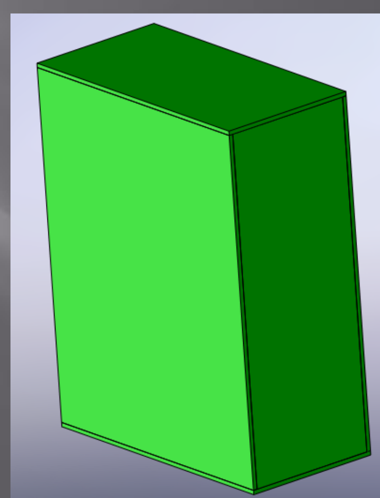




Dimensions: (HxWxD)
(24.75"x30"x14.875")
Contains ovens, stoves, and griddles

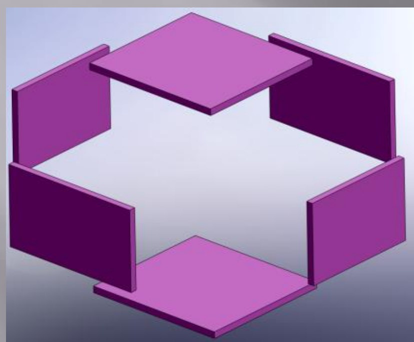
Refrigerator

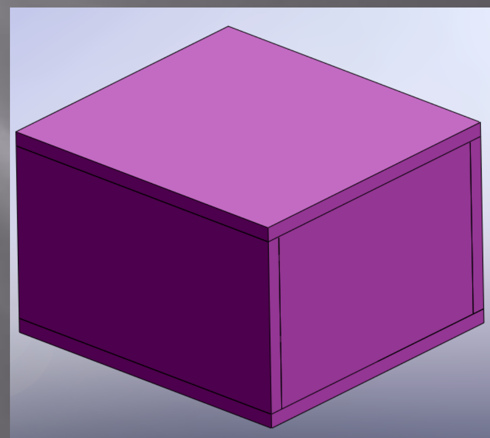




Dimensions: (HxWxD)
(42.25"x33"x16.5")

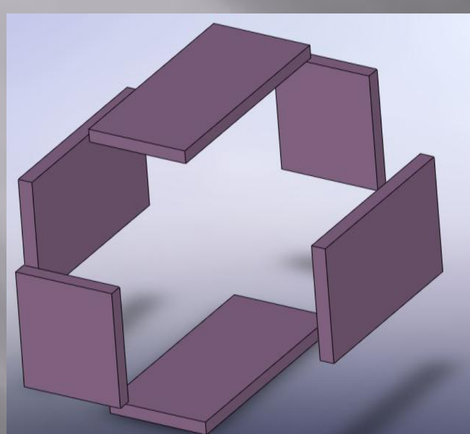
Microwave

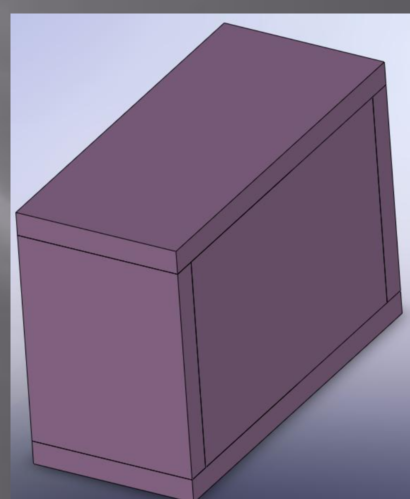




Dimensions: (HxWxD)
(7.125"x10.875"x10.125")

Fryer



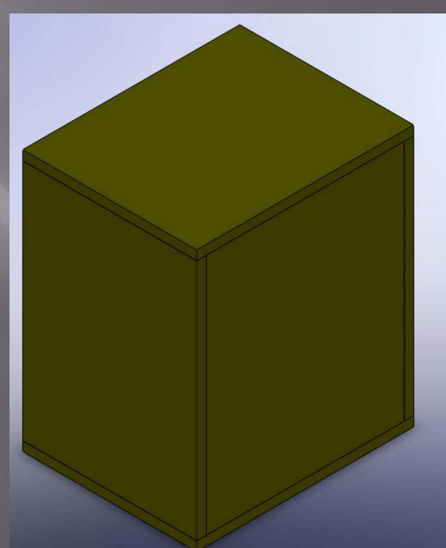


Dimensions: (HxWxD)
(5.5"x3.5"x7.75")
Multiple will be used

Sink

Dimensions: (HxWxD)
(21.125″x11.625″x11.75″)

Toilet



Dimensions: (HxWxD)
(13.78″x9.155″x11.415″)

Storage

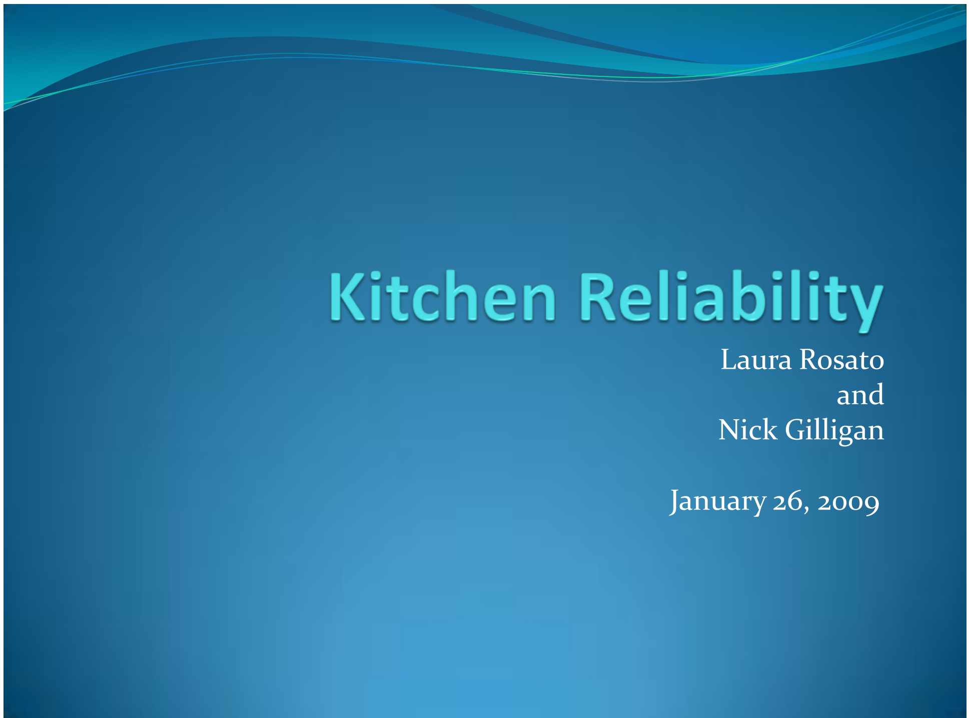
- Centralized bathroom design
  - Kitchen storage on both sides
- Guns in floor
- Water in ceiling
- Waste in floor
- Water Filter under sink
- Fuel below/beside generator

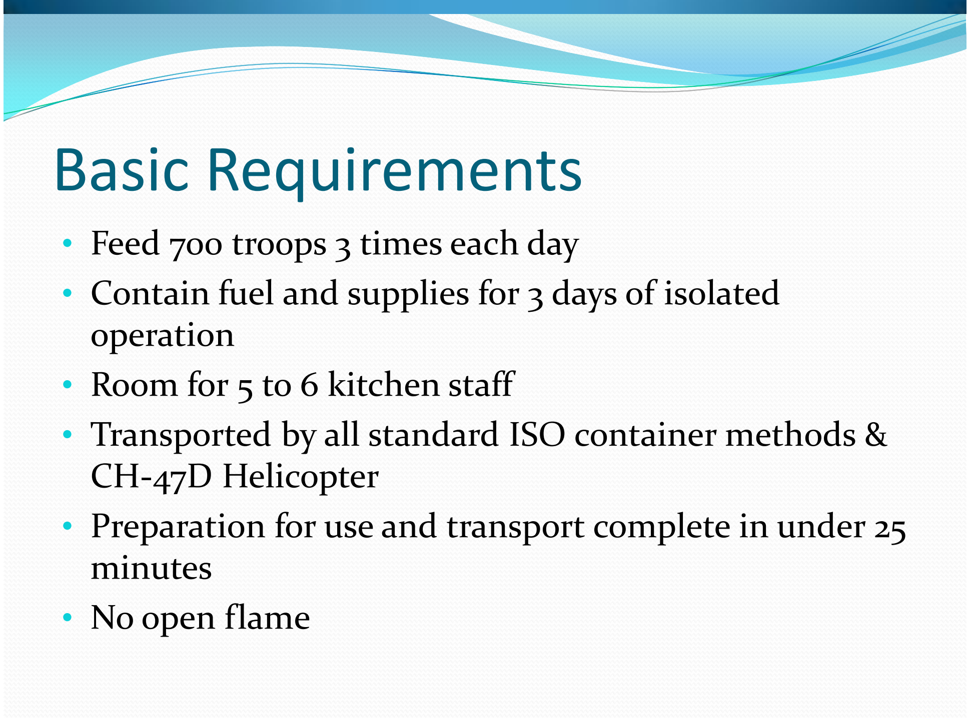
Summary

- Questions?

- Happy Holidays

A.4 Kitchen Reliability





Setup & Takedown Requirements

- To be completed in under 25 minutes
- All powered controls to have manual backups
- All parts and supplies to be contained within shipping container
- No more than kitchen staff required for setup and takedown in allotted time

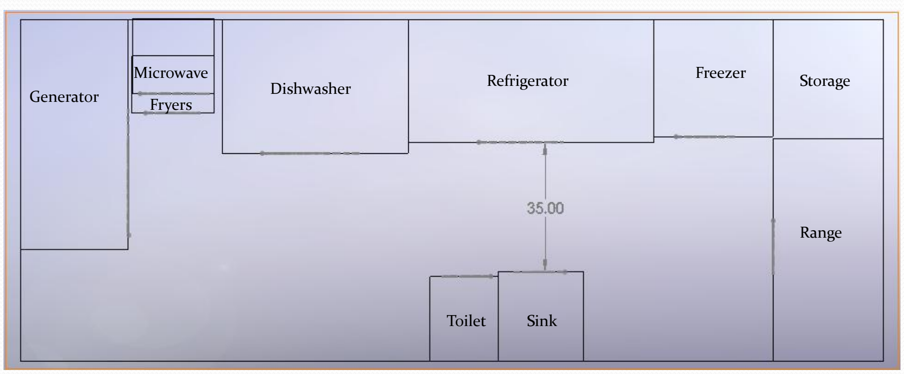
Background Research

- Containers
  - Development
  - Standards/Specs
  - Applications
  - Transportation
  - Failure Modes
  - Options and Custom Materials
- Other
  - Storage
  - Anchoring

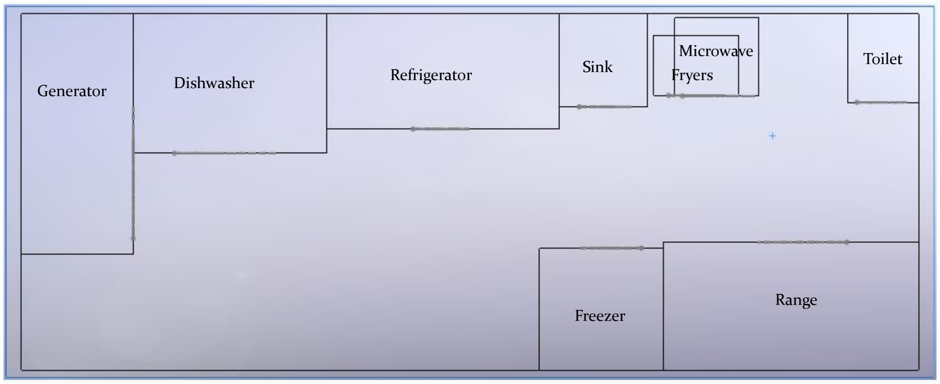
Background continued

- Appliances
  - Refrigeration Units
  - Stove-top Cooking
    - Griddle
    - Fryer
  - Oven
  - Water Purification
  - Generator
  - Dishwasher
  - Sink
  - Microwave
  - Toilet/Shower

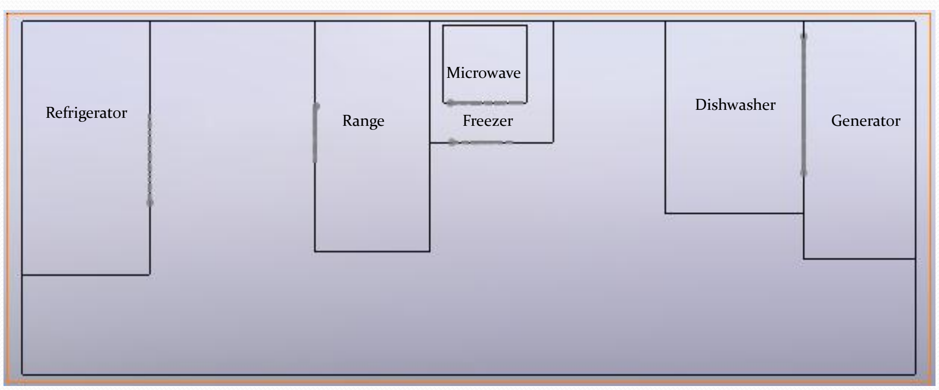
Layout Design 1



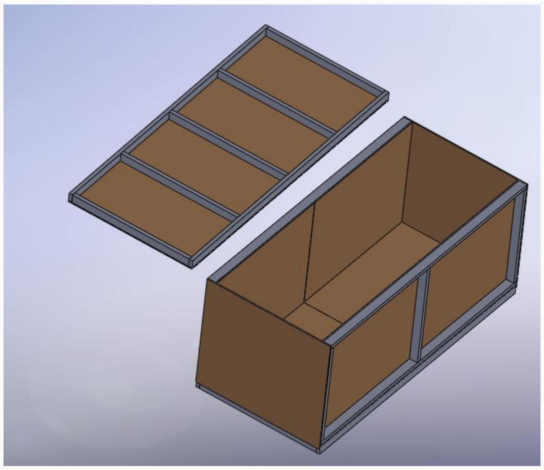
Layout Design 2



Layout Design 3



Prototype Design



Internal Dimensions:
(HxWxD)
(45.5”x46”x115.5”)

Prototype Material List

- 16 sheets of 4’ x 8’ x ½” Plywood
- 16 2” x 4” x 10’ Timbers
- 2 boxes 3” Nails
- 2 boxes 2” Drywall Screws
- Wood Glue

Completed Tasks

- Background Research
  - Background Section of Final Report
- Three Layout Designs
  - Three fully designed configurations
  - Other configurations considered
- Half Sized Prototype Design (CAD Drawings)
  - Container and appliances to be made of two by fours and plywood
- Prototype Material List
  - Items needed to complete half sized prototype

Goals

- Decide on current focus
  - Build Prototype
    - Acquire materials and tools
    - Build prototype and decide on best configuration
  - Complete Water System Design
    - Water usage requirements
    - Filter types/location
    - Storage tank geometry/location
    - Waste water storage
    - Pump size/location
    - Rainwater collection
    - Plumbing
    - Create master operating manual

Goals Continued

- Accomplish tasks associated with chosen focus
- Complete report
- Submit findings (to Army)

A.5 Suspension

Suspension

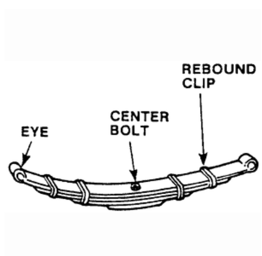
Nick Gilligan and Laura Rosato
February 12, 2009

Container Transportation Modes

- Truck/Flatbed
- Ship
- Helicopter
- Crane/Tank
  - Hooks/Magnets
- Train

Suspension:
Leaf Springs

- Curved Steel Plates
- Attached to all faces
  - Provides support for impact in any direction
- Come in a variety of sizes and strengths

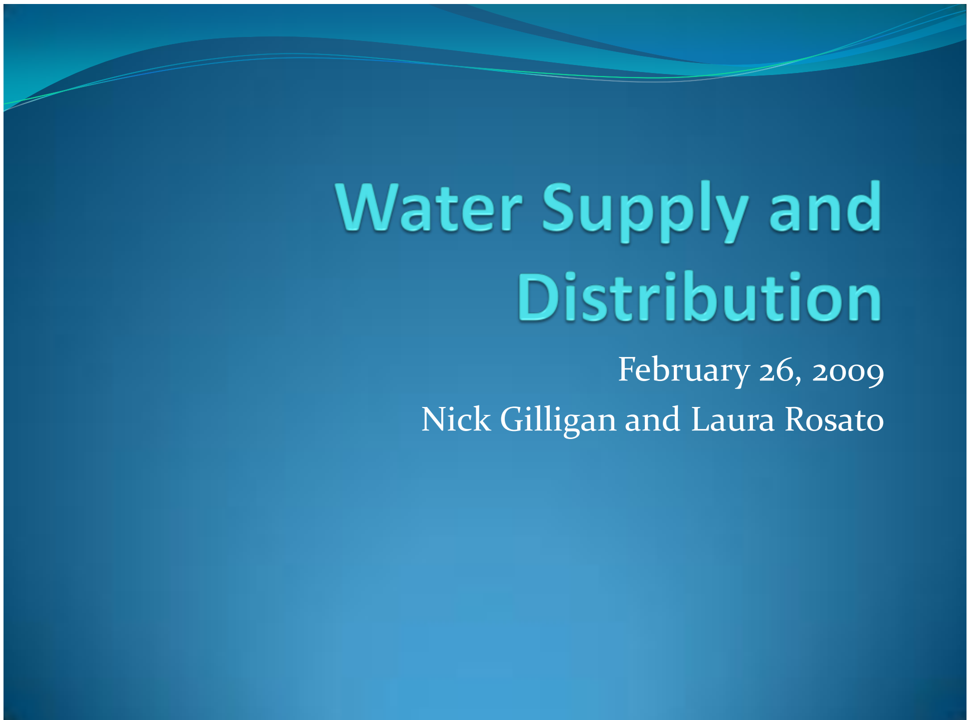


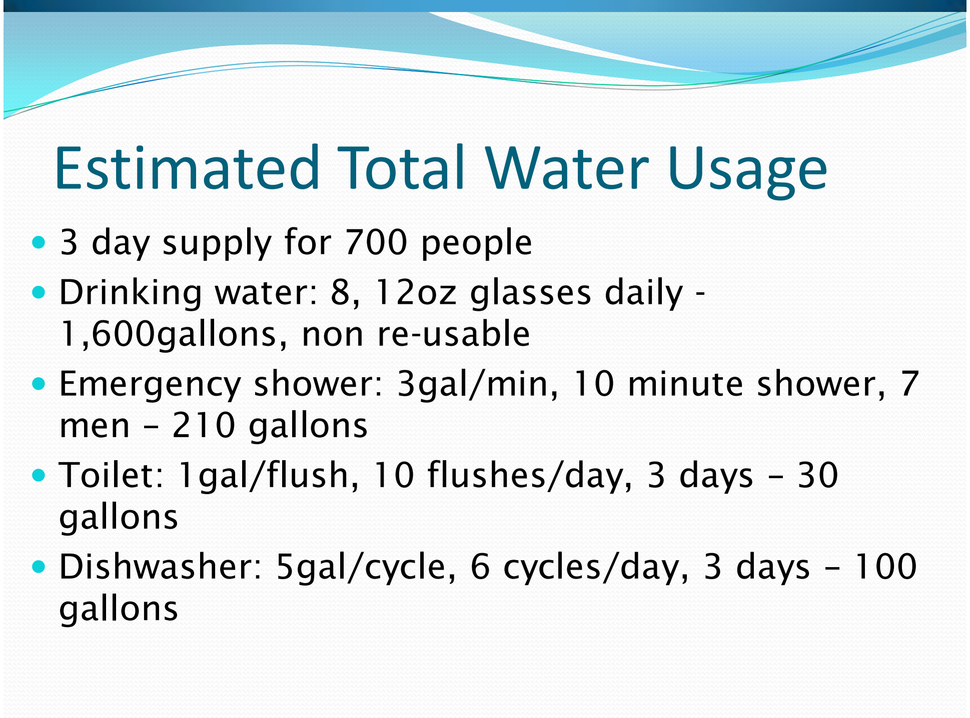
http://www.team-bhp.com/forum/attachments/technical-stuff/68505d1226322927-leaf-spring-suspension-modification-okay-leafspring.gif

Suspension: Coils

- Traditional
  - Springs of varying stiffness
- Magnetic (Cadillac)
  - Spring in magnetic fluid
  - Viscosity of fluid changes with application of magnetic force (magneto-rheological fluid)
- Magnetic (Bose)
  - Electromagnetic coil provides force on a piston/strut

A.6 Water Supply and Distribution





Filtration Methods

- Mesh Filter: 10μm particles, 65gal/min, self cleaning, up to 150psi, up to 150˚F
  - http://www.valveandfilter.com/
- Ultraviolet Light: organisms, 52gal/min, bulb replacement once per year
  - http://www.home-water-purifiers-and-filters.com/products.php

To be Discussed

- 2,000 gallons non re-usable water
  - 16,700lb, 267 ft^3 (20'x8'x1.7')
  - Max container payload is 47,900lb
  - Other drinking water sources needed!

To be Discussed cont.

- Materials/ Tools
  - <$400
  - Must buy materials and fill out reimbursement slip
- Focus (where the project is going)
  - Prototype
  - Design: water, suspension, structure, fixtures/lighting etc.

A.7 Kitchen Reliability: CE Final Presentation

Kitchen Reliability

Laura Rosato

Advisor: Professor DeFalco and Professor Fofana

Project Goals

- Design a portable kitchen for the army
  - Must fit within a 20'x8'x8.5' shipping container
  - Feed 700 soldiers 3 meals a day
  - Contain supplies for 3 days of operation
  - Easily operated by a trained staff of 5 to 6
  - Can be transported using standard methods
  - Setup and take down must take less than 25 minutes
- Make significant improvements over Army design
  - Reduce total weight
  - Reduce setup and take down times
- Perform basic structural and vibration analysis'

Design Process

- Background Research
  - Previous design failures
  - Shipping containers
  - Appliances
  - Anchors
  - Suspension
  - Modes of transportation
- Create CAD drawings
- Create layout designs

Design Process Continued

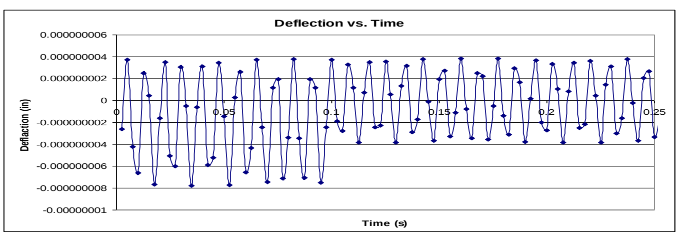
- Analyze designs for the following:
  - Weight distribution
  - Open floor and wall area
  - Accessibility of appliances
  - Potential for accidents
  - Ease of human movement
  - Sanitation issues
  - Relative proximity of cooking appliances
  - Location of water using appliances in relation to other appliances
  - Potential fluids and electrical designs
- Water system design
- Perform structural analysis
- Perform vibration analysis

Results

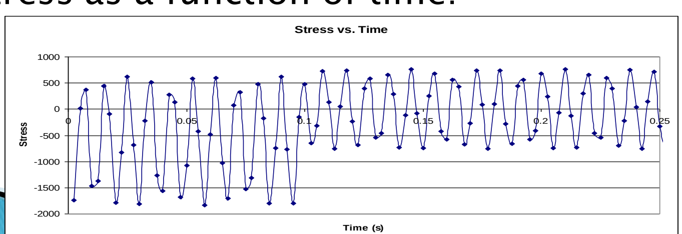
- 5 possible layout designs created
  - Center of gravity for all did not exceed 10 inches from center
  - All had sufficient working, moving, wall and floor space
  - Some had potential sanitation issues
- Water supply system:
  - Total water needed cannot be stored in container
  - Re-usable can be stored and filtered
  - Minimum container size is 45 gallons ($6ft^3$, 375lb)
- Standard shipping container structure:
  - Support needed near any modifications
  - Reinforcement needed at joints, bolts and hinges

Results Continued

- Deflection as a function of time:



- Stress as a function of time:



Recommendations

- Future MQP groups will need to complete:
  - Water, fuel, waste and electrical designs
  - Further structural analysis
  - Final anchor design
  - Storage design
  - Security design
  - Build and test a working prototype

Questions?

A.8 Kitchen Reliability: ME Poster

Kitchen Reliability

Nick Gilligan and Laura Rosato
Mechanical Engineering Department
Civil and Environmental Engineering Department
Professor Fofana and Professor DeFalco

Objectives

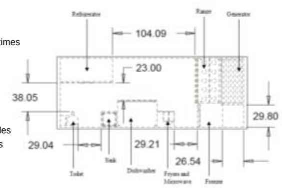
- Design a portable kitchen to be used by the army
- Fit within a standard 20x8x8 shipping container
- Feed 700 soldiers 3 meals a day for 3 days
- Withstand multiple modes of transport
- Improve army initial design
  - Reduce total weight
  - Significantly reduce setup and take down times

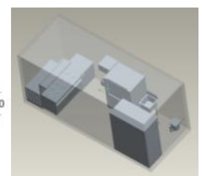
Methods

- Research and choose appropriate appliances
- Research shipping containers
  - Materials, sizes, modifications, failure modes
- Design appropriate anchors for the appliances
- Calculate water usage
- Create detailed CAD model
  - Perform mass properties analysis
- Create and optimize layout designs
- Perform a structural analysis
- Perform a basic vibration analysis
  - Impact force from drop at low elevation
  - Find maximum stress created due to vibrations
- Parts and supplies stored within container
- Secure all appliances within container
- Use appliances with dual purposes

Results

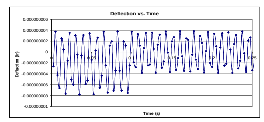
- Magnetic anchors determined to be best suited for application
- Total water cannot be stored in container, only reusable water
- 8 layout designs created (sample below)



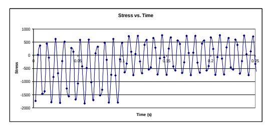


- Each design was evaluated for the following features:
  - Weight distribution
  - Open floor area
  - Open wall area for doors and serving windows
  - Ease of access to each appliance
  - Potential for accidents or failures
  - Potential movement of people through the kitchen
  - Sanitation issues
  - Relative proximity of cooking appliances
  - Location of water using appliances to other appliances
  - Potential water or electrical system design problems

- Standard container determined to be structurally sufficient
  - Additional structural support needed near openings
  - Additional reinforcement needed by bolts, joints and hinges
- Deflection due to vibration as a function of time:



- Stress caused by vibration as a function of time:



- Further design work is needed to create a useable kitchen:
  - Complete water system design
  - Further structural analysis
  - Lighting design
  - Complete anchor design
  - Storage design
  - Security system design
  - Build and test working prototype

B: Spreadsheets

B.1 Bill of Materials

Item	Quantity	Make	Model	Price ($)	Height	Width	Depth	Internal Volume	Weight (lb)	Min Temp	Max Temp	Power	Notes	Link	
Box					8	8	20		5,000						
APPLIANCES															
Refrigerator	1	Beverage Air	PRI2-1AS-XDX	6,514	84.5	66	33	73.4	777	36	38	8 amp 115V		http://www.foodservice	
Freezer	1	Delfield	4532N	2,857	36	32	31.5	6.9	280	-5	0	9.5 amp 120V		http://www.foodservice	
Water Purifier															
Microwave	1	Amana	RCS10MPSA	672	14.25	21.75	20.25	1.215703125	55			13.2 amp 120V		http://www.foodservice	
Oven	2	Cadco, Ltd.	TESXAF195	2,399	20	31.5	32	3.85	142	175	500	24.4 amp 210V 5.6kW		http://www.bigtray.cor	
Dishwasher	1	Douglas Machine	SD-20		71.125	50	36	16.85641819					727-461-3477	http://www	http://www.
Stove															
Hotplate															
Griddle	1	Star	548TGD	1,806	15.5	48	27.88		350	150	450	57.8/66.7 amp 220V 16kW	4 heating sections	http://www.foodservice	
Range	1	Vulcan Hart	VULE60FL	8,079	59.5	60	29.75		815				6" adj legs	http://www.bigtray.cor	
Hotplate												2kW each	6, 9.5"		
Griddle						24						10kW each	2 controls		
Oven										150	500	5kW each	2 convection		
Fryer	3	Equipex	RF5S	446	11	7	15.5	10 lbs oil	12			15 amp 1.75kW	22lb/hr fries	http://www.foodservice	
Sink	1	Trade Advantage	MKS1-P	304	42.25	23.25	23.5	2.625	33			0			
Generator	1	Guardian	QT0316		34	29	62		935			30kW		http://www.guardiange	
BATHROOM															
Tiolet		Jabsco	29120-3000	139.88	27.56	18.31	22.83		24			0		http://www.westmarine	
Shower															
Total				19903.88	481.31				7955						

B.2 Vibrations Data

L	240	in
E	30000000	psi
I	40000000	in^4
k	16666666667	lb/in
w	1387.604664	1/s
m	8656	lb
F0	790967.911	lb
c	51	in

t (s)	delta-0	delta		Stress
0.0005	6.32244E-07	1.03391E-05	9.70686E-06	49.50500213
0.001	1.63946E-05	2.24181E-05	6.02349E-06	30.71978176
0.0015	4.65195E-05	2.41319E-05	-2.23876E-05	-114.17682
0.002	7.70783E-05	1.4688E-05	-6.23903E-05	-318.1904452
0.0025	9.39419E-05	-1.54697E-06	-9.54889E-05	-486.9934029
0.003	8.93133E-	-1.70667E-05	-0.00010638	-542.5379981

	05			
0.0035	6.53325E-05	-2.46955E-05	-9.0028E-05	-459.1426451
0.004	3.30873E-05	-2.09061E-05	-5.39933E-05	-275.3659993
0.0045	7.48654E-06	-7.45052E-06	-1.49371E-05	-76.17898661
0.005	3.67027E-07	9.44984E-06	9.08281E-06	46.32233361
0.0055	1.50205E-05	2.1981E-05	6.96045E-06	35.49828026
0.006	4.46718E-05	2.4349E-05	-2.03229E-05	-103.6465399
0.0065	7.56114E-05	1.5459E-05	-6.01524E-05	-306.7771613
0.007	9.3534E-05	-5.7859E-07	-9.41126E-05	-479.9741584
0.0075	9.01529E-05	-1.63487E-05	-0.000106502	-543.1582092
0.008	6.70315E-05	-2.45598E-05	-9.15913E-05	-467.1155512
0.0085	3.48601E-05	-2.14154E-05	-5.62755E-05	-287.0052494
0.009	8.51349E-06	-8.36946E-06	-1.6883E-05	-86.10305984
0.0095	1.73295E-07	8.54622E-06	8.37293E-06	42.70192934
0.01	1.36957E-05	2.15105E-05	7.8148E-06	39.8554742
0.0105		2.45292E-05	2.45292E-05	125.0986745
0.011		1.62065E-05	1.62065E-05	82.65332619
0.0115		3.90668E-07	3.90668E-07	1.99240582
0.012		-1.56058E-05	-1.56058E-05	-79.58972282
0.0125		-2.43868E-05	-2.43868E-05	-124.3727663
0.013		-2.18923E-05	-2.18923E-05	-111.6508474
0.0135		-9.2757E-06	-9.2757E-06	-47.30606944
0.014		7.62963E-06	7.62963E-06	38.91113143
0.0145		2.10073E-05	2.10073E-05	107.1373909
0.015		2.46721E-05	2.46721E-05	125.827632
0.0155		1.69295E-05	1.69295E-05	86.34023935
0.016		1.35933E-06	1.35933E-06	6.932594331
0.0165		-1.48393E-05	-1.48393E-05	-75.68040334
0.017		-2.41768E-05	-2.41768E-05	-123.3018279
0.0175		-2.2336E-05	-2.2336E-05	-113.9134488
0.018		-1.01679E-05	-1.01679E-05	-51.85607491
0.0185		6.70146E-06	6.70146E-06	34.17746137
0.019		2.04723E-05	2.04723E-05	104.4087148
0.0195		2.47776E-05	2.47776E-05	126.3655799
0.02		1.76267E-05	1.76267E-05	89.89608578
0.0205		2.32593E-06	2.32593E-06	11.86225898
0.021		-1.40502E-05	-1.40502E-05	-71.65619903

0.0215		-2.39301E-05	-2.39301E-05	-122.043714
0.022		-2.27457E-05	-2.27457E-05	-116.0031267
0.0225		-1.10446E-05	-1.10446E-05	-56.32736151
0.023		5.76312E-06	5.76312E-06	29.39190904
0.0235		1.99062E-05	1.99062E-05	101.5215436
0.024		2.48454E-05	2.48454E-05	126.7117016
0.0245		1.82972E-05	1.82972E-05	93.3154676
0.025		3.289E-06	3.289E-06	16.77391642
0.0255		-1.32398E-05	-1.32398E-05	-67.52321874
0.026		-2.36471E-05	-2.36471E-05	-120.6003347
0.0265		-2.31209E-05	-2.31209E-05	-117.9167088
0.027		-1.19045E-05	-1.19045E-05	-60.7131417
0.0275		4.81603E-06	4.81603E-06	24.56173902
0.028		1.93099E-05	1.93099E-05	98.48025998
0.0285		2.48756E-05	2.48756E-05	126.8654715
0.029		1.89398E-05	1.89398E-05	96.59319411
0.0295		4.24708E-06	4.24708E-06	21.66011061
0.03		-1.24094E-05	-1.24094E-05	-63.28773644
0.0305		-2.33282E-05	-2.33282E-05	-118.9738808
0.031		-2.3461E-05	-2.3461E-05	-119.6512902
0.0315		-1.27464E-05	-1.27464E-05	-65.00675776
0.032		3.86162E-06	3.86162E-06	19.69428365
0.0325		1.86842E-05	1.86842E-05	95.28948079
0.033		2.4868E-05	2.4868E-05	126.8266564
0.0335		1.95538E-05	1.95538E-05	99.72428963
0.034		5.19871E-06	5.19871E-06	26.51342419
0.0345		-1.156E-05	-1.156E-05	-58.95618171
0.035		-2.29739E-05	-2.29739E-05	-117.1668216
0.0355		-2.37655E-05	-2.37655E-05	-121.2042379
0.036		-1.3569E-05	-1.3569E-05	-69.20169186
0.0365		2.90136E-06	2.90136E-06	14.79693183
0.037		1.80302E-05	1.80302E-05	91.95404967
0.0375		2.48226E-05	2.48226E-05	126.5953152
0.038		2.0138E-05	2.0138E-05	102.7040011
0.0385		6.14245E-06	6.14245E-06	31.3264897
0.039		-1.06932E-05	-1.06932E-05	-54.53512996
0.0395		-2.25847E-05	-2.25847E-05	-115.1819
0.04		-2.4034E-05	-2.4034E-05	-122.5731944
0.0405		-1.43709E-05	-1.43709E-05	-73.291576
0.041		1.93669E-06	1.93669E-06	9.877117888
0.0415		1.73488E-05	1.73488E-05	88.47902991
0.042		2.47396E-05	2.47396E-05	126.1717989
0.0425		2.06917E-05	2.06917E-05	105.5278052
0.043		7.07686E-06	7.07686E-06	36.09200078
0.0435		-9.81006E-06	-9.81006E-06	-50.03129245
0.044		-2.21612E-05	-2.21612E-05	-113.0221293
0.0445		-2.42659E-05	-2.42659E-05	-123.7560815

0.045		-1.5151E-05	-1.5151E-05	-77.2702016
0.0455		9.6908E-07	9.6908E-07	4.942310222
0.046		1.66411E-05	1.66411E-05	84.86969668
0.0465		2.4619E-05	2.4619E-05	125.5567505
0.047		2.1214E-05	2.1214E-05	108.1914153
0.0475		8.00053E-06	8.00053E-06	40.80272326
0.048		-8.91206E-06	-8.91206E-06	-45.45150614
0.0485		-2.17041E-05	-2.17041E-05	-110.6907881
0.049		-2.4461E-05	-2.4461E-05	-124.7511038
0.0495		-1.59081E-05	-1.59081E-05	-81.13152903
0.05		1.23819E-18	1.23819E-18	6.31478E-12
0.0505		1.59081E-05	1.59081E-05	81.13152903
0.051		2.4461E-05	2.4461E-05	124.7511038
0.0515		2.17041E-05	2.17041E-05	110.6907881
0.052		8.91206E-06	8.91206E-06	45.45150614
0.0525		-8.00053E-06	-8.00053E-06	-40.80272326
0.053		-2.1214E-05	-2.1214E-05	-108.1914153
0.0535		-2.4619E-05	-2.4619E-05	-125.5567505
0.054		-1.66411E-05	-1.66411E-05	-84.86969668
0.0545		-9.6908E-07	-9.6908E-07	-4.942310222
0.055		1.5151E-05	1.5151E-05	77.2702016
0.0555		2.42659E-05	2.42659E-05	123.7560815
0.056		2.21612E-05	2.21612E-05	113.0221293
0.0565		9.81006E-06	9.81006E-06	50.03129245
0.057		-7.07686E-06	-7.07686E-06	-36.09200078
0.0575		-2.06917E-05	-2.06917E-05	-105.5278052
0.058		-2.47396E-05	-2.47396E-05	-126.1717989
0.0585		-1.73488E-05	-1.73488E-05	-88.47902991
0.059		-1.93669E-06	-1.93669E-06	-9.877117888
0.0595		1.43709E-05	1.43709E-05	73.291576
0.06		2.4034E-05	2.4034E-05	122.5731944
0.0605		2.25847E-05	2.25847E-05	115.1819

C: Equations and Derivations

C.1 Vibrations

$$K = \frac{192EI}{L^3} \quad \left[\frac{\frac{lb}{in^2}in^4}{in^3}\right]$$

$$\omega = \sqrt{K/m} \; \left[\frac{1}{s}\right]$$

$$insert\ impact\ force\ equation!!!!$$

$$x_1(t) = \frac{F_0}{K}[1 - \cos\omega_n(t - t_0)]$$

$$x_2(t) = \frac{F_0}{K}[\cos\omega_n(t - t_0) - \cos\omega_n t]$$

K is the equivalent stiffness of the system

E is Young's Modulus in pounds per square inch (psi)

I is the moment of inertia in inches to the fourth (in^4)

L is the length of the corresponding side

ω_n is the natural frequency of the system

m is the total mass of the system

x_1 is the resulting vibration for time between the initial impact (t=0) and the start time (t=0.1 seconds)in inches

x_2 is the resulting vibration after 0.1 seconds in inches

t is the time in seconds

C.2 Stress

$$\sigma = \frac{Mc}{I} \quad \left[\frac{lb \cdot in \cdot in}{in}\right]$$

$$M = Fd = \delta K d$$

$$\sigma = \frac{\delta K dc}{I}$$

σ is the stress in pounds per square inch (psi)

M is the moment in pound inches (lb-in)

c is the distance from neutral axis to point of maximum stress in inches (in)

d is the length of the side in inches (in)