Final Report:
Rotating Center Console

Engineering Design
24-441, Fall 2006

Team 9
'The Alien Invasion'

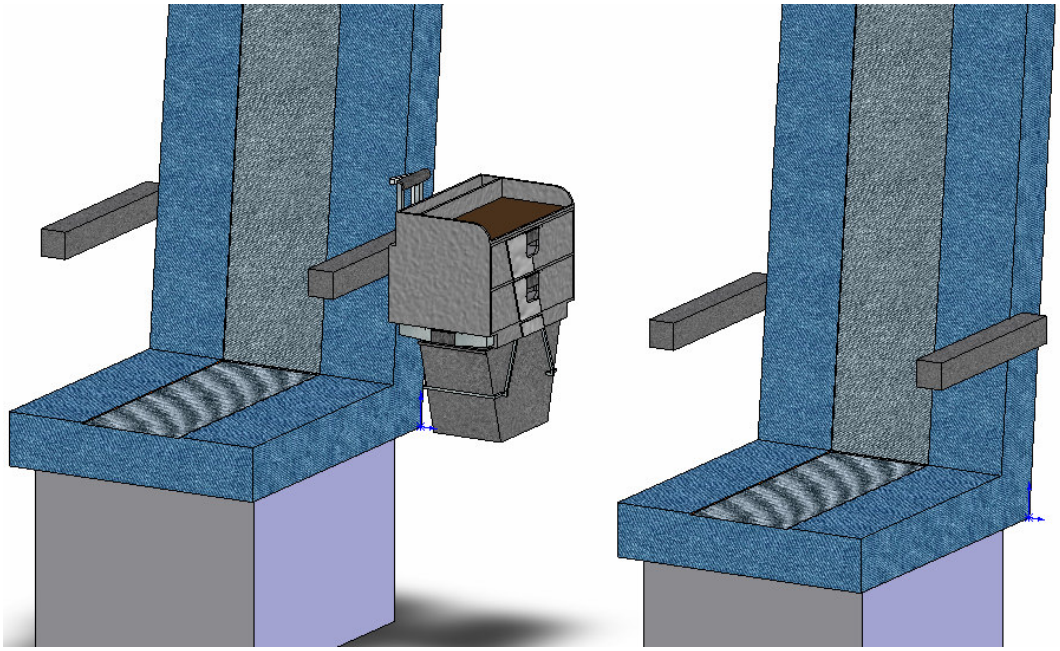

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Table of Contents

Executive Summary:

The goal of our project was to design an improvement to the interior of a truck cabin to improve the retention rate for aging truck drivers. The problem was interesting because of the massive potential of changes or additions that could be made to the current situation. Our proposed solution to this problem is a *rotating center console* which resulted from of a lot of user research, use of numerous product development and engineering tools, brainstorming sessions and conceptual design tools. Our final design adds utility to the living space of a truck cabin and also adds value to storage options while driving. Our design also uniquely addresses the problem of a lack of a trash receptacle in the interior of a truck cabin.

After numerous refinements of our design, we decided to rotate our console by using a double hinge mechanism attached to the back of the passenger seat that stows away flush behind the seat. While in use, the console is perpendicular to the driver's seat within arms reach of the driver. Furthermore, our design has a secure locking mechanism that latches the console in place in both its retracted and deployed position. The lock is designed to withstand crash forces of 20G and will not unlatch with potential to cause harm to the driver.

The prototype of our design effectively demonstrates the intended mobility and use of the console. It easily swings out of the center area clearing the path to the rear of the truck cabin. There is ample for storage of files and folders, medicine and smaller miscellaneous objects. The removable, replaceable garbage is also integrated with the console and demonstrates how different parts interface with each other. Also, our prototype easily locks in both intended positions clearly demonstrating our final design.

This design is geared to aging truck drivers because they have special range of motion issues in accessing items in the standard storage configuration of a truck. Furthermore, they require additional items such as regular medicine within easy access which is facilitated by our design. Our design is also universal in its nature since it generally improves storage and organization while driving and most importantly provides a feasible outlet to trash that is generated during driving. All in all, our design achieves the goals of this project in an effective manner and is easily extendable to further uses that can further add value.

Project Overview

The goal of our project was to design an improvement to the interior of a truck cabin to improve the retention rate for aging truck drivers. The problem was interesting because of the massive potential of changes or additions that could be made to the current situation. Our proposed solution to this problem is a *rotating center console* which resulted from of a lot of user research, use of numerous product development and engineering tools, brainstorming sessions and conceptual design tools. Our final design adds utility to the living space of a truck cabin and also adds value to storage options while driving. Our design also uniquely addresses the problem of a lack of a trash receptacle in the interior of a truck cabin.

The feasibility of our design is further improved upon and analyzed by the solid modeling techniques used in subsequent sections and practical issues are considered in the prototyping and design for manufacture sections. The need for our design is demonstrated in the following section that clearly illustrates a Product Opportunity Gap (POG) and a real need for our solution. We have also considered after-market solutions to the current POG and surveyed patents that pertain to our design. Furthermore, we used product development tools, presented in later sections, such as Value Opportunity Analysis (VOA), PUGH Charts and House of Quality to dwindle down our ideas and decide on the final version of our design. Last, we considered business implications and risk surrounding our design if it were to be manufactured and introduced into the marketplace.

Current Utilization of Space

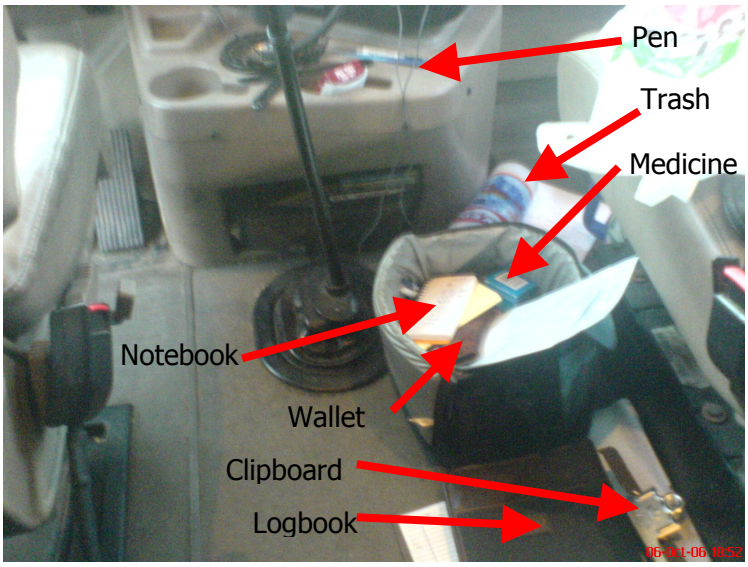

Figure 1 - Current Space Utilization Example

The picture taken above (fig 3) is from a truck parked at a truck stop in Claysville, PA. As you can observe in the picture, the truck driver attempted organizing his essential belongings in an open bag like container which he has placed at the side of the passenger seat. Furthermore, within the bag, his belongings are cluttered and he has to reach in and feel around to retrieve what he is looking for while driving which is dangerous and undesirable. Also, we observe that there is trash strewn on the truck floor which raises sanitary concerns and he has his clipboard and log book thrown on the floor in the center which is easy to retrieve but also very easy to lose in the mess. This is only an example of a plethora of home-made solutions truck drivers attempted in order to maximize utility of the center space. The most alarming aspect of most of the solutions is that there was no regard for **Design for Safety** as the drivers simply tried to maximize convenience. Also, the observed mess in the truck cabin was also a common theme of our research indicating a need for a solution that organized that space in a clean, safe and efficient manner.

Need to Use the Space Identified

There is a need for truck drivers to use the space between the passenger seat and the driver seat for organization and storage simply because the existing storage locations are hard to reach and not easy to access. Furthermore, while driving, these compartments become unsafe to reach. Also, existing storage bins seldom have a specific purpose and the 'one-size fits all' approach tends not to be the best design approach.

Figure 2a - Left Overhead Compartment

Figure 2b - Front Overhead Compartment

As you can see from the photographs above (fig 2a & 2b), the driver is forced to be at full-stretch in order to access his storage while seated which is a serious problem for aging truck drivers. As drivers get older, they will have a more constricted range of motion making existing solutions even more unfeasible and this is why our developed solution is a real attempt at solving this problem.

Our Design: Rotating Center Console

Our design is a rotating center console whose purpose is to add functional storage space within a truck and to improve organization ability of the truck driver. Furthermore, our console is designed to provide an outlet for trash generated during truck operation and stow it away until it's ready to be disposed off. The unique added value of our design is that the functions described above will be accessible to the driver within arm's reach while he is driving the truck.

The physical space the console uses is the dead space between the driver and the passenger seat and is locked into position on the passenger seat in an orthogonal position to the driver seat. (See Figures Below) While not in use, the console is designed to swing back and stow away behind the passenger seat where there is another lock to hold the console in place. Therefore, the rotating nature of the console keeps the passageway between the front of the truck cabin and the back free of any obstacles giving the truck driver easy access to the rear. An aspect to note is that for safety considerations the console is designed to be latched in and out of position when the truck is stationary and the locking mechanism is deliberately positioned to force the driver to do so.

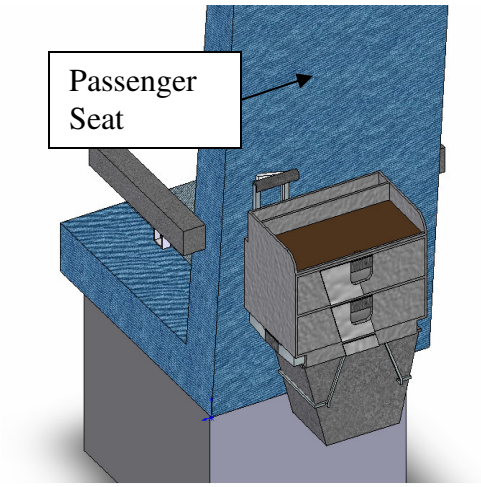

Figure 3a: Retracted Position

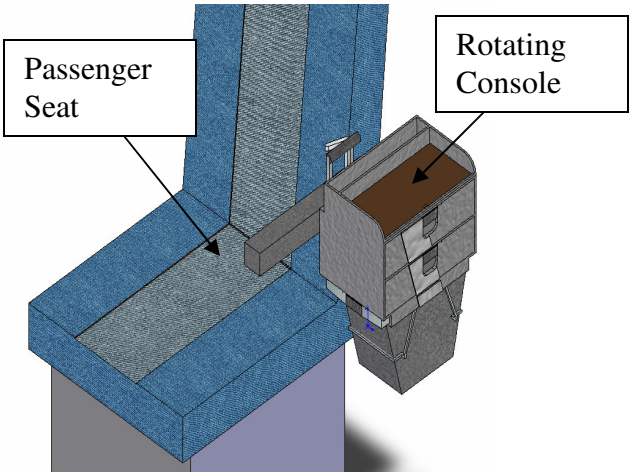

Figure 3b: Deployed Position

Details of Product Concept

Our working solution is a rotating console system attached to the back of the passenger seat by means of a supporting arm with two rotary hinge joints. The console itself contains two drawers - one partitioned drawer designed for easily accessible medicine storage and organization, the other a non-partitioned drawer for miscellaneous items and smaller paperwork. The dimensions of each drawer as indicated below is 12"across, 6.4" deep and 3" height which allows adequate space allocated for its functions described above. The enclosed tray area on top is designed for the driver to store small quick-access items he could want, such as his wallet or keys. It has potential to be further refined for use as quick-access space for the driver's cell phone. Also, there is an 8" deep, 1.6" x 11.6" space behind the drawers designed for storage of paperwork, a log book, and his clipboard. Therefore, in order to incorporate all the functions described, the console is slated to be 9" tall, 12" x 8" box (See figures below).

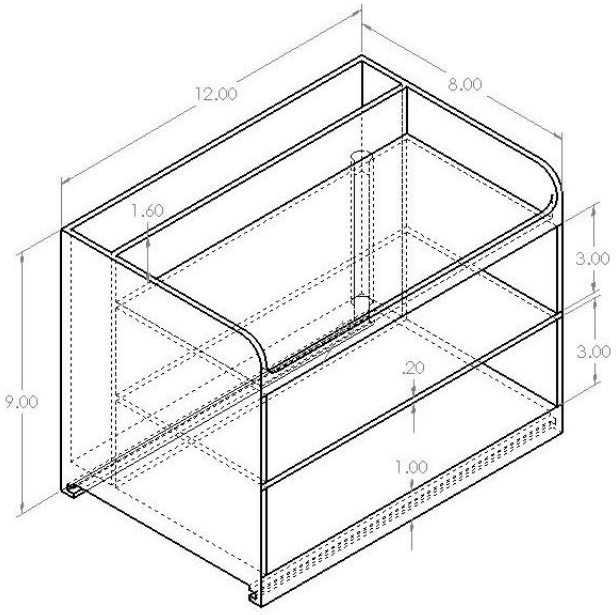

Figure 4a - Wire Frame Diagram (Console): Isometric View

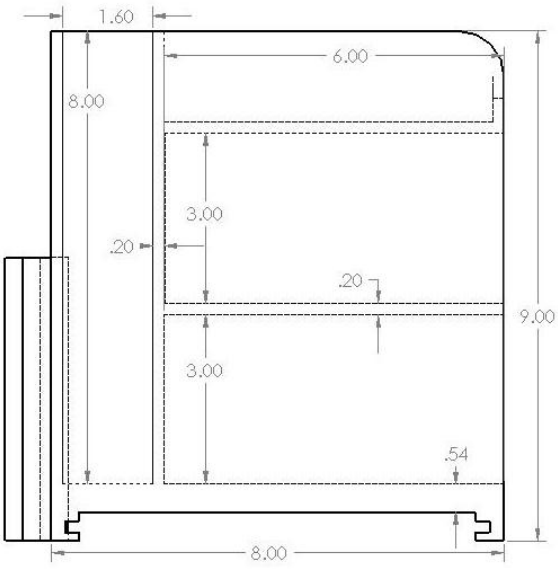

Figure4b-Wire Frame Diagram: Front View

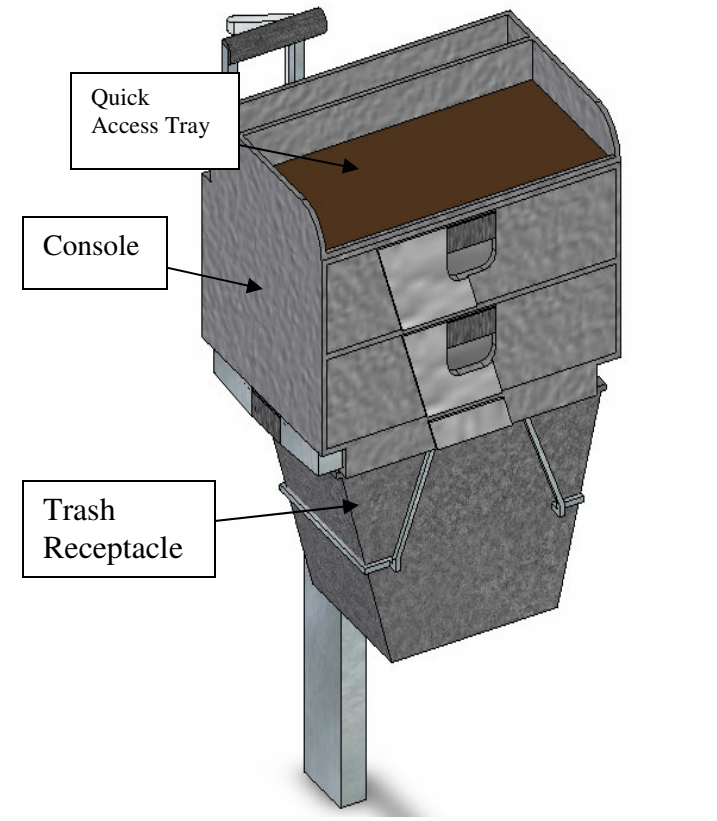

Figure 5a: Front View of Console

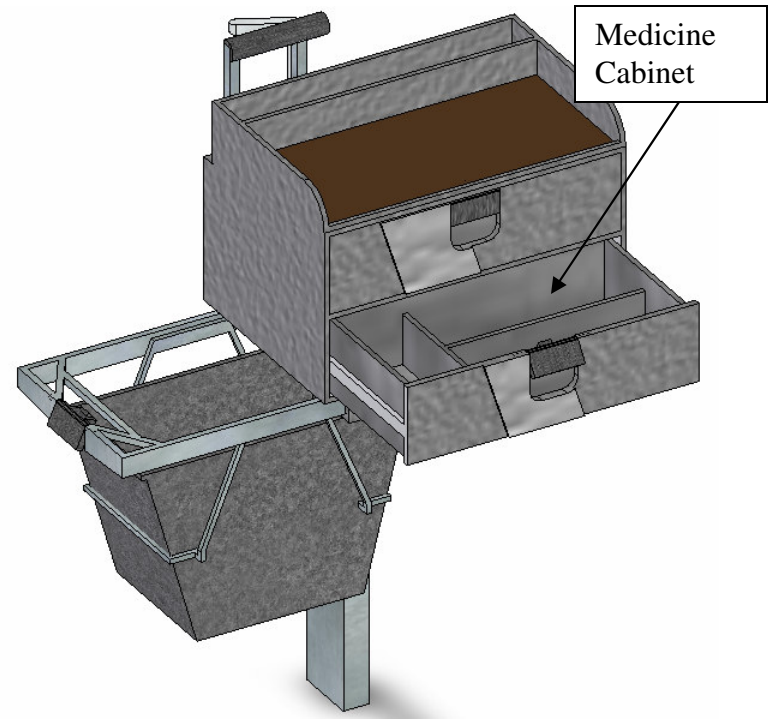

Figure 5b: Utilized View of Console

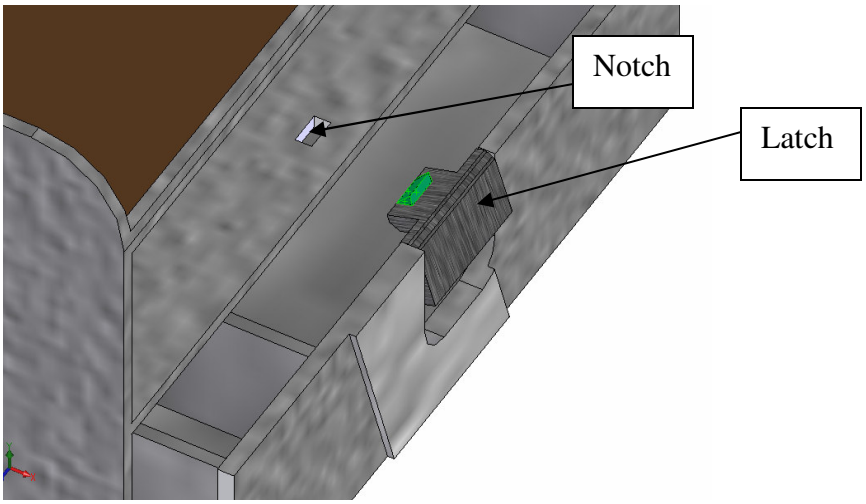

Figure 5c: Detail of Latching Mechanism

The drawers in the console as seen above (Figure 3a/c) open and close using a latch mechanism similar to the glove box in a car. This ensures that the drawers will not slide out inadvertently while the truck is in motion when it encounters vibrations of 8 Hz. Furthermore, the drawers can be unlatched and opened in one fluid motion and the truck

driver does not need to look over while opening the drawers. The drawers slide out on rails and are comfortable to slide back and forth like ordinary drawers.

The drawers are further detailed to give compartmentalized storage options for medicine kit as illustrated below. The drawer has different compartments to organize medicine in anyway the truck driver deems fit. Its designed to distinguish between bottles, pills and packages of medicine or in categories such as daily's and emergencies.

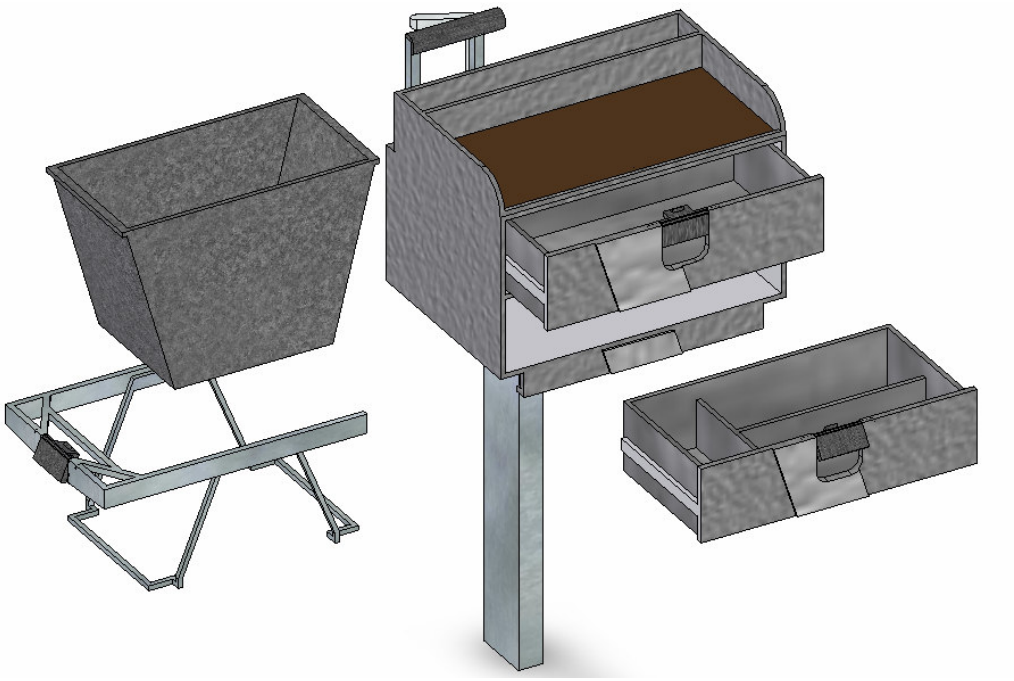

Figure 6: Exploded view of Console Interface

Conceptualizing further, the diagram above (Figure 6) illustrates how all the major features of our console interface in its fully utilized position. Underneath the main console unit, the trash receptacle is designed to slide out in the forward direction mimicking the motion of the truck. The console above the trash receptacle provides enclosed space so that most of the odor of the trash does not escape to the truck interior. Also, one can use the drawers and the trash can simultaneously. Also, using the drawers does not hinder access to the quick-access item tray and having items on the tray does not

hinder the driver from reaching to the clipboard holder at the back. Last, our design adds functionality to the interior of the truck without interfering with any of the existing systems.

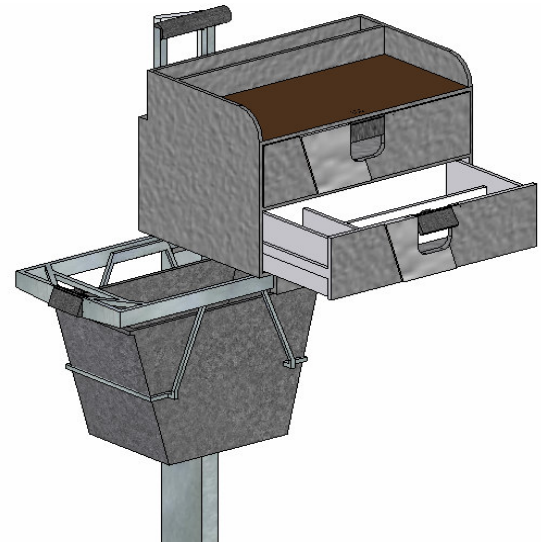

Figure 7a: Interface with Console

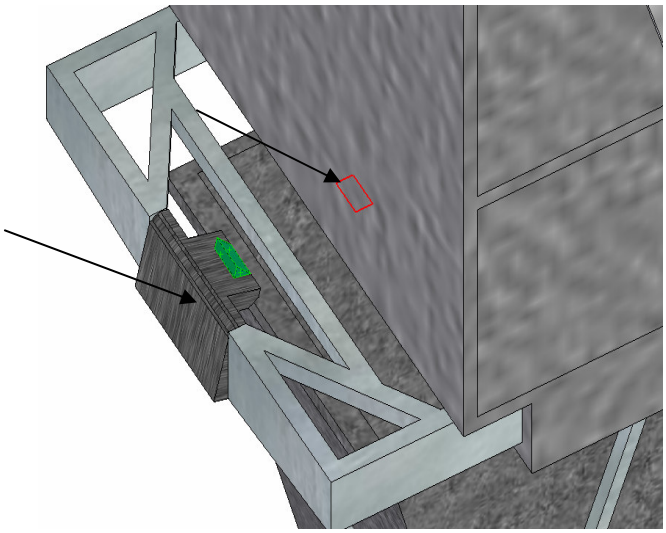

Figure 7b: Trash Locking Mechanism

The figure above illustrates how the trash receptacle is to interfaces with the rest of the console. It is attached to the bottom and slides in and out laterally giving the truck driver enough room to dispose their trash. The mechanism has rails attached to the bottom of the console on which the trash bucket slides in and out. The trash can is designed to be lined with regular trash bags facilitating easy replacement. Furthermore, the latching system is the same as the console drawers in order to keep the design consistent and making manufacture a little easier. Last, there is a cage in which the trash bucket is held which also provides flexibility to the actual trash can that is used in our design.

13 Now, we address the problem of getting the console out of the way when it is not in use. Even early on in the design process, it was clear that this is one of the most important attributes - indeed perhaps *the* most important attribute to make the console usable. We needed to ensure that the driver will have unrestrained access to the sleeping quarters. While the space between the driver and passenger seats was ideal for use as organized storage space, we decided to use the available space behind the passenger seat to stow the console when not in use. Therefore, we have a tradeoff between defined physical and kinematic constraints which were to make the console small enough and to make it move in a very particular way. Kinematic constraints on the rotating arm are at a 90º angle to each other, and could not be satisfied by simply rotating the console 180º - while it would get it out of the walkway, it would interfere with rear cabin space functionality. If the console was shortened to accommodate this problem, it would drastically compromise console functionality. Therefore, our design is an expression of optimizing benefits given the tradeoff described above.

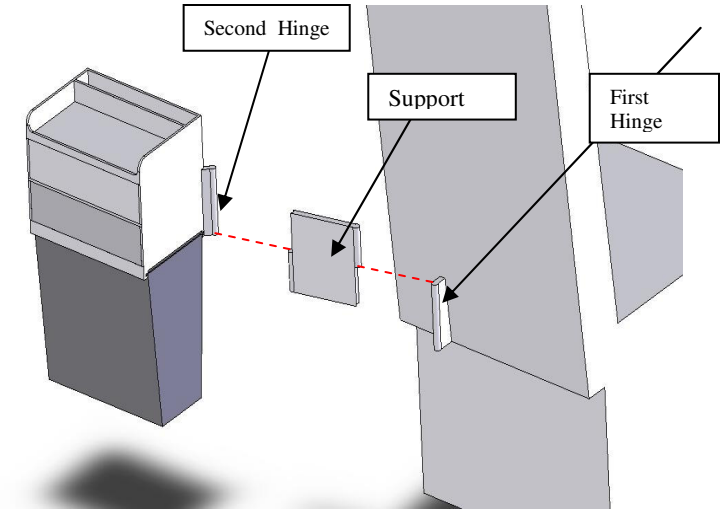

Figure 8a: Exploded Hinge Mechanism

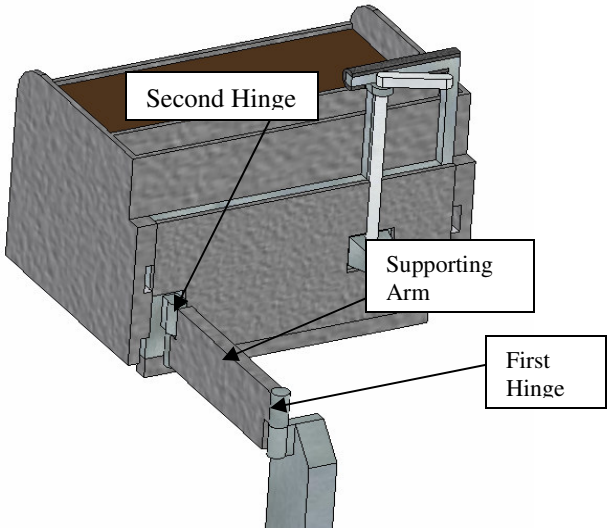

Figure 8b: Hinge Support (Back View)

In order to get over the tradeoff, we have used a double hinge mechanism to move the console out of the center space and stow it behind the passenger seat. When attaching the console from the back to the side of the seat, the first hinge rotates 180 degrees to move the console in a position as seen in the figure above. Then, the second hinge moves the console another 90 degrees which wraps around the passenger seat flush with the side. Also, the size of the console also universally fits within the constraint of the truck dimensions between the two seats and allows for enough room for the console to rotate, swing around and fit comfortably behind the passenger seat of most trucks.

Another reason to use the double hinge was because it was necessary to orient the console in such a way as not to intrude upon the rear cabin space and present an obstacle to accessing other storage compartments; which meant putting the console as flush against the back of the seat as possible. Therefore, the second hinge on the back allows the console to rotate 180 degrees and stow out of the way which is essential. This can be seen in the figures below:

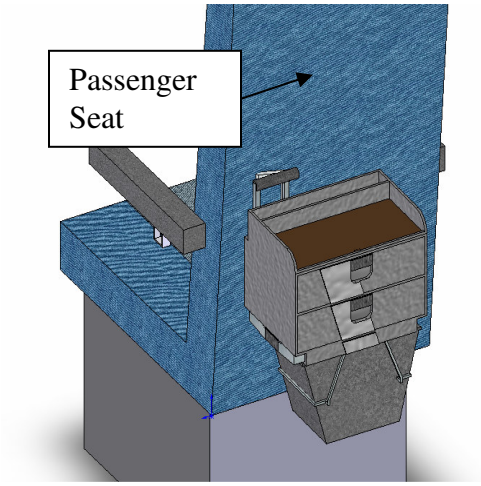

Figure 9a: Retracted Position

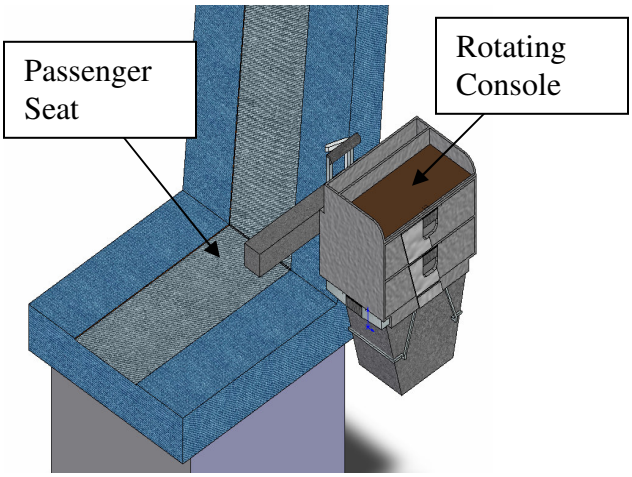

Figure 9b: Deployed Position

The kinematics of our solution are again shown below (figures 7a & 7b); the hinge mechanism is shaded a darker gray, and is attached to the back of the passenger seat (forward direction of cab travel indicated with arrow). This clearly illustrates how we intend to stow away our console when not in use.

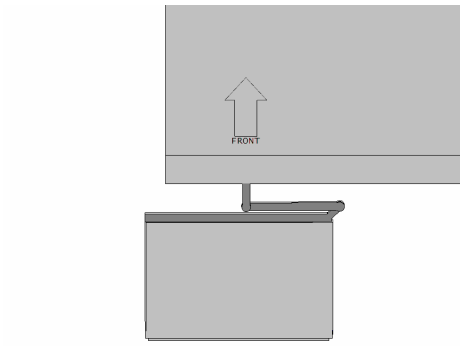

Figure 10a: Top View Retracted

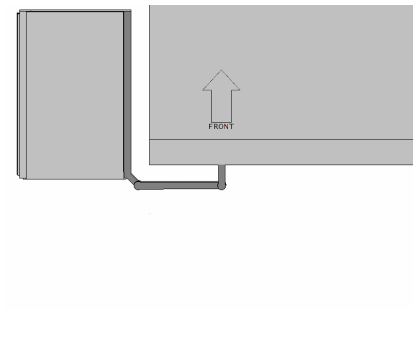

Figure 10b: Top View Deployed

In addition to an effective method for storing the console out of the way in order to facilitate movement between the front and rear cab areas, the console can be utilized from the sleeping quarters while in the retracted position. This provides easy access to all the same functionality as does the deployed position does for the driver's seat (see fig 8 side).

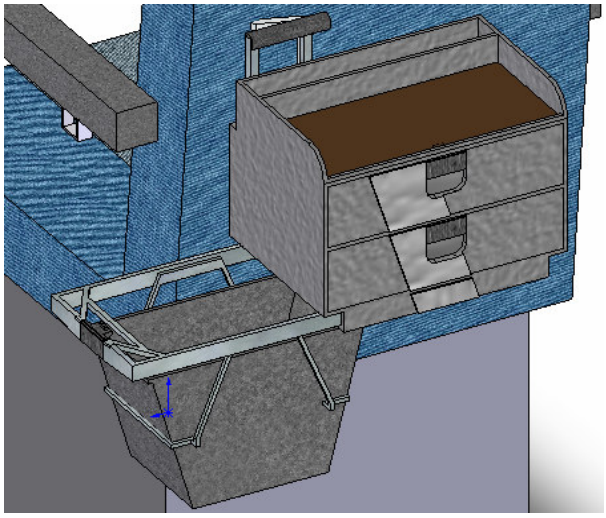

Figure 11: Console used in Retracted Position

At this point, we developed the locking mechanism for the console on the side of the passenger seat and a duplicate mechanism at the back to ensure that it does not get unlatched when the truck is in motion. This mechanism is critical to our design and makes it feasible to incorporate within a moving truck. Furthermore, the mechanism is

designed keeping in mind ease of use for aging truck drivers and is made so that the console be latched and unlatched rather easily. Also, our design does not compromise safety and as seen in our analysis later, as it can withstand the shocks and vibrations in a normal truck.

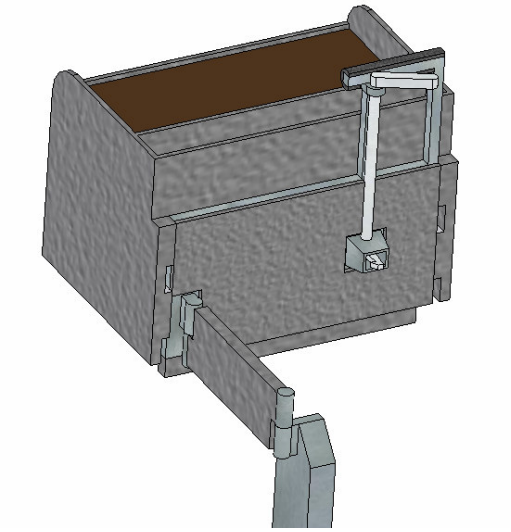

Figure 12a: Back Panel of Console

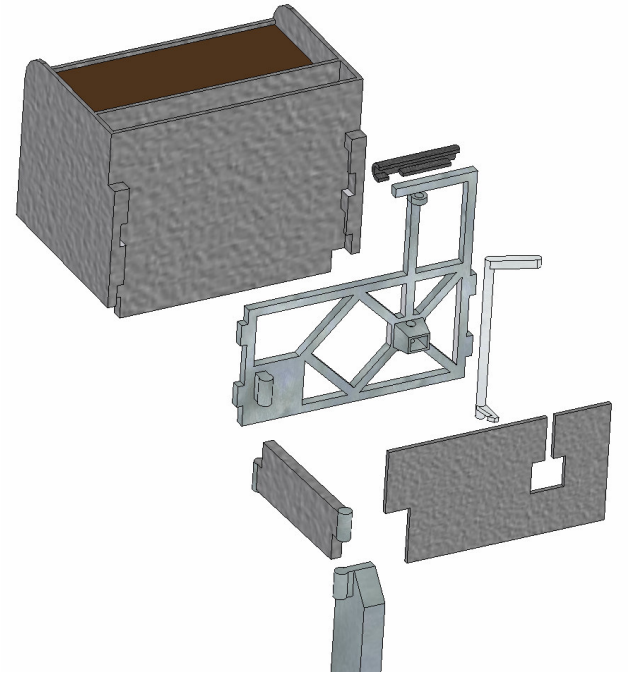

Figure 12b: Exploded view of Back Panel

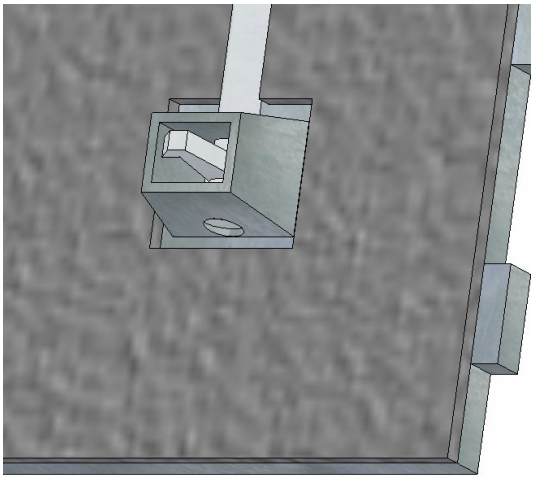

Figure 12c: Notched Arm

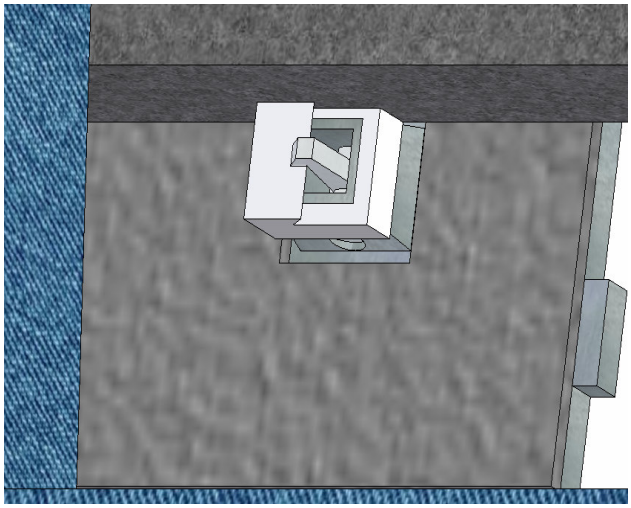

Figure 12d: Notched Arm (Locked)

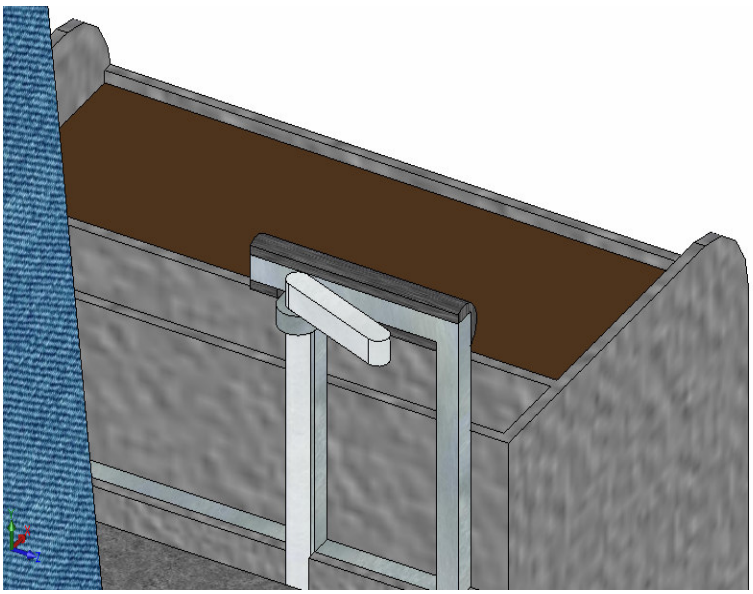

Figure 12e: Spring Loaded Lever

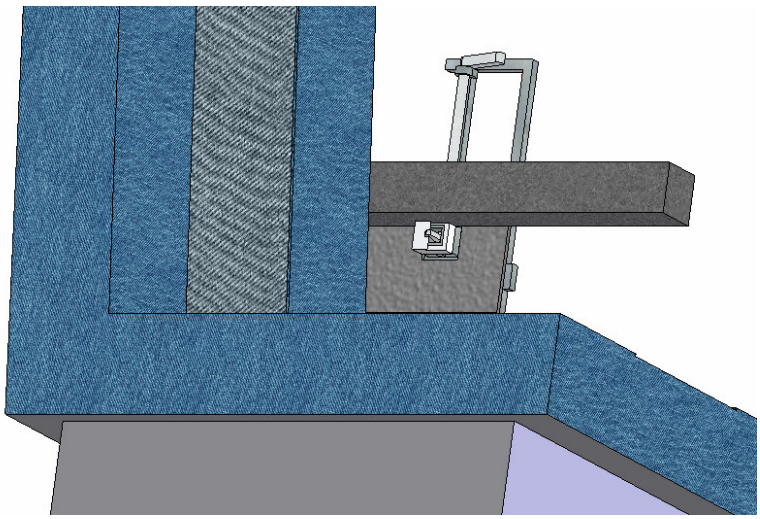

Figure 12f: Latched under passenger armrest

There is a spring-loaded handle that rotates a bar which is connected to the notched arm which slides into place into the locking slot as illustrated above. When the mechanism is latched, only a force in the plane of the lever will actuate the notched arm which will unlock the mechanism. There needs to be a substantial force in the plane of the lever and the position of the spring in that plane ensures that the mechanism unlocks slowly. The design of the handle is also ergonomic so that the truck driver can easily grasp it and pull on it to unlock the mechanism. Furthermore, the driver can rotate the console holding this lever arm in order to bring it from the deployed to the retracted position or vice-versa.

The group arrived at this idea after much research and brainstorming many ideas that provides the functionality described above. It had to be reliable enough and account for vibrations, so that it does not get easily unlocked when the truck is on a bumpy road

or the trucker brakes hard. Last, the locking mechanism is also adequate for situations if the truck gets into a serious accident such that the console will not unlock by itself and swing out in a dangerous way. The numerical modeling to prove this feasibility is done in a subsequent section.

Patent Search:

We did a complete patent search on www.uspto.gov which is the official website of the United States Patent and Trademark Office to check for patents similar to our design. The top 4 closest patent results in our search were:

	PAT. NO.		Title
1	5839542	T	Industrial truck with an operating console
2	5788015	T	Industrial truck with a driver's seat
3	5743585	T	Truck cab console with integral trash container
4	4726566	T	Truck-mounted cable pulling system

Figure 13 - Patent Search

Patent # 5743585 titled "Truck cab console with integral trash container" is comparatively the closest to our console solution; however it was not similar to our console solution. The abstract of this patent states:

*"A trash container apparatus is provided integral with a truck cab **console**. A pivotable trash door is positioned on the cab **console** to allow access to the inside of the trash container for disposing trash therein. The inner sides of the trash container have protrusions to retain the top edge of a trash bag so that the bag lines the container and is capable of receiving trash. The trash container is movable from a closed position to an open position. In the open position, the container is positioned in the area substantially in front of the passenger seat to allow access to the inside of the container for removing any accumulated trash. Slide rails attached to the container are capable of sliding along guide tracks attached to the cab **console** for moving the container from a closed to an open position, or vice versa. The trash container has a handle for grasping when being moved."*

This patent was issued on June 14, 1996 and is different from our solution because we are offering an integrated approach that uses a double pivot system whereas the above system only targets a trash receptacle primarily on sliding rails.

Development Work: Our Prototype

Our most important prototyping goal was to illustrate the feasibility of our double hinge design mechanism and its ability to move our center console from its deployed to the retracted position and vice-versa easily and effectively. Now, in order to build the rotating mechanism we first built the center console and then attached the hinge and the rotating arm to its back. We decided to use wood (despite it not being our material of choice) for building as it's cheap, easily accessible and easy to work to suit to our needs.

In order to prototype the central part of our console, we purchased a self-assemble pair of drawers from IKEA that mimicked the dimensions (larger in depth) of our central console. The prototype of our drawers does not have the latching system as in our design, but are adequate for demonstrational purposes. We have added features such as the storage space at the rear for a clipboard or a file, and a trash receptacle at the bottom. However, since the rotating and locking mechanism are the most important to prove feasibility, we have concentrated on that aspect in our prototype.

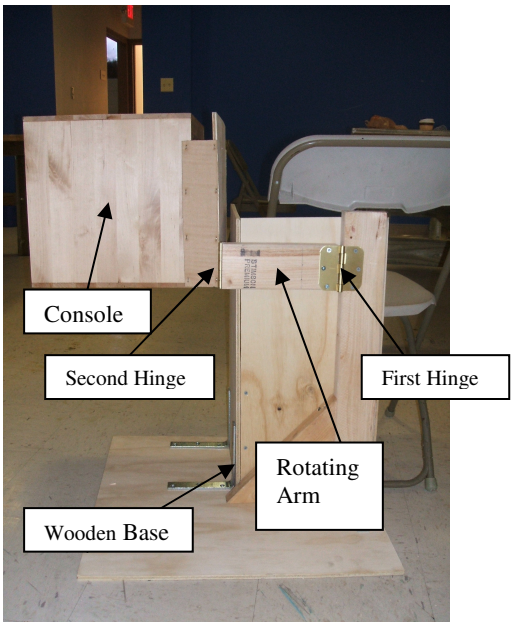

Figure 14: Prototype Rear View

Now, in order to illustrate feasibility, we built a wooden base on which the rotating console will swivel. The base is cut out so that any chair can be placed in position to illustrate how the console will swing around the passenger seat to stow away at the back. In the picture above, the chair gives a good perspective on how we envision the console to rest in the deployed position relative to the passenger seat in term's of height and distance from the chair.

We used the double hinged arm mechanism that enables the center console to be rotated in its deployed and retracted position. Also, two hinges add sturdiness to our console, and also adds a factor of safety for extra weight on the console. The hinge mechanism works as designed and the console has 270° of freedom, and thus can be easily positioned back behind the passenger's seat. The rotating arm was half of the console's width since our calculations showed that it was the optimum length in order for it to be useful in rotating the console, as well as in keeping the bending of the console minimized. The prototype swivels exactly as imagined and will be able to navigate the constricted interior of the truck in the manner in which we designed it.

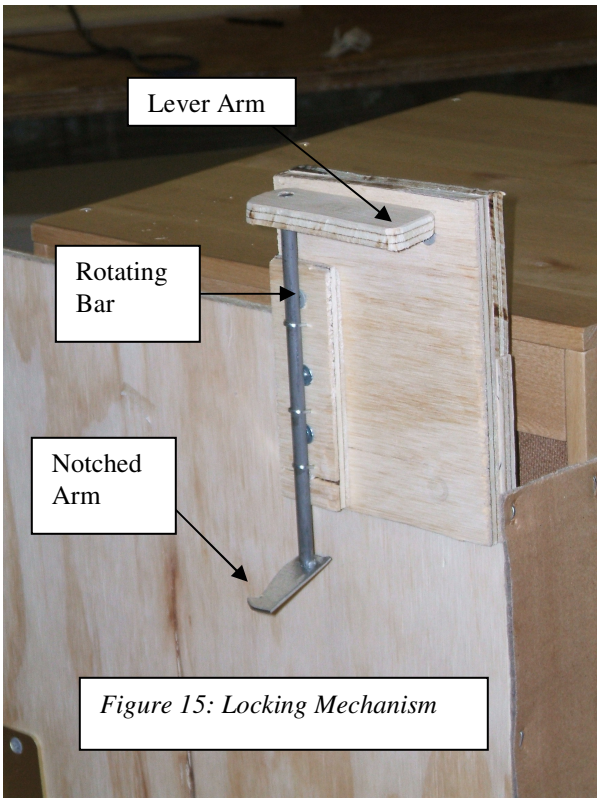

Figure 15: Locking Mechanism

The second key design element was the locking mechanism (See Figure); arguably the most important. We used a piece of plywood roughly cut in the shape of the designed lever arm to put a steel bar through. The bar is attached to the lever arm using friction and glue in order to transfer the lateral motion of the lever arm into a twisting motion to the bar. The rotating bar is connected to a notched arm, bent and shaped out of sheet metal, which locks into a bracket attached to the back of our base. In our actual design, the notched arm is connected to a wooden block which will be plush under the armrest of the passenger seat.

We faced a few constraints while trying to prototype our design. The first constraint was building the console to its specified dimensions. We were able to only find

rails for the drawers that were too long at home improvement stores such as Home Depot and Lowes. Thus we were compelled to make the prototype dimensions bigger than our designed dimensions. We managed to find a set of self-assembly drawers which were close to the size of our console drawers, except they were slightly deeper. The second constraint we faced was materials. Since we had limited experience working with different materials and had access to power tools, we decided to make our prototype out of wood. This made our console much heavier than what it actually should be, and thus the console started bending under its own weight which will not be a problem if the materials specified for our design is used.

The prototype discussed above explained the technicalities of the mechanisms used in our console design. We built another prototype which simply illustrated the designed features of our console. The built prototype is much larger than our designed dimensions; however it is an accurate physical model in terms of our designed features.

Figure 16a: Driver's Seat View

Figure 16b: Front View

Both figures above are with the rotating center console in its deployed position, between the driver and passenger seat. Also, the trash receptacle is in an open rather than stored position. In Figure 16a above, we are able to see how the console would look like from the truck driver's seat. He would have instant accessibility to the drawers as well as the quick access tray and the clipboard holder. He may have to lean slightly low to pull the trash receptacle out, but our console is ergonomically designed so that he could easily do so without taking his eyes off the road while doing so, and thus there is no problem of safety issue. Figure 16b above shows the front view of the console and the driver seat from the dashboard. There is adequate space for the truck driver to pull out the drawers towards him.

Design for Manufacture:

Since we were limited by the materials we could obtain and work with, we built the console out of wood. The weight of the wooden console loaded the hinged arms causing it to bend about its own weight. For the console to be manufactured, we recommend using a light, tough and durable thermoplastic similar to the material used to make the cup holders in the existing trucks. The skeleton of our design can be molded into shape using heat-resistant techniques to add strength and toughness to the material. Also, the skeleton of the design has to be sturdy and be able to resist bending moments about weight added to it and also has to be acoustically attuned with the rest of the truck interiors.

The second important aspect of our design is the rotating arm which has to have material properties of stiffness and strength so that it is able to resist large twisting and bending moments it will be subject to. Therefore, the plastic it is molded out of has to have resin which has high impact strength. The hinges that the console is fixed on can be a standard design able to carry at least 180lbs each. The strength of the hinges is important as the entire load of the console is distributed over the two hinges and they must not fail easily. Also, they have to be dependable for a long time outlasting the life of the truck so that these parts do not have to be replaced at any time.

Both drawers in the console are the same size and can be made at the same time. For the medicine drawer, we have designed removable partitions that can be slotted into the drawer. These partitions can be machined using cheap plastic materials that we suggest the drawers also be made out in an effort to save costs.

The support arm of our console in our actual design is attached to the passenger seat which is directly bolted to the ground and thus our console will be integrated within the truck. The passenger seat bolted to the ground provides ample support for the mechanism and will not bend or deform due the added weight of the console.

Static Analysis of Design

We have modeled our design as the console attached to two different hinges which are connected to the support arm. The second hinge is the one attached to the back of the passenger seat and therefore we fixed it to have zero degrees of freedom in all six motions. We applied constant pressure on the top surface of the console to model uniform loading when the console is in use or is in the worst case of its misuse when someone is leaning on it. We estimate the total weight of the console in normal use to not exceed 40 lbs and we considered a factor of safety of 4 for possible misuse. We used solid modeling type Solid 187 in ANSYS 10.0 and assumed a homogeneous plastic with a Young's Modulus of 5*10^5 psi and a density of 0.0361 lbs/in^3 with the Poisson ratio at 0.4. It is important to note that in while analyzing our CAD model in ANSYS, we assumed that the whole model is made from a homogeneous plastic. However, in reality, the hinges, arm support, and the locking notch would be made out of metal. We recommend using A36 steel which is inexpensive and has a sufficiently high yield strength.

A) Intended loaded weight of (40 lbs) (Unlocked)

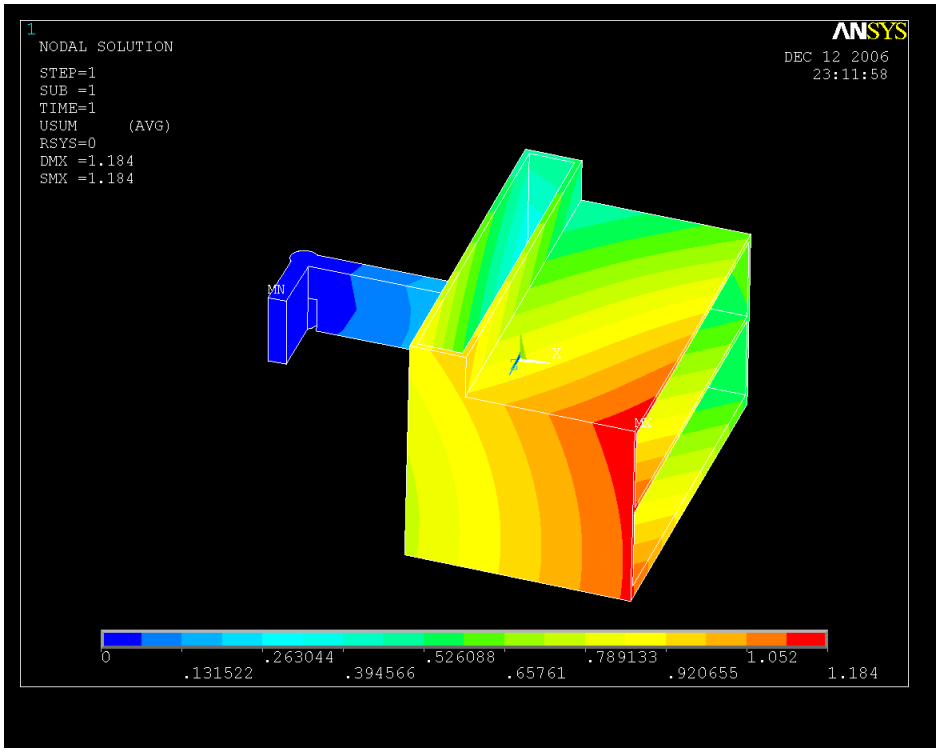

Figure 17a: Isometric View of Downward Displacement

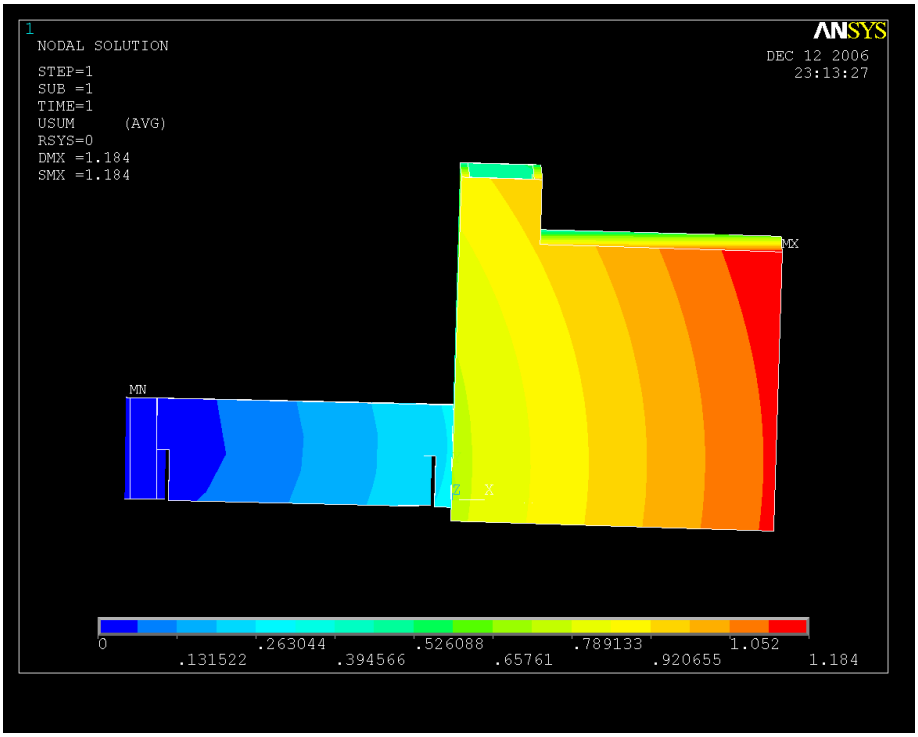

Figure 17b: Side View of Downward Displacement

The figures above show that the maximum displacement for the console is expected to be around 1 inch which is at its right front corner. This displacement is indicative of a value that may be expected when using an extremely light-weight plastic in construction of the console. We accept 1 inch as an acceptable value for deflection as it is not noticeable in daily use and does not cause unbearable stress concentrations at the hinges or support arm that may cause the structure to fail. Furthermore, there is potential for the material properties to be further refined in ANSYS that will yield more accurate results that show that there is little or no deflection.

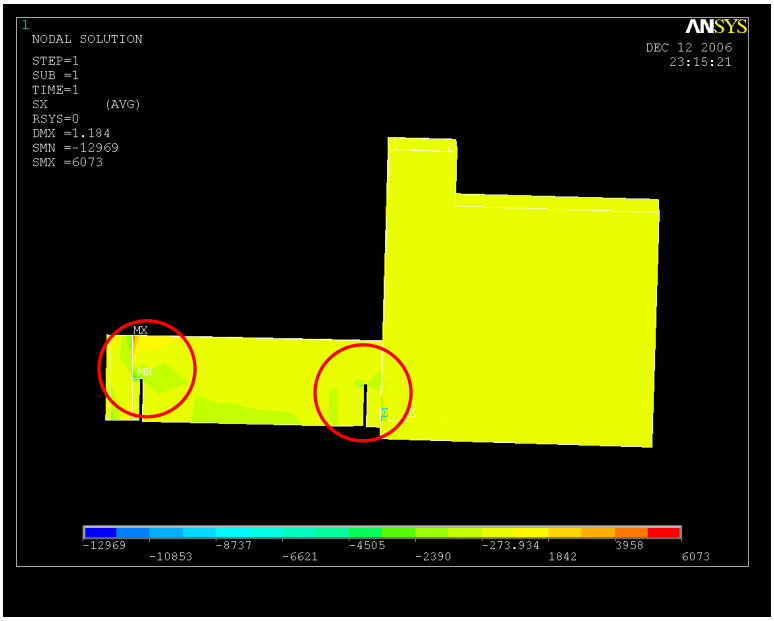

Figure 18a: Stress Concentration in the X

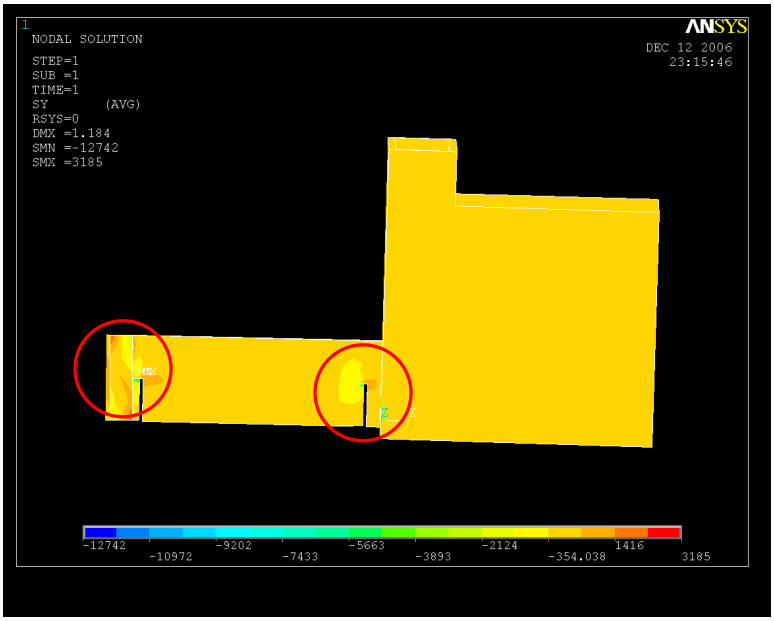

Figure 18b: Stress Concentration in the Y

The figures above show the stress concentrations in both the X and the Y directions are at both the hinges of our design. These regions are marked by the red circles on both diagrams and show the region where the design will fail first. Therefore, we have used industrial hinges in our design that are intended for taking a load of 180 lbs each and can sustain these loads over a long period of time.

B) Someone Leaning on the Console (180 lbs) (Unlocked)

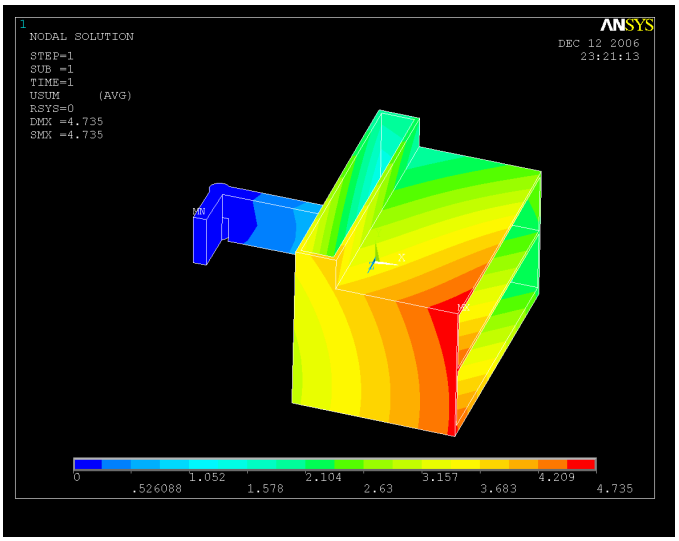

Figure 19a: Isometric View of Displacement

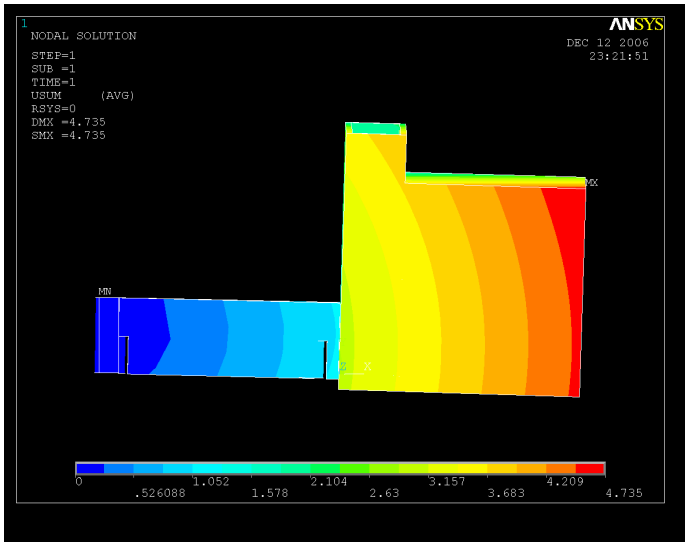

Figure 19b: Side view of Displacement

The figures above show the maximum displacement value to be 4.75 inches when the top surface is loaded to be roughly 180 lbs. This shows that the displacement of our console is not extraordinary and the entire support system should be able to absorb the stresses induced due to this unnatural loading. Furthermore, this kind of pressure is only possible when the truck is stationary which means that the vibrations of the truck will not contribute to the displacement.

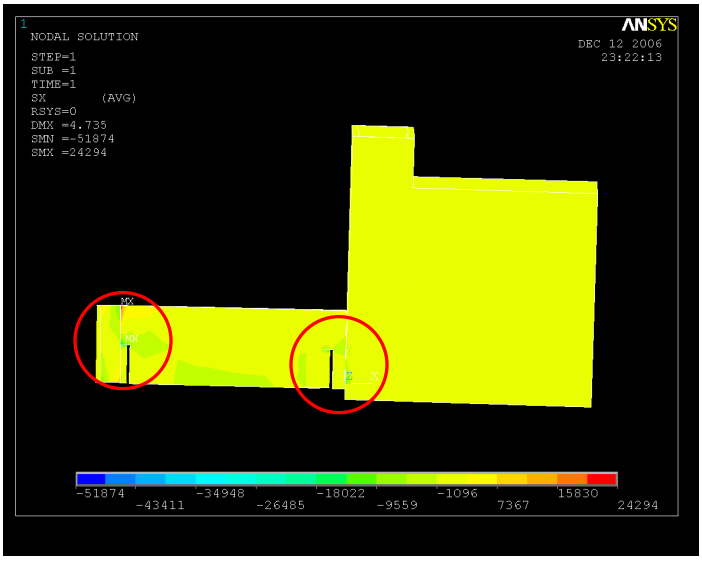

Figure 20a: Stress in the X Direction

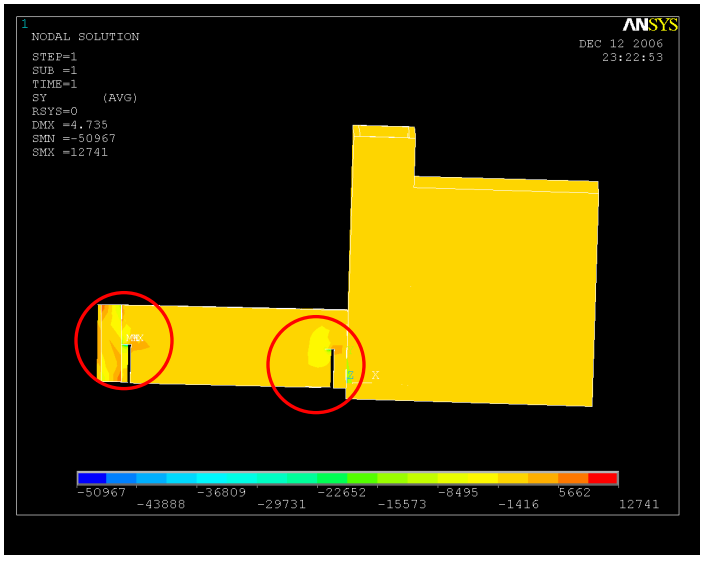

Figure 20b: Stress in the Y Direction

The stress values at their most concentrated regions are -9500 psi in the X Direction and -8495 psi in the Y Direction. Estimated compressive yield strength for the steel arm is estimated to be 36 ksi which is much greater than the two values generated above. Therefore, the model indicates that even in the extreme loading conditions, the support arm will not fail. The highest stress concentrations occur in the region where the hinges are connected to the support arm which is highlighted by red circles in the following figures.

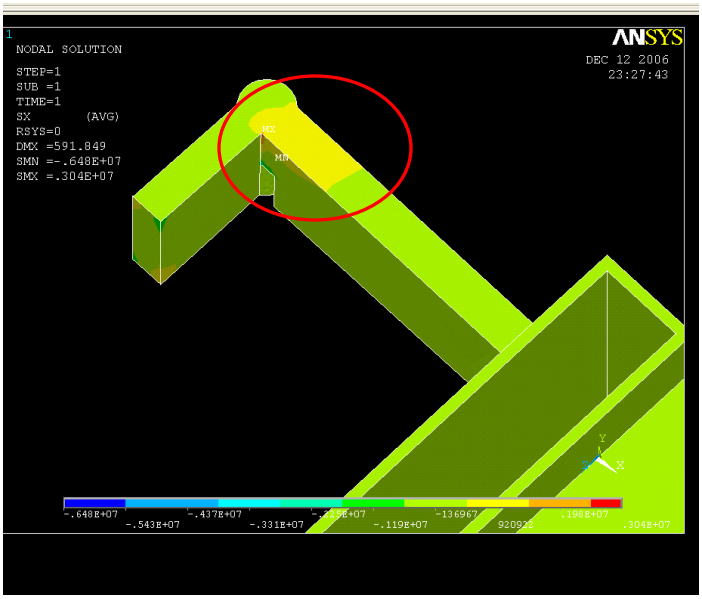

Figure 21a: Stressed Region around 1st Hinge

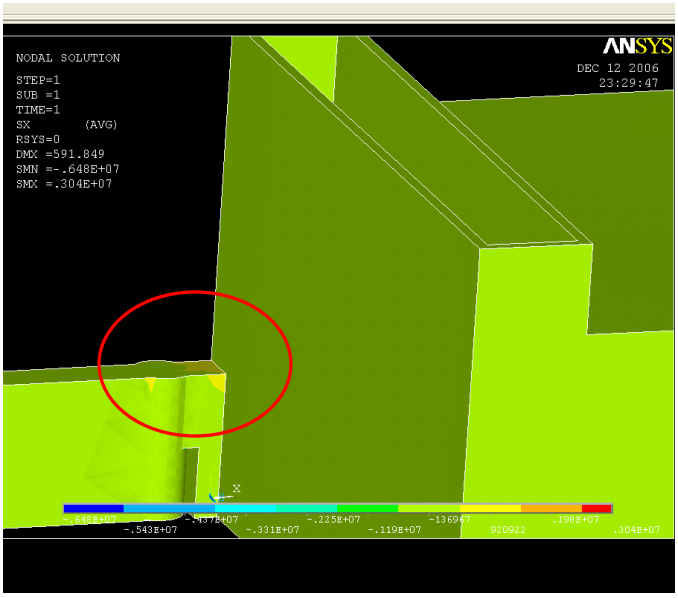

Figure 21b: Stressed Region around 2nd Hinge

Vibration Analysis

A) Vibration Analysis – Modal (Unlocked)

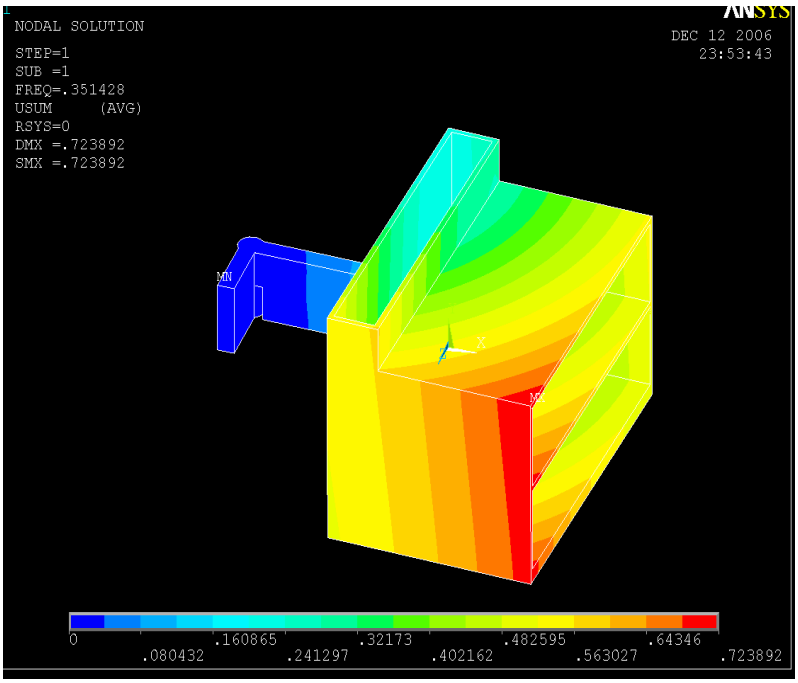

Figure 22a: 1st Mode of Vibration – 0.4Hz

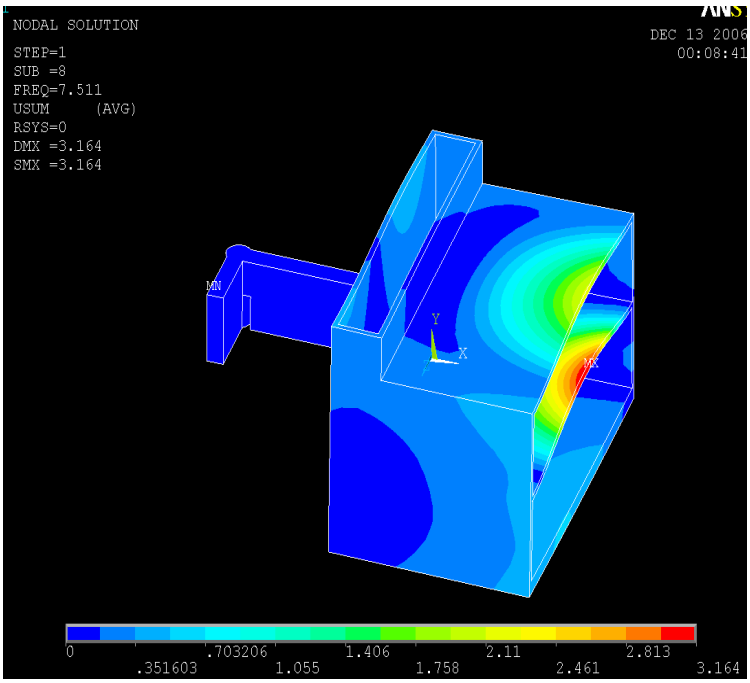

Figure 22b: 8th Mode of Vibration: 8 Hz

The figures above show different modes of vibration when using the Bloc-Lanzcos Method for extraction of modes. The figure on the right shows the displacement during the truck in motion at its excitation frequency of 8Hz. The analysis shows that there is a surprisingly small deflection of the console its main structural areas such as the locking area and the hinge supports. This result satisfies one of the criteria for our design to be installed and used in a moving truck. The figure on the left is the first mode of vibration and has results similar to when the console is only loaded with a 40 lbs weight. The analysis above also indicates the importance of selecting the plastic material with the correct density whose resulting mass has an amplitude ratio which is not amplified at the frequency of a moving truck.

B) Vibration Analysis – Modal (Locked)

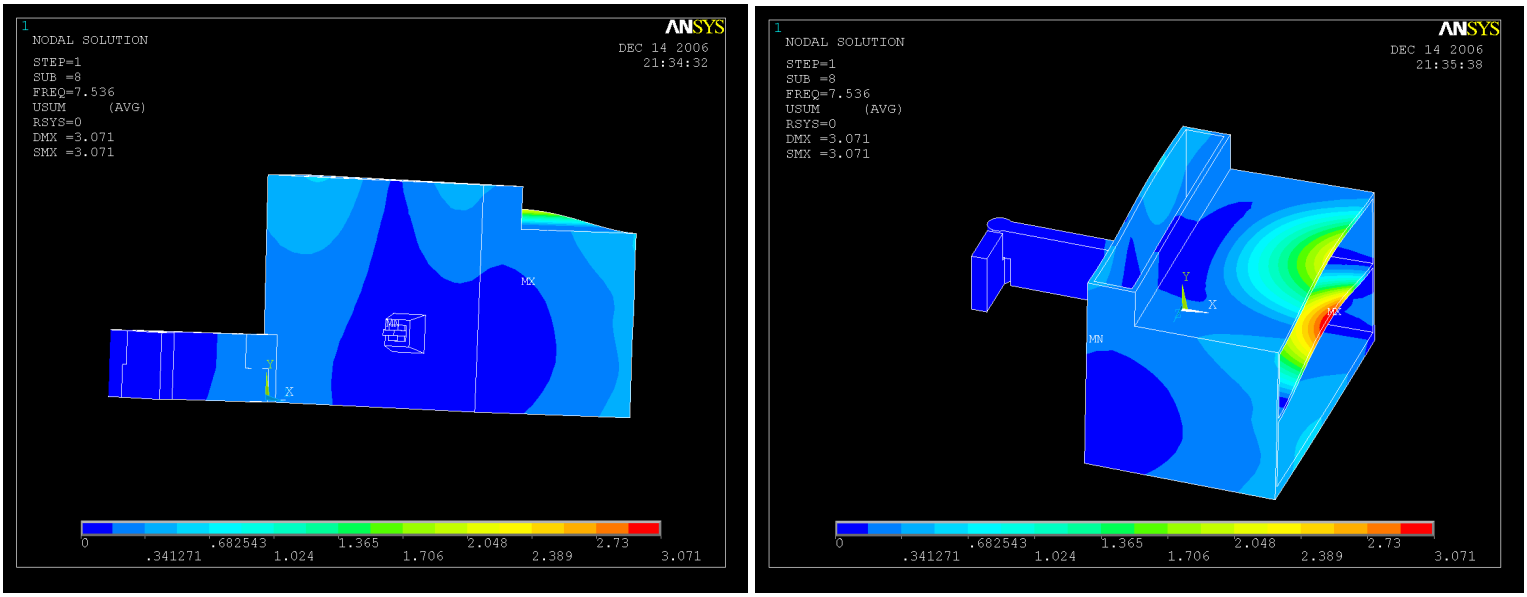

Figure 23: Different Views of the 8th Mode of Vibration: 8 Hz

The figures above show different modes of vibration when using the Bloc-Lanzcos Method for extraction of modes when the console is locked into position (deployed). Both figures show the displacement during the truck in motion at its excitation frequency of 8Hz. The analysis shows that there is a surprisingly small deflection of the console its main structural areas such as the locking area and the hinge supports. This result satisfies one of the criteria for our design to be installed and used in a moving truck. The figure on the left shows the low displacement which is desirable around the back of the console where it locks into place. The isometric view on the right shows that maximum deflection is expected at the partition of the console and we believe that if the drawers are modeled as full, the deflection will be much reduced. Therefore, our design looks promising and the values suggest it to be a feasible solution for the interior of a truck. However, having said this, more extensive and accurate analysis is required before any real manufacturing decisions are made.

Crash Analysis

A) Displacement Analysis with Unnatural Forces (Locked)

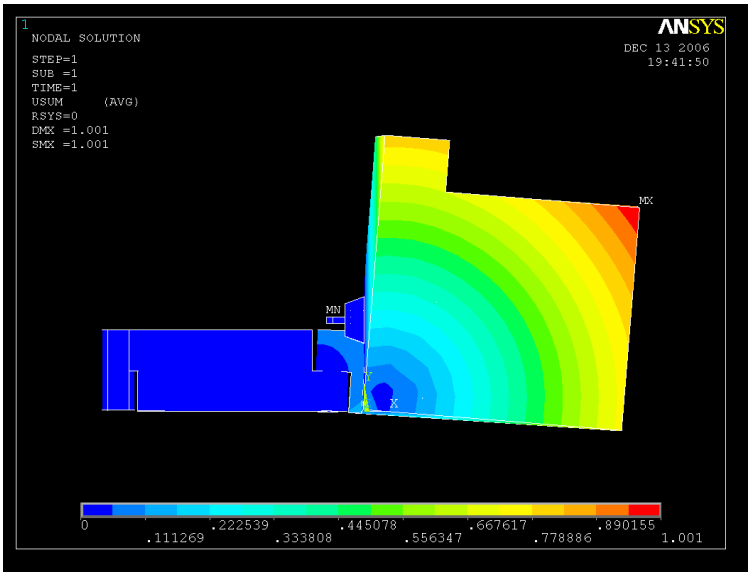

Figure 24a: Isometric View of Displacement

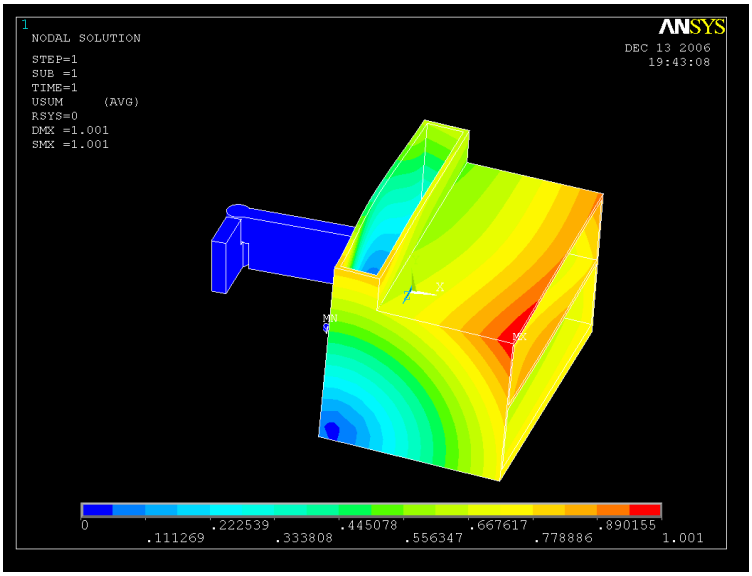

Figure 24b: Side view of Displacement

We exercised a crash analysis of our console in a situation where there may is a maximum force of 20g (644lbs) on the console, pointing towards the driver. The goal here was to make sure that the console would not break from either of its hinges and smash into the driver, in case of an accident. The figures above show that in such an accident, the console would displace downwards by only 1 inch, which does not pose much of a threat, and is fairly acceptable. This analysis does assume the hinge does not come unhooked and it is designed to withstand the stated force above without unlatching.

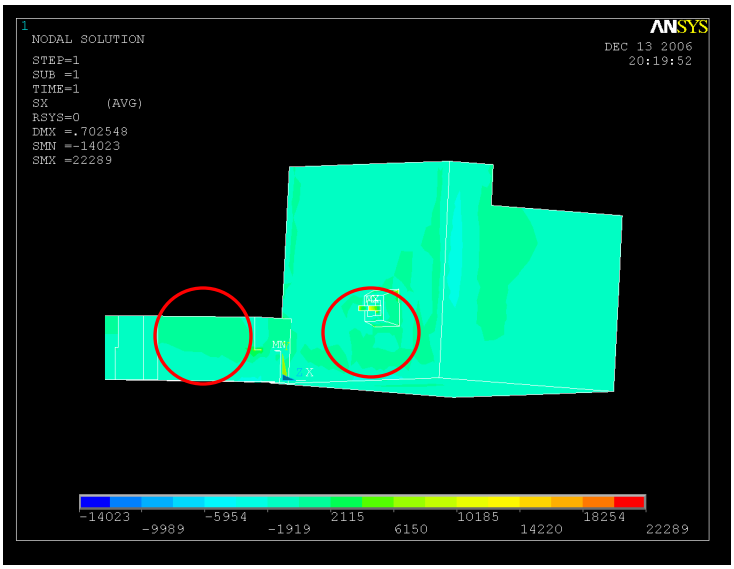

Figure 25a: Stress in the X Direction

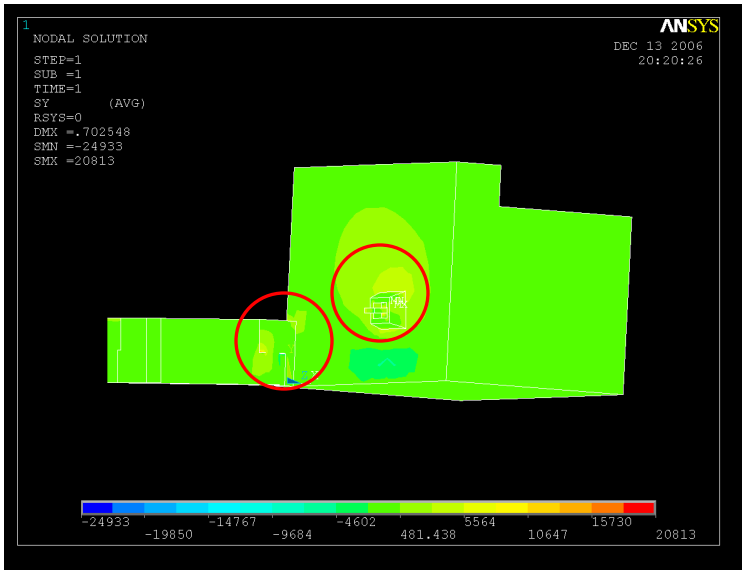

Figure 25b: Stress in the Y Direction

The contour plots above show the regions of maximum stress, which are in accord with what we anticipated. From this stress analysis, we see that the most concentrated region in the X direction has a compressive stress of less than 12000psi and a tensile stress of approximately 2000psi. This is within the 36000psi yield strength value of A36 steel that we recommend. In the Y direction, we see higher stress values. The most concentrated regions have a maximum compressive stress of approximately 10000psi and a tensile stress of 5500psi. If we had made everything out of a homogeneous plastic, then there would have been danger of the console snapping at the hinge or notch and causing injuries to the truck driver. However, manufacturing this part of the console out of metal makes the design safe, even in an accident.

Process of Reaching Final Design

The road to our solution of a rotating center console took many interesting twists but the group believes that this is an optimal design that will help maximize the retention rate for aging drivers since the product enhances driving experience in a usable and friendly manner.

The idea took shape in the many brainstorming sessions (Appendix A) that were held in order to satisfy the opportunity of improving the utilization of space between the driver and passenger seat. We started out with sixty different feasible solutions which ranged from improved office space, improved organization and extra storage to a central fridge and food storage to a coffee pot holder. We used the Value Opportunity Analysis tools (VOA) to identify important attributes and goals for our final solution. In order to further identify the most important features of the design, we visited truck stops and interviewed 15 different drivers to ascertain which features are most important to them. This was done by creating a survey (Appendix B) that asked drivers to rank the best solutions and some of the most consistent results to further evaluate possible solutions were used. We also gathered important inputs by conversing with truck drivers and taking photographs of truck interiors to document current situations. From the interviews and surveys conducted, the group decided that the key features were improved organization of paperwork, immediate access to essential items while driving and improved trash disposal system. After this, we brainstormed mechanisms and console designs that allowed us to incorporate these features in the most efficient manner possible.

The process of finalizing our mechanism started with identifying that drivers prefer to move back and forth in their truck cabin without being obstructed. Therefore,

we considered rails, tracks, hinges, and numerous other devices which allowed us to move the console out of the way easily. At first, tracks seemed to be the best solution and different center consoles and track locations implementing the track idea. After a meeting with Professor Cagan, it was determined that the tracks would not be the most ideal method of moving the console as debris or miscellaneous objects could block its tracks. The old movement solutions were taken out and analyzed again before hinges were chosen as the new solution.

New consoles designs were then drawn. (Appendix C) The new designs restricted the size of our console since we had to consider the space required in smaller long-haul trucks for the entire console to swing back and forth. We decided to utilize the dead space behind the passenger seat in order to store the console in its retracted position. We then used Pugh charts in order to short-list designs that we could use. After this, we conducted research again and results indicated that we settle on integrating the desired features on a rotating center console which stows out of place behind the passenger seat while not in use.

At this point, we ran into another issue which was deciding how the console would lock into place so that it secure while the truck was in motion. Different types of locks were discussed but the safest and easiest to engage locks were picked. After much debate a spring loaded lever that extends from the back of the console was chosen. The truck driver simply needs to pull on the lever and rotate the mechanism to the back where it locks into place. The spring loaded lock makes it safe since it cannot displace with simple vibrations and forces while the truck is in motion. It requires a concentrated

twisting moment on the lever. Therefore, this locking design was decided only once the overall mechanism was decided.

At this point, we generated preliminary CAD Models that illustrated our design principle and the console's intended use. The model conceptualized the double hinge mechanism and the different locking and stowing position our console has. It also clearly lays out the different compartments that satisfy each of the important features that were identified above. Lastly, it also illustrates the locking and unlocking mechanism of our console, why it is safe and how it works.

After developing a workable design, we considered QFD Analysis by constructing the house of quality which ties in customer needs and wants to the actual features and attributes of our console. This helped us further conceptualize the applicability and usability of our design. The QFD Analysis proved to be satisfactory and we decided to document the design as our final solution to the opportunity we identified at the start of our process. We then revisited the VOA tools to ascertain whether our designs were able to complete the goals laid down at the start of the process and were satisfied with the results.

To sum it up, the final concept was generated after trips to truck stops, interviews with drivers, numerous brainstorming sessions, analyzing VOA's and matrices and conceptualizing a wide variety of possible solutions. In the end, we arrived at the final solution which neatly integrates key factors that we identified and does satisfy a real need in the marketplace.

Aging Truck Drivers: How our Design in Useful?

Our design is very appealing to aging long-haul truck drivers because of its ease of use, usefulness in organizing and stowing important items and the improvement in hygiene inside the truck. Firstly, the console is designed to be accessed within arms reach of aging truck drivers while the truck is in motion. Therefore, drivers are able to store important items such as medicine and do not need to take their eyes of the road in trying to locate these items while driving. Secondly, the console is easy to unlock and move out of the way and takes into account physical constraints that aging drivers face. Thirdly, the console has an integrated trash disposal system which means that aging truck drivers can collect their trash in an organized fashion and do not have to spend time cleaning up the mess they create while driving. Even while driving, they do not have to bear the filth of open wrappers and empty cans and can dispose it in the center console. Lastly, we designed our console keeping the aging truck driver in mind, but the final design has universal applications and all truck drivers can benefit from its use.

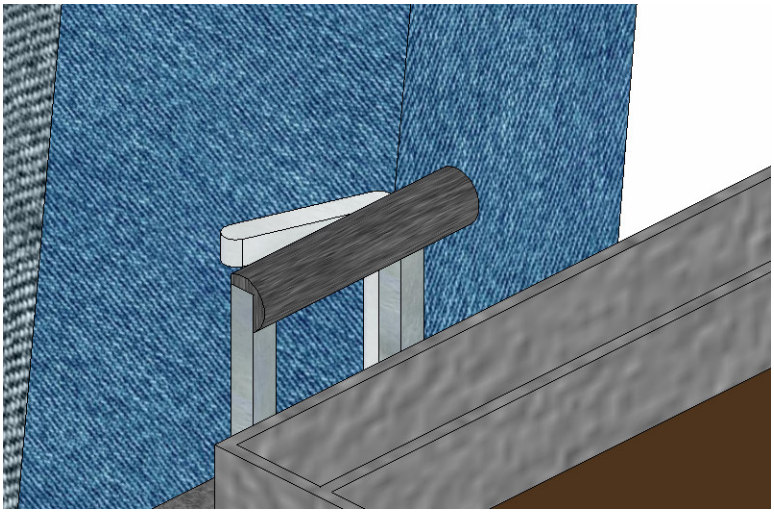

Figure 26: Engage Lever in 1 plane of motion

User Feedback

We conducted extensive research by taking animations of our CAD model as well as our prototype to truck stops in the outskirts of Pittsburgh, and received first hand user feedback from approximately 25 truck drivers. The majority of the truck drivers we interviewed were over 40 years old, thus classifying in our necessary segment of aging truck drivers.

A sample of our user feedback form is available in Appendix #. The combined result of the feedback we obtained is shown below:

User Feedback	***Rotating Center Console***
Features:	Average Rating (1 = useless/poor, 5 = very useful/excellent)
Quick-Access Tray	3.5
Medicine Drawer	4
Paperwork Storage	4.6
Clipboard Holder	4.4
Trash Receptacle	4.6
Design:	
Size	3.8
Location (Passenger Side)	4.7
Retractable and Deployed Positions	4.5
Locking Mechanism	4
Product Characteristics:	
Useful	4.1
Usable	3.8
Aesthetics	2.8
Comfort	3.2
Desirable	3.9

Figure 27: User Feedback from Truck Stops

Since we did not have any pictures of a finished product available, it was sometimes difficult for the truck drivers to visualize how well the console would fit overall inside their respective trucks. We took the time to explain the design, mechanisms, features offered, and the ergonomics of use through our CAD model as well

as the prototype, in the simplest possible manner, enabling the truck driver to give us valuable feedback based on it.

The results further bore witness that the functionality of the console is very good; the lowest average rating on any feature being 3.5. The average rating on size as a design component was a 3.8. It was lower than what we expected, since some truck drivers were of the opinion of having a larger console. However, the space between the driver and passenger seat was a key constraint while dimensioning our console, and we feel we have designed an optimally sized console based on our analysis, in order for it to be universally accepted in different trucks while still being a useful, usable and desirable product. Most of the truck drivers were pleased with the location of the console being on the passenger side. They also found the double hinged mechanism, which rotated the console to its deployed and retracted positions, to be interesting and acceptable. A few truck drivers were apprehensive about the reliability of the locking mechanism and whether it would stay intact on a bumpy road, since we did not have an exact physical model of the mechanism. However, we took the time to explain our mechanism in adequate detail for them to feel fairly comfortable. The ratings on the product characteristics were modest yet acceptable. We demonstrated a crude prototype, which was not able to correctly represent the aesthetics of the final built-in product in the truck. The truck drivers were not able to visualize the finished product well, and thus gave mixed ratings in terms of its aesthetics. In addition, some of them resisted change, and had mixed feelings about the whole idea of a console taking up the space between the driver and passenger seat; although majority of the truck drivers found the solution to be exciting. Overall, we were fairly satisfied with the results obtained to our console design.

Problems with After-market Alternatives

There are multiple after-market solutions available that attempt to solve the problems faced by truck drivers indicated above. The problem with these products is that they do not offer an integrated solution that takes into account factors like safety, usability and cost considerations.

For instance, the Case Logic (fig 4a) is available for $35, promises to provide organized storage because of the different specific compartments the pouch has. However, it does not remove the fundamental problem of the driver having to reach uncomfortably on the floor for an item while driving. Furthermore, the driver in most cases would be forced to remove it out of the way in order to access the back of the truck. Another safety problem is that the product is slipping and sliding along the truck floor when the truck is in motion causing instability to the stored items in the case. Other alternatives are bulky consoles that range around $200 (fig 4b, 4c) that can be attached to the floor of the truck but there seem to be no readily available integrated approach that alleviates at least some if not most of the problems highlighted above.

Figure 28a - Case Logic Product

Figure 28b - Aftermarket Solution

Figure 28c - Aftermarket Solution

Set Factors

The product concept of the rotating center console has social, economic and technical impacts that are important and need to be considered. First of all, our design increases peace of mind of aging truck drivers while they are driving the truck. They have access to essential items such as their medicine kit without ever having to take their eyes of the road. Furthermore, having communication devices within arm's reach increases their connectivity with their wives and loved ones which is an important social impact. The trash receptacle in our design facilitates better hygiene and a better work environment for the truck driver which is an important improvement. Better driving conditions will help facilitate better driver retention and also shows thought and effort put into driver needs by trucking companies. Also, our console helps dispel the stereotype of truck driving to be a 'dirty' and 'unclean' job by giving truck drivers a better opportunity to control their work environment. Therefore, integration of our design within the truck interior will also help increase the confidence of the aging truck drivers to do their job effectively by increasing the comfort of driving a truck for a long time.

The economic factors are essential for every organization while considering installing a new design. Our console has a high desirability and usability for the price. The console would improve driver productivity and happiness by improving the organization and cleanliness. Thus, truck companies would be willing to pay for the console in order to keep their drivers happy. This would help reduce driver turnover rate and attract new drivers to the company

There are many constraints on how the console could be built. The size and weight are the two major constraints. If the console was too big, it would not rotate out of

the gap between the driver and passenger seat. If it was too small, then nothing useful could be stored in the drawers. The weight of the console could cause it to collapse. If it was too heavy, then the double hinged arms would fail. This would render the console useless as it would not be able to rotate. Thus, building the prototype out of heavy materials would be problematic. Another difficulty involved is the locking mechanism. It would have to be strong enough to withstand 20G's during a crash and 8 Hz while the truck was driving. Conforming the console to safety regulations was also considered because it would be attached to the passenger seat. The console could not touch the seat belt lock so that the passenger could be safe. Thus, it would lock into the armrest, allowing the passenger to still wear his seatbelt. Lastly, driver ergonomics was considered. The console had to rotate out of the aisle so that the driver could comfortably move to the cabin without jumping over it.

Some added values are that the console is convenient and desirable. From interviewing the drivers, we found that they liked the idea of a rotating console as it could swing to the back and not interfere with their movement to the back of the truck. The medicine drawer was also liked as pills and bandages could be organized and grabbed within hands reach. The sliding garbage would keep the cabin clean and important documents, files and folders could be stored and reached easily while driving.

VOA Current State/Goals

		Low	Medium	High
Emotion	Adventure			
	Independence			
	Security			
	Sensuality			
	Confidence			
	Power			
Ergonomics	Comfort			
	Safety			
	Ease of use			
Aesthetics	Visual			
	Auditory			
	Tactile			
	Olfactory			
	Taste			
Identity	Point in time			
	Sense of place			
	Personality			
Impact	Social			
	Environmental			
Core Tech	Reliable			
	Enabling			
Quality	Craftsmanship			
	Durability			
Profit Impact				
Brand Impact				
Extendable				

The grey lines in the VOA diagram above shows the current state of affairs of the utilization of space between the driver and the passenger seat. The orange lines indicate the goals we set ourselves in order to conceptualize our final product and all the aspects we hoped to achieve. As one can see from the diagram above, there is huge room for improvement we are trying to capitalize on.

First of all, the current state does not offer much to the driver as there is nothing useful located in the space. In most trucks visited, this space is usually littered with garbage or documents and folders. A couple drivers have built their own console to keep themselves better organized but it is designed for one purpose. If anything, this space serves as a trash area and over time, hinders the movement of the driver to the back of the truck. Many of these categories are listed in the low to medium range because there is very little to offer in the current state. Specifically, the categories that we are targeting for a large improvement are security, confidence, comfort, safety and ease of use. These factors are important in considering driver retention rate especially for the aging truck driver. For instance, we felt like we could dramatically improve the ease of use and comfort in accessing the center space and we also wanted to make the truck environment safer. Another important goal we set ourselves was to make a large social and environmental impact by facilitating a clean truck environment which is a dramatic improvement. Another key feature we considered is to make our design enabling which would greatly add usability and value to our final product solution.

VOA Final Design: Retractable Center Console

		Low	Medium	High
Emotion	Adventure			
	Independence			
	Security			
	Sensuality			
	Confidence			
	Power			
Ergonomics	Comfort			
	Safety			
	Ease of use			
Aesthetics	Visual			
	Auditory			
	Tactile			
	Olfactory			
	Taste			
Identity	Point in time			
	Sense of place			
	Personality			
Impact	Social			
	Environmental			
Core Tech	Reliable			
	Enabling			
Quality	Craftsmanship			
	Durability			
Profit Impact				
Brand Impact				
Extendable				

The final design VOA is significantly better than the current state VOA. Each category has been improved even though we weren't able to completely achieve all of our set goals. First of all, most of the categories are in the medium to high sections instead of the low to medium as demonstrated on the previous VOA. We were able to address our intended categories simply because we were designing something new to fit into the empty space, a solution that does not exist right now.

Now, we achieved high scores for the ergonomics of comfort, safety and ease of use which were the focal point of our solution and greatly enhance the truck driving experience. The retractable console is within arms reach while driving and stores important items in an organized manner, making the product more ergonomically useful. Social and environmental aspects are also improved because the driver does not have to deal with as much of a disheveled, messy and dirty environment with our solution. Another important aspect is that the design is extendable which means that it lends itself to modifications if other important aspects come to the fore in the future. Aesthetics are important for adding items within a truck cabin and our solution lends itself to be visually appealing. Therefore, the retractable center console meets some very important attributes in a very satisfactory manner.

PUGH Charts

ATTRIBUTE	Retractable center console	Ceiling storage	**Extend dash storage**	Make seat extensions	Passenger leg space
easy to use	1	-1	**D**	0	-1
Size	1	1	**A**	1	0
Ergonomic	1	-1	**T**	1	-1
easily accessible	1	-1	**U**	0	-1
Marketable	0	-1	**M**	0	-1
shock resistance	-1	-1	**D**	0	0
Comfort	1	-1	**A**	0	0
Safety	0	-1	**T**	0	1
TOTAL	4	-6	**0**	2	-3

Figure 29: Pugh Chart - Solutions

The Pugh Chart above helped in selecting the solutions based on engineering characteristics from customer attributes. These were considered in line with the key features discussed above. The group decided to choose the extendable dash storage as the DATUM since the dash board already includes cups and mobile holders in the current trucks, and thus, could easily be extendable with added features in it. However, after discussing potential solutions, we chose the **multi-purpose retractable center console** since it had highest ratings on the Pugh Chart and was deemed the best overall solution. It was considered to be better in terms of ergonomics, size, comfort and most importantly, accessibility. The only negative point, compared to its DATUM, was that since it would be a retractable mechanism with a double hinge mechanism, it may not be as shock proof as an extendable design to the dash board.

ATTRIBUTE	Hole in the ground	**Latch**	Notch	Keyed cam lock
ease of use	-1	**D**	1	-1
Size	-1	**A**	0	0
ergonomic	-1	**T**	1	-1
ease of accessibility	-1	**U**	1	-1
marketable	1	**M**	1	1
shock resistant	-1	**D**	0	1
comfort	1	**A**	1	-1
safety	-1	**T**	0	1
TOTAL	-4	**0**	5	-1

Figure 30: Pugh Chart – Locking Mechanism

The group decided to put all the brainstormed potential locking mechanisms to our console in a PUGH chart and see which mechanism would be the most suitable, by comparing them with the attributes above. We chose the latches to be the DATUM since they are already being used in cars. 'Hole in the ground' is a mechanism where there would be a long, vertical rod, which would be locked into a hole in the ground. Similar to the locking mechanisms found in bathrooms. Using a **notch as a mechanism in our double-hinged console** seems to be the viable and the best option, as shown from the PUGH chart. There were no negative attributes to using the notch and was better than the keyed cam lock and hole in the ground in terms of ease of use, ergonomics and ease of accessibility. Using a latch was the second best option, but the results of using a notch were much better.

Business Implications:

The premise of our rotating console is that it will be offered as an additional option in International trucks. We envision the console in its final form to be cheap, effective and easy to install allowing International to provide a useful and thoughtful option in their trucks which will be appreciated by both, fleet owners and owner-operators trying to keep driving comfort up while keeping their cost down. Another position that International can leverage is using the rotating console as a differentiation strategy that specifically targets the aging truck driver by giving thought to lifestyle conditions unique to them.

Also, there are universal implications such as more hygienic truck interiors and a better organized work-space which is not only appealing to the truck drivers but the truck owners as well. Reasonably, if the truck conditions are cleaner, then the average health of the truck driver will improve which saves the company health benefit costs and also reduces social costs of truck driving; both aspects that International can market. Another aspect that makes our product extremely marketable is that its use is left up to the individual preferences of the truck drivers, serving a wide variety of intended use and audiences. Our console is also easily extendable and adaptable which means that International can develop unique fits and solutions for specific driver situations which will make their trucks more appealing in a market where there seems to be a lack of cheap useful options.

We estimate the actual cost of producing and installing our console on a large scale to be anywhere from $20-$80 depending on the types of material used and the workmanship hours put into the final product. There is flexibility in the standardized

parts and manufacturability options that can be used to manufacture our console which enables International to take advantage of different options for economies of scale.

Having made the arguments above, it is important to consider that these are just preliminary research findings and estimated revenue streams that are being considered. Extensive market research is required to explore its potential impact and is a good idea for International to do before it considers the idea for launch. Also, market research will also help focus the differentiation and branding strategies that International may choose to pursue.

Risk Analysis

There are two different categories of risks that the rotating center console may encounter. First, there are risks associated with the use and safety of the design and the integrated mechanism within a truck interior. Second, there is a risk associated with the product failing to solve the current problems in the manner it envisions and thus, becomes a market failure. Both types of risks add costs associated with product development and their assessment is important.

To begin with, our design is contoured and shaped in a manner which is ergonomic for use inside a truck cabin and should be only used for its intended purpose of storage and trash disposal. However, there is a risk of misuse of our console as a desk space or a flat writing space which might cause the structure to bend or break depending on the applied load. We have considered a reasonable factor of safety for intended use but sudden applied dynamic loads can cause a build-up of huge stresses which might cause the overall structure to fail. On the other hand, the wear and tear of the rotating hinge mechanism will outlive the life of the truck and promises to be a sturdy design. The last system risk we consider is the locking mechanism and making sure that under no circumstances of the truck's 'normal' mode of operation does it come unhooked in either position (deployed/retracted). However, there is a risk that 'unnatural' forces encountered during a truck accident might accidentally unlock our rotating console making it a safety hazard despite accounting for it in our static analysis. Therefore, the design of a specialized fail-safe mechanism for locking in the event of an accident is an improvement we can make to our design

There is also a risk of our rotating center console failing to capture the intended market with the owner-operators and fleet owners. They would be unwilling to make an investment in a truck option that they feel is not important. This means that International could be in a position where a lot of time and money is wasted that went into the development and testing of the rotating console. Moreover, supply chain logistics and dedicated materials, processes and parts to the console will only add to costs and cause additional losses. Therefore, the risk of failure in the market can only be nullified by making a useful and desirable product (which we believe it already is) and conducting efficient market research to ensure that the target market is exposed to the utility of our product and are willing to pay for using it. If there is negative feedback, then we can make changes to our design accordingly and then re-design the product to be more marketable.

Having considered the risks above, our product is still a robust design that serves an actual market 'gap'. Advantages of our design is that the product can be manufactured cheap using standardized parts and established processes allowing International to bring the product to market at inexpensive rates. Furthermore, the center console from our research indicated it will really help organize truck drivers and allow them to have better hygienic conditions in their truck; both situations that truck drivers feel are necessary. Also, the mechanism of the console is easy to rotate and secure behind the passenger seat when not in use, giving free access to the back of the truck. Lastly, the console has the advantage of being in arms reach while driving, allowing truck drivers to access essential items without ever taking their eyes off the road.

Final Analysis:

In conclusion, the design works well and is extremely feasible. The group was able to identify a useful, usable and desirable opportunity to improve driving/lifestyle conditions for long-haul aging truck drivers. Designing a center console with mobility was a big hit with many drivers who were interviewed. It implemented numerous problems experienced by the drivers such as cluster, lack of storage for important documents, little room and order pertaining to medicine and immense build ups of garbage. The console would address and offer a suitable solution to of all these problems.

Two drawers would provide enough storage for medicine and smaller miscellaneous objects. A bin at the back of the console would house important documents for the road such as maps, directions and important forms to be filled out. A sliding garbage container would enable the cabin to be cleaner. The garbage dispenser could be removed and replaced when it becomes too dirty in order to keep everything very hygienic.

A sturdy locking mechanism was designed and re-designed to secure the console while the truck was moving. The console would be fastened to the back of the passenger seat when the truck is not moving and to the side of the passenger seat while it is moving.

Since this is only a prototype, improvements are necessary if the design is to go to production. A light, durable plastic would need to be used instead of wood. Stronger hinges and sturdier locks would have to be built for the console to be used perfectly.

To cut costs, the console should be integrated into each International truck. This would not only minimize the production and installation costs but would also simplify the time spent installing the console individually. If anything, the console would cost almost

nothing relative to the cost of producing a brand new truck. Installing the unit into already existing trucks may pose a problem but nothing that can be solved quickly.

The marketing aspect of this console would actually generate nearly a $10 000 profit for only ten installed units. Over a larger number of trucks, this extra income will become fairly large and extremely significant.

The risks are also minute as there are only two major concerns: safety of the design and failure to retain existing drivers. The former is not too big of a problem as modifications can be made to enhance the safety. The failure to retain drivers is also minute as many interviewees have openly stated that they would welcome the addition of the console. Thus, the failure to retain existing drivers with the addition of the console would be low.

Over the semester, many opportunities and solutions were developed to tackle the goal presented by International. Many problems would be solved with the addition of a center console and the group felt that the ability to solve many smaller problems as opposed to one giant one would not be beneficial.