iCart

A product of

World Innovative Technologies

WIT Inc.

Department of GPD: Team 8

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Executive Summary

After going through rigorous sessions of brainstorming to come up with the idea that addresses one of the most basic and prevalent need of people, a consensus was reached: to cater to the need of consumers to have a facility to carry merchandise from the store to the car and from the car to the house. This need creates an immense potential for a shopping cart that can fit in a car's trunk along with the groceries. To fill this need, WIT Inc.'s Department of GPD has developed the iCart. Not only does the iCart make business sense, it makes environmental sense as well by reducing the total number of carts needed in the market and hence helping save resources and energy. This is made possible with the help of the Internet which makes the whole system closed loop by enabling sharing of the iCarts between consumers living in close proximity housing.

By doing intense market studies and surveys, it is concluded that the limiting point during the entire shopping experience of a consumer is the shopping cart that must be left outside the store. This is the case firstly because carts belong to individual stores and secondly because current carts cannot fit in a car's trunk. Reversing both the current limitations, the iCart's unique selling point is that it can be used by the consumer anytime and at any store since now he owns the cart and can take it anywhere in his car trunk. Additionally, the consumer no longer needs to unload and reload merchandise from the shopping cart to the car trunk or carry heavy bags by hand.

The innovation in design of the iCart is evident in the fact that it can fit in 95% of the trunks of cars, trucks, SUVs, etc. without compromising on the amount of groceries. Also, the unique lifting mechanism of the basket is both easy to operate and control. Even with these remarkable capabilities, the iCart remains light enough to be operated by 95% of the population.

iCart will be a viable service in countries like the United States (primary market) and South Korea (secondary market) where the general trend is to shop in bulk and to drive a car to the store. The iCart will be shared by people living in close proximity housings in these countries, like apartment complexes. There will be docking stations provided for each iCart, which will be connected to the iCart's online site where the status and location of the iCart stations can be seen. This will also facilitate reservation and various store location information.

There is no current cart commercially available in the market that is owned by the consumer and can so easily fit in a car trunk with the groceries. This gives a tremendous competitive advantage to the iCart by being the first to tap a new market.

A thorough manufacturing and business plan keeps costs to a minimum and helps ensure substantial profit in the first year. Manufacturing will be outsourced to China where all part production and sub-assembly will occur. The location for final assembly will vary based on the market. Current demand, based on market research, is for 2.6 million iCarts in United States of America (US) alone. So that each cart may be shared among multiple households, the iCart system (iCart, docking station, and the service) is sold to landlords or owners of apartment complexes instead of directly to consumers. This gives the chance to make a better product whose cost will be spread out across many users. Initial product launch is planned for the US market only. When the goals in the primary market are met and success is registered, the iCart will be launched in South Korea at cheaper rates to get a stronghold in the market and to entice people to use the system.

1. Introduction

Our Company, World Innovative Technologies Inc., has a long tradition of finding engineering solutions for customers' problems all over the world. Due to the environmental and resource problems prevalent these days, sustainability has become a very big topic. We take it very seriously and try to work against this problem by developing and designing sustainable, global products. The next product with which we want to come out in the global market will be an Internet-ready, mechanical product which will enable closed-loop economy by its reuse, remanufacture, reduction of resources used, or ability to be recycled. The product must also address consumer needs of at least two markets in developed countries.

The product that we are designing is an innovative solution to the limitations of the current shopping cart. For developing such a product, WIT chose some of its engineers from all over the world to form an international team. There are two mechanical engineers from Seoul, Korea, an aerospace and an industrial engineer from Michigan, United States and also an industrial and an aeronautic engineer from Berlin, Germany. So the team is equipped with all the required competencies for developing a new and innovative product – creativity, CAD, economics, mechanical knowledge, and programming. This report details the product development done by the team over the past three months.

2. Needs Identification and Problem Statement

Our first task was to find a product that suits our company's new image and meets all project requirements like Internet readiness and closed-loop economy. The product also should provide a solution for a special customer need in different developed countries to make it a global product. Some of those needs were picked up by our team and several fitting product ideas were created. Following is a list of the five top ideas that our team considered:

1. *Collapsible Shopping Cart*: fit in car trunk, carry groceries from car to home, shared by users
2. *Multipurpose LCD Picture Frame*: features of planner, clock, audio/video player, weather etc.
3. *Smart Kitchen Scale*: display list of ingredients, weigh them while pouring, help in cooking
4. *Health Monitoring Device*: record blood pressure, heart rate, etc., send data to doctor, use as emotion detector for live online chat
5. *Pet Feeding machine*: remotely feed the pet every day, check pet's condition

To find the final product that our team wanted to develop we ranked those 5 ideas by using different ranking criteria. Each team member evaluated the product according to its feasibility and how well it meets the requirements. Every product got 1 (least) to 5 (best) points for each criterion. The following table shows the result of the ranking.

Table 1: Final Product Ranking

	Smart Kitchen Scale	LCD frame	Collapsible Shopping Cart	Health monitoring device	Feeding Machine
Internet ready	19	22	13	24	15
Closed loop	11	13	22	21	13
Global	21	19	20	20	12
Prototype ease	19	19	18	17	21
In budget	20	15	19	17	20
In time	20	22	17	13	20
Creative	21	13	22	18	23
Useful	11	17	23	17	12
Total	**142**	**140**	**154**	**147**	**136**

After considering all the final ideas closely, we came to a consensus to go ahead with developing a collapsible shopping cart for consumers that they can put into their car trunk, without removing the groceries, and take home. Through this project, we have the opportunity to use our abilities to directly address an unsatisfied need. By doing a small analysis of the current shopping cart situation in the U.S, it became clear that shopping can be made more enjoyable and more efficient. Developing a fit-in-trunk and take-home shopping cart requires mechanism designing, structural analysis, and extensive market studying for the target consumers and also for the cart specifications to accommodate the wide variety of trunk sizes currently on the market. In order to save resources and develop an efficient sustainability model, it is imperative to enable sharing of the carts. Here, internet-readiness plays a vital role. On the whole, this project enables us to use all the tools we have to deliver a product that innovatively solves a common problem.

Problem Statement: ***To provide the user with an easy and effective way to carry merchandise from the store to his car and from his car to his residence***

To solve this problem we don't want the supermarkets to buy the grocery carts but the owners/landlords of apartment houses. Then all people who are living in the same apartment complex can share some of these carts. The idea is that a person who wants to go shopping can look online if there is a cart available at the moment. The information comes from a docking station where all carts are stored and which would be on each floor of the apartment complex or in a common yard. The user can also make a reservation. So the internet-readiness of this product enables convenient sharing and supports the closed-loop aspect by reducing the number of carts required. Additionally, the fact that the people are made responsible for their own cart will reduce the high number of stolen or destroyed ones.

To make this way of using a grocery cart possible we are redesigning the cart to fit into the trunk of a car, truck or SUV by proposing a consumer-friendly mechanism. The advantage for the consumer is that he can take his own shopping cart to the supermarket which allows him to use the same device to carry items during shopping, from the store to the car, and from the car to his house. He is no longer forced to leave the cart in the store and carry the groceries in heavy plastic or paper bags from the car to the house.

3. Market Analysis

There are two major factors that determine the markets: the amount of shopping done in big stores in a country, and the number of households with cars living in close proximity housings. In US, the vast majority of shopping is done in big retail stores. In South Korea, around 48% of the total retail sales occur in big stores and this number is growing. According to the 2000 Census, there are 37.35 million households in close proximity to each other in US. Close proximity housing is broken down into three different types: single-family attached, apartment buildings with 2-4 units, and apartment buildings with 5 units or more. In total, this constitutes about 31% of total households in US. Also, there are 160 million vehicles among US households, averaging around 1.9 vehicles per household. This justifies the assumption to consider that each household has at least one car. And the design of our cart enables it to fit in 95% of all car trunks. Similarly in the 7 major cities of South Korea, according to the 2005 Korean Census, there are 5.75 million households[1] located in close proximity, which accounts for 85.19% of all households in those cities. Due to these reasons, the primary and secondary markets were chosen to be US and South Korea, respectively. Because our cart is designed to fit in 95% of vehicles, our target market consists of 95% of the 37.35 million households in U.S, and 95% of the 5.75 million households in South Korea.

Based on the survey conducted for consumers in Ann Arbor, US and in Seoul, S. Korea, we found in both markets that about 95% of people fill their grocery cart to the brim. It was also concluded that all the people carry the goods from their car to the house in plastic/paper bags and have to make more than one trip from the car to the house. Additionally, the survey showed that out of 60 people (having cars) surveyed, 44 (73.33%) people would prefer to have a cart that they could fit in their car trunk and take home. In Korea, similar data was obtained stating that out of 35 people, 25 (71.5%) would prefer a collapsible cart to fit in their car trunks. For the detailed Survey Questionnaire and Storyboard example, visit http://icart.docdis.de/appendix/.

Since this product's intent is to be shared by people living in an apartment complex or similar close-proximity housing, our direct customers would not be the actual user but the owners/landlords/property management companies of such housing complexes. The entire setup, which includes a certain number of iCarts based on the number of households in that building complex and accompanying docking station, would be purchased or leased by the owners/landlords. The motivation to do so could be a monetary incentive, such as a monthly service fee charged by the landlord to his tenants, along with environmental, social or competitive motivations. Since the stores would be saving their resources, and also based on the store surveys conducted, they can help promote this system to the apartment. The details are discussed in the Business Plan. Assuming that the survey sample size is sufficient to assume the values for the entire population, our total potential consumers would be:

- 73.33% of 95% of 37.35 million households in US = 26.02 million households
- 71.5% of 95% of 5.75 million households in S. Korea = 3.91 million households

In US, most of the grocery and other retail shopping is done in big stores like Wal-Mart, Meijer, Kroger, etc. There are 2,515 Kroger supermarket stores in the US, 3,808 Wal-Mart stores (supercenters, discount stores, Sam's Clubs), 433 Costco stores, and plenty more stores. The total number of stores[2] where shopping carts are used is in excess of 25,000. After talking to representatives of Kroger and Wal-Mart it was estimated that each store maintains around 500 carts on average, and around 5-7 percent of the carts are replaced each year due to cart loss or failure. Each cart costs around $150. Based on the data collected, it can be estimated that the total cost of cart losses per annum is around $93,750,000 (for 5% cart loss).This data was also collected for South Korea. There are 276 big stores in South Korea[4] with each store having around 1000 carts[5]. The carts are replaced at an annual rate of around 7 percent, with each cart costing around $130. This amounts to a total annual loss of $2,511,600.

Currently the total number of carts in US is around 12.5 million (number of stores multiplied by number of carts per store) and the total number of households in US is around 116.5 million. This means that there are 9.3 households per cart. The savings from closed loop is based on the fact that the iCart system is being shared by a greater number of households. By implementing the iCart system, the number of carts in the stores would significantly decrease. If, on average, 10 households share an iCart, the number of carts covering 26.02 million households (our potential consumers) would then be 2.6 million. The number of carts in stores currently required to support this same population is 2.8 million. Hence the net savings in carts would be 0.2 million in US alone. Then there would be savings due to less loss of carts per annum. Since the carts are owned/shared by consumers, this brings a sense of responsibility. This in conjunction with a sturdy, long-lasting design will ensure that the iCart replacement rate is significantly lower than that of current shopping carts. Even new stores would not need to buy as many carts, leading to further savings. As public awareness of the iCart grows, more iCarts can be installed in housing units to increase flexibility. See Appendix 1 for a table summarizing the resource savings made possible by sharing the iCart system.

Similarly for South Korea, there are in total 14 million households. But most of the big shopping centers and the population using them are concentrated in cities like Seoul, Bussan, and five other major cities which constitute around 48.2% of total population[3]. Therefore there are 6.75 million households sharing 276,000 carts. This means there are around 24.46 households per cart. This statistic shows that there are many more households depending on smaller number of stores and carts in S. Korea than in US. In order to break even, we will have to keep the ratio of households per cart at 24.46 in S. Korea. But as discussed above, the resulting savings from implementing the iCart system would enable more iCarts to be installed in the future, thus decreasing the burden on each iCart.

Another major saving from using the iCart system is a drastic decrease in shopping bags, both plastic and paper. There are currently 14 billion plastic bags[6] and 10 billion paper bags[6] used each year in U.S alone. By implementing the iCart system for our predicted consumers (approx. 22% of total households), there will be a savings of around 3 billion plastic bags and 2.2 billion paper bags per year. This would save the shopping stores around $880 million dollars each year (22% of annual cost to US retailers for giving away "free" bags[6]). Moreover, there are plenty of environmental benefits to that as well.

There are a lot of moving sidewalks leading between floors in many S. Korean superstores. This is unique to S. Korea and requires a platform structure for the iCart to function effectively. This special need can be met by utilizing a special kind of wheel that locks on inclined, moving sidewalks. Using this type of platform design where the frame is universal but the other components are customized to the market, makes this a more realizable global product.

Our team used the Internet to conduct an extensive search for existing patented and competitive designs[3]. Currently, there are a few collapsible carts of different shapes and sizes on the market meant for individual users. One design uses a complex system of gears and linkages to raise and lower the basket. Our design is distinctly different from the existing designs that we found. First, the basket of our design is not collapsing and secondly we will use a simple screw mechanism to raise and lower the basket. Furthermore, the ability to slide on forklift-like forks is distinctly unique to our product as well as is the ability to separate the basket from the frame. Also, using the Internet in conjunction with a docking station is unique to our product.

4. Product Engineering

The shopping carts in use today are antiquated and therefore need to be renovated to reflect the needs of modern shoppers. It is currently customary for shoppers to use a cart while at a particular store and leave the cart behind when returning home. When the shoppers return home, they must carry the bags from the car to the house, often making several trips and sometimes over long distances. To address this inconvenience, our team was tasked to innovatively redesign the modern shopping cart.

For our direct customer to have interest in providing the iCart as a service, it is necessary that the cart be versatile enough to appeal to a wide variety of users. Therefore the cart must be small enough to fit into any of the wide variety of car trunks that are currently on the market while still providing sufficient carrying capacity. To ensure that the cart meets these criteria, our team conducted extensive research into current shopping cart dimensions and the trunk dimensions of both US and S. Korean vehicles (see Appendix 2 for detailed dimensions). From this research we determined the size limitations imposed on our cart. In addition to size limitations, our cart must also meet many other requirements to ensure that it fulfills the needs and desires of every type of user. Some of these requirements are mandatory for the functionality of the cart while others are only desires that should be met as much as possible. Table 2 lists the detailed requirements expected of the iCart.

Table 2: Requirement List

	Requirement	Details and Constraints
Demand	Accommodate height of 95% of target vehicles	Height of bottom of basket can adjust between 76 – 119 cm
	Fit into trunk of 95% of common compact cars	Basket dimensions max: 74 cm x 26 cm x 76 cm
	Conform to standard aisle width limitations	Total width does not exceed 59 cm
	Frame can support any load that fits in basket	Frame can support weight of basket when filled with water
	95% of males and females can lift frame	Weight of frame less than 17.83 kg as prescribed by NIOSH
	Wheels accommodate moving sidewalks	Locking mechanism compatible with sidewalk grooves
Desire	No external power source needed for operation	Basket can be raised/lowered using only the human energy
	Cart disassembles/reassembles quickly	Cart consists of two pieces or less
	Users remotely view when carts are available	Cart must be connected to internet when in storage

After defining the requirements to which the cart must adhere, we developed a function structure (see Appendix 3). The function structure is a flowchart depicting the inputs and outputs for each step of the shopping experience. This is a useful tool for visualizing the method by which a user interacts with the iCart from start to end. Next we brainstormed a plethora of possible sub-functions and working principles for the cart. From this wide array of possibilities, we chose the most realistic and feasible sub-functions for accomplishing our design requirements. The sub-functions that we chose to focus on are the following:

- Raise/lower basket
- Collapse frame
- Move basket laterally
- Recognize when in storage
- Lock basket in place
- Carry items
- Move in U.S
- Move in S. Korea

These sub-functions were defined keeping in mind a general, preferred way of inserting the basket into the vehicle. Initially we considered a multitude of methods such as using stretcher-style legs or a lift-and-put mechanism. When designing our second, more refined set of working principles, we decided that only one general method provided enough safety for the vehicle. The general method can be seen in Figure 1. Note that the images in this figure represent only a general idea for the cart and do not reflect our final design.

Figure 1: Inserting the basket into the trunk

The process makes use of two components: a collapsible frame and a basket in which all shopping items are contained. To load the basket into the vehicle, the cart/basket assembly is brought next to the vehicle and the basket is raised so that the bottom of the basket is higher than the opening to the trunk. The basket is then slid forward on the supporting forks so that it is inside the trunk. The basket can then be lowered down into the trunk and then disconnected from the frame. The frame can now be collapsed and placed into the vehicle on top of the basket. To remove the basket from the vehicle, these steps are reversed.

To accomplish the sub-functions, keeping in mind the general method we wanted to use, we designed and sketched detailed working principles (Appendix 4). Before deciding on a final design, we created many design alternatives that we ranked according to their ability to satisfy the functions and requirements of the cart. Each team member created a design alternative by choosing a working principle for each sub-function and then combined them into a possible cart design (Appendix 5). To decide among the design alternatives, we created a ranking system where each design was judged based on a common set of criteria. The ranking process was performed through the following steps (see Appendix 5 for numeric results of ranking process):

1. Each team member subjectively ranks the criteria based on their importance to the final design and an average weight for each criterion is calculated
2. Each team member scores each design alternative based on the criteria
3. For each design, the scores for each criterion are added, then multiplied by the average weight for that criterion
4. For each design, the total weighted score for all the criteria are added to get a final score
5. The design with the highest final score wins

The design that received the highest ranking can be seen in Appendix 5. This design, like the others, makes use of two hydraulic cylinders to raise and lower the basket. This turns out to be problematic because after extensive research about hydraulic, pneumatic and other linear actuators, we found out that there was no commercial cylinder available which could provide the required actuation for the preferred weight and cost. Therefore, in our final design, we replaced the hydraulic cylinders with a mechanical screw and crank system that achieves the same purpose but without the cost and weight associated with using hydraulic cylinders.

Our final design, shown in figure 2, uses a forklift inspired approach to raise and lower the basket (A). See Appendix 6 for dimensioned drawings of all the cart elements. To adjust the height of the basket, the user rotates the long handle (B) on the top of the frame. This handle is attached to the vertical bars (C) by pins (D) (that have protrusions at the ends to keep the handle and bars in place) that come out of the ends of the handle and go into the tops of the vertical bars. The beveled gears (E) on the ends of the handle and at the tops of the vertical bars transfer this rotation to the vertical bars themselves. The top portion of the vertical bars has a male thread and the bottom portion has a female thread. As the male portion rotates, it threads into or out of the female portion, thus adjusting the height.

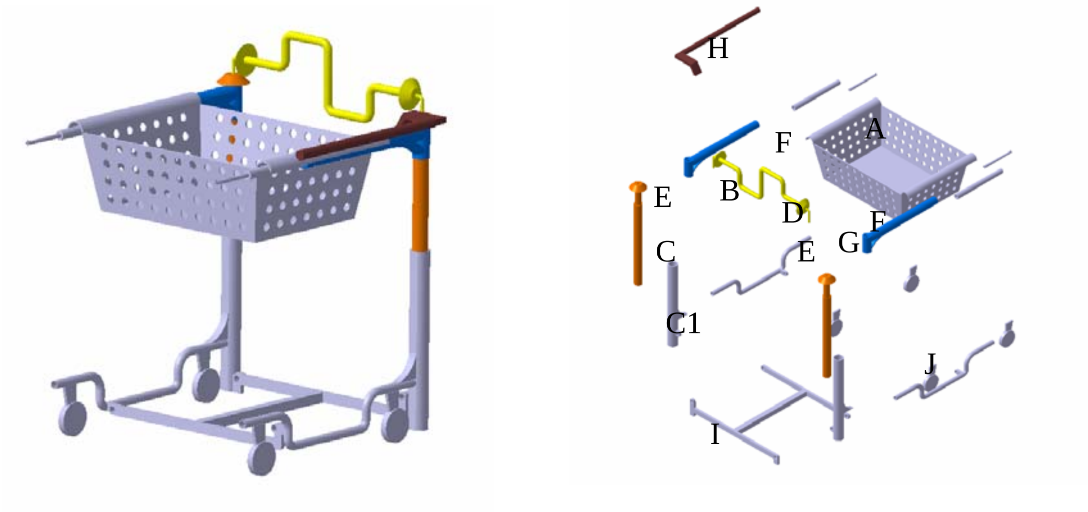


Figure 2: (a) Total cart design (b) Exploded view

The forks (F) are attached to the male portion of the vertical bars by lubricated bearing joints (G) that allow the male bars to rotate without disturbing the forks. The forks themselves are telescopic so that they can be extended during insertion/removal of the basket from the trunk.

The basket is made of injection molded plastic. Attached to the basket is a handle (H) by which the user can push the cart during shopping. On the underside of the hook-shaped handles by which the basket hangs from the forks are small bumps. The purpose of these is to decrease the surface area and therefore the friction so that the basket can easily slide on the forks without the need for complicated bearings or wheels. On the end of the forks are small, up-turned hooks that lock the basket in place when the forks are fully contracted.

The female portion of the vertical bars is attached to the crosspiece (H) by hinges (C1) located slightly above the bottom of the tube. These hinges allow the vertical bars to fold inwards to a collapsed position after the basket is removed. One hinge is higher than the other so that, when collapsed, the forks will lay one on top of the other. Also, each vertical bar and the crosspiece extend downward beyond the hinge so that, when in the upright position, the vertical bars are prevented from extending beyond 90 degrees.

The bars of the base (I) to which the wheels (J) are attached have indentions for the wheel mounting. The bars of the base are attached to the vertical bars so that when the frame is collapsed, the wheels rotate from a vertical position to a horizontal position. Having this indention reduces the amount by which the wheels stick out beyond the base of the frame. This is essential for keeping the collapsed frame to a length that can still fit inside the trunk.

To accommodate the different needs of the US and S. Korean markets, our cart makes use of a platform product structure. The frame and basket are the core elements and only the wheels need to change to accommodate the different markets. This is advantageous as this easily implemented modification allows the iCart to take advantage of a global marketplace.

The different wheels are needed so that, in S. Korea, the iCart will be compatible with the numerous moving sidewalks used in stores to transport shoppers from one level to the next. The moving sidewalks are inclined, requiring special wheels to prevent the cart from rolling away. The wheel shown in Figure 3(a) has a grooved surface that meshes with the surface of the moving sidewalk. The wheel is locked in place by the block attached to the sides of the wheel. When on a standard surface, this block is elevated above the ground by the wheels. However, when on a moving sidewalk, the wheels fall into with grooved surface, thus bringing the block into contact with the sidewalk and locking the cart in place. This wheel design makes the cart suitable to the S. Korean market. However, having this design in the US market would be an unnecessary complication and would seem unusual to most users. Therefore, a standard US shopping cart wheel can replace the S. Korean wheel so that the cart is marketable to both countries.

Figure 3: (a) Wheel for S. Korean market (b) Wheel for US market

By sharing one iCart among multiple households, we reduce the total amount of material resources used for the production of carts. This is possible because with shoppers switching to the iCart, stores can reduce their cart inventory by a quantity greater than the number of iCarts that will be produced. Therefore the net number of carts needed to service the population will decrease, thus saving material resources.

To achieve these savings in resources, the iCart must be able to be shared among multiple households living in close proximity to one another. To enable this sharing, the iCart couples with a communal docking station where carts are stored when they are not in use. When stored, the docking station detects the cart and sends a signal to a scheduling website (http://icart.docdis.de/). This website acts as a coordinating liaison between the carts and the users. From the website, users are able to see how many carts are available, reserve a cart for a particular time period, and see what time carts were checked out. Landlords can use the website to monitor cart usage, impose fees if desired, and keep in touch with WIT Inc. regarding any product support requirements. The Internet is imperative for the reduction in resources made possible with the iCart as it provides the reliability and convenience required to make sharing of the iCart realistic and enjoyable. The docking station is also a critical part of the overall system as it provides the necessary infrastructure for storing the cart and linking the cart to the Internet, thus enabling sharing of the cart among a community.

The docking station is made up of units, each capable of storing one cart. With each cart comes one docking station unit so that the total capacity of the docking station exactly matches the total number of carts. Figure 4 shows the design of a single docking station unit. The individual units can be arranged in whatever configuration fits in best with the facilities. The main features of an individual docking station unit are a rectangular bar and two small pegs that hold the folded cart similarly to how a dishwasher holds a plate. Connected over the horizontal bar is a strip with a long button. When the frame of the cart is slid into the docking station, it will lay against the horizontal bar which will depress this button and send a signal to the website indicating the cart is now available.

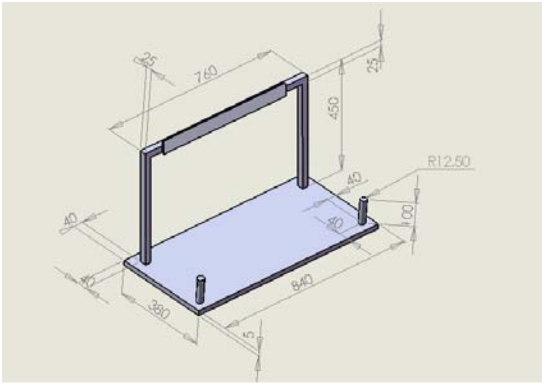


Figure 4: One unit of the Docking Station (millimeters)

When there are multiple docking station units placed one after the other, the pegs can be replaced by the bars of the next unit. This way only the unit in front will have the pegs. The docking station does not have any built in theft protection system at this point.

To prepare for manufacturing, it is beneficial to have a Bill of Materials (see Appendix 7). This is a list of each item required to construct one cart and one docking station. This list assists our effort to account for the required quantity of every item needed for manufacturing and to prepare for acquisition of those materials. The materials used for prototyping will vary in some ways, the details of which will be discussed in the Prototype section.

After settling on a final design, we performed a structural analysis of the critical pieces of the frame to ensure that that they are capable of supporting the maximum realistic load. For our purposes, this load is defined as the weight of a volume of water equal to the volume of the basket. The total volume of the basket is 0.0733 m^3. The mass of this volume of water, at 1 g/cm^3, is 73.3 kg. Therefore, the weight of the water-filled basket is 718 N. This results in a distributed load, f_o, on each fork of f_o=413 N/m.

Because the forks and the vertical bars bear the majority of the moment due to the load, they are the primary concern in this structural analysis (Appendix 8). The information desired from the analysis is the cross-sectional dimension required to provide adequate stability. We defined our tolerance by specifying 0.64 cm as the maximum acceptable deflection in either the forks or the vertical bars. This quantity was chosen subjectively as the maximum amount of deflection that will not result in loss of performance or irritation to the user. Figure 5 depicts the minimum cross-sectional dimensions that will provide the desired structural stability.

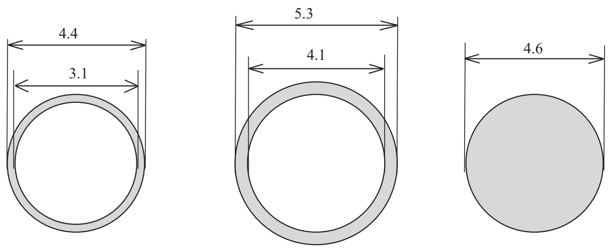


Figure 5: (a) Main fork (b) Female vertical (c) Male vertical

For a detailed structural and stress analysis performed using CATIA, please refer to http://icart.docdis.de/appendix/

All other pieces of the frame were designed using these dimensions as a benchmark. After the dimensions of every piece had been determined, we evaluated the total weight of the frame. Based on the National Institute for Occupational Safety and Health (NIOSH) 1991 Lifting Guidelines, the maximum Recommended Weight Limit (RWL) lift-able by 95% of men and women is 17.83 kg (Appendix 9). To insert the cart into the trunk, the user will lift the frame from the ground into the trunk. The current weight of the frame, excluding the wheels is 16.72 kg. This is more than a kilogram less that the RWL but still leaves some room for improvement (see Appendix 9 for detailed weight calculations). For detailed static state prediction of 5% percentile female done at maximum lowering down posture (limiting condition) for 40 lbs load acting downwards, please refer to Appendix 10. The current design employs Aluminum as the single building material of the frame. Future design work will include research into alternate materials that will continue to provide the structural support and permit a lower-weight frame.

There are three critical parts upon which the entire cart system depends. The raising/lowering mechanism makes the cart adjustable so that it can accommodate all brands of vehicles. This ability is critical for the success of the system as it maximizes the potential market. The ability for the basket to extend laterally on the forks allows the basket to be inserted into any car without causing damage to the vehicle. This is critical for ensuring that the user is happy with the cart. The docking station allows the cart to be shared among many users thus saving resources and making the system affordable. This is critical as affordability is a very important criterion to the user and by sharing the carts, the cost to each user will be minimized.

5. Product Manufacturing

Almost all of the iCart is made of aluminum except for the basket, bevel gears and wheels. The price of aluminum, based on current rates is around $2.30 per kilogram[7]. This aluminum has to be processed to from sheets or tubes or pipes, which add to the cost. Considering that the weight of the Aluminum on the iCart is 16 kg, but assuming 20% material waste due to machining, the cost of raw material is around $36.8. This makes the cost for the aluminum part of the frame around $44.16. From various sources, the cost of the remaining materials is estimated. The wheels used in both markets already exist and are in common usage. The bevel gears' cost is estimated from online sources like Mc-Master Carr and then approximated down for mass production. The basket is made of plastic and can be made by injection molding. The cost of the completed basket is estimated by using the current rates of plastic to be used, and the process cost based on quantity and complexity of the basket.

The docking station is made of a mild steel plate and a bar bent into an inverted 'U'. Based on the dimensions of the docking station, the weight of the station is around 23 kg (density of mild steel is 7700 kg/m^3). Table 3 shows the quantities and cost of each material required.

Table 3: Material cost

Material	Quantity required	Cost/unit	Total cost
Aluminum	19.2 kg	$2.30[7]	$44.16 (incl. 20% material waste)
Wheels	4	$7 for U.S[8] $10 for S. Korea	$28 for U.S $40 for S. Korea
Bevel Gears	2 pairs	$35[9]	$70
Basket	1	$14[10]	$14
Mild Steel	23 kg	$0.85[7]	$19.77
Internet kit (incl. other electronics)	1	$10	$10
Total cost of the raw material of the iCart			$185.93 for U.S $197.93 for S. Korea

This is an estimate of cost of raw material to be used to make the entire iCart system. In a production process, there are fixed costs and variable costs. The primary fixed cost is infrastructure, which includes real-estate, buildings, machines, etc. The variable costs are for raw material (as discussed in Table 3), labor, transportation, overhead expenditure, etc. To keep the total cost per iCart to a minimum, it is necessary to have a high volume of production. To accomplish this during the first fiscal year, 2008-2009, a small manufacturing/assembly unit will be set up to produce approximately 25,000 iCart systems (discussed in detail in the Business Plan). Further reduction in cost will be achieved by outsourcing the manufacturing processes. This will reduce the infrastructure cost, labor cost and initial capital. This has a few other advantages as well. The various parts of the iCart will be made at already well-established manufacturing units, hence ensuring quality and economy. It will be the responsibility of these manufacturing units to acquire raw material, manage waste, and manage overhead.

There were two major cheap manufacturing countries considered for making the parts before importing them for final assembly: Mexico and China. Finally, China is the country chosen to perform all manufacturing of parts for the iCart. This decision is based on the fact that China is an exceptionally cheap and dependable manufacturer and for its close proximity to our secondary market, which will reduce shipping costs. The costs incurred by WIT at this stage will be those charged by the manufacturer and those for shipping of parts before final assembly.

Assembly of the manufactured parts will occur in two locations. For the primary market, the proposed site for final assembly is Detroit, Michigan due to its proximity to manufacturing facilities and to the US branch office of WIT Inc. in Ann Arbor. In order to save on the assembly costs in Detroit, all sub-parts that can be assembled and still be easily shipped without occupying extra space will be done in China. This means that each side of the cart will be welded separately and shipped. Similarly, the side supports will be welded to the base plate of the docking station and shipped side by side. At the Detroit assembly plant, only a small number of machine tools will be needed to modify any parts with minor defects. Because the Detroit location will be responsible only for assembly, there will be low labor costs and high production rate. For the secondary market, assembly will occur in China through the same source which is used for the manufacturing of parts. Due to the propinquity of China and S. Korea, the extra cost of shipping a fully assembled cart system is small enough to be justified by the reduction of an additional assembly plant.

The detailed Bill of Material, presented in Table 4, discusses each part's production process, quantity, dimensions and the form in which it is received at the final assembly plant.

Table 4: Detailed Bill of Material for the Final Product

Item No.	Assembly	Intermediate	Purchase Items	Units	Material	Dim. of material (millimeters)	Prod. Process	Status after supplier
1	Foldable Frame [1]	Vertical Frame [1]	Male Vertical Bars	2	Al	D46, L620	Tu, Th	Sub-assembly 1
			Female Vertical Tubes	2	Al	OD58, ID46, L525	Bo, Th	
			Bevel Gears	2	Hdn St	PD 60	Pre-man	
			Hinges	2	Al	15 × 25 × 30	Mi, Dr	
		Base [1]	Wheels	4	P.uthane	N/A	Pre-man	
			Lateral Bars	2	Al	OD25, ID20, L750	Fo, Tu	
			Angle Plates	2	Al	S75 × S75 × W15	Mi, Dr	
			Hinges	2	Al	15 × 25 × 30	Mi, Dr	
		Forks [2]	Telescopic Tubes, Size A	2	Al	OD$_1$50, ID$_1$44,	Bo, Tu	
			Telescopic Tubes, Size B	2	Al	L$_1$533.5,	Bo, Tu	
			Telescopic Tubes, Size C	2	Al	L$_2$200,L$_3$200	Bo, Tu	
			Bearing Joints	2	Al	OD51, ID38, L100	Bo, Mi	
		Crosspiece [1]	Rectangular Bars	2	Al	660 × 30 × 15	Sa, Mi	
			Rectangular Bar	1	Al	520 × 30 × 15	Sa, Mi	
			Hinges	4	Al	15 × 25 × 30	Mi, Dr	
		Handle [1]	Handle Bar	1	Al	OD25, ID20, L900	Fo, Tu	
			Bevel Gears	2	Hdn St	PD60	Pre-man	
			Pins	2	Stls St	D10, L100	Fo	
2	Docking Station [1]		Base Plate	1	M St	840 × 380 × 5	Mi, Dr	Sub-assembly 2
			Side Support	1	M St	1660 × 25 × 25	Mi, Sa	
			Pegs	2	M St	D25, L100	Mi, Sa	
			Button Sensor + Internet Kit	1	--		Pre-man	
3			Basket	1	Plastic	1075 × 930 ×5	Inj Mo	
			Bolts	4	M St	PD10, L30	Pre-man	

Legend:
Materials: Al: Aluminum; Hdn St: Hardened Steel; P.uthane: Polyuthane; Stls St: Stainless Steel; M St: Mild Steel
Prod. Process: Tu: Turning; Th: Threading; Bo: Boring; Pre-man: Pre-manufactured; Mi: Milling; Dr: Drilling; Fo: Forging; Sa: Sawing; Inj Mo: Injection Molding

As only the manufactured parts are received by our unit, all the material is procured by the manufacturer, after being given the specifications and Bill of Material by WIT.

Except for the Internet kit and wheels, all the parts are made by machining processes in a machine shop by one manufacturer. The Internet kit will be procured by another manufacturer, and will be sent to the first manufacturer for assembly and shipping. The wheels will be purchased from standard suppliers and sent to the manufacturing center. All the welding attachments are made in China itself. Only the assembly is done at the final location for US market.

The inventory will be maintained at the Detroit assembly location for US market. In the beginning, it is understandable that the sales will be low and hence the inventory will be more. But this will be an added benefit once the sales pick up after the advertisements and word-of-mouth publicity. The inventory will help cover the burden on the manufacturer to speed up the process. The final cost of the system and the customer pricing is done in the Business Plan.

6. Prototype

To clearly show the critical aspects of our design, we constructed a working, half-scale prototype (Figure 6). The critical aspects we identified are the method for raising and lowering the basket, the method for extending the basket laterally, and the way in which the cart is connected to the Internet via the docking station. These aspects of the prototype are the same as the actual design, but other aspects of the prototype were modified due to limited facilities, materials, time, and money.

Figure 6: Working prototype a) the iCart in motion b) iCart collapsed on Docking Station

The primary material of the prototype is steel as opposed to aluminum which is used in the actual product. This switch is done for the better workability and greater availability of steel. However, some parts are still made of aluminum. This mixture of materials was chosen due to availability at the time of construction. A drawback of using steel is the increased weight of the cart. While total weight of the frame is important for the actual product, the weight is not one of the critical aspects of the design that we are showing with the prototype. Furthermore, because the prototype is built to half-scale, the extra weight of the steel will not cause the total weight to be an issue while lifting the frame during any demonstration.

The prototype is built to half-scale for the increased ease in construction and transportation. Smaller parts require less material and are therefore easier and cheaper to acquire. Additionally, using smaller parts provides substantial weight savings so that using steel as the primary material does not make the cart unreasonably heavy. Parts for the prototype needed to be transported from their location of construction to Berlin for integration. The smaller sized parts made this process substantially easier as well.

The prototype makes use of office chair wheels as opposed to those used by the actual product. These wheels were chosen for their price and availability, and they do perform the basic function of rolling in all directions. The wheels used on the actual product are more robust and customized to each market. However, the actual wheels are already produced and used on existing carts. Therefore, while the wheels are an important aspect of the cart, their cost is not justifiable for the prototype.

To show how the cart is stored and connected to the Internet, one docking station unit is made for the prototype. Because of its modularity, the functionality of the docking station can be shown with only one unit and additional units can be simulated by switches connected to the Internet kit. The docking station for the prototype differs from the actual design by using a wood as opposed to metal base due to the price and availability. The switch in the prototype is placed at the center of the horizontal bar of the docking station. This switch is then connected to a thin metallic plate, which is directly over the horizontal bar. This plate is connected to the bar with a spring that will ensure that whenever the plate is pressed by the weight of the cart, the button below it is also pressed. This configuration increases the effectiveness of the docking station by allowing for variability in the way the frame is placed. As long as it is lying inclined on the bars of the docking station, the signal will be transmitted. This design of the prototype docking station is consistent with the design of the actual docking station except for the fact that it is half the size of the actual.

The product website (http://icart.docdis.de) constitutes the non-physical portion of the prototype. The website demonstrates the process by which available carts can be viewed and reserved. It does not demonstrate other features that are not critical to the functionality of the cart system. Also the website's geographic options are limited to one location in Ann Arbor as this is sufficient for showing how the website would work for any other location as well.

To effectively utilize the budgets allotted to each university, we distributed the construction of prototype parts. The base frame of the cart, the base of the docking station, and the telescopic forks were constructed in Germany, the basket and docking station, excluding the base plate were made in S. Korea, and the vertical bars and crosspiece were made in US. All parts were then delivered to Berlin for integration. The team members of each university, in conjunction with their machine shop experts, constructed their respective prototype parts.

Every team was responsible for the organization of the local manufacturing. The sourcing strategies and possibilities were different. In Germany, materials were obtained from a locksmith's shop where machines were also available for construction. In S. Korea, materials were obtained from local stores. In US, materials were obtained from the machine shop, McMaster-Carr, and local stores, and then assembled in the machine shop.

To ensure that all pieces of the prototype were able to be integrated with limited frustration, we prepared a Bill of Materials (Table 5) to summarize the parts used by each location. By carefully planning the construction to be done at each location, we ensured that all the parts were accounted for and that all parts were made to correct dimensions.

Table 5: Bill of Material for the prototype

No.	Item	Intermediate	Purchase Item	Units	Material	Price of material
Berlin						
1	Telescopic Forks		Tube Ø 20mm	600mm	Steel	Free
2			Tube Ø 15mm	20mm	Steel	Free
3			Tube Ø 10mm	500mm	Steel	Free
4			Washer Ø 10mm	2pcs	Steel	Free
5	Base Frame	H-Frame	Rectangular Bars side length 10mm	1000mm	Steel	Free
6		Side Bars	Rectangular Bars side length 15mm	1300mm	Steel	Free
7			Hollow Tube Ø 15mm	150m	Steel	Free
8		Wheels	Office chair wheels	4pcs	Plastic	Free
Michigan						
9	Vertical bars	Male vertical bars	Tube with external thread Ø 15 mm	500mm	Aluminum	Free
10		Female vertical bars	Hollow Tube with internal thread Ø15mm	530mm	Aluminum	Free
11			Bevel Gears with 15 cogs	4	Steel	$32ea
12	Crank		Tube Ø 15 mm	450mm	Copper	Free
13			Corner Piece Ø	8pcs	Copper	$0.62ea
14			Metal sheet	2pcs	Aluminum	Free
Korea						
15	Basket			1	Steel	$13
Berlin (during Final Meeting)						
16	Docking Station	Side Support	Rectangular Bars side length 50 mm	1000mm	Wood	Free
17		Pegs	Tube Ø 10mm	2pcs	Steel	Free
18		Base Plate	Wood Plate	1piece	Wood	Free
19		Internet Kit		1piece		Free
20		Cables	--	--	--	8€
21		Box & Switches		17pcs		24€

Even though the prototype is a little different from the original product, the original CAD drawings provided sufficient detail for prototype construction. The original dimensions were simply divided by two for the prototype manufacturing and assembly plan. Team members at each location used one common set of drawings to ensure that the critical dimensions of all parts were correct. The units of dimensions used in the US machine shop were English, while they were S.I. at the other two locations. Due to this, there were some clearances kept to make up for any errors or mismatch.

7. Business Plan

Any business requires start-up capital and infrastructure. WIT Inc. has set aside $30,000 for sampling of a few carts, advertisement, and exhibition at Design Expos, as well as other services needed to reach the customers. Assuming that the product is well accepted in the market, WIT will go ahead and carry out the full scale plan. To make a plan for entering the US market, it is first necessary to consider production capacity. The total number of working days per year in US is approximately 247 (5 day week – 13 holidays) with an eight-hour workday[11]. The production volume is dependent upon this as well as the number of close-proximity housing units agreeing to use the iCart. Considering both these factors, a volume of approximately 100 iCarts and docking stations per day fits the bill. This means if there are 10 workers employed to assemble the carts in Detroit, each worker needs to produce only 10 iCarts and docking stations per day. This means the initial annual US production will be 24,700 iCart systems. And since the proposed number of households sharing an iCart is 10, the 24,700 iCarts will cater to 247,000 housing units in the first year.

The product will be initially launched only in the US market. This will provide an opportunity to ensure success and build confidence before extending into the S. Korean market. The feedback from the primary market's launch will be studied and the profit will be utilized to establish the iCart system in the secondary market. This process will delay the launch of iCart in S. Korea by one year. This time will also be used to collaborate with the large shopping centers in S. Korea to ensure successful propagation of the iCart system when it is time for launch.

Before calculating profits, it is necessary to calculate the cost to manufacture each iCart. From the Product Manufacturing, the cost of the raw material used for the entire iCart system is approximately $186 for U.S product and $198 for S. Korean product. This is the variable cost considering the total capital involved. The other costs are the commission and manufacturing charges charged by the China manufacturer, shipping costs from China to U.S, road transportation costs, infrastructure cost in Detroit, labor cost for final assembly, salaries and overhead expenditures. Based on the number of iCart systems produced, all these other costs can be approximated to be 20% of the initial material cost. The cost price of each iCart system should then be approximately $220 for both the markets. This is so because there is no final assembly and other costs involved for that in S. Korea. By leaving a margin of $30 per cart, the selling price will be $250. The total sales will then be $6.175 million, with a gross profit of $741,000 in the first year. The net profit during the first fiscal year would be $711,000 after removing the start-up cost from the gross profit.

The above figures are only for the primary market. As described in the market analysis, the initial number of households per cart in S. Korea needs to be kept at 24.46. This means that there will be 6.75 million households sharing 276,000 carts. By starting with an initial 10,000 iCart systems per annum, 244,600 households will be served in the first year. Due to this small number of iCart systems being supplied to South Korea, all the manufacturing and assembly will be done at the Chinese manufacturer. The completed iCart systems will be shipped to the home distribution location, Seoul, because Seoul has the most number of shopping centers in South Korea and most of the people are living in apartment complexes. From there, ground transportation will be the preferred means to install the systems in the apartment complexes.

To make the iCart suitable for the S. Korean market, it is necessary to install different wheels suited to the needs of the S. Korean shopper. As described in the Product Engineering section, the wheels of the iCart in South Korea need the ability to lock in place on inclined, moving sidewalks. This differs from the US where normal shopping-cart wheels will be used. Thus the manufacturer will assemble the South Korean wheels to the carts scheduled for shipment to that market. Since everything is made in China and the shipping costs are much less to ship the iCart systems to South Korea than to US, the higher price for the iCart material cost due to the unique wheels is compensated by these savings. The selling price can therefore be kept the same at $250.

The iCart system is for the benefit of not only the consumers but also for the shopping centers to reduce the cost of maintaining their shopping carts. The market analysis shows the interest of shopping centers to reduce/remove the carts maintained by the stores. The shopping centers can thus help in propagating the use of iCart systems by distributing flyers, encouraging people to use the iCart, and giving out discount coupons to people using the iCart. If a large shopping center chain like Wal-Mart or Kroger is further interested, the whole or part of the iCart system project can be sponsored by it. This will take care of some of the capital to be invested by WIT Inc. In return, the iCart website will have the store advertisements and their locations in each city on the map. The latest deals offered by the stores can also be listed. Since the iCart is an Internet-ready product, it can also be advertised on websites of shopping stores, bringing revenue for them.

This process of propagating the iCart system will be the same for both the primary and secondary markets, with the difference of website domains. The website for US will have US specific stores, deals, and other advertisements. The site for South Korea will be in Korean rather than English and will have store and product information specific to the local market. In both countries, print and multimedia will be utilized as well to make the consumers aware of the iCart's availability.

The main incentives for the consumers to use the iCart system are the ease of transferring the merchandise from the store to the house, the discount coupons from shopping stores and their contribution towards saving the environment.

As mentioned earlier, the customers of the iCart system are the landlords and owners of close proximity housing. In order for them to buy the system, their motivation will be monetary as well as social. Since more than 70% of the consumers prefer the iCart system in their apartment complex (based on the surveys), the apartment complex authorities will be motivated to make their occupants happy. After paying for the system initially to WIT, they may charge the residents a nominal monthly fee, as they do for other services they provide. Also, even without the monthly fees, this is an added facility offered by the apartment complex. This would help in improving the customer rating of the complex and hence improve their quality. The services provided by WIT for repair, updating, or addition of carts can be included in the first payment. There will also be an option to make the payment in installments.

8. Project Summary

The goal of our project is to design a product to address a need while satisfying basic requirements. To acknowledge the increasing effort to reduce environmental impact, our product is required to use the Internet to enable a closed-loop design. Furthermore, our product needs to take advantage of a global marketplace by using a platform design. Our team chose to satisfy these requirements by designing a shopping cart that can fit into the trunk of a user's car. The problem that this product solves is the difficulty of transporting many items from a user's car to his apartment.

We performed an extensive market analysis to determine where the ideal location to sell the iCart would be. We identified the United States as our primary market and South Korea as our secondary market. Both of these countries have plentiful, close-proximity housing and large stores to which the shoppers generally drive their vehicles for shopping. Because of these properties, these markets have the highest potential for sales and the infrastructure to allow cart sharing and thus resource savings.

The Internet enables closed-loop design by providing an efficient means for sharing the carts between many households. The efficiency of the Internet sharing system means that more households can share each iCart than currently share each cart at a store. Therefore the net number of carts needed for a population decreases as a result of introducing the iCart along with an Internet sharing system. The plastic and paper shopping bags are also reduced as a consequence.

In S. Korea, inclined moving sidewalks require a special wheel that prevents the cart from rolling backwards yet does not inhibit operation on other surfaces. However, in the US, a wheel with this design is unnecessary and would seem unusual. To accommodate these differences, we have made use of a platform design where the wheels are customized to each market and the rest of the cart and docking station compose the core.

The three critical components of the iCart are the ability to raise and lower the basket, extend the basket laterally and the internet connectivity provided through the docking station. To display these functions, we have built a working prototype. The prototype is half size and is modified from the original design to accommodate our limited resources, time, and money. What is not modified is the method by which the critical design components are accomplished.

Although actual manufacturing is beyond the scope of this project, we have created a plan by which full-scale manufacturing could occur. The total cost of materials to be used for each iCart system is calculated. China is chosen as the outsourced manufacturer to produce all the parts and some sub-assemblies for U.S market and the entire system for the S. Korean market. A new Bill of Material is prepared for each part, discussing its dimensions, production process and status after the manufacturer's shop.

We have devised a business plan to ensure that the sales of the iCart are successful and that our potential market is fully utilized. The product will be launched first in the US and then in S. Korea after the feedback from the US success. Launch in the secondary market will begin one year after the primary market. Around 24,700 iCart systems will be produced in the first fiscal year 2008-2009, which are entirely for the U.S market. The cost of each iCart system to WIT is calculated and is the same for both markets. The selling price and the margin are kept at a nominal value of $250 and $30, respectively. The shopping stores will be involved in advertising through web and print medium. There will be incentives for the housing complex owners to try this new system.

Through the combination of all aspects of the project, the iCart has the potential to revolutionize the shopping experience. This can happen by turning the time, frustration and drudgery of multiple trips between the car and apartment into a quick, easy, and efficient process, enjoyed by users around the world.

9. Lessons Learned

Performing product development in coordination with an international team of engineers has been a remarkable learning opportunity. At the top of the list of lessons learned is clearly the need for effective communication. This is an important aspect of any team effort but its importance is greatly amplified when working with team members of different countries across the globe. In any language, there are subtleties that are only learned from years of everyday usage. However, when working with people of different lingual backgrounds, these subtleties can become the source of confusion and mistakes. It is therefore important to deliberate carefully over how and what is said to ensure that all information is conveyed clearly and correctly.

Methods for achieving effective communication were discovered as the need for them developed. We used Ctools as a means for sharing files related to the project. We used Skype in conjunction with Mebeam (www.mebeam.com) for videoconferences between team members. We used email extensively for keeping the whole team up-to-date with work being done at each location. A method we did not find effective was team meetings using a common chat room without voice support. This proved to be too slow to effectively discuss a meaningful volume of information.

The need for a systematic approach to problem solving also became apparent during the course of the project. Common agreement on important issues amongst a group can be rare. With a systematic approach to debating and determining a solution, time and effort are conserved for additional tasks, allowing for a superior overall product.

Collective hard work throughout the course of the project ensured that all goals were completed. The long-term goal was to design a means of carrying groceries from the car to the apartment while satisfying the top-level requirements of having an Internet-enabled, closed-loop design and global marketability. The work presented in this report represents the effective attainment of this goal.

Appendix 1: Summary of Market Research

	U.S.A.	S. Korea
Total households (million)	116.50	14.00
Total households considered (million)	116.50	6.75
Total households in close proximity (million)	37.35	5.75
Percentage of car trunk sizes considered (%)	95.00	95.00
Percentage of people wanting iCart (%)	73.33	71.50
Our target Consumers (million)	**26.02**	**3.91**
Number of big stores	25,000	276
Average number of carts per store	500	1,000
Average cost of each cart (US dollars)	150	130
Percentage of carts replaced each yr (%)	5	7
Total cost of cart loss/repair each yr (US dollars)	**93,750,000**	**2,511,600**
Number of households per cart	9.32	24.46
Proposed number of households per iCart for target	10.00	24.46
Net savings in carts	**189,841**	**At par; savings in future**

Appendix 2: Detailed Dimensions

Table A2.1 has dimensions, in centimeters, of a wide variety of vehicles in both the US and S. Korean market. The legend explains what each measurement represents.

Table A2.1: Vehicle dimensions

	Type	**Height**					**Depth**				**Width**
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
U.S	car	33	66	15	51	36	20	23	43	99	86
	car	33	71	18	51	33	23	30	53	107	91
	car	30	74	13	34	22	23	N/A	N/A	84	76
	car	36	71	15	53	38	20	25	46	102	86
	car	41	84	28	53	25	28	25	53	99	84
	car	38	84	25	53	28	18	30	48	97	84
	car	28	81	18	43	25	23	28	51	107	74
	car	33	69	10	48	38	23	13	36	99	76
	car	38	79	24	53	29	18	25	43	104	94
	car	33	66	13	51	38	23	25	48	99	76
	car	33	72	15	48	33	18	20	38	91	76
	SUV	36	74	0	91	91	32	8	39	102	122
	SUV	41	84	0	84	84	36	25	61	89	119
	SUV	52	91	0	88	88	36	0	36	76	107
	SUV	41	79	0	71	71	28	0	28	81	99
	SUV	52	89	0	74	74	33	0	33	77	104
	SUV	41	79	0	83	83	25	10	36	97	99
	SUV	38	76	0	86	86	30	N/A	N/A	91	117
	SUV	38	71	0	76	76	25	13	38	91	94
	van	37	69	0	99	99	32	20	52	130	119
	truck	41	89	0	N/A	N/A	66	N/A	N/A	168	140
	truck	37	88	0	N/A	N/A	56	N/A	N/A	150	124
	truck	51	94	0	N/A	N/A	69	N/A	N/A	196	145
S. Korea	Car	30	69	17	48	33	22	32	55	89	93
	Car	N/A	70	21	55	33	22	30	52	83	80
	Car	N/A	62	15	45	30	21	N/A	N/A	105	80
	Car	N/A	63	18	45	27	21	N/A	N/A	89	92

Legend

A: Ground to bottom of bumper

B: Ground to lip

C: Bottom of trunk to lip

D: Bottom to top of trunk

E: Lip to top of trunk

F: Outside of bumper to lip

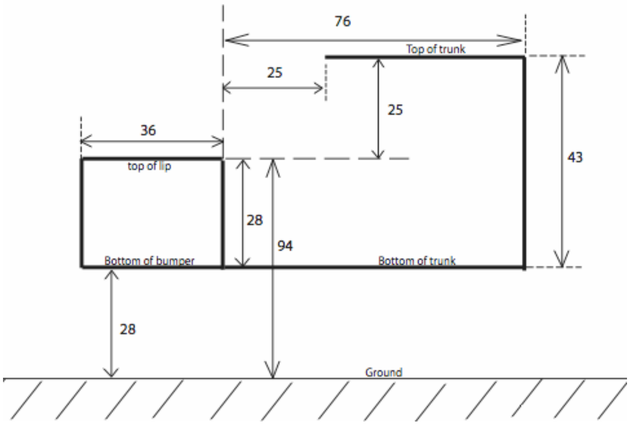
G: Lip to overhang

H: Lip to back of trunk

I: Narrowest width of opening

	Car	N/A	63	17	45	28	21	N/A	N/A	89	92
	Car	N/A	63	19	45	26	22	N/A	N/A	92	92
	Car	N/A	66	18	47	29	21	N/A	N/A	100	85
	SUV	42	68	N/A	94	N/A	20	N/A	N/A	115	95
	SUV	N/A	76	0	80	80	0	86	86	86	114

From the dimensions, we established a "worst-case" scenario. This is represented in Figure A2.1a as a trunk with all the dimensions that are most difficult for our cart to comply with. In addition to various trunk-size limitations, we also had to consider aisle-width limitations. We took dimensions of a standard shopping cart and used this as a benchmark while designing the iCart. Figure A2.1b shows the dimensions of a standard, American shopping cart.



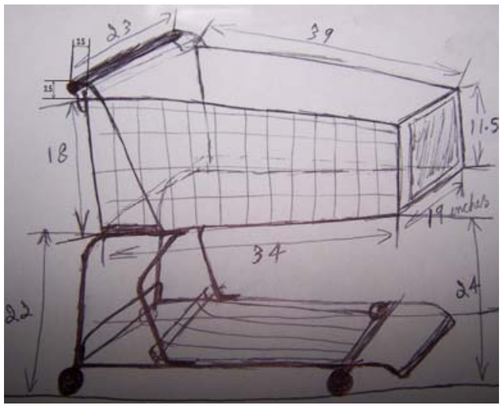


Figure A2.1 (a) "Worst-case" scenario (centimeters) (b) Standard shopping cart dimensions (inches)

Appendix 3: Function Flowchart

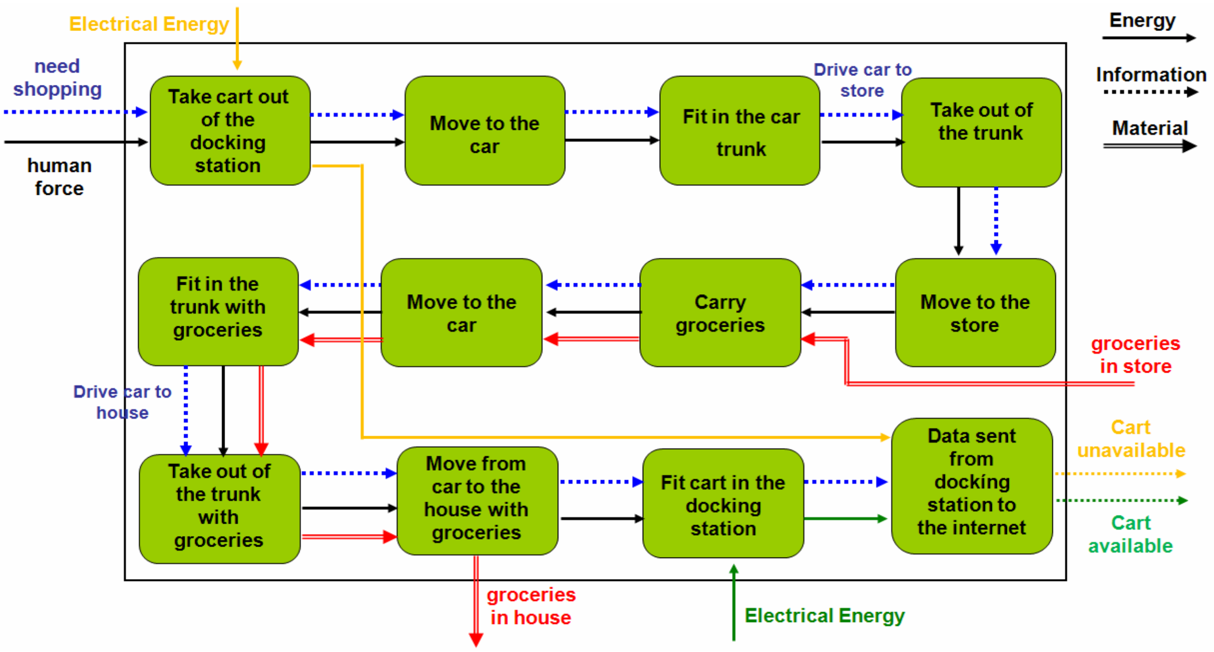
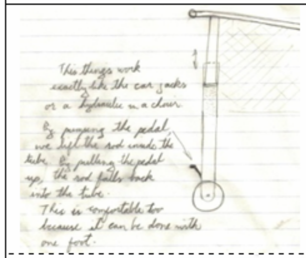
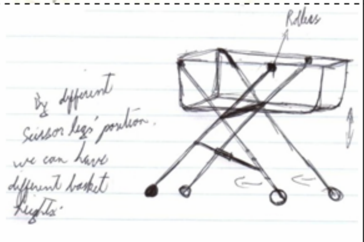


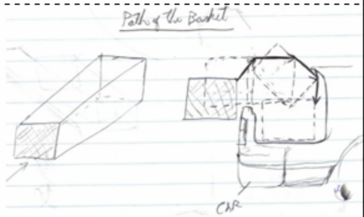
Figure A3.1: Functional Flowchart

Appendix 4: Functional Sketches

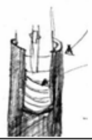
Raise/lower basket



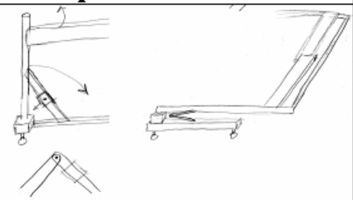


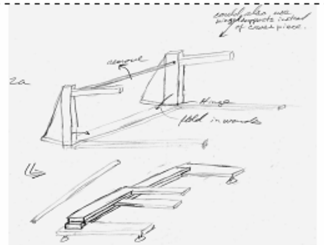


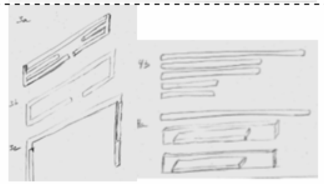
Lift and put mechanism

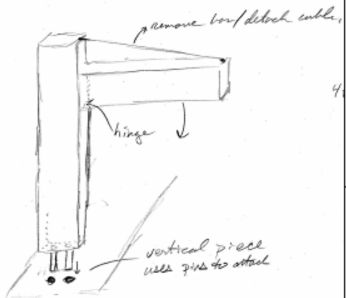


Collapse the frame

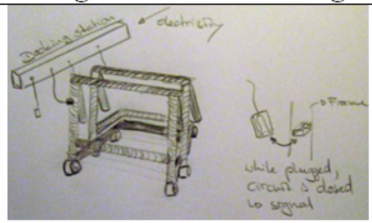


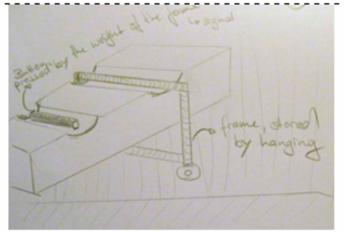


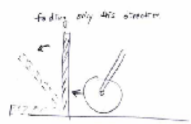


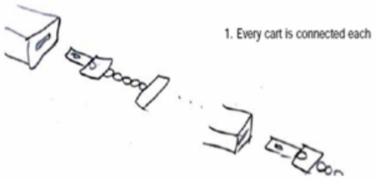


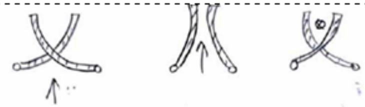
Recognize when in storage



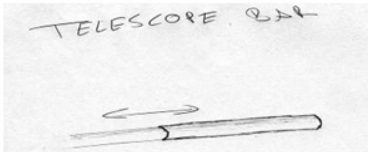


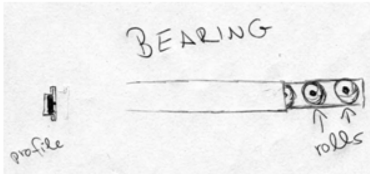




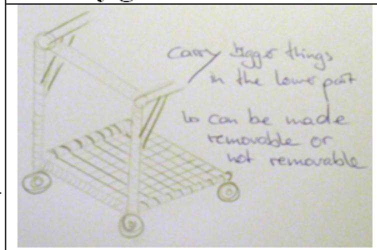


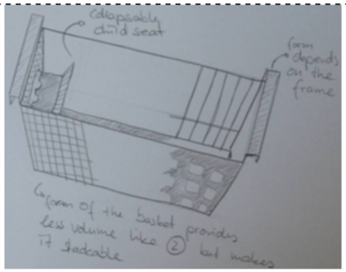
Move the basket laterally



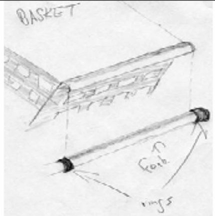


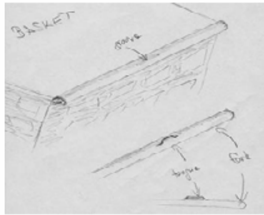
Carry groceries

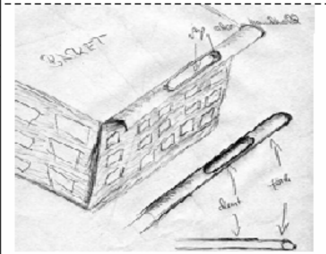




Lock the basket in place







Moving


Moving in the USA


Moving in Korea

Appendix 5: Design Alternatives and Ranking

After designing working principles for each sub-function, each team member combined the working principles into different design alternative. Figure A5.1 shows three of the proposed final designs.

Figure A5.1: (Clockwise starting from top) Design 3, Design 4, and Design 5

After creating design alternatives, we ranked the designs by a set of common, weighted criteria (Table A5.1). Then, the design that received the highest total number of points won the ranking (Table A5.2).

Table A5.1: Weight assigned to criteria

	Weight assigned by each team member (A-F) (1 for least important)						
Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**Average**
least force to adjust height	15	13	15	14	13	10	80
fits easily in the car trunk	11	14	12	10	14	13	74
easy to take out from trunk	12	15	9	15	9	12	72
easy to lock basket to frame	13	10	10	13	10	11	67
light weight	14	9	14	4	11	8	60
frame collapses quickly	9	12	11	9	12	5	58
durable	4	5	3	5	15	15	47
easy to move	1	8	8	8	8	14	47
least number for parts after collapsing	10	11	5	7	7	3	43
maximum height adjustment	7	2	7	12	3	6	37
easy to store	5	7	2	11	5	7	37
approximate price	6	6	13	3	4	2	34
fits different sized baskets	8	1	6	6	1	4	26
feels strong	2	4	1	2	2	9	20
theft protection	3	3	4	1	6	1	18

Table A5.2: Rankings of each design alternative

Criteria	Total of rankings given by each team member				
	Design 1	**Design 2**	**Design 3**	**Design 4**	**Design 5**
least force to adjust height	16	10	17	16	12
fits easily in the car trunk	11	9	12	10	9
easy to take out from trunk	12	12	16	14	11
easy to lock basket to frame	14	15	16	17	13
light weight	15	11	17	15	20
frame collapses quickly	18	12	17	16	20
durable	13	18	14	15	13
easy to move	16	16	19	18	13
least number for parts after collapsing	17	12	14	15	22
maximum height adjustment	13	14	17	16	14
easy to store	11	11	16	16	13
approximate price	16	8	17	16	16
fits different sized baskets	6	16	7	7	4
feels strong	15	18	11	15	8
theft protection	1	2	1	1	1
Weighted Total	9840	8814	10850	10419	9642

Appendix 6: Dimensioned Drawings of Cart Elements

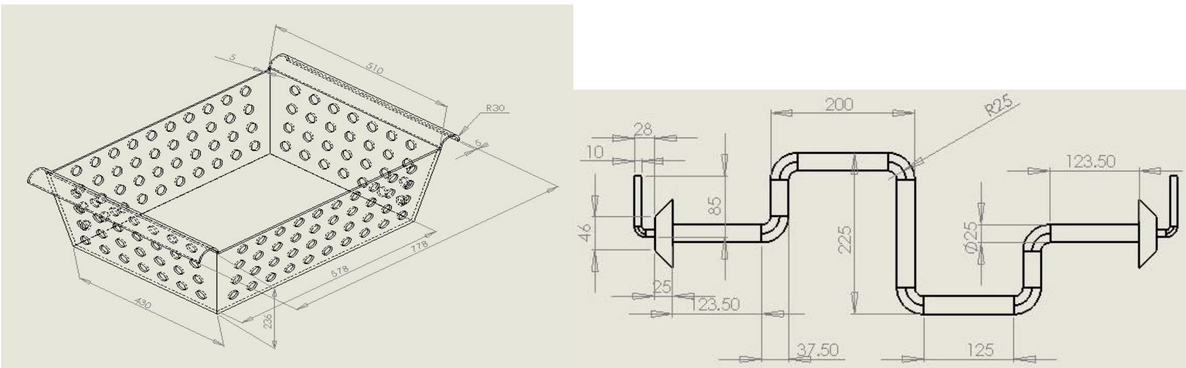


Figure A6.1: (a) Basket (b) Crank handle

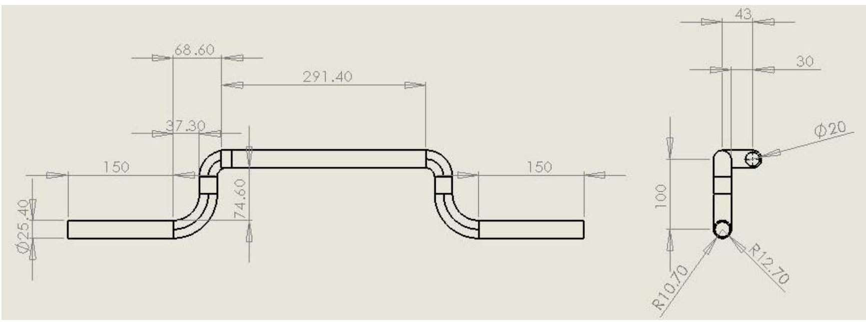


Figure A6.5: Wheel support

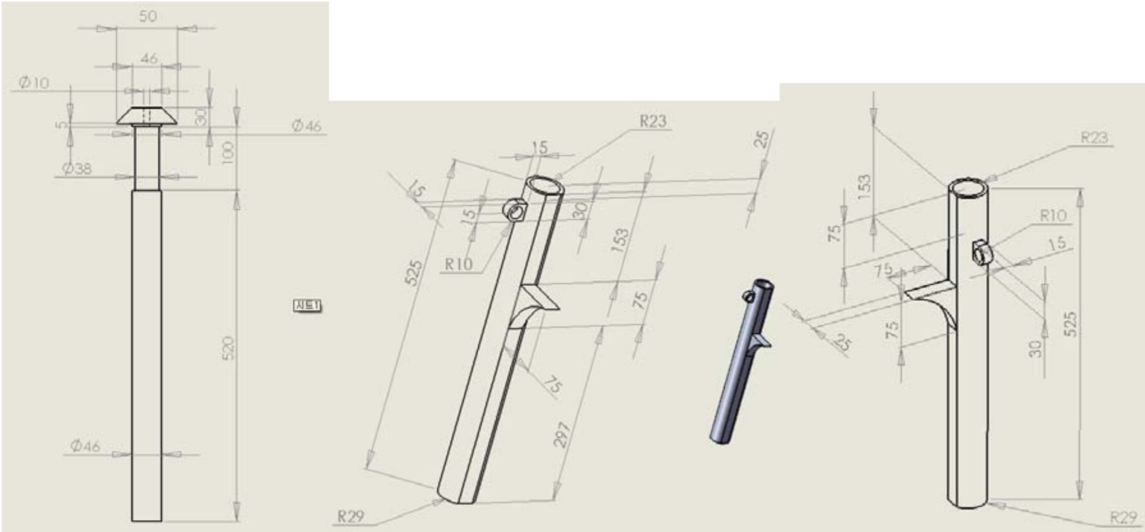


Figure A6.2: (a) Male vertical bar (b) Left female vertical (c) Right female vertical

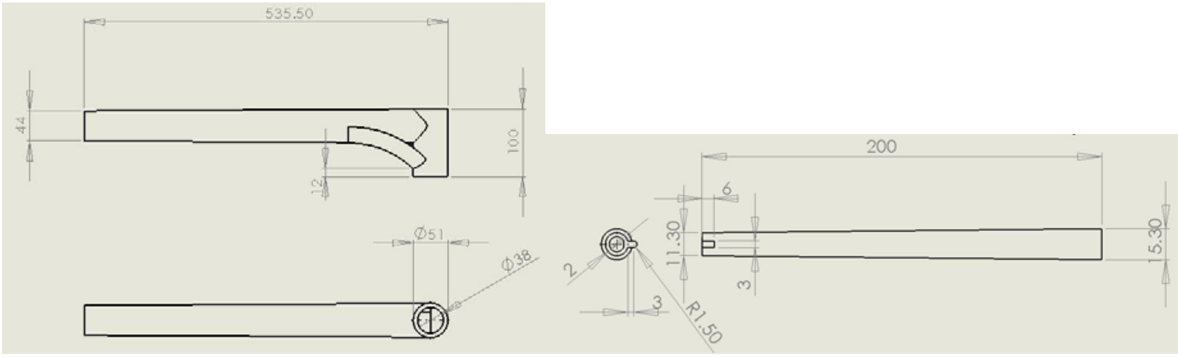


Figure A6.3: (a) Main fork and bearing (b) Fork extension

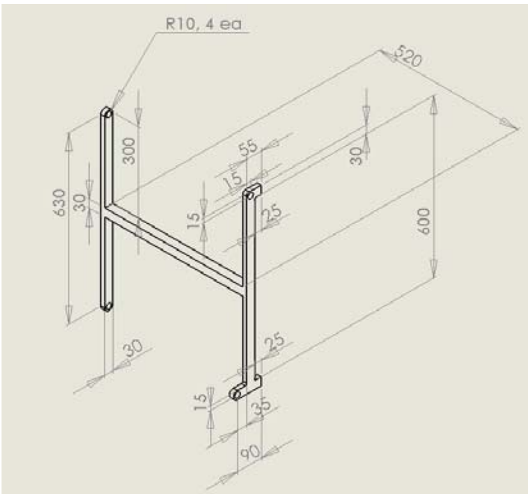


Figure A6.4: H-frame Crosspiece

Appendix 7: Design Hierarchy and Detailed Bill of Materials

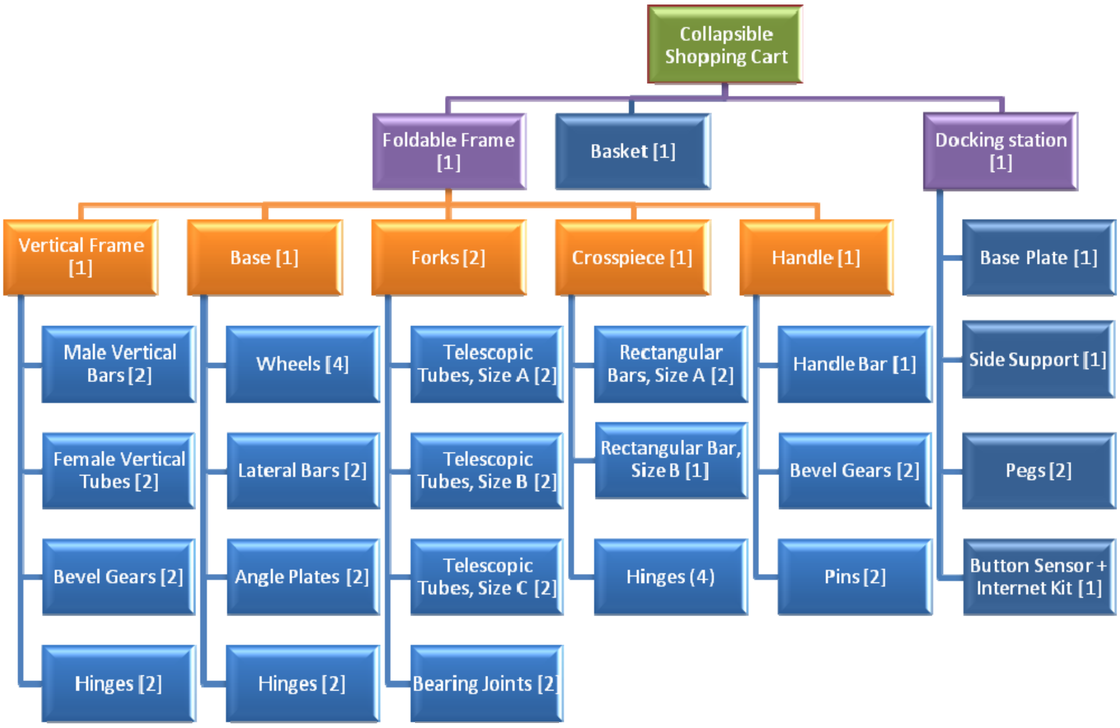


Figure A7.1: Design Hierarchy

Appendix 8: Detailed Structural Analysis

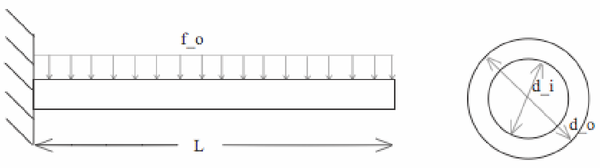


Figure A8.1: Loading on main fork

In our structural analysis, we use slender beam theory. Also, we simplified both the forks and the vertical bars to cantilevered beams. Start with the governing fourth order differential equation:

$$EI\frac{d^4v}{dx^4} = f_o \qquad (1)$$

The coordinate system is such that y is down, x is to the right, and z is into the page. E is the modulus of elasticity, I is the bending moment of inertia about the z-axis, v is the deflection in the y-direction, f_o is the distributed loading in the y-direction.

Integrate three times to get an equation for

$$v(x) = \frac{f_o x^4}{24EI} + \frac{c_1 x^3}{6} + \frac{c_2 x^2}{2} + c_3 x + c_4 \qquad (2)$$

where c_1, c_2, c_3, and c_4 are constants of integration. Now assign boundary conditions:

$$v(0)=0$$
$$\frac{dv(0)}{dx}=0$$
$$M(L)=EI\frac{d^2v(L)}{dx^2}=0 \qquad (3)$$
$$V(L)=-EI\frac{d^3v(L)}{dx^3}=0$$

where V is the internal shear force and M is the internal moment. Apply the boundary conditions and solve for the constants gives:

$$c_1=\frac{f_oL^2}{EI}$$
$$c_2=\frac{f_oL^2}{EI} \qquad (4)$$
$$c_3=c_4=0$$

This gives an equation for the deflection of the beam as a function of x:

$$v(x)=\frac{f_ox^4}{24EI}-\frac{f_oLx^3}{6EI}+\frac{f_oL^2x^2}{4EI} \qquad (5)$$

The maximum deflection occurs at the tip so plug in x=L to get:

$$v(L)=\frac{f_oL^4}{24EI}-\frac{f_oL^4}{6EI}+\frac{f_oL^4}{4EI} \qquad (6)$$

Now perform a similar procedure to get the deflection equation for the vertical bars:

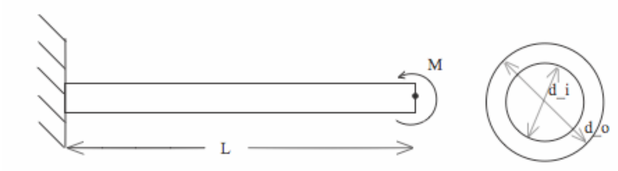


Figure A8.2: Loading on vertical bars

Now the governing fourth-order differential equation becomes: $EI\frac{d^4v}{dx^4}=0$ (7)

Integrate three times to get an equation for v(x): $v(x)=\frac{c_1x^3}{6}+\frac{c_2x^2}{2}+c_3x+c_4$ (8)

The moment applied to the vertical bars is due to the forks. Therefore, M can be calculated by looking at the internal moment of the fork at x=0. This allows us to define all the necessary boundary conditions:

$$v(0)=0$$
$$\frac{dv(0)}{dx}=0$$
$$M(L)=EI\left(\frac{d^2v(L)}{dx^2}\right)=\frac{f_oL_{forks}^2}{2(EI)_{bars}} \qquad (9)$$
$$V(L)=-EI\frac{d^3v(L)}{dx^3}=0$$

Apply the boundary conditions and solve for the constants gives:

$$c_1=c_3=c_4=0$$
$$c_2=\frac{f_oL_{forks}^2}{2(EI)_{bars}} \qquad (10)$$

This gives an equation for the deflection of the beam as a function of x:

$$v(x)=\frac{f_oL_{forks}^2x^2}{4(EI)_{bars}} \qquad (11)$$

The maximum deflection occurs at the tip so plug in x=L to get:

$$v(L)=\frac{f_oL_{forks}^2L_{bars}^2}{4(EI)_{bars}} \qquad (12)$$

In equations 5 and 11, f_o, L_{forks}, and L_{bars} are all set by the dimensions of the cart, and v(L) is set to be the maximum allowed tip deflection. E is determined by the material, Aluminum, and is a constant. The only variable left to determine is I which can be found by plugging in the values for all other known variables.

The resulting moments of inertia are I_{forks}=6.8e-8 m^4 and I_{bars}=1.8e-7 m^4. Now it is possible to calculate the cross-sectional dimensions for the forks and for the vertical bars that will produce these moments of inertia. The equation for the moment of inertia of a tube is as follows:

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) \quad (13)$$

For the elements of the frame to be of adequate stiffness, the bending moments of inertia must be greater than or equal to the values specified above. Plugging in the dimensions of the forks and of the male and female vertical bars gives the following moments of inertia:

$$\begin{aligned} I_{forks} &= 1.4x10^{-7}m^4 \\ I_{male} &= 2.2x10^{-7}m^4 \\ I_{female} &= 2.5x10^{-7}m^4 \end{aligned} \quad (14)$$

These are all above the required values and therefore verify that the forks and vertical bars of the frame will have the necessary structural rigidity to keep the frame from deflecting beyond the acceptable amount at the tips of the forks or at the tips of the vertical bars.

To verify our structural analysis, we used CATIA to calculate the deflections of our actual design. This and further structural stress analysis can be found at http://icart.docdis.de/appendix/

Appendix 9: Weight Calculations

Based on the National Institute for Occupational Safety and Health (NIOSH) 1991 Lifting Guidelines, in order to calculate the Recommended Weight Limit (RWL), there are 6 different limiting criteria.

	In our case	Multiplying factors
Initial Horizontal Location of Load	Less than 10 in. from body	HM = 1.00
Initial Vertical Location of Load	Less than 5 in. from ground	VM = 0.82
Vertical Lifting Distance	Around 20 in.	DM = 0.94
Frequency	Less than 1 per hour	FM = 1.00
Asymmetry	No asymmetry	AM = 1.00
Coupling of Hands	Good coupling	CM = 1.00

According to the equation:

RWL = 51 × (HM) × (VM) × (DM) × (FM) × (AM) × (CM) lbs

Therefore, RWL = 38.922 lbs = 17.83 kg

For the cart system to be successful, it must be possible for users to lift the collapsed frame into the trunk. To ensure that this is possible, we performed a weight analysis. We did this by calculating the volume of each piece of the frame, multiplying by the density of Aluminum (2.7 g/cm^3), then summing the resulting masses to get the total mass of the frame. Figure A9.1 shows the calculations for each piece of the frame.

Table A9.1: Detailed weight calculations

Piece	**length (cm)**	**inner diameter (cm)**	**outer diameter (cm)**	**volume (cm^3)**	**mass (kg)**
female vertical	52.5	4.6	5.3	285.7	0.772
female vertical	52.5	4.6	5.3	285.7	0.772
male vertical	65.0	0.0	4.6	1080.2	2.917
male vertical	65.0	0.0	4.6	1080.2	2.917
fork 1	51.0	3.4	4.7	421.8	1.139
fork 2	34.0	1.7	3.0	163.2	0.441
fork 3	20.0	1.5	2.8	87.8	0.237
fork 1	51.0	3.4	4.7	421.8	1.139
fork 2	34.0	1.7	3.0	163.2	0.441
fork 3	20.0	1.5	2.8	87.8	0.237
handle	109.7	0.0	2.5	538.5	1.454
wheel support	91.0	4.0	5.0	643.2	1.737
wheel support	91.0	4.0	5.0	643.2	1.737
H-frame base long	66	1.5	3	297	0.8019
base long	66	1.5	3	297	0.8019
base short	52	1.5	3	234	0.6318
Total mass					**18.17**

But the weight of the handle need not be included in the weight to be lifted by the user because according to the current design, the handle can be separated from the rest of the frame before it's collapsed and put in the car trunk. Therefore, the actual weight to be lifted by the user at a time is **16.72 kg**.

Appendix 10: Body Strength Capability and Motion Analysis

Since the task of lifting the iCart is to be carried out each time during the shopping, it was extremely necessary to constrain the weight of the iCart to permissible values. In the Figure A10.1 the static state prediction of 5% percentile female is done at maximum lowering down posture (limiting condition) for 40 lbs load acting downwards. All the strength percent capabilities are in safe regions.

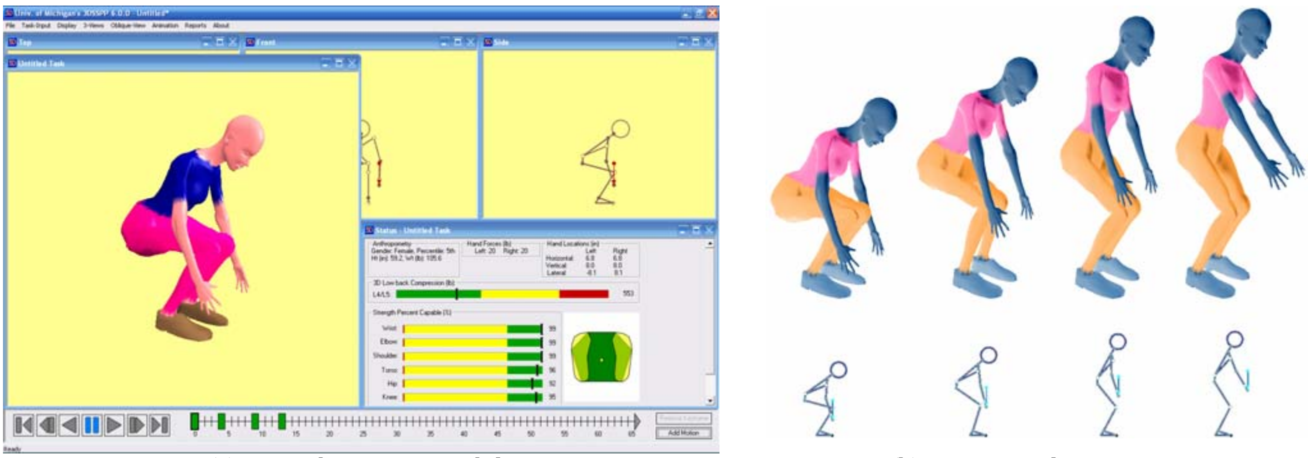


Figure A10.1: (a) Strength Percent Capability (b) Motion Prediction

References

[1]http://www.korea.net/korea/kor_loca.asp?code=F0103
[2] http://supermarketnews.com/retail_financial/2006_top_75_north_american_food_retailers_429/index.html
[3] http://www.pat2pdf.org/patents/pat6328329.pdf, http://www.pat2pdf.org/patents/pat5028060.pdf, http://www.pat2pdf.org/patents/pat4055357.pdf, http://www.pat2pdf.org/patents/pat6024527.pdf, http://www.pat2pdf.org/patents/pat6042128.pdf, http://www.pat2pdf.org/patents/pat4765646.pdf, http://www.pat2pdf.org/patents/pat4492388.pdf, http://www.stacksandstacks.com/kitchen/shopping-carts/

[4] http://www.gnnews.co.kr/view.php?section=SEFG&no=157641

[5] http://www.kukinews.com/news/article/view.asp?page=1&gCode=soc&arcid=0920647400&cp=nv

http://news.naver.com/main/read.nhn?mid=etc&sid1=102&mode=LPOD&oid=015&aid=0000169606

[6] http://www.myownbag.com/activism.html

[7] http://www.metalprices.com/#

[8] http://premiercarts.com/wheels_and_casters.htm

[9] www.mcmaster.com

[10] http://kazmer.uml.edu/Software/JavaCost/index.htm

[11] http://www.infoplease.com/ipa/A0922052.html