DOGGO

Final Technical Report

Analytical Product Design - Team 9
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I. Introduction

Design Problem Definition

Following much research, reflection on the issues we encounter in our lives, and survey responses, we decided to define our analytical design project by the following problem definition statement:

"An unrestrained dog in a vehicle may divert the driver's attention away from the road and would be in danger of experiencing severe injury in the event of an accident, potentially causing injury to the human occupants as well."

This problem definition has been refined since our Problem Definition Report to better describe our desired design purpose, inform us about our target customers, and define the scope of our physical design effort. It also pushes us away from the norms of human-centric design, opening up our creativity to consider the dog's perspective in finding a solution to this problem.

Target User

In the literature review, we get the demographic information of dog owners in the United States and the car use proportion among them. The pet owner demographics continue to shift in the recent years. According to a 2017 report on pet population and ownership trends in the US from Packaged Facts, 54.6 percent of US households owned pets in 2017, equaling approximately 66.8 million households. This percentage has not risen or fallen significantly in the past few years, but among those households, pet ownership varies by age, ethnicity and gender. During the past decade, a majority of pet owners in the US were middle aged. In fact, the median age of pet owners increased slightly between 2006 and 2016, according to a survey from Simmons Market Research. As the baby boomer generation ages, they have taken more interest in pets for companionship and health benefits. According to Packaged Facts' 2017 report, in 2015 and 2016, the oldest of the boomers began to turn 70, and the percentage of pet owners in the 70-plus age group rose to about 40 percent. As millennials begin to outnumber baby boomers, however, this particular pet owner demographic has reached its tipping point. According to the demographic data, we decided to target both millennials and baby boomers as our users.

Personas

In an effort to understand the target customers for our product, which promises to deliver improved dog safety in vehicles, we constructed two largely opposing personas. These personas help us to visualize the diversity of our potential customers and inform us on how to account for these differences in our design. The two personas constructed are, for Amy:

Personal Profile:
Amy, 67 y/o, female, married with kids and grand-kids
Retired accountant after 40 yrs. of work
Got her first dog after retirement to keep her company
Takes her dog wherever she goes, especially on scenic drives

Role:
Retiree who enjoys relaxing and playing with her grandkids

Context:
Lives comfortably off of a fixed income retirement plan

and for Jack:

Personal Profile:
Jack, 18 y/o, male, single
Recent high school graduate
Loves all pets, but especially dogs
Works as a dog-sitter in his local community
Drives to pick up dogs from their owners and take them to the park

Role:
Summer worker trying to make money before going to college

Context:
Comes from a lower middle-class family
Has 3 younger siblings

Hence it is clear that the two personas constructed are quite opposite: Amy is 67 while Jack is 18, Amy is married with many children and grandchildren while Jack is single, and Amy enjoys her dog in retirement while Jack works with dogs as a summer job.

These stark differences will ensure that our final product is designed while taking into consideration the lifestyles, abilities, and budgets of all potential customers. It must be easily lifted, installed, and used by the young and old alike. Also, it must be tastefully designed for casual drives while simultaneously boasting utilitarian durability. And of course, it must be well within the budgets of both fixed-income retirees and young entrepreneurs.

Scenarios

In an effort to understand how our customers might use our product in their cars, we created two scenarios surrounding each of our two personas described above. From that, we try to understand their feelings, emotions, and user experience details. For Amy:

> *On a sunny day, Amy is going on a day-trip to the national park nearby with her husband and dog, a one-year-old Beagle. The dog is very active, full of energy, and cannot stay quiet in the back seat. The dog jumps and rolls about, barking and looking out of the window. It is hard for Amy and her husband to keep the dog quiet and still, so they just let it be free to what it wants. After a happy day at the park, the dog gets very tired and dirty. Amy puts a hammock-style cover on the back seat for the dog, but it is still smelly and puts its dirty paws on the windows. Although it was a wonderful day-trip, cleaning up the dirt and smells is a bit of a hassle.*

And for Jack:

> *At 9:00 AM, Jack gets up and starts working his summer dog-sitting job, picking up dogs and taking them to the park. He has three dogs to take care of for the day, a 6-year old American Eskimo, a four-year-old Canaan, and a ten-year-old Australian Terrier. They are all different sizes and with very different personalities. Jack is a dog lover and likes his job very much. However, he doesn't like the idea of sticking dogs in the back seat and using uncomfortable harnesses on them. Because Jack drives alone, it is difficult for him to keep the dogs well behaved and drive at the same time. Jack has to tolerate the dogs' barking and squirming while trying his best to remain concentrated. In summer, he needs to clean his car daily and sprays a lot of air fresheners to make up for the dogs' mess.*

From these scenarios, we gather that our customers might want a product designed to reduce distractions, restrain the dogs, but still keep them comfortable in the car. These two personas playing out their respective scenarios should hopefully represent a good cross-section of dog owners and our potential customers.

Justifications of Problem Selection

Research has shown that "In a car crash at 35 miles per hour, an unrestrained 60-pound dog becomes a 2,700-pound projectile. The force of that impact could kill both the dog and the car's human occupants"(Siler). This fact is underscored by a 2011 Kurgo and AAA survey of people who frequently drive with their pets. The survey found that "while 64% of drivers admitted to engaging in a potentially distracting pet-related activity, and 29% admitted to actually being distracted by their pets, a full 84% allowed their pets to ride unrestrained"(Pets).

Properly restraining a pet can also prevent distracted driving, which can lead to car accidents. A recent study has found that, similar to texting while driving, having unrestrained pets in the car can prevent drivers from keeping their eyes on the road at all times and can lead to potentially severe accidents. Hence, unrestrained pets will not only contribute to distracted driving, but also pose an increased danger to themselves and humans in the event of a car accident.

Results from Survey I: Problem Definition

According to Survey I, 92.6% of respondents are 19 to 30 years old, making our survey population young adults. We then asked where they put their dogs in the car. Most of them put them on the seats. 30% of the people put dogs in the front seat. 55% of the people put dogs in the back seats. However, there are 2 out of 47 people (4%) who put dogs on their lap while driving. Although this is a small percentage of people, we must insist that it is a very dangerous activity and will very likely cause distractions while driving.

To understand how people feel distracted while driving with their dogs, we asked respondents to estimate the level of distraction caused by their pets. It is surprising to find that people rate dogs in the back seat as more distracting than those in the front seat. Another interesting finding is that the two people who hold dogs in their lap while driving, they only rated 1/10 and 2/10 for distraction. This oddity is probably because people only bring their dogs into the front seat or hold them on their lap if they are very obedient, which is less likely to cause distractions while driving.

User Experience Context

The User Experience Context is split between the fields of Physical Ergonomics and Cognitive Ergonomics. Both will be important considerations in the creation of our design.

Physical Ergonomics will primarily impact the size, weight, ease of installation, and ease of use involving a real dog. Thus, size and weight will be constrained to allow easy handling by a single person both inside and outside of the vehicle. Ease of installation and ease of use will also be constrained to help reduce physical strain of attaching the product to the vehicle, manipulating it into position, and seating/unseating a dog in the product.

Cognitive Ergonomics follows hand-in-hand by also impacting the ease of installation and ease of use, but also the aesthetic elements of our product design. In order to have good cognitive ergonomics, we will focus on reducing the steps necessary to install the product and seat/unseat a dog, resulting in fewer steps to remember, demanding a lower cognitive load, and causing less frustration. To further ease the cognitive strain, we will design the product to be aesthetically pleasing, trying hard to make it fit in with a car's interior design and the user's style preferences.

Business Context

The Business Context is comprised of all aspects that make a business successful, such as profitability, competitiveness, uniqueness, and manufacturability.

In designing our product, we must be careful to always consider the costs of the raw materials and labor hours that will go into producing every product. In order to ensure profitability, we will have to add a margin to the material and labor costs of our product, netting us enough returns to sustain our business. Product pricing does not operate in a vacuum, however, and thus the profit margin cannot be too exorbitant.

We must also ensure that our product is priced competitively in the global marketplace in order to guarantee a steady stream of sales. A great deal of market research has been done, and will continue to be expanded upon, to better inform our ultimate pricing decision. After all, we wish our product to be accessible to a majority of potential consumers who have a personal need for such a dog safety product.

In hand with the previous aspect, our design must stand out in the marketplace as a unique solution to what is a well-documented problem. There are already a number of products on the market which claim to answer our exact design problem. While abiding by copyright and patent laws, we will have to design a solution to our problem which has never been done before and which exploits a particular market gap. Though we will go into more detail on this topic later in the report, our product can be surmised as being less expensive than most competitors while providing greater security for the dog and fewer distractions to the driver than any other product on the market.

Finally, the most critical aspect of the design is ensuring that it is manufacturable. We could design the most brilliant dog safety product ever devised, in theory, but it would be useless without proof that it is viable for mass production. This means that our design will have to be innovative, yet simple to manufacture at relatively low unit and fixed costs.

Ecological Context

The Ecological Context of our product must also inform how we go about designing it. Unfortunately, due to the realities of building high strength and durable products, it will be a challenge to incorporate recycled or recyclable materials in our design. However, we will do our best to research our options and fulfill our textile needs with recycled or recyclable industrial fabrics. We will also design our product to be manufactured efficiently, producing as little material waste—such as metal, fabric, and plastic—as possible. Furthermore, by building a very durable design that can survive years of regular use, we can prevent our customers from hastily discarding our product in the garbage after a short time. By doing so, we can help to reduce the waste produced by our product throughout its life cycle, from manufacture to its eventual discarding in the distant future.

Regulatory Context

The Regulatory Context has the potential to dictate many of our final design decisions. Since our product will be used in cars as a safety implement for dogs and to reduce distractions to drivers, we must make sure to operate within the bounds of National Highway Traffic Safety Administration (NHTSA) and their Federal Motor Vehicle Safety Standards (FMVSS). We must make sure that our product is well secured in the car and that the dog seated in our product is well restrained to prevent the entire system from becoming a projectile in the event of a car crash. Today, as several U.S. states begin to mandate that dogs be restrained somehow while riding in a car, we must ensure that our product meets all state government requirements so that our customers can use it legally anywhere in the country. It is also important that we adhere to the more general product safety guidelines laid out by regulatory bodies like the Consumer Product Safety Commission (CPSC). Though there are no such government regulatory bodies for pet-related products, we aim to adhere to the guidelines laid out by the non-profit organization Center for Pet Safety. Finally, we will have to maintain documented and de facto industry standards to verify that our manufactured design is as durable and high-quality as intended.

Social Context

It is important that our final product fits into the social context of the world it is used in. We are especially driven to ensure that the manufacture of our product provides good paying jobs to as many people as is feasible for our business. It is also important to consider the benefits resulting from people using our product. By reducing distracted driving and restraining dogs in cars, our product will certainly help to keep people in and around the user's car safer from fatal and non-fatal accidents. This reduces the stress caused throughout society by the loss of loved ones, including pets, and helps to increase peace of mind when on the road. As far as we can predict at this point, there do not seem to be any apparent social downsides to our product.

II. Design Objectives and Requirements

Attributes

Safety for the Dog and Passengers

Dog owners often bring their dogs into their cars with them, but there are no suitable seats or safety belts in the car for their use. This allows the dogs to wander the vehicle freely. If a car accident occurs, the unrestrained dog could become airborne within the car, almost certainly injuring the dog and any passengers it may fly into. Thus, our product will provide the dogs a place to sit, restrained in place, ensuring their safety and that of the passengers in the event of an accident.

Ease of Installation in the Car

Cars currently on the market do not have special seats for dogs, so owners need to install add-on seats for them. However, such seats must be rigidly mounted in the car to meet the necessary safety requirements we have laid out. At the same time, the seats must be convenient to install and uninstall as the owner wishes since they may not want it in their car on a daily basis. We will design our product to interface with a wide variety of cars, simply and securely, so that a single person can install and uninstall the seat with minimal effort.

Comfortable for Dogs

Though the buyer and operator of the seat are obviously human, the end-user of the potential product will be the dog. Therefore, the product will be designed with dog comfort in mind to minimize squirming and barking while in the car.

Reduces Driver Distractions

As there are no suitable restraints for pets in cars on the market today, dogs are allowed to jump from seat to seat and hang precariously out of open windows. Such dog activity in a car poses a significant distraction to the driver, who is simultaneously trying to drive and calm their dog. Our product will be designed to reduce the likelihood of dogs distracting their drivers by keeping them restrained in a single location. Though not promising a complete elimination of all distractions, the design will certainly help to reduce them and keep the driver more focussed on driving.

Durable Construction

Our product design must be able to withstand both a dog and the dynamic environment of a car's interior. We will design it to support the dog's weight, be resilient to bites and scratches, and survive the bending moments imparted during turns, acceleration, and crashes.

Affordable Price

As we wish to appeal to a wide swath of potential customers and be competitive on the open market, we try to keep the costs of material and labor, and add a modest profit margin.

Characteristics

Weight

Weight will first be measured theoretically in the CAD program in which the product will be designed. Once the product is fully manufactured, then it will be weighed on a scale. Our objective is to minimize weight while still meeting all other product requirements laid out herein. This is constrained by our desire for the product to be one-person portable and the requirement that it does not damage car seats during extended use.

Size

The size will be measured first in the CAD program in which the product will be designed, and then the manufactured product will be measured using calipers and a ruler. Our objective is to optimize the size to be able to accommodate a reasonable variety of dog sizes, while ideally focussing on medium-size dogs (35 lbs - 65 lbs). This is constrained by the size of the car's seat it is meant to be installed on and the desire for the product to be stowed and handled by a single person.

Cost

The cost of the final product will be based on the materials and labor used, the economies of scale in mass production, and market norms. Our objective is to minimize costs while maintaining a suitable profit margin to ensure profitability. The primary constraint is that the product is within the budget of a majority of our potential customers.

Steps to Install

This will be determined by testing the final product and counting the number of steps necessary to install it. Our objective is to minimize the number of steps to ease use and support our design's cognitive ergonomics. We have set an arbitrary constraint of at most only 10 steps to install the product in a car.

Dog's Seat Area

The seating area will be determined based on its surface area and adjustability. Our objective is to optimize the seating area to accommodate various size dogs. The only constraint is that the product must fit within the bounds of an existing car's seat.

Time to Seat and Unseat Dog

These times will be measured by timed tests of both seating and unseating a dog in the final product. Our objective is to minimize the time required in order to ease human strain and promote good cognitive ergonomics. We have set an arbitrary constraint that the seating and unseating times be kept under 1 minute.

Materials Chosen

The choice of materials will be based on qualifications for the intended tasks using CAD and

FEA software. Our objective is to use suitably strong, light, and cost-effective materials in our final product to meet the other requirements specified herein. This is constrained by the necessity to survive a dynamic car environment while holding a large dog, meet weight requirements, and minimize material costs. Meanwhile, we must make sure that the dog is comfortable while using our product and that the materials used can be easily cleaned of dog hair and bodily fluids. This will help to ensure the longevity of our product, making it a good investment for our customers.

Stability while Driving

This will be measured by performing FEA stress and deformation analysis and by testing the final prototype using an actual dog. Our objective is to keep the product and dog stable in a driving car without overstressing the product's physical structure. This is constrained by the material requirements herein and the obligation to prevent damage to the car.

Objectives and Requirements

Based on the attributes and their associated characteristics identified herein, we have developed a set of objectives for our product design to meet, as well as requirements that are to be essentially non-negotiable aspects of our design.

Our objectives are to minimize the weight and optimize the size of the product so that it can be easily handled by a single person. Following from this, we have set objectives to minimize cost, minimize the number of steps required to install the product in a car, and minimize the time needed to seat or unseat a dog in the product. All of these objectives are aimed at reducing the financial, physical, and cognitive stress placed on the user of our product. We have also set objectives to directly benefit the dog's experience as the end-user of our product, such as optimizing seating space by making it adjustable to the dog's size and maintaining stability while the car is driving. All of these objectives, however, are directly related to our driving objective for the project; the use of strong, lightweight, and cost-effective materials.

The requirements we have laid out dictate that, at the very least, our final product be structurally sound under the loadings of a medium-sized dog, weighing a maximum of 65 lbs, during a crash scenario, that the product doesn't damage the car during extended use, and that the entire product be easily handled by a single person.

Mapping Matrix

In order to better understand how our attributes and characteristics relate to one another, we constructed the mapping matrix in Table 1 on the following page. The foremost observation that can be drawn from this mapping matrix is that the choice of materials is the driving characteristic of the design. This supports our prior assertion that the driving objective of the product design is the use of strong, lightweight, and cost-effective materials.

Table 1. Mapping from Attributes to Characteristics

Attributes	Weight	Size	Cost	Steps to Install	Dog's Seat Area	Time to Seat/Unseat Dog	Materials Chosen	Stability while Driving
Safety for the Dog and Passengers	X	X			X		X	X
Ease of Installation in Car				X				
Comfortable for Dogs		X			X	X		
Reduces Driver Distraction							X	X
Durable Construction			X				X	
Affordable Price			X				X	

Key Attribute Selection

Informed by the mapping matrix of Table 1, showing which characteristics relate to which attribute, and our own sense of direction with our design, we have chosen two key attributes that will determine the success of our product.

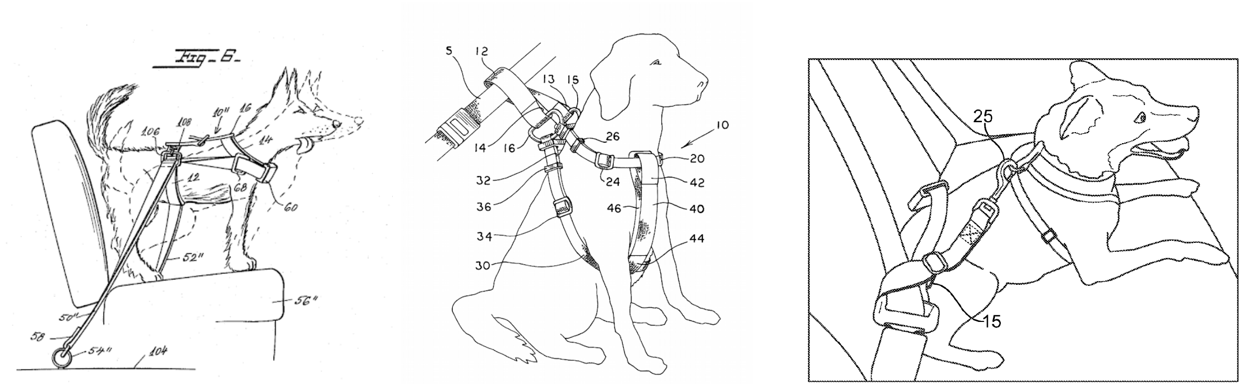
Primarily, our design must fulfill the attribute of Safety for the Dog and Passengers. In total, five characteristics define our success in this endeavor, the most of any attribute: Weight, Size, Dog's Seat Area, Materials Chosen, and Stability while Driving. Thus, our design absolutely must ensure that the dog remains restrained in its seat to protect it from injury and prevent it from becoming airporn and injuring car passengers in the event of an accident.

Our second key attribute is that our product must be designed for dog comfort. Three characteristics contribute to this attribute: Size, Weight, and Time to Seat/Unseat a Dog. It is important to optimize comfort to minimize the squirming, barking, or otherwise distracting dog behaviors while using our product. By minimizing the time taken to seat and unseat the dog, we will also seek to lessen the cognitive and physical stresses on both the dog and the owner.

III. Previous Designs

Patent Search

After extensive patent searching, we found that people have tried to create harnesses for dogs to be worn in automobiles as early as in the 1960s. The two images shown in Figure 1 are of two patent records from 1967 and 1999, respectively. Figure 1. (a) and (b) are similar to the dog harnesses currently on the market. Figure 1. (c) has the same idea as the potential design that makes use of vehicle seat belt to fasten the pet.



(a) (b) (c)

Figure 1. (a) Safety Harness and Collar 1967 **(b)** Dog Car Restraint 1999 **(c)** Vehicular dog restraint 2014

Similar Products on the Market

To better consider the product features, it is important to search for existing products in the market and compare their functionality. There are four typical kinds of product for dogs traveling safety in the market. They are hammock-style cover, HDP Deluxe Lookout Dog Car Seat, Gunner Kennels and Dog Car Harness. The followings are the pictures and comparison of the advantages and disadvantages of the products.

(a) (b) (c) (d)

Figure 2. (a) Hammock-style Cover; **(b)** HDP Deluxe Lookout Dog Car Seat; **(c)** Gunner Kennels; **(d)** Dog Car Harness

Hammock-style Cover features covering the whole back seat. This product maximizes the activity area for pets to sit or lay down. It is at the highest level of comfortability among the four products. However, there is no functionality to ensure the safety of dogs. Once an accident happens, this product cannot protect the dog from injury.

HDP Deluxe Lookout Dog Car Seat is a cage-based product so that drivers can put their dogs into the seating area. The cage feature helps to restrain dogs' movement within a small area. It prevents pets from moving constantly. However, due to the size limit, large dogs cannot sit within this product. It also does not have the functionality to guarantee safety.

Gunner Kennels is a pet travel crate constructed by hard materials. Even if there is a car accident, pets will not get severely injured due to the structure of the crate. The product also has some tie-down strap kits. It guarantees safety for pets. However, a small closed space is not comfortable enough for dogs, especially for long-distance travel.

Dog Car Harness is a very common product for restraining dogs. It may force dogs moving around within a certain area. However, less harness product has a connection to the vehicle.

Table 2. Prices, Advantages, and Disadvantages of four similar products

	Price	**Advantage(s)**	**Disadvantage(s)**
Hammock-style Cover	$25	Comfortable	Not safe No restrictions on dog's movements
HDP Deluxe Lookout Dog Car Seat	$36	Comfortable Limits dog's movement	Only for small dogs Not Safe
Gunner Kennels	$599 + $75	Safe	Uncomfortable
Dog Car Harness	$105	Safe	Uncomfortable

Market Gap

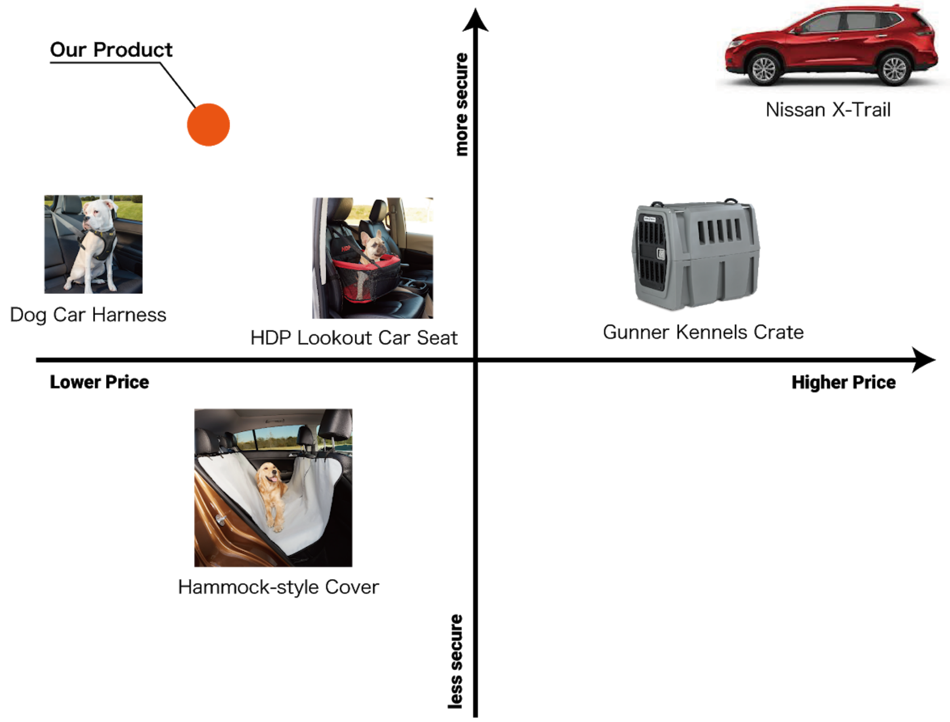


Figure 3. Pet Travel Product Positioning

We can see a market gap from the diagram. We have a few affordable products which can protect pets and keep them from distracting drivers. As we compared products in the market, we find that these products usually can only accomplish one functionality from secure and comfortability. The price also varies greatly among different products. That is to say, no product in the market is affordable as well as safe and comfortable for dogs. Results from Survey I show that 85% of people prefer to place their dogs in the seat (front and rear) instead of in the trunk. As a result, we aim to create a product that is both comfortable and safe for dogs to sit in the seat. We set the price of the product below, which will be affordable for most of the customers. As a result, our product can attract customers from its price and functionalities, and occupy the market.

IV. Concept Generation and Selection

Functional Decomposition

By approaching our product from the viewpoint of dog safety, as described in our problem definition statement, we arrived at the following functional decomposition graphic. This shows, among other things, how increasing safety branches into both dog-related and driver-related effects which simultaneously lower dog anxiety and reduce driver distractions.

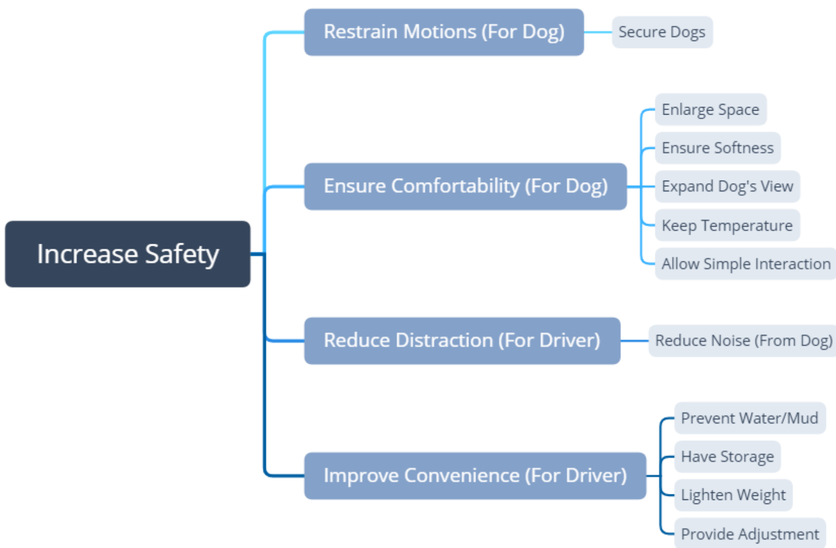


Figure 4. A graphic illustrating the Functional Decomposition

Results from Reverse Design

For the reverse design, we purchased a dog vest that represented our product design intent and which was composed of materials similar to those we would likely use in our final design *(see Appendix D, Figure D-1 for images)*. We identified the main functions of the vest as: warmly clothe the dog, allow the use of a collar or harness, and provide a storage pouch on the dog itself. The dog vest seemed roughly made and of only moderate quality, likely due in part to its relatively low $20 cost. The fabrics used were not particularly soft or easily cleanable, representing the exact opposite of the design attributes we are seeking in our product. Also, the dog vest used hook-and-loop and sewn-on metal rings for fasteners. We tested both, applying tensile stress with our hands until failure, and determined that these fasteners would be far too weak for our high-stress, automotive applications. From this, we learned that we should use comfortable, yet strong, industrial fabrics and rugged fasteners which have been tested to withstand the stresses exacted by a 65 lb dog in a moving car.

We determined that the target customers are adventurous dog owners who like taking their dogs with them on outdoor hikes in cooler weather while still ensuring their dog's safety and comfort. This is a very similar customer pool to the one our product is aiming to target: dog owners who like taking their dogs with them in the car wherever they drive, but who are also very conscious of their and their dog's safety. Further research showed that the market for such dog supplies in the United States is approximately 60 million households spending approximately $70 billion a year on dog supplies. We also found no reason to suggest that this product we reverse-designed or our final product couldn't be marketed widely abroad, opening up a large, yet unquantifiable, potential market.

Results from Survey II: Conceptual Design

From Survey II, we had 27 participants providing valuable results while only 30% of them have at least one dog. Detailed results are shown in Appendix C.

Analyzing the open-ended questions about what products people currently use to restrain their dogs, the results vary for different sized dogs. For large dogs (86 - 135 lbs), people usually use a dog hammock that covers the entire back seat or they keep their dogs in the trunk. For small dogs (16 - 35 lbs) and medium dogs (36 - 85 lbs), people prefer to hold them in their arms, place them in transport cages, or secure them somehow using seat belts.

The survey also showed that most people (89%) are safety conscious about their dogs and want to restrict their dogs to some degree in the car. Of those, the plurality of respondents (48%) want to keep their dogs partially restrained, allowing their dogs to move in a small, usually seat-sized area. The most popular features, which respondents want from our product, are designing it to be universal for all car platforms and improving the dog's view out the window. Other possible features include integrated storage and chew toys to entertain the dog.

We also asked about which activities drivers usually engage in with their dogs while driving. Results show that activities like petting, watching, talking and reaching to interact with dogs are most common for drivers.

Based on the conjoint survey questions, we determined the relative importance of product price, weight, installation time, and materials used to our potential customers. Respondents cared most about the price and the materials used while caring least about the weight of the product. The desired price for our product is $40 or less. With regard to materials, people prefer that we use industrial fabrics which are highly moisture-resistant and easy to clean. Of the less important attributes, people prefer that installation time does not exceed 3 minutes and that the weight remains below 5 Ibs.

Results from Quick Concept Prototyping

After team brainstorming, two small-scale concepts were generated, each focussing on a different feature of our product: comfort and dog entertainment *(see Appendix D, Figure D-2 for images)*. Two of our team members focussed on comfort, conceptualizing an in-car dog bed. This focussed on the use of soft materials, namely upholstery fabric wrapped around a foam core. The shape of the concept was also designed for optimal comfort, having a padded backrest and railings along the sides to prevent the dog from rolling off. The other two team members focussed on dog entertainment, conceptualizing an in-car dog seat with integral stairs so that the dog could climb up to the window and lookout. The thought behind this was to keep the dog entertained by the environment instead of feeling claustrophobic and irritated in the confines of the back seat. Both of these small-scale concepts have informed the design process and elements from each will be incorporated into our final concept.

Key Concepts Examined

Concept 1

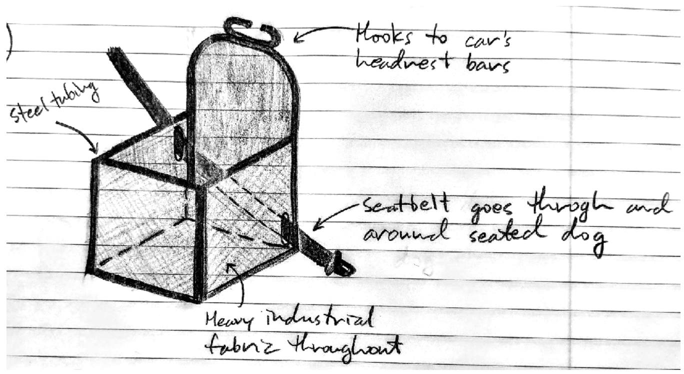


Figure 5. Concept 1 of our in-car dog restraint

Concept 1 is a half-closed cage made of rigid beams and panels of tough fabric with holes on both sides for the seat belt to pass through. The pro is that the concept is fixed to the seat in two ways, the connection with the seat belt and the connection with the metal bars of the headrest. However, the con is that there is no protection for the dog itself in the cage. The dog would be free to move around inside or even jump out of this concept and wander the vehicle.

Concept 2

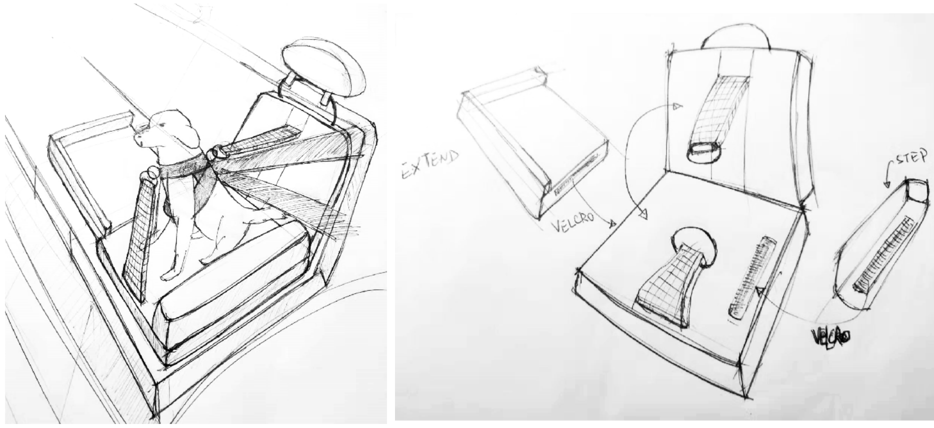
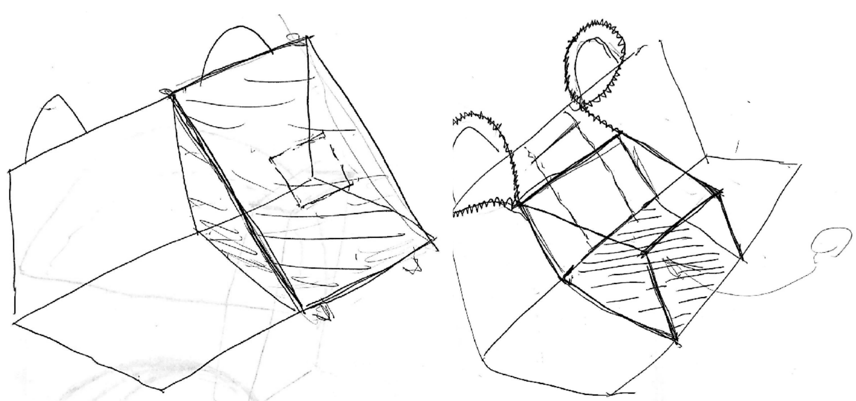


Figure 6. Concept 2 of our in-car dog restraint

Concept 2 is a modular, expandable dog seat that is attached to the car seat via the metal bars of the headrest and a dog harness that goes directly on the pet's body. There are two built-in belts that fasten the dog harness to the seat which supplement the regular seat belt which passes through the harness and provides a majority of the restraint. The pro is that dog owners can partly customize the seat and car space to meet their individual dog's needs. The con is that the concept calls for the parallel designing of two items, a seat and a harness.

Concept 3



(a) **(b)**

Figure 7. Concepts 3 **(a)** and **(b)** of our in-car dog restraint

Concept 3 (a) is a triangular space with a square hole on top. The pros are low cost and simplicity. It only needs three panels of weblike fabric and a soft bottom panel. However, the cons are that it does not use the available space as much as possible and does not provide protection for the pet in the event of accidents. Concept 3(b) is a cube-shaped restraint which is situated in the middle of the back seat and is connected to the seats by fastening to both rear headrests. The pro is that owners can see their dog's activity and that dogs can also see their owner, allowing for some interactions between them.

Concept 4

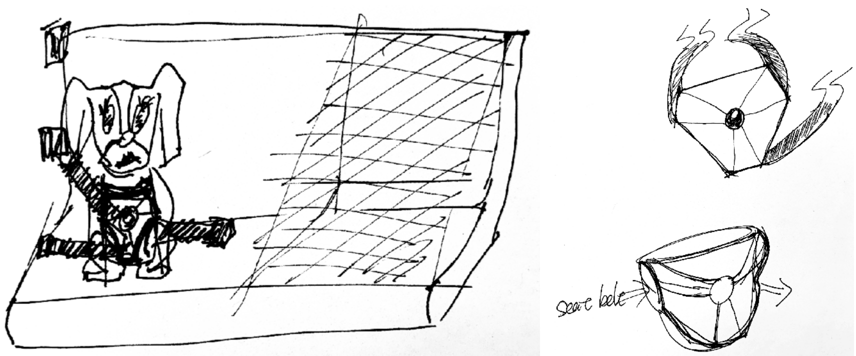
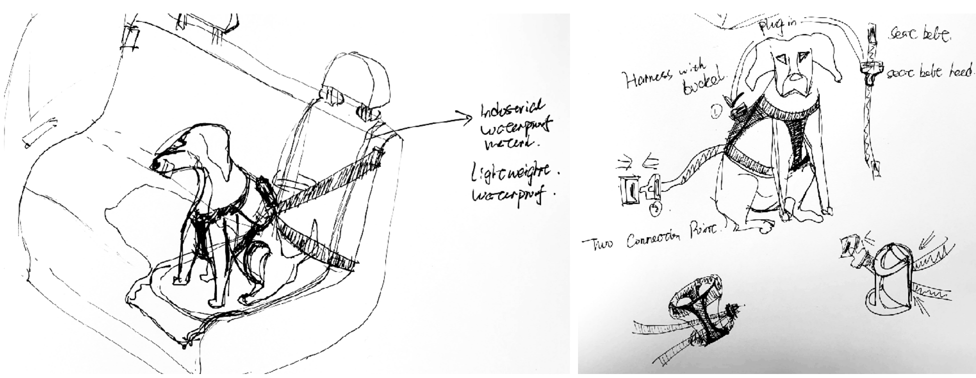


Figure 8. Concept 4 of our in-car dog restraint

The most interesting part of Concept 4 is the electric haptic feedback device attached to dog's harness. It can vibrate to imitate a dog's stable heart rate. So, the pro is that when the device detects an irregular heartbeat, due to intense emotions or activity, it will begin to vibrate at a stable rate to calm the dog and reduce its distraction to the driver. The con is price, as it would be more expensive to integrate such technology into our otherwise non-electrified, physical product.

Concept 5



(a) **(b)**

Figure 9. Concepts 5 **(a)** and **(b)** of our in-car dog restraint

Concept 5 (a) is a redesigned dog harness which has a special gap to let the seat belt pass through. In Concept 5 (b), the harness itself has a seat belt buckle that can be directly fastened to the seat. The pro of both is that the dog, via the harness, is directly restrained by the seat belt and kept from wandering to the front seat of the car, potentially diverting the driver's attention, or from being flung about in an accident. However, the cons are that it does not improve the dog's comfort in any way and that there are already similar products on the market.

Concept Selection

The following Pugh Chart in Table 3 was made to quantitatively compare the qualities of our Key Concepts based on the criteria of design attributes. The weights (multipliers) associated with each of the attributes was informed by the results of our Surveys I and II, and by our Mapping Matrix. The concepts were each ranked out of five (5) points for each attribute.

Table 3. Pugh Chart comparing Key Concepts and identifying the Best Concept

Attribute	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Safety for the Dog and Passengers	3.0x	2	5	2	3	4
Ease of Installation in Car	1.0x	4	3	4	5	5
Comfortable for Dogs	3.0x	4	4	4	3	3
Reduces Driver Distractions	2.0x	4	5	4	5	5
Durable Construction	2.0x	4	5	3	4	4
Affordable Price	3.0x	5	3	5	3	4
	Totals:	53	59	51	50	56

V. Selected Design Concept

Final Concept

Concept Sketch

Informed by the results of our pro/con analysis of Key Concepts and the findings of our Pugh Chart, we arrived at the following final concept sketch. Since our Pugh Chart resulted in very close total scores for all of our concepts, the final concept incorporates several of the best features of each.

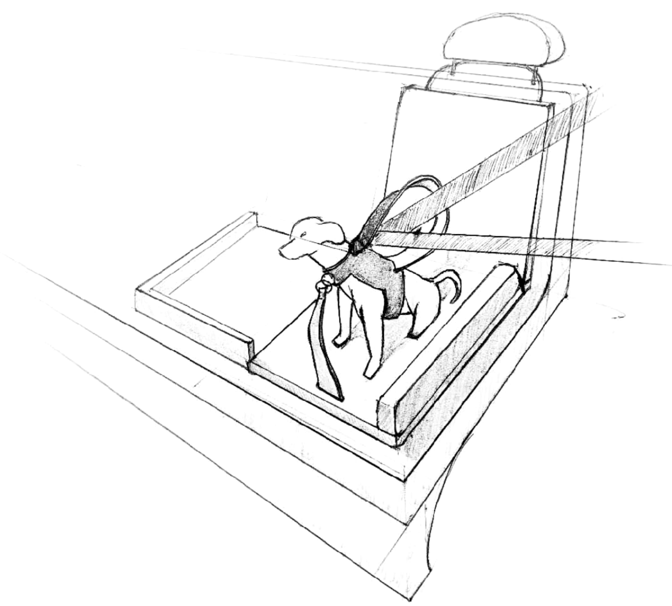


Figure 10. Final Concept of our in-car dog restraint

Description of Functionality

The main functions of our design are to keep the dog safe and comfortable while preventing it from diverting driver attention *(see Appendix D, Figure D-3 for a graphic representation of functionality)*. For the safety function, the dog harness has a large, adjustable-length strap loop on the back so that the car's seat belt can pass through and fasten the dog to the car. The adjustable-length strap allows for some user flexibility to give the dog more or less freedom of motion. For the comfort function, we will use a dense foam material as the core of the seat and a waterproof, industrial fabric as the top-layer upholstery, granting both softness and durability. For the storage function, a pocket was built in to the harness, allowing the dog to carry small items. Another interesting feature is that the product was designed around the "all in one" concept. The foldable and expandable seat includes all of the provisions for a food bowl, a step for the dog to stand on and look out the window, and the necessary safety harness elements. When not needed, the dog restraint system can be folded to the size of a small suitcase and be stored in the trunk. When needed, it can be easily unfolded and installed in the car with minimal steps.

Alpha Prototype

We spent 6 hours total making our alpha prototype to represent our final concept as accurately as possible given our limited resources at this stage. To do so, we found and used dense foam, nylon straps with buckles, felt, hook-and-loop fasteners, linen stitching, nylon fabric, waterproof plastic tarps, etc. The dense foam, nylon fabric, linen stitching, and waterproof plastic materials were chosen in the interest of dog comfort and ease of cleaning to simulate the types of materials we will likely use in our final prototype. The use of nylon straps, hook-and-loop strips, plastic buckles, linen stitching, and hot glue fasteners is a proxy for the more rugged fasteners to be used in our final product, but still, serve to illustrate the safety functions of our concept. The following is an image of our alpha prototype.

(a) **(b)**

Figure 11. (a) the harness and **(b)** the seat (mounted in a car) of our Alpha Prototype of our Final Concept

It is worth noting that we were able to successfully test our harness design of Figure 11 (a) on an actual dog owned by one of our team members. The harness fits well and the dog did not seem at all uncomfortable with the situation. In our opinion, this forms a preliminary proof-of-concept for this part of our design.

Path to Embodiment

Proceeding to the embodiment phase, we will need to perform significant research into materials, attachment points on car seats, and dog comfort. The concept sketches generated so far will be revised in response to the capabilities of the materials selected. The selection of these materials will be predicated on the input received from the University of Michigan's Transportation Research Institute (UMTRI) with regard to anticipated acceleration during a crash and the strength required to survive such an event. Thus, we will ensure that the materials we purchase are either rated to a certain strength by the supplier, or tested by our team in person, to ensure that they meet crash test survivability requirements. Based on the most up-to-date sketches, CAD models will be created to better visualize our product. We will then take this design to the dog experts at the Humane Society of Huron Valley to receive their comments, suggestions, and conditional approval. This will provide us the opportunity to further refine our design and reinforce our confidence in its functional success. We will further explore options for the secure and universal attachment of our product in cars, and the optimization of our harness and seat system to meet dogs' anatomical constraints and desires.

Required Resources

In order to enter the full production phase, we would first needed to establish a reliable source for materials and purchase the sewing machines required for assembly. We would need to purchase sufficient quantities of waterproof industrial fabrics, dense upholstery foam to form the core of our seat, and strong nylon webbing and plastic buckles to secure the harness to both the seat belt and our dog seat. For the most part, we would need to use a sewing machine and various methods of shaping/cutting dense foam in order to assemble a final product in our production facility. In terms of labor, we would need to hire several full-time employees to remedy, or replace, the manufacturing effort currently being undertaken by our team members. All of these resources would need to be tracked carefully so that we can predict, to a reasonable degree of certainty, the material, tooling, and labor resources that would be required to maintain a full, industrialized production run and remain profitable.

Manufacturing Plan

The manufacturing processes involved in building our product revolve predominantly around sewing fabrics and shaping dense foam. As such, our manufacturing plans largely focussed on precisely measuring fabrics with yard sticks, cutting them down to shape with rotary cutters, pinning them together in mockups, and then sewing them using a sewing machine. During this process, each member of our team learned to properly maintain and operate a sewing machine so that they could contribute to the manufacturing effort. The dense foam core was cut and formed using scissors and razor blades into a rectangular shape with gently rounded corners. Thus, overall, we have not required the use of either the machine shop or the mechatronics lab whatsoever.

Alternative Concepts

Even though we are quite confident in the market viability, effectiveness, and manufacturability of our final concept design, it is important that we consider alternates in the event of significant setbacks. If we need to pivot our project away from the current concept, we would likely re-focus our efforts on a concept focussed solely on dog harnesses, as in Key Concepts 4 and 5. Then, instead of splitting our efforts between the two parallel developments of the seat and harness, we can focus on a more technologically refined dog harness alone. By redirecting the costs and resources of the seat, we could integrate the haptic feedback device of Key Concept 4, which was previously discounted due to excessive cost and complexity.

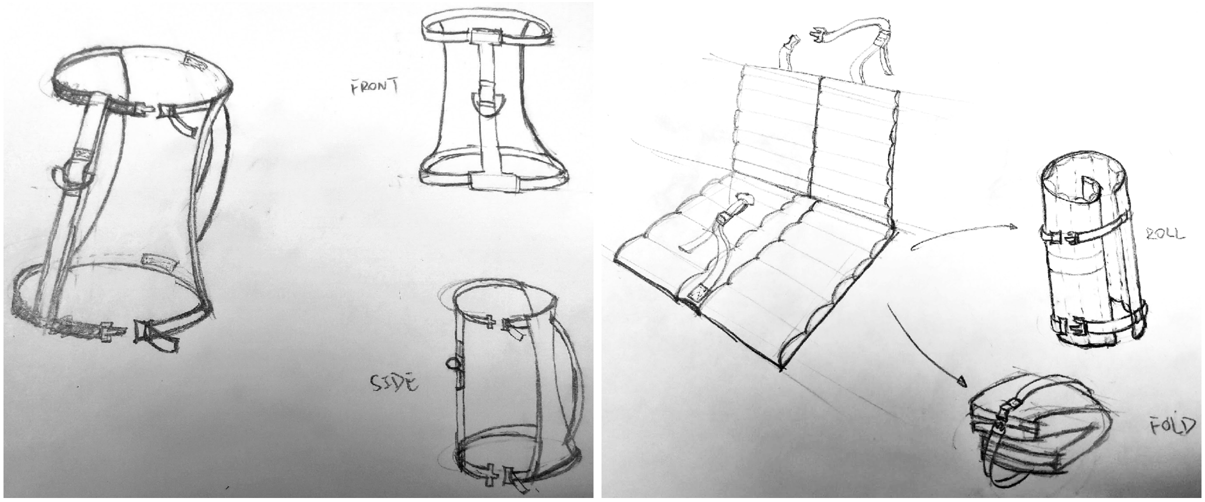
VI. Design Embodiment

Product Functionality

The main functions reflected in the design embodiment phase of our product are to secure the dog in the event of an accident, promote dog comfort, and allow for easy human interaction with our product while carrying, installing, and uninstalling it. To fulfill the security function, we chose materials strong enough to, in theory, restrain a 22 lb dog during a 30g-acceleration car crash event. This is made possible by a matrix of nylon webbing, depicted in Figure 13, which wraps around the dog and allows the car's seat belt to pass through a large loop on the dog's back, restraining the dog securely in the car. For the comfort function, we used dense upholstery-grade foam as the core of the seat and a ripstop waterproof fabric as the top layer, granting both softness and durability. Parallel rows of stitching added across the dog seat effectively corrugated it, granting greater strength against bending in one direction, while allowing the product to be easily rolled up in the other. This contributes to the function of improved human interaction by allowing our product to be rolled up into a small, cylindrical package, bound by two nylon webbing straps, and carried effortlessly like a one-shoulder backpack. When not needed, the dog restraint system, rolled up to the size of a yoga mat, can be easily stored anywhere in the vehicle. Installation and uninstallation are also very simple tasks, with the nylon webbing straps used to bind the rolled up product doubling as the straps used to attach the seat to the car seat's headrest. As an added storage function, a pocket was built in to the harness to allow the dog to carry small items as necessary. Both of the items included in our product, the seat and the harness, can be wiped down with a damp cloth so they maintain a brand-new appearance.

Beta Prototype Sketch

The sketches shown in Figure 12 on the following page are refined versions of those created during the design selection phase of product development and reflect the product functionality described above. On the sear mat part, a strip pattern was designed on the mat in order to roll up the parts and easily to take. The webbing and buckle connection was designed for both connecting to the car seat and attaching user's shoulder for carry. On the harness part, two metal rings were designed on both front and back side. The front side ring is for connecting the seat mat. And the back side ring is for connecting dog leash occasionally. The buckles on upper and lower webbing are fixed to one end of waterproof jacket in order to make the dog feel more comfortable while using the harness in the car. They were used as the design reference for the manufacturing of our Beta Prototype.

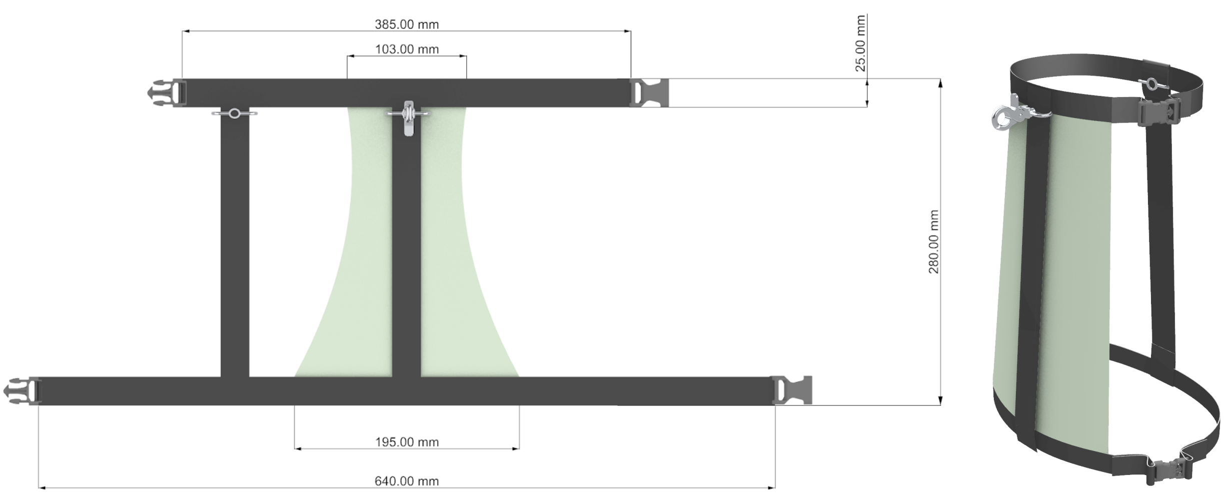


(a) **(b)**

Figure 12. Sketches of our Design Embodiment Beta Prototype depicting **(a)** the dog harness and **(b)** the dog seat

Beta Prototype CAD Model

The following Figures 13 and 14 are the views of the CAD models generated based on our Beta Prototype sketches above. These were created using Rhino 3D software to provide a visual representation of our product. This software was chosen over more common offerings such as SolidWorks and AutoCAD due to our product's greater emphasis on flowing design forms and lesser emphasis on precise engineering modeling. This decision and the underlying rationale will be discussed further in the engineering analysis section of this report.



(a) **(b)**

Figure 13. CAD models of our Design Embodiment Beta Prototype depicting **(a)** the dog harness laid out flat, displaying critical dimensions and **(b)** the dog harness in its wearable configuration with all fasteners engaged

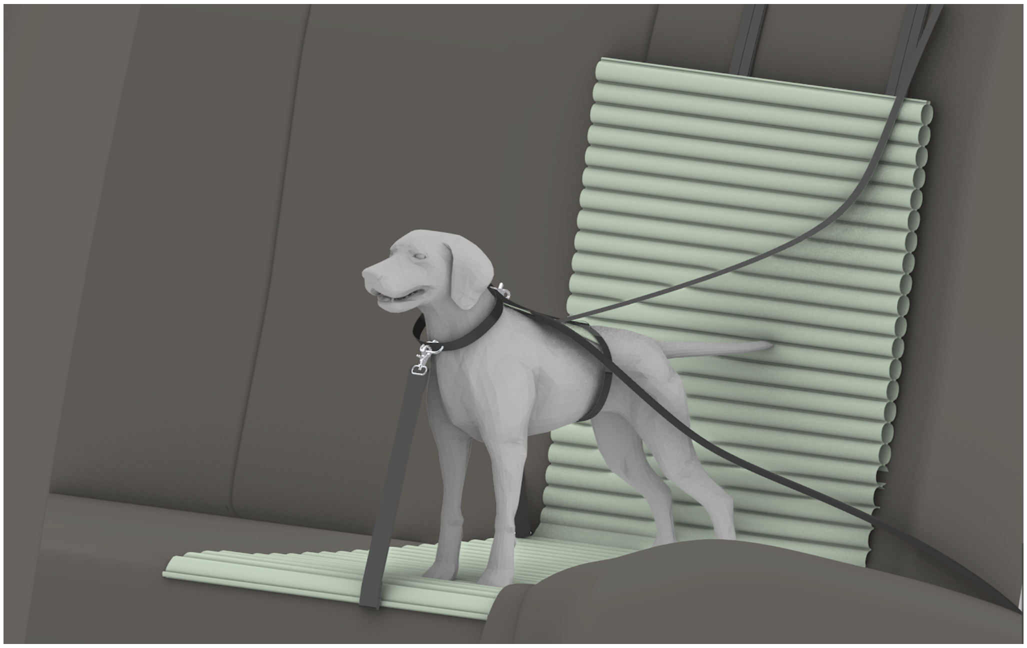


Figure 14. CAD model of the entire Design Embodiment Beta Prototype as installed in a car with a mock dog

Beta Prototype

Our team conceptualized and built our Beta Prototype, shown in Figure 15, over the course of approximately 20 hours total of hands-on work, leading to a total of approximately 60 man-hours between our four team members. At the beginning, this included the time required to order materials, organize them, and visualize how they would be used. We then needed to gain access to the Sewing Studio in the Stamps School of Art and Design, which required all of our team members to undergo training on the use and basic maintenance of the sewing machines provided in the studio. This studio was chosen because it is the only location on campus that has the number of sewing machines and associated resources necessary to manufacture our product. With materials and studio access secured, we set out to manufacture our Beta Prototype.

To manufacture our Beta Prototype, we used nylon webbing, ripstop waterproof fabric, dense upholstery foam, plastic buckles, metal D-rings, and metal lobster clasps, all held together with a combination of black and white sewing thread. The nylon webbing was used as the straps on the dog harness and the dog seat. Ripstop waterproof fabric was used as the fabric element on the back of the dog harness, incorporating a pocket, and as the fabric outer layer of the dog seat. The core of the seat was made out of dense upholstery foam which we cut down to size and shaped ourselves to take the rectangular, rounded-corner form seen in Figure 15 (a) below. The plastic buckles were used to fasten the dog's harness, fasten the seat to the car's headrest, and bind the seat together when rolled up, as shown in Figure 15 (b). The metal D-rings and lobster clasps were used to provide attachment points on the front and back of the dog harness, allowing the harness to be attached to the seat, as seen in Figure 5 (a), or for a leash to be attached in either location. The assembly of the various materials used in this prototype was all done using a sewing machine with either black or white sewing thread, including the corrugation of the dog seat seen in Figure 15 (a).

(a) (b)

Figure 15. The Beta Prototype **(a)** during functional testing which was performed on a team member's dog in a car and **(b)** when rolled up and carried like a one-shoulder backpack (See product demo at: https://vimeo.com/371638202)

Engineering Analysis

Following extensive internal contemplation and seeking external advice, our team decided to take a somewhat unorthodox approach to engineering analysis. Since our product is made almost entirely of flexible, fabric elements, it was not advantageous for us to use classic CAD software, such as SolidWorks or AutoCAD. Likewise, it was not feasible for us to conduct Finite Element Analysis (FEA) on our product's load-bearing structures. Therefore, the extent of engineering analysis performed by our team was limited, up until the point of design embodiment, to the careful selection of materials which met our product's strength requirements.

To fulfill these requirements, we chose to use 1.0 in wide nylon webbing rated to 660 lbf as the main load-bearing material in our design. This is strong enough, in theory, to restrain a 22 lb dog during a 30g-acceleration car crash event, based on input we received from the University of Michigan's Transportation Research Institute (UMTRI). To further improve our design's load-bearing potential, we designed the harness' nylon webbing matrix with statics and mechanics principles in mind. In doing so, we distributed the hypothetical load imparted by an accident to at least two joints for each nylon webbing segment. We also built in redundancies and distributed the load across the dog's body to increase the chances of survival.

These design optimization efforts to distribute load, however, made the stitching connecting the pieces of nylon webbing the weakest point in our design. As such, we followed industry best-practices for high strength stitching by using a high number of stitches per inch (SPI) and the multi-thread chain stitch method to impart the highest possible strength into our product wherever possible. Of course, upon entering full scale production, the stitching used on our product would be of vastly higher quality than that done free-hand by our team.

With our Beta Prototype completed and manufacturing standards established, we intend to either use this prototype, or reproduce portions of it, for product testing. Two of the test options which we are exploring are a mock-up crash test performed with UMTRI and an isolated tensile test of our nylon webbing/stitching. These tests would be invaluable in identifying the deficiencies of our design, leading us to refine the design and improve manufacturing practices where needed.

Functional Optimization Analysis

Once again, following extensive internal contemplation and seeking external advice, our team arrived at the conclusion that performing Functional Optimization Analysis for our product based on the given Excel Solver optimization model would be impractical. This is because the size and shape of our product are already well pre-defined by a number of factors, including the size of dogs it is made for and the size of average seats in cars, for example. Furthermore, of the factors in our project which we do have control over, it is nearly impossible to optimize any of them without obtaining an edge case. An edge case being, for instance, the least cost of the given range or the highest strength of a given range. Therefore, we have optimized our product based on expert testimonies from the University of Michigan's Transportation Research Institute (UMTRI) and the Humane Society of Huron Valley instead of using computational methods.

Bill of Materials and Manufacturing Plans

Table 4 on the following page shows the list of materials used for each of the two major components of our product, the seat and the harness, along with the quantities used of each and their respective prices.

Table 4. Bill of Materials

Part	Material Name	Quantity	Price	Total
Car Seat	Upholstery Foam, 1" thick	6 ft^2	\$1.79 / ft^2	\$10.74
	Nylon Webbing, 1" wide	12 ft	\$0.37 / ft	\$4.44
	Plastic Buckle, for 1" webbing	x4	\$0.15 / ea	\$0.45
	Metal Lobster Clasps, for 1" webbing	x1	\$0.11 / ea	\$0.11
	Ripstop Waterproof Fabric	12 ft^2	\$0.37 / ft^2	\$4.44
Harness	Plastic Buckle, for 1" webbing	x3	\$0.15 / ea	\$0.45
	Metal D-Ring, for 1" webbing	x1	\$0.06 / ea	\$0.06
	Metal Lobster Clasp, for 1" webbing	x1	\$0.11 / ea	\$0.11
	Ripstop Waterproof Fabric	1.4 ft^2	\$0.37 / ft^2	\$0.52
	Nylon Webbing, 1" wide	4.5 ft	\$0.37 / ft	\$1.68
Both	Polyester Sewing Thread (1x Black and 1x White Spool)	2 spools	\$1.19 / ea	\$2.38

To manufacture the dog seat, the 1" thick upholstery foam was first cut down to a size of approximately 24"x44". Then, the corners were rounded off using a razor blade and scissors. A 12 ft^2 piece of ripstop waterproof fabric, measuring approximately 28"x92", was cut using a rotary cutter and wrapped around the upholstery foam such that the edges could be sewn together all around the foam pad. With the foam surrounded by the ripstop fabric, additional lines of stitching were added at approximately 2.5" apart, parallel to the shorter side of the foam pad, to corrugate it. Following this step, the three nylon webbing straps shown in Figure 13 were sewn on to the dog seat's surface. The nylon webbing strap meant to connect to the dog's harness was measured to about 18", while the two nylon webbing straps used to attach the seat to the car's headrest would measure about 40" each. Buckles and lobster clasps were added to the ends of these nylon webbing straps as indicated in our CAD model in Figure 13.

To manufacture the dog harness, we first cut a 1.4 ft^2 piece of waterproof ripstop fabric into two identical pieces of approximately 12"x8" in size. Both were then shaped using scissors to be of identical shapes as seen in Figure 13 (a). The two identical pieces of fabric were then laid one atop the other and their edges were sewn together. Nylon webbing straps were then cut to the dimensions shown in Figure 13 (a) and sewn onto the ripstop fabric as shown in the figure. Plastic buckles, D-rings, and lobster clasps were then sewn onto the nylon straps, once again, as shown, to take the appearance of model in Figure 13 (b).

Ecological Audit

Product Design Review

In this stage of design embodiment, the amount of materials used were optimized on the basis of cutting length, ergonomic needs, and the product's context environment. The selection of materials was considered based on material component requirements, lifecycle, engineering properties, cost, and user comfort perception with the purpose of providing safety for dogs in vehicles.

To determine the sustainability of the product with regards to energy usage and CO_2 emissions, the ecological audit study was to be performed to balance the decisions of material selection on product attributes and environmental sustainability. This study, however, could not be performed in full as the resources did not exist to quantify the environmental impacts of the materials chosen in our iterated prototypes (alpha prototype and beta prototype). Thus, our best ethical judgement was applied in place of definitive data when material selection decisions arose.

Function and Functional Unit of The System

The product has the significant function of restraining the dog and lessening dangerous distractions in a vehicle. The functional units, i.e. the load-bearing elements, of the design system are the stitched webbing connections. As such, those elements must be of the highest strength and quality, regardless of ecological considerations.

System Diagram

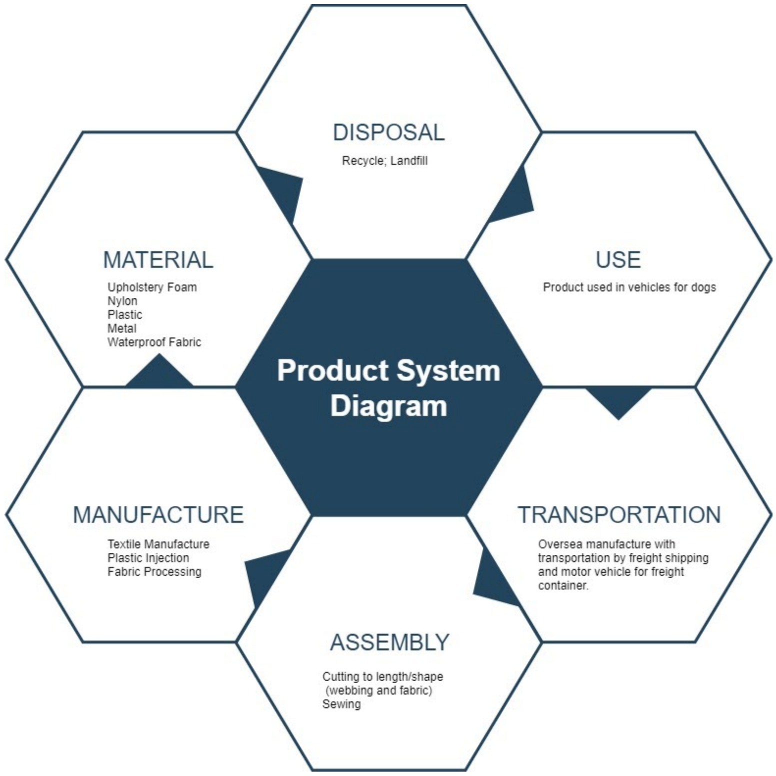


Figure 16. System Diagram of our Product

Output from CES Edupack Eco-Audit

Unfortunately, the CES Edupack Eco-Audit software does not have the resources necessary to carry out ecological audit analysis for the materials used in our product. This is because we have made extensive use of fabrics in our project, instead of rigid engineering materials. Therefore, further analysis is required in this field.

Design Failure Modes and Effects Analysis

Design Failure Mode and Effect Analysis (DFMEA) reduce the risk used in the design process and identify the risks of the design and its subsystems and sub-functions. DFMEA identifies the potential risks and failure modes of design and quantifies them by assigning a Risk Priority Number (RPN). The risk level was decided by designer's observation on acceptable or unacceptable level. The RPN was calculated as the product of Severity Value (SEV), Occurrence Value(OCC), and Detectability Value (DET): RPN = SEV x OCC x DET. The tables in Appendix H were used to identify the rating values of SEV, OCC, and DET associated with each failure effect in order to calculate RPN. Table 5 on the following page shows the different parts of the DFMEA analysis and their results:

Table 5. DFMEA Analysis Results

Item/ Function	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Cause(s) of Failure	Current Design Controls	Detection Method	OCC	DET	RPN
1. Seat Mat	Buckle Failure	Seat mat fails to connect to the car seat.	4	Crash Accident; Pull to failure; Material deforms due to the temperature.	High temperature resistant materials; Position the buckle to the certain area that won't be overpulled.	Visual Detection	2	2	16
	Strip Sewing Failure	Appereance; Dog heath.	6	External and internal materials might be eaten by mistake; Sewing strings are broken.	Use of strong material of string for sewing strip pattern.	Visual Detection	4	2	48
	Webbing Failure	Seat mat fails to connect to the dog; Seat mat fails to connect to the car seat.	4	Crash Accident; Pull to failure; Sewing strings are broken.	Position the webbing sewing connection to the certain area that won't be overpulled; Use of strong mateiral of string for sewing the webbing connections.	Visual Detection	4	3	48
	Clip Failure	Seat mat fails to connect to the car seat.	4	Crash Accident; Pull to failure; Material deforms due to the temperature.	High temperature resistant materials; Position the buckle to the certain area that won't be overpulled.	Visual Detection	2	2	16
2. Sear Harness	Buckle Failure	Dog fails to connect to the car belt.	9	Crash Accident; Pull to failure; Material deforms due to the temperature.	High temperature resistant materials; Position the buckle to the certain area that won't be overpulled.	Visual Detection	2	2	36
	Back Jacket Failure	Sewing sturcture of webbing connections.	5	Sewing strings are broken.	Use of strong material of string.	Visual Detection	3	3	45
	Zip Failure	Damage of storage function.	3	Sewing strings are broken.	Use of strong material of string.	Visual Detection	3	3	27
	Webbing Failure	Dog fails to connect to the car belt; dog fails to connect to the seat mat.	8	Crash Accident; Pull to failure; Sewing strings are broken.	Position the webbing sewing connection to the certain area that won't be overpulled; Use of strong mateiral of string for sewing the webbing connections.	Visual Detection	4	3	96
	Clip Failure	Dog fails to connect to the car belt.	8	Crash Accident; Pull to failure; Material deforms due to the temperature.	High temperature resistant materials; Position the buckle to the certain area that won't be overpulled.	Visual Detection	2	2	32

Product Liability Checklist

In the product liability checklist, our business gets a score of 90 points. This means that our product is at the control established status level. The detailed data to back up this analysis can be found in Appendix I.

Table 6. Product Liability Checklist Results

	TOTAL NO. OF 'YES' ANSWERS	90
Excellent Control	108 – 100	
Control Established	99 – 90	
Acceptable but Below Average Control	89 – 85	
Improvement Required	84 – 70 & Below	

Note: In isolated instances, a few answers may vary because of the nature of certain products or their characteristics. The above scoring chart has been weighted for these variations which, therefore, will not affect self-evaluations.

Adapted from a publication by Fred. S. James & Co. Inc. ([illegible]) prior to its acquisition by Transamerica Inc.

VII. Emotional and Aesthetic Analysis

Results from Survey III: Kansei Analysis

From Survey Survey III: Kansei, we received valuable feedback from 16 participants by sending the survey out to classmates and publishing it on social media platforms. The detailed results of the survey are shown in Appendix F.

In the creation of our survey, we broke down our design into three specific perceptions of functionality: comfort, security, and fun appearance. Each perception could be rated from -2 (Not Very…) to 2 (Very…). According to Figure F-5, the composition of option (1,1,1), which is colored blue and pink, has woven solid fabric, and a metal insert buckle gets the highest fun perception at 1.176. The compositions of options (1,-1,-1) and (-1,-1,-1) tied in getting the highest comfort perception at 1.633. They are composed of the same lush fleece fabric and plastic buckles. For the security perception, option (1,-1,-1) gets the highest score at 1.162. They are composed of red and blue colors,lush fleece fabric, and plastic buckles. The two options deemed to have the overall best perceptions were options (1,-1,1) and (-1,-1,1). This informed us that the choice of color is not critical to the design, but that perceptions of comfort and security are.

Humane Society Interview

Considering that our product mainly focuses on the dog's user experience, there is only so much data that we can gather as we cannot actually know how dogs feel and what they think. Hence, we set up a meeting with a specialist at the Humane Society of Huron Valley, someone who knows dogs better than almost any other human.

This meeting gave us a lot of useful information and opened our eyes to unique perspectives which we had never considered before. Chiefly, this was a suggestion that we weigh the mental comfort of a dog more heavily in our design. We learned that dogs usually feel anxious when it is their first time placed in a new environment, so we need to somehow establish a positive mindset for the dog when using our product. Also, we were told to avoid using anything in our product which could be chewed, unless it is an intentional chew toy of course. Finally, we were advised that dogs are very sensitive to smell, and thus not to use materials in our product with obnoxious, industrial fragrances. Towards the end of our meeting, we were shown a dog harness product similar to our called *Easy Walker*, shown in Figure 17 on the following page.

Figure 17. The Easy Walker Dog Harness

Having gathered much valuable information from our meeting at the Humane Society of Huron Valley, we incorporated a number of design features/decisions into our Beta Prototype. These features included the choice of fasteners, the width of nylon webbing used, and the texture and scent of fabrics selected. Having now completed our Beta Prototype, we have sent our demonstration video to the experts at the humane society for comment and suggestions about further design improvements with the dog's interests in mind.

VIII. Economic Analysis

Market Size Estimation

To begin with our economic analysis, we started to estimate an appropriate market size for our Doggo product. Because we do not have access to the sales data of pet travel product already on the market, we have to make a vague estimation of market size based on some online retailers like Chewy and Kurgo.

According to a survey of pet owners, there were approximately 89.7 million dogs owned in the United States in 2017. This is an increase of over 20% since the beginning of the survey period in 2000, when around 68 million dogs were owned in the United States. According to CityLab, about 80% of Americans own cars. Therefore, we will assume that the number of dog owners is distributed evenly in the number of car owners and is increasing. Hence, there are approximately 71 million dogs that may be transported in a car at some point in their lives. So, the market size is potentially very large, far exceeding the sales numbers in some online shops. Based on this, we will aim to target all dog owners who own cars and wish to transport their dogs safely in them.

Cost Analysis

First of all, it is important to state that costs have been computed based on our intended location of manufacture, Dong Nai, Vietnam. The total material cost for one unit of our product, based on the Beta Prototype manufacturing Bill of Materials, is estimated to be $5.82. According to our estimations of labor costs in the Vietnamese textile industry, the average hourly salary for a sewing machine operator is approximately $3.00 per hour. Given our experiences manufacturing our Beta Prototype, and acknowledging our relative lack of experience in sewing, we estimate that our product could be completed with a total labor cost of $2.53 per unit. Combined with other variable cost factors such as packaging, shipping, and tariffs, the total variable cost equals $14.62 per unit produced. The fixed costs involved in standing up a full production run of our product will include the manufacturing center leasing, the purchase of industrial sewing machines and equipment, and the various fees and licenses associated with opening a business in Vietnam. Therefore, in our business plan, we liberally estimate needing $1.5 million to cover immediate business start-up fixed costs.

Linear Demand Model

The following linear demand model, shown in Figure 18, was generated based on the online purchase histories of several products similar to ours on Amazon.com. This data was interpreted and extrapolated to be our best estimate of annual sales of the products. By plotting these products, we were able to generate an approximate equation for the demand curve of our product.

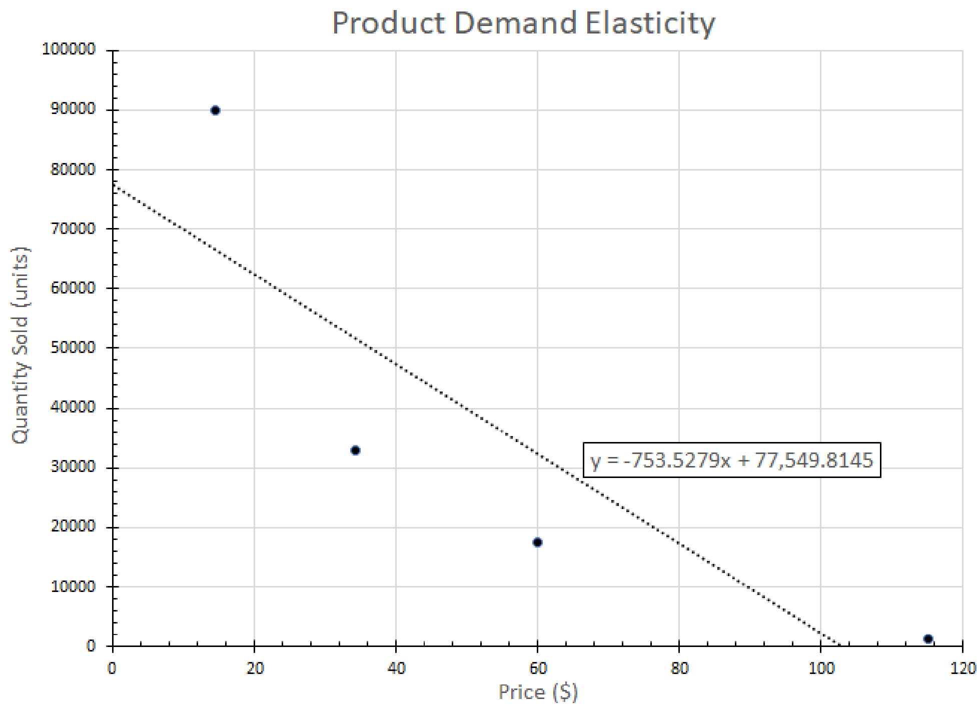


Figure 18. Product Demand Elasticity Model based on online purchase data of similar products

Thus, the quantity of products sold sold at a certain price can be modeled by the Equation 1 below:

$$Quantity = 77549.8145 - 753.5279 * Price \tag{1}$$

Linear Profit Maximization

The profit maximization model on the following page, shown in Figure 19, was created by applying the following Equations 2-4:

$$Revenue = Quantity * Price \tag{2}$$

$$Cost = 50000 + 31.22 * Quantity \tag{3}$$

$$Profit = Revenue - Cost \tag{4}$$

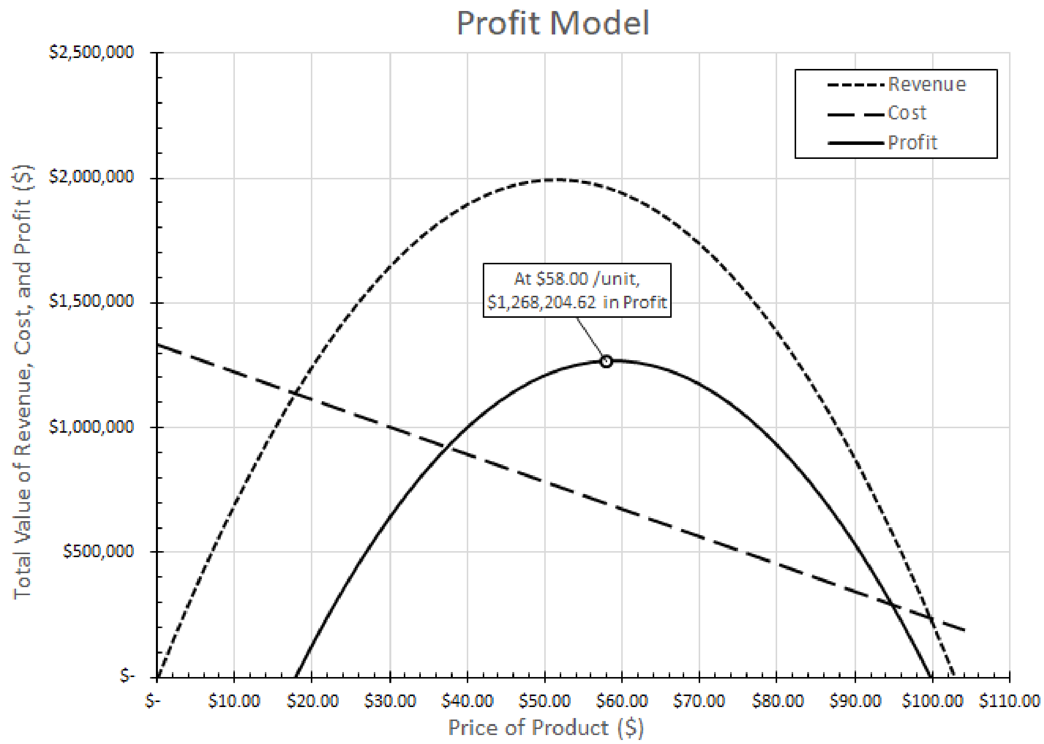


Figure 19. DOGGO Profit Model showing that $58.00/unit is the profit-maximizing MSRP

Based on the profit-maximizing MSRP of $58.00/unit shown in Figure 19, we can expect to make nearly $1.27 million in annual profits. This, of course, is an initial estimate which does not fully account for the possible effects of economies of scale, which would reduce variable costs and change this model's outcome.

IX. Marketing Model

Results from Survey IV: Conjoint Analysis

The conjoint analysis performed using the data from Survey IV provided our team with a lot of valuable information. First, it showed that those surveyed prioritize price heavily over all other factors. Here 57% of respondents placed price as more important than product weight (26.7%), product warranty length (14.5%), and rated dog weight (1.8%), as seen in Figure G-2 in Appendix G. Also, our data showed that a majority of dog owners surveyed had medium sized dogs weighing 36-85 lbs. However, it is worth noting that more than half of our respondents were not dog owners, so the veracity of our survey results may be questionable.

Interpretation of Marketing Model Results

The most interesting results of Survey IV came in the form of the part worth ("beta") values generated by the Sawtooth CBC software. The spline plots of part worths and attributes can be seen in Figure G-1 in Appendix G. The part worths very accurately reflect the relative importance figures discussed above. The part worths for price were very extreme values, the part worths for product weight and warranty were much lower, and the part worths for rated dog weight were much lower still.

Also interesting was the linearity of both the price and warranty spline plots, indicating that there are indeed very clear optimal choices in both cases (lower price and longer warranty). The product weight and rated dog weight spline plots, on the other hand, displayed more of a plateau before plummeting to negative utility. This indicates that the respondents are more open to tradeoffs in these two attributes than they are in price and warranty.

Due to the extreme nature of part worth values in this marketing model, however, price and product weight completely dominate the market share modeling equations. Therefore, in this model, only products that cost $20 and weigh 1lb are viable, with any other combination yielding 0% market share in comparison. Hence, the model conveys a strong message that warranty and rated dog weight are the discriminating factors in securing market share, even though those two attributes were rated least important to the consumer in other data sets.

X. Design Optimization

Full-Model Profit Maximization

Based on the part worth data obtained from Survey IV, we were able to generate a more robust profit maximization model which incorporated the real-world human psychology of decision making. This aspect was a challenge for us as there are few products on the market that are comparable to ours, making it difficult to simulate true market competition. Also, due to the extreme values in our part worth data, as described before, it is very hard to generate truly competitive alternatives to our product without either one sweeping the market with 100% share. Once of the few competitive market models which we were able to generate is shown in Figure 20 on the following page.

Attribute Information from Conjoint Survey

Price			
Level	$20	$40	$60
Est. Beta	114.30	-2.40	-111.90
Product Weight			
Level	1	5	10
Est. Beta	32.40	20.10	-52.50
Warranty Length			
Level	6	12	18
Est. Beta	-24.30	2.40	22.00
Rated Dog Weight			
Level	20	40	60
Est. Beta	2.80	1.50	-4.40

Manufacturing Costs

Fixed Cost	$ 1,500,000.00		
Variable Cost	Cost	per	Unit Cost
Total VC	$ 14.62	unit	$ 14.62

Market Capture

Our Product	Specification	Part Worth Spline Functions	Competitive Product	
Price	$58.00	-101.274	$58.00	-101.27
Product Weight	1.7	33.189168	1.0	32.4
Warranty Length	18.00	22	18.00	22
Rated Dog Weight	22	2.877	20	2.8
	"V"	% of Market that Chooses Our Product		
Our Product	-43.21	70.395%		
Competitive Product	-44.07	29.605%		
No Choice	-159.30	0.000%		

Market Size

Total Consumers	100,000
Qm	70395

Profitability = Revenue - Costs

Revenue	$ 4,082,897
Costs	$ 2,529,172
Profit	**$ 1,553,725**

Figure 20. Example Inputs and Outputs of Competitive Market Profit Maximization

Judging by this model, it is clear that the MSRP of our product is significantly hampering our competitiveness on the open market. This is evidenced by the significantly negative part worth of -101.274. Meanwhile, all other part worths are quite strongly positive. However, due to the imbalance of part worth magnitudes, our product is only remotely competitive if the competing product is also priced at the same level.

Optimized Price and Design Variables

Our design is already well optimized in three of the four attributes evaluated in Survey IV, namely product weight, warranty length, and rated dog weight. In all of those attributes, our product displays near optimal part worth values. Price, however, has a serious negative impact on our profitability. As it stands, any competing product which undercuts our MSRP would immediately take our entire market share. Thankfully, since we have set our $58.00 MSRP well above our $14.62 variable cost, we reserve the ability to reduce our product's price significantly in order to remain competitive on the market, albeit at lower profit margins.

We have devised a plan in response to this realization to maximize our profit and maintain our market foothold. Initially, realizing that we are entering a relatively uncontested market where there are few true competitors, we will set MSRP according to the initial linear profit model at $58.00. This will allow us to maximize profit in the short term and quickly pay off our $1.5 in investments. As competitors arise, we will reduce the price incrementally to at least maintain our market share, and ideally grow our market share at a consistent 10% annual growth rate. This plan should optimize our business' viability, profitability, and stability in the long term.

XI. Business Analysis

Pro-forma Income and Cost Projections

Table 7 below shows the Pro-forma Income and Cost Projection for the first 6 years of operation. Initial investment, equipment purchases, and all the preparations for manufacturing occur in Year 0. In Year 1, DOGGO will hit the market and sales are projected to reach a conservative 50,000 units. Sales are projected to grow from there by maintaining a conservative 10% annual growth rate. The total expenditures are based on employee salaries, office needs, logistics, and maintenance. In Year 0, we will start by hiring the Production Manager who will help to build up the plant and train the newly hired hourly workers. The running cash balance will top $15 million in Year 5 based on these estimates.

Table 7. Pro-forma Cash Flow Analysis

Pro-forma Cash Flow Analysis						
Project Year	**0**	**1**	**2**	**3**	**4**	**5**
Calendar Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
QTY Sold	**0**	**50,000**	**55,000**	**60,500**	**66,550**	**73,205**
Income						
Initial Personal Investment	$0	$0	$0	$0	$0	$0
Investor Contributions	$1,500,000	$0	$0	$0	$0	$0
Product Revenue	$0	$2,900,000	$3,190,000	$3,509,000	$3,859,900	$4,245,890
Total Income	$1,500,000	$2,900,000	$3,190,000	$3,509,000	$3,859,900	$4,245,890
Expense						
Eqmt and Launch Investment	$163,000	$0	$0	$0	$0	$0
Facility	$24,000	$24,000	$24,000	$24,000	$24,000	$24,000
Material Cost	$0	$291,000	$320,100	$352,110	$387,321	$426,053
Manufacturing Cost	$0	$4,000	$4,000	$4,000	$4,000	$4,000
Salaried Staff	$12,193	$12,193	$12,193	$12,193	$12,193	$12,193
Hourly.Staff (2 workers)	$0	$12,480	$12,480	$12,480	$12,480	$12,480
Office Needs	$500	$150	$150	$150	$150	$150
Logistics (Shipping & Tariff)	$0	$244,500	$268,950	$295,845	$325,430	$357,972
Total Expenses	$199,693	$588,323	$641,873	$700,778	$765,574	$836,849
Qtrly Cash Balance	$1,300,307	$2,311,677	$2,548,127	$2,808,222	$3,094,327	$3,409,041
Running Cash Balance	$1,300,307	$3,611,984	$6,160,111	$8,968,333	$12,062,660	$15,471,701

NPV Analysis

Net Present Value is defined by the cash flows expected to be received over 5 years. Here we assume that 50,000 units will be sold annually. Based on investment costs, annual operating costs from the previous section, and annual income, the NPV of DOGGO was determined to be $8,317,659, as seen in Table 8 below.

Table 8. NPV of DOGGO

Net Present Value		
		Dong Nai Facility
Useful Life	[years]	5
Investment Cost	[$]	-$1,500,000
Annual Operating Cos	[$]	-$569,323
Annual Income	[$]	$2,900,000
Salvage Value	[$]	$0
Interest Rate		0.06
Total Time	[years]	5.00
Life Time Periods		1
Investment Cost #1	[$]	($1,500,000)
Investment Cost #2	[$]	$0
Investment Cost #3	[$]	$0
Investment Cost #4	[$]	$0
Investment Cost Total	[$]	($1,500,000)
Operating Cost	[$]	($2,398,196)
Annual Income	[$]	$12,215,855
Salvage Value Period 1	[$]	$0
Salvage Value Period 2	[$]	$0
Salvage Value Period 3	[$]	$0
Salvage Value Period 4	[$]	$0
Total Salvage Value	[$]	$0
NPV	[$]	**$8,317,659**

Break-Even Analysis

Based on the break-even analysis in Table 9 on the following page, we expect to break-even in Quarter 3 of the 1st year of business without requiring any extra investment. The exact time to break even is 0.68 years.

Table 9. Break Even Analysis

Break Even Analysis		
		Dong Nai Facility
Useful Life	[years]	1
Investment Cost	[$]	-$1,500,000
Annual Operating Cos	[$]	-$569,323
Annual Income	[$]	$2,900,000
Salvage Value	[$]	$0
Interest Rate		0.06
Total Time	[years]	**0.68**
Life Time Periods		1.00
Investment Cost #1		($1,500,000)
Investment Cost #2		$0
Investment Cost #3		$0
Investment Cost #4		$0
Investment Cost Total		($1,500,000)
Operating Cost		-366,411
Annual Income		1,866,411
Salvage Value Period 1		0
Salvage Value Period 2		0
Salvage Value Period 3		0
Salvage Value Period 4		0
Total Salvage Value		0
NPV		**0**

Business Projection Assumptions

- Base-year units sold: 50,000
- Same number of employees for the first five years.
- Salary/hourly growth rate is the same as the interest rate for the five year period
- Interest Rate: 6%
- MSRP: $58.00
- Sales growth rate: 10%

Appendix A. References

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11. Custom Sewing Price List: How Much to Charge for Sewing https://sewingiscool.com/how-much-to-charge-for-sewing/#tab-con-2

Appendix B. Survey I Data

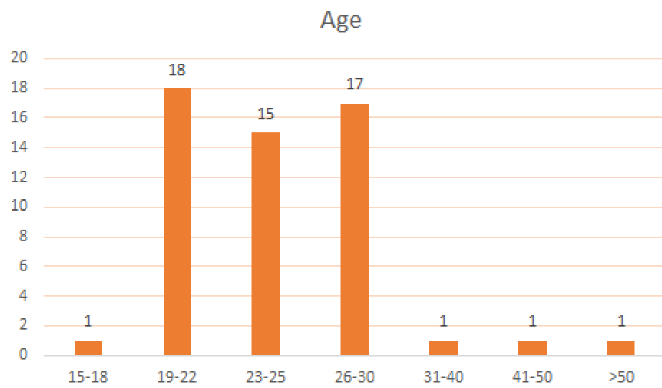


Figure B-1. Survey Responses showing the majority of respondents are 19 to 30 years old

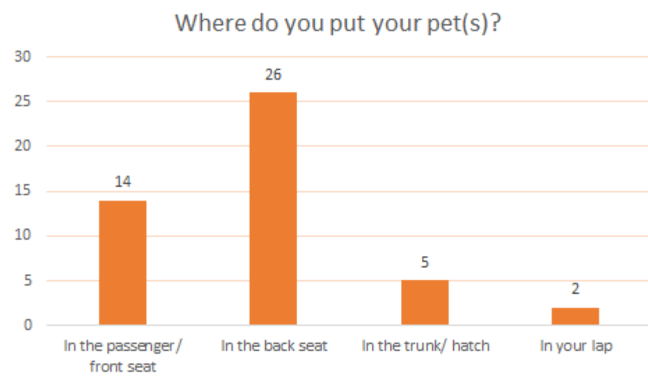
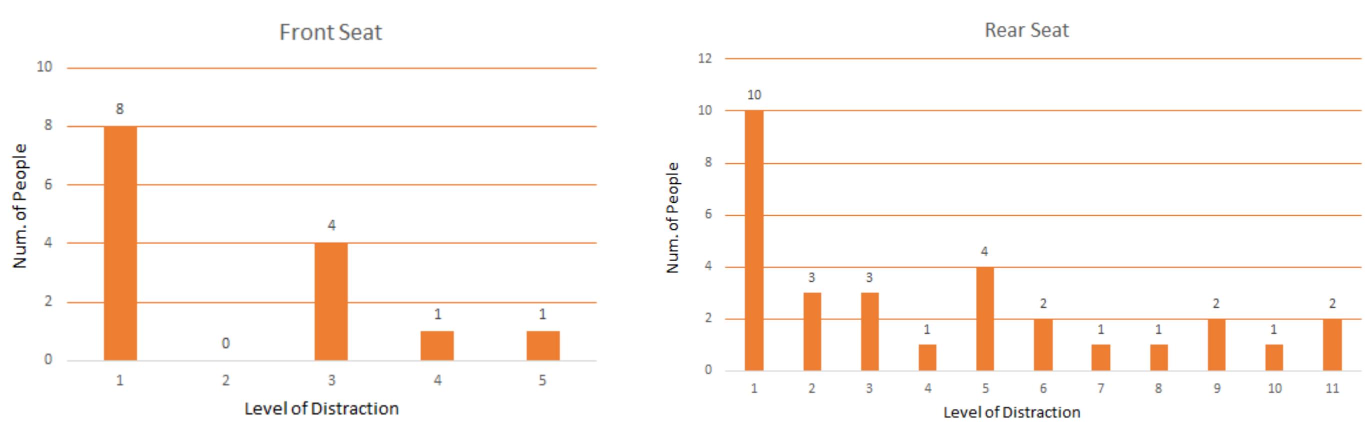


Figure B-2. Survey Responses showing the Back Seat as the most common place for Dogs in cars



(1) (2)

Figure B-3. The Level of Distraction from Dogs in (1) the Front and (2) the Rear Seats.

Appendix C. Survey II Data

There are 27 valid responses with 19 (70%) candidates who do not have dog(s) and 8 (30%) candidates have dog(s).

Conjoint Questions

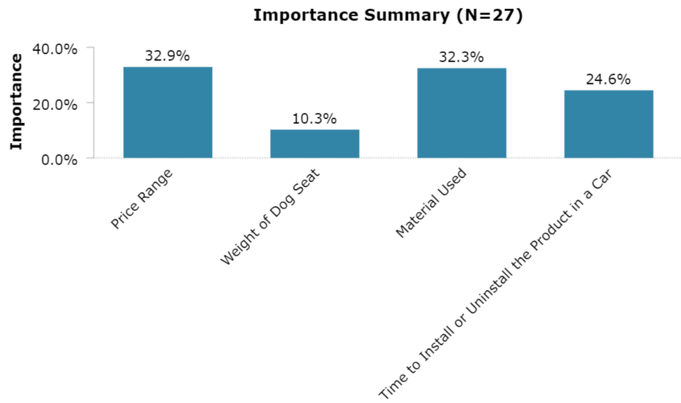


Figure C-1. Conjoint survey data showing Price and Materials Used as the most important attributes (relatively) to our design

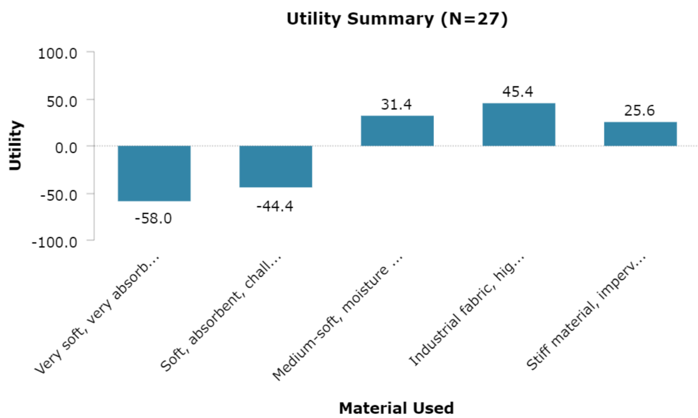


Figure C-2. Conjoint survey data showing Material Preferences focusing on more industrial, easily cleanable materials

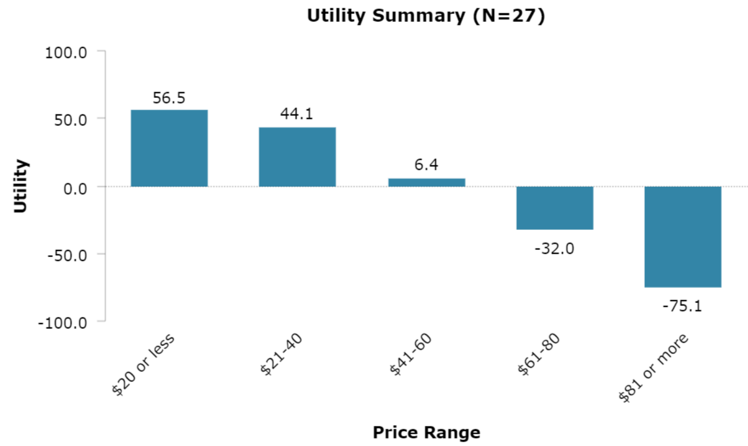


Figure C-3. Conjoint survey data showing Price Preferences heavily skewed to the lower end of the spectrum, $40 and below

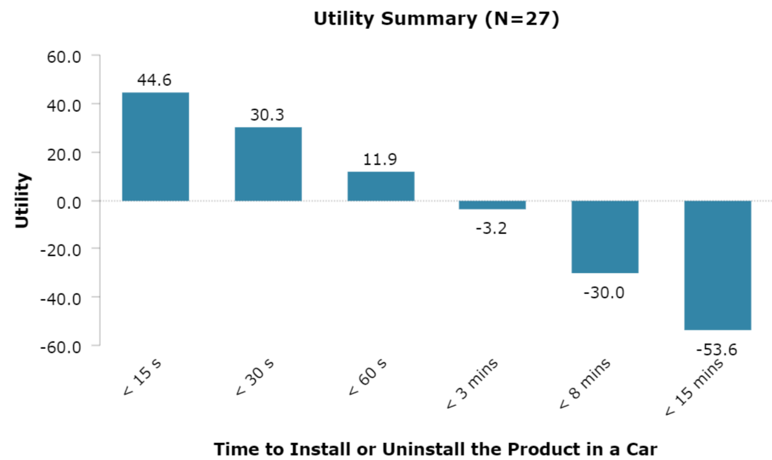


Figure C-4. Conjoint survey data showing Install / Uninstall Time Preferences heavily skewed to the shorter lengths of time, 60 seconds of less

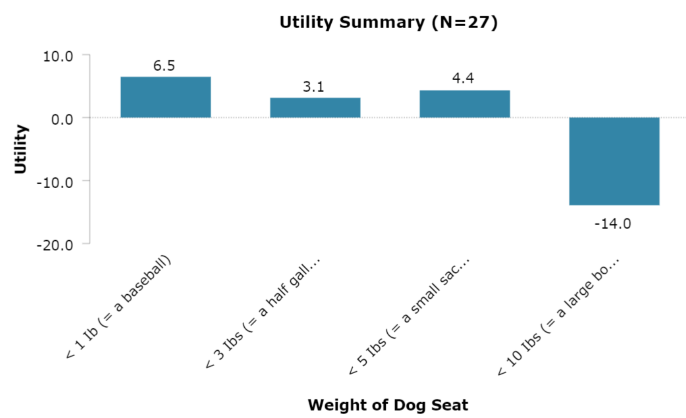


Figure C-5. Conjoint survey data showing Product Weight Preferences generally in favor of a final product weight of 5 lbs or less

Functional Questions

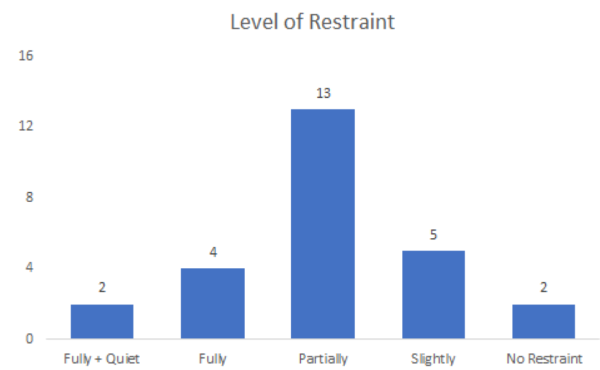


Figure C-6. Survey data showing a strong preference for the dog to be only Partially Restrained

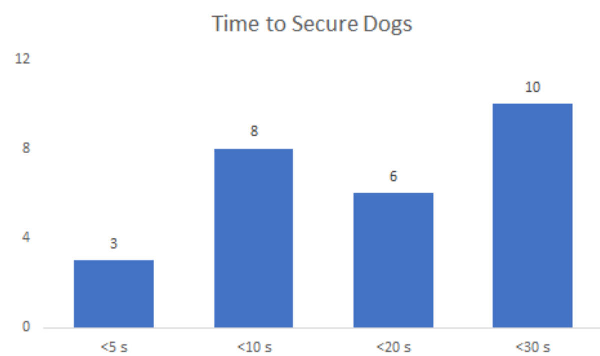


Figure C-7. Survey data showing essentially no preference in our customers' Time to Secure Dogs in our product

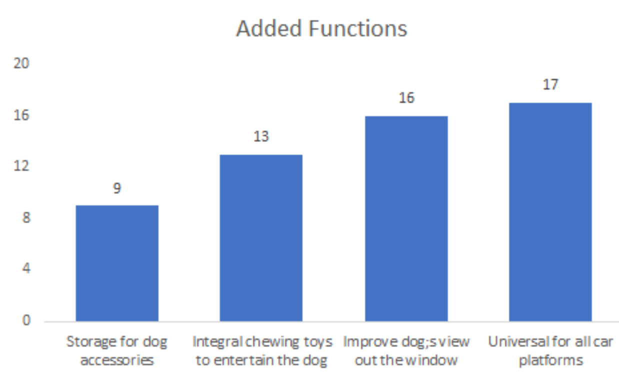


Figure C-8. Survey data showing that the most desired functions of our product are to be Universal for all Cars and to Improve the Dog's View out the Window

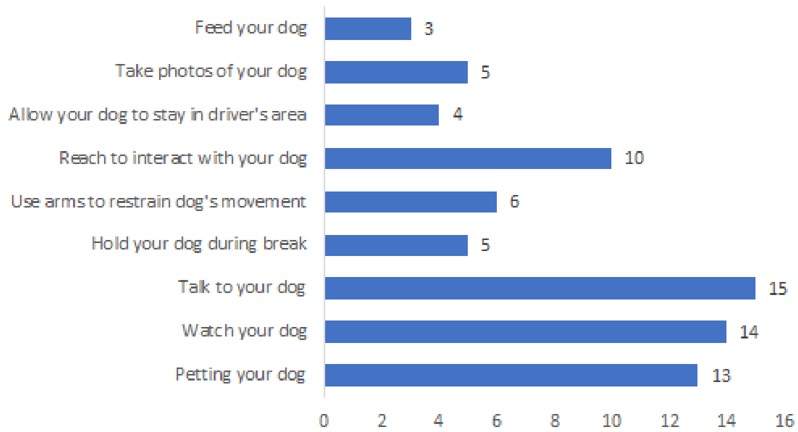
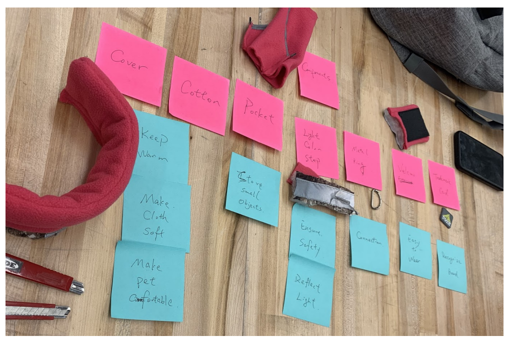


Figure C-9. Survey data showing the most common interactions drivers have with their dogs while driving

Appendix D. Concept Generation - Additional Figures

Results from Reverse Design

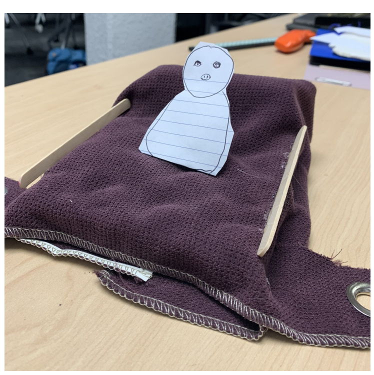
(a) **(b)** **(c)** **(d)**

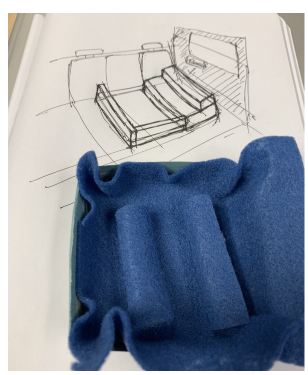


(e)

Figure D-1. A photographic record of our **(a)(b)(c)(d)** Reverse Design activity and **(e)** the associated Functional Decomposition flowchart

Results from Quick Concept Prototyping





(a) **(b)**

Figure D-2. The two Quick Concept Prototypes we generated with **(a)** being the concept focussed on dog comfort and **(b)** being the concept focussed on dog entertainment

Final Concept

Description of Functionality

Figure D-3. Functional Diagram showing the linked product features

Alpha Prototype

(a) **(b)**

Figure D-4. **(a)** The way to lift **(b)**Layout of function modules

(a) **(b)**

Figure D-6. **(a)** Put it in car **(b)**Put it on dog

Appendix E. Design Embodiment - Additional Figures

RESERVED

Appendix F. Survey III Data

X1 X2 X3	perception	#of r	weighted responses	Y1 Average Scores	perception	#of responses	weighted responses	Y2 Average Scores	perception	#of responses	weighted responses	Y3 Average Scores
1 1 1	2 Very fun	5	10		Very comfortable	1	2		Very secure	6	12	
	1 Slightly fun	9	9		Slightly comfortable	11	11		Slightly secure	7	7	
	0 Neutral	3	0		Neutral	2	0		Neutral	4	0	
	-1 Slightly not fun	0	0		Slightly not comfortable	3	-3		Slightly not secure	0	0	
	-2 very not fun	0	0	1.12	very not comfortable	0	0	0.59	very not secure	0	0	1.12
-1 1 1	2 Very fun	5	10		Very comfortable	1	2		Very secure	8	16	
	1 Slightly fun	6	6		Slightly comfortable	11	11		Slightly secure	6	6	
	0 Neutral	3	0		Neutral	3	0		Neutral	3	0	
	-1 Slightly not fun	2	-2		Slightly not comfortable	2	-2		Slightly not secure	0	0	
	-2 very not fun	1	-2	0.71	very not comfortable	0	0	0.65	very not secure	0	0	1.29
-1 1 -1	2 Very fun	4	8		Very comfortable	7	14		Very secure	1	2	
	1 Slightly fun	7	7		Slightly comfortable	1	1		Slightly secure	7	7	
	0 Neutral	4	0		Neutral	8	0		Neutral	5	0	
	-1 Slightly not fun	1	-1		Slightly not comfortable	1	-1		Slightly not secure	4	-4	
	-2 very not fun	1	-2	0.71	very not comfortable	0	0	0.82	very not secure	0	0	0.29
1 -1 -1	2 Very fun	5	10		Very comfortable	14	28		Very secure	1	2	
	1 Slightly fun	10	10		Slightly comfortable	3	3		Slightly secure	8	8	
	0 Neutral	2	0		Neutral	0	0		Neutral	3	0	
	-1 Slightly not fun	0	0		Slightly not comfortable	0	0		Slightly not secure	5	-5	
	-2 very not fun	0	0	1.18	very not comfortable	0	0	1.82	very not secure	0	0	0.29
1 -1 1	2 Very fun	5	10		Very comfortable	14	28		Very secure	7	14	
	1 Slightly fun	9	9		Slightly comfortable	1	1		Slightly secure	4	4	
	0 Neutral	2	0		Neutral	2	0		Neutral	4	0	
	-1 Slightly not fun	1	-1		Slightly not comfortable	0	0		Slightly not secure	2	-2	
	-2 very not fun	0	0	1.06	very not comfortable	0	0	1.71	very not secure	0	0	0.94
1 1 -1	2 Very fun	5	10		Very comfortable	1	2		Very secure	3	6	
	1 Slightly fun	9	9		Slightly comfortable	8	8		Slightly secure	5	5	
	0 Neutral	3	0		Neutral	6	0		Neutral	5	0	
	-1 Slightly not fun	0	0		Slightly not comfortable	2	-2		Slightly not secure	4	-4	
	-2 very not fun	0	0	1.12	very not comfortable	0	0	0.47	very not secure	0	0	0.41
-1 -1 1	2 Very fun	5	10		Very comfortable	12	24		Very secure	6	12	
	1 Slightly fun	7	7		Slightly comfortable	2	2		Slightly secure	5	5	
	0 Neutral	4	0		Neutral	3	0		Neutral	5	0	
	-1 Slightly not fun	0	0		Slightly not comfortable	0	0		Slightly not secure	1	-1	
	-2 very not fun	1	-2	0.88	very not comfortable	0	0	1.53	very not secure	0	0	1.00
-1 -1 -1	2 Very fun	5	10		Very comfortable	12	24		Very secure	2	4	
	1 Slightly fun	7	7		Slightly comfortable	3	3		Slightly secure	5	5	
	0 Neutral	3	0		Neutral	2	0		Neutral	5	0	
	-1 Slightly not fun	1	-1		Slightly not comfortable	0	0		Slightly not secure	5	-5	
	-2 very not fun	1	-2	0.82	very not comfortable	0	0	1.59	very not secure	0	0	0.53

X1	X2	X3	Y1	Y2	Y3
1	1	1	1.1	0.6	1.12
-1	1	1	0.7	0.6	1.29
-1	1	-1	0.7	0.8	0.29
1	-1	-1	1.2	1.8	0.29
1	-1	1	1.1	1.7	0.94
1	1	-1	1.1	0.5	0.41
-1	-1	1	0.9	1.5	1.00
-1	-1	-1	0.8	1.6	0.53

Figure F-1. Average score for each design option

SUMMARY OUTPUT								
回归统计								
Multiple R	0.96339244							
R Square	0.928125							
Adjusted R S	0.87421875							
标准误差	0.14105387							
观测值	8							
方差分析								
	df	SS	MS	F	Significance F			
回归分析	3	1.02768166	0.34256055	17.2173913	0.00945099			
残差	4	0.07958478	0.01989619					
总计	7	1.10726644						
	Coefficients	标准误差	t Stat	P-value	Lower 95%	Upper 95%	下限 95.0%	上限 95.0%
Intercept	0.735	0.050	14.744	0.000	0.597	0.874	0.597	0.874
X Variable 1	-0.044	0.050	-0.885	0.426	-0.183	0.094	-0.183	0.094
X Variable 2	0.044	0.050	0.885	0.426	-0.094	0.183	-0.094	0.183
X Variable 3	0.353	0.050	7.077	0.002	0.214	0.491	0.214	0.491

Y1 = 0.735=0.044X1 +0.044X2+0.353X3

Figure F-2. Regression of Comfort Perception

SUMMARY OUTPUT	
回归统计	
Multiple R	0.97531451
R Square	0.95123839
Adjusted R S	0.91466718
标准误差	0.16507312
观测值	8

方差分析

	df	SS	MS	F	Significance F
回归分析	3	2.12629758	0.70876586	26.010582	0.00438504
残差	4	0.10899654	0.02724913		
总计	7	2.23529412			

	Coefficients	标准误差	t Stat	P-value	Lower 95%	Upper 95%	下限 95.0%	上限 95.0%
Intercept	1.147	0.058	19.654	0.000	0.985	1.309	0.985	1.309
X Variable 1	0.000	0.058	0.000	1.000	-0.162	0.162	-0.162	0.162
X Variable 2	-0.515	0.058	-8.819	0.001	-0.677	-0.353	-0.677	-0.353
X Variable 3	-0.029	0.058	-0.504	0.641	-0.191	0.133	-0.191	0.133

Y2 = 1.147 -	0X1 - 0.515X2- 0.029X3

Figure F-3. Regression of Fun Perception

SUMMARY OUTPUT	
回归统计	
Multiple R	0.962572
R Square	0.926544
Adjusted R S	0.871452
标准误差	0.068977
观测值	8

方差分析

	df	SS	MS	F	Significance F
回归分析	3	0.240052	0.080017	16.81818	0.009866
残差	4	0.019031	0.004758		
总计	7	0.259083			

	Coefficients	标准误差	t Stat	P-value	Lower 95%	Upper 95%	下限 95.0%	上限 95.0%
Intercept	0.949	0.024	38.895	0.000	0.881	1.016	0.881	1.016
X Variable 1	0.169	0.024	6.935	0.002	0.101	0.237	0.101	0.237
X Variable 2	-0.037	0.024	-1.508	0.206	-0.104	0.031	-0.104	0.031
X Variable 3	-0.007	0.024	-0.302	0.778	-0.075	0.060	-0.075	0.060

Y3 = 0.949-	0.169X1-0.037X2-0.007X3

Figure F-4. Regression of Secure Perception

FUN OBJECTIVE

Y1 = 0.735+0.044X1 +0.044X2+0.353X3

COMFORTABLE OBJECTIVE

Y2 = 1.147 +0X1 - 0.515X2- 0.029X3

SECURE OBJECTIVE

Y3 = 0.949+0.169X1-0.037X2-0.007X3

Design Characteristics			Perception		
X1 color	X2 Material	X3 Joint	Y1	Y2	Y3
1	1	1	1.176	0.603	1.074
-1	1	1	1.088	0.603	0.736
-1	1	-1	0.382	0.661	0.75
1	-1	-1	0.382	1.691	1.162
1	-1	1	1.088	1.633	1.148
1	1	-1	0.47	0.661	1.088
-1	-1	1	1	1.633	0.81
-1	-1	-1	0.294	1.691	0.824

Figure F-5. Optimization (tradeoff space)

Figure F-6. Design Option 1

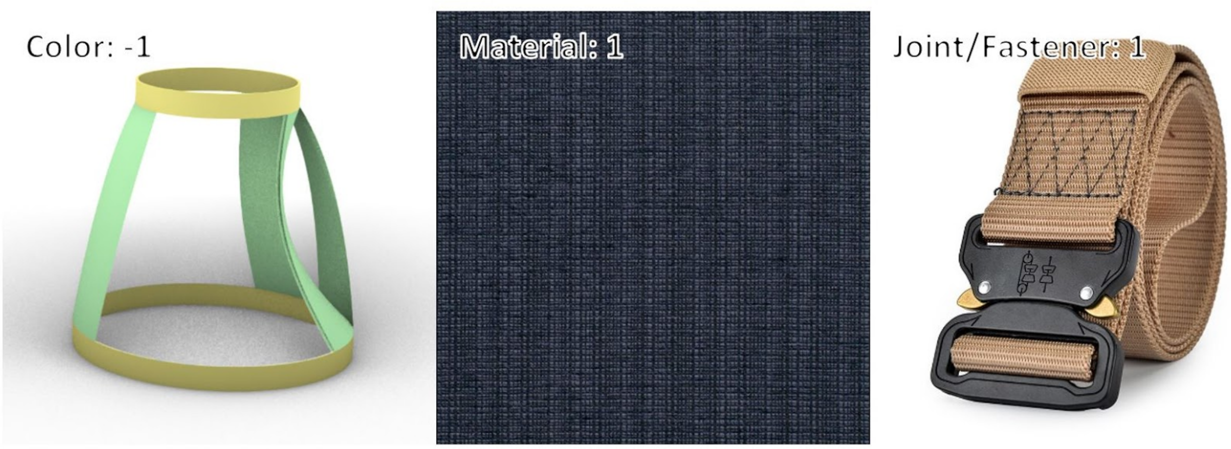


Figure F-7. Design Option 2

Figure F-8. Design Option 3

Figure F-9. Design Option 4

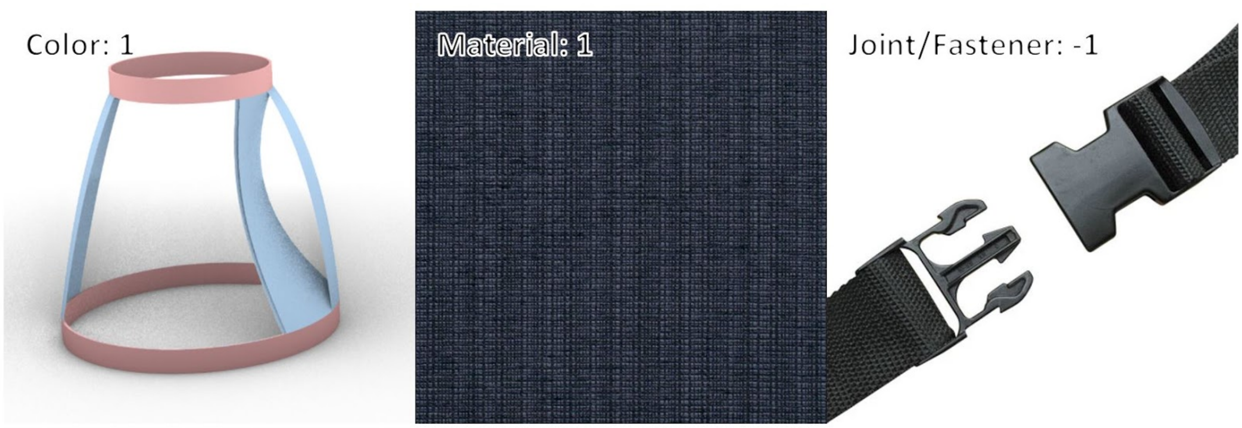


Figure F-10. Design Option 5

Figure F-11. Design Option 6

Figure F-12. Design Option 7

Figure F-13. Design Option 8

Appendix G. Survey IV Data

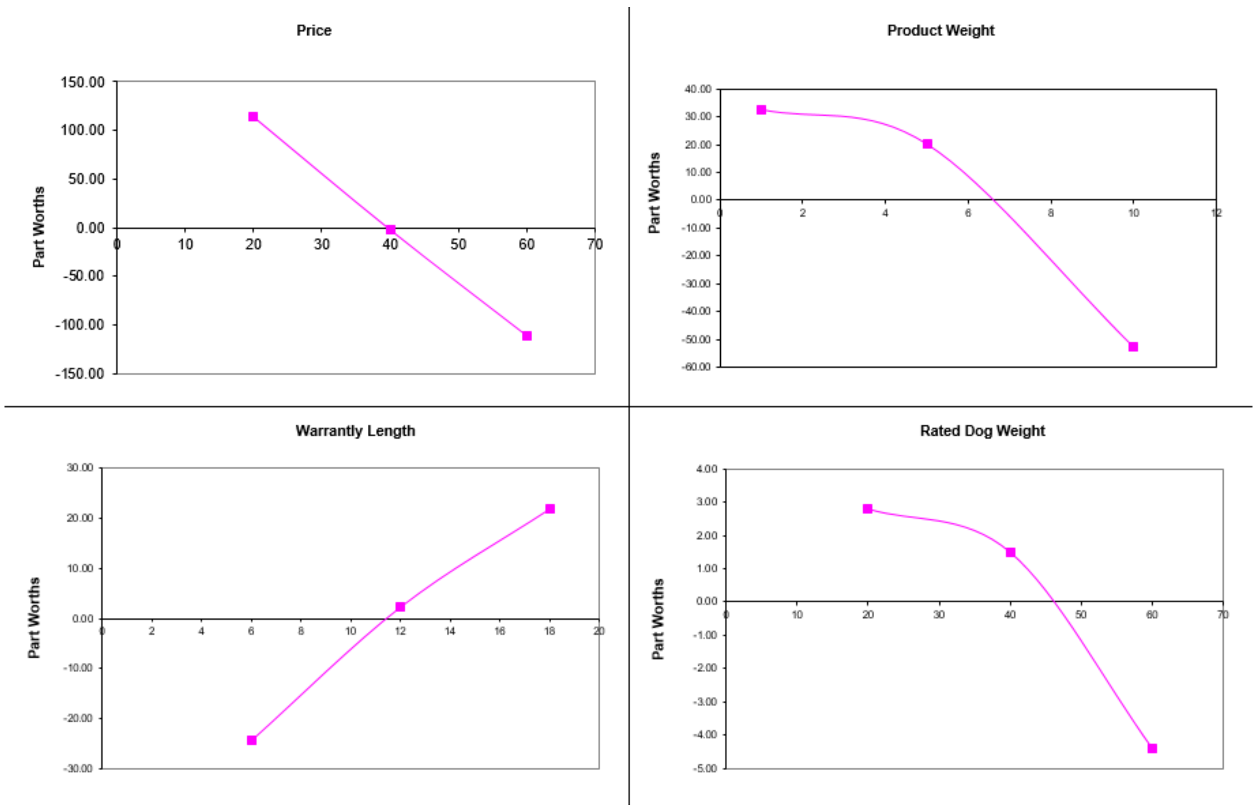


Figure G-1. CBC Part Worth Plots for our 4 Attributes

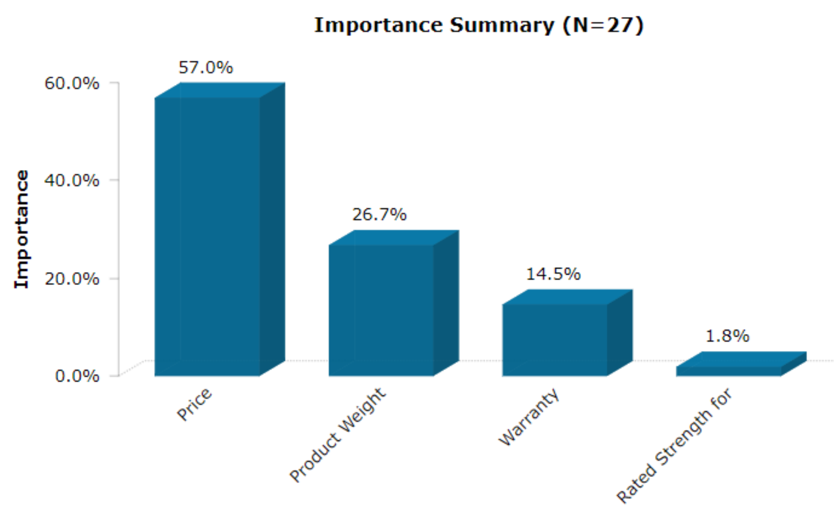


Figure G-2. Ranking of Attribute Importance, showing Price as the Primary Factor

Appendix H. DFMEA Tables

Table H-1. Severity Value Level

Rating Value (SEV)	Description	Definition (Severity)
10	Dangerously High	Failure could injure a customer.
9	Extremely High	Failure would result in non-compliance with federal regulations.
8	Very High	Failure results in a product unfit for use.
7	High	Failure results in a high degree of customer dissatisfaction
6	Moderate	Failure results in a partial malfunction of the product (subsystem or sub-component)
5	Low	Failure causes a performances loss warranting a complaint
4	Very Low	Failure can be overcome with modifications to product, but there is a performance loss.
3	Minor	Failure creates a nuisance to the customer, but this does not result in performance loss.
2	Very Minor	Failure may not be apparent, but it has minor effects on the product.
1	None	Failure is not noticeable and does not affect the product.

Table H-2. Occurrence Value Level

Rating Value (OCC)	Description	Potential Failure Rate
10	Very High – Failure is almost inevitable	More than one occurrence per day or probability of more than 3 in 10 occurrences
9	High – Failure occurs almost as often as not	One occurrence every three to four days or probability of 3 in 10 occurrences
8	High – Repeated failures	One occurrence per week or probability of 5 in 100 occurrences
7	High – Failures occur often	One occurrence per month or 1 in 100 occurrences
6	Moderately High – Frequent failures	One occurrence every 3 months or 3 in 1,000 occurrences
5	Moderate – Occasional failures	One occurrence every 6 months to 1 year or 5 in 10,000 occurrences
4	Moderately Low – Infrequent failures	One occurrence per year or 6 in 100,000 occurrences
3	Low – Relatively few failures	One occurrence every 1-3 years or 6 in ten million occurrences

2	Low – Failures are few and far between	One occurrence every 3-5 years or 2 in one billion occurrences
1	Remote – Failure is unlikely	One occurrence greater than 5 years or less than 2 in one billion occurrences

Table H-3. Detectability Level

DET Rating	Definition of Detectability
5	Undetectable until a catastrophe occurs (likelihood to reach customer = very high)
4	Detectable only by customer service and/or during service (likelihood to reach customer = high)
3	Detectable before reaching the customer (likelihood to reach customer = moderate or significant)
2	Detectable after release but before production (likelihood to reach customer = low or minor)
1	Will be detected before product release (likelihood to reach customer = very low to none)

Appendix I. Product Liability Checklist

Table I-1. Full Chart of the Product Liability Checklist

	A	B	C	D
1	PRODUCT LIABILITY SCORECARD			
2				
3		YES	NO OR DON'T KNOW	
4	KNOW YOUR PRODUCT			
5	Do you know who will use your product?			
6	Do you know who could use your product?			
7	Do you know the number of incidents involving your product?			
8	Do you know the number of liability claims involving your product?			
9	Do you know where your product is sold?			
10	Do you know where your product is stored?			
11	Do you know where your product is used?			
12	Do you know the design life of your product?			
13	Could the loss occur during the design life?			
14	Could the loss occur after the design life?			
15	Could the loss occur during disposal of your product?			
16	Can the loss occur during the placement and/or installation of your product?			
17	Can the loss occur during the operation and/or use of your product?			
18	Can the loss occur during the transportation of your product?			
19	Can your product be used by someone unable to understand its use or instructions because of age or language barrier?			
20	Can it cause personal injuries through proper use?			
21	Can it cause personal injuries through improper use?			
22	Can it cause property damage?			
23	Can it cause an inconvenience? (Due to production delay, etc.)			
24	Could the loss be caused by malfunction of the product?			
25	Could the loss be caused by misuse of the product?			
26	Could the loss be caused by physical breakdown of the product?			
27	Could the loss be caused by inherent hazard of the product?			
28	Could the loss be caused by a part or component manufactured by your company?			
29	Could the loss be caused by a part or component manufactured by others?			
30	Could the loss occur by your failure to instruct the user?			
31	Could the loss be caused by your failure to warn the user of the inherent hazard?			
32	Could the loss occur by your misinforming the user?			
33	Can your product be damaged during shipment?			
34	Can your product cause personal injury and/or property damage during shipment?			
35	NO. OF 'YES' ANSWERS		17	
36				
37	YOUR ORGANIZATION'S RESISTANCE FACTOR			
38	Can you define top management's attitude towards the sale of the product?			
39	Can you define top management's attitude towards the design of your product?			
40	Can you define top management's attitude towards the manufacture of the product?			
41	Can you define top management's attitude towards the sale of the product?			
42	Can you define how this attitude is communicated to others?			
43	Is there a written corporate policy concerning product safety?			
44	Do you know your employees' attitude towards your company?			
45	Do you know the attitudes of your employees towards your product?			
46	Can you define how product safety responsibility is conveyed?			
47	Can you name the member of management responsible for product safety?			
48	Do you know how many other members of management have clearly defined product safety responsibilities?			
49	Were your answers to the above based on a recent survey (as opposed to your opinion)?			
50	NO. OF 'YES' ANSWERS		7	
51				
52	DESIGN ATTITUDES			
53	Does your company have a formalized policy on product design?			
54	Is your company philosophy on product design based on safe use?			
55	Is your company's philosophy on product design based on safe design?			
56	Is your product performance evaluation adequate?			
57	Have you undertaken a specialized hazard analysis of your product?			
58	Do you know all the codes and standards applicable to your product?			
59	Do you know the difference between a code and standard concerning your products?			
60	Is your company involved in establishing updated codes and standards?			
61	Are your industry codes and standards adequate for the user's protection?			
62	Do you attempt to exceed industry standards?			
63	Do you know who is responsible for product design?			
64	Do you know how much safety engineering is involved in product design?			
65	Do you know how much human factor engineering is involved in product design?			
66	Are inherent uncontrolled hazards identified for the user?			
67	Is design approved by a licensed engineer?			
68	Do you know how critical parts of the product are identified?			
69	Are design limitations clearly and permanently marked on the product?			
70	Can you identify in-house test procedures of the finished product and design?			
71	Can you identify outside agency testing procedures of finished product and design?			
72	Have procedures been developed to handle product accident information?			
73	Have procedures been developed to handle incident and complaint information?			
74	NO. OF 'YES' ANSWERS		19	
75				
76	PRODUCTION DESIGN			
77	Has a study been made on the production flow to determine adverse effects on the design criteria of the product?			
78	Do you have control over production requirements for materials used?			
79	Have quality production standards been established?			
80	Is there a separation of responsibilities between production and quality control?			
81	Are transportation and packaging standards being followed?			
82	NO. OF 'YES' ANSWERS		5	

76	PRODUCTION DESIGN		
77	Has a study been made on the production flow to determine adverse effects on the design criteria of the product?		
78	Do you have control over production requirements for materials used?		
79	Have quality production standards been established?		
80	Is there a separation of responsibilities between production and quality control?		
81	Are transportation and packaging standards being followed?		
82	NO. OF 'YES' ANSWERS		5

	A	B	C
83			
84	PRODUCTION PROCEDURES		
85	Are raw material and component parts inspected and tested to assure that they meet design and purchase order standards?		
86	Do you know the type of records maintained of inspection and test? Are those records adequate?		
87	Are performance requirements of component parts conveyed to suppliers?		
88	Are performance requirements of raw materials conveyed to suppliers?		
89	Are quality control procedures adequate?		
90	Are quality control procedures clearly defined?		
91	Are procedures for handling rejects and/or unsatisfactory products clearly defined?		
92	Are the procedures for handling rejects and/or unsatisfactory products practiced?		
93	Are critical parts permanently identified by manufacturer?		
94	Are critical parts permanently identified as to date of manufacture?		
95	Are protective devices in place before shipment?		
96	Are all protective warnings in place before shipment?		
97	NO. OF 'YES' ANSWERS		11
98			
99	SELLING PROCEDURES		
100	Have specific training procedures concerning use of the product been established for field personnel?		
101	Is wording of promotional material reviewed to assure that the product and its use are correctly implied?		
102	Are promotional pictures reviewed to assure that the product and its use are correctly implied?		
103	Are promotional technical data reviewed to assure the product and its use are correctly implied?		
104	Is the wording of product labeling reviewed to assure that the product and its use are correctly implied?		
105	Is product labeling reviewed to assure that technical figures are correct?		
106	Is wording of instructional material reviewed to assure the product and its use are correctly implied?		
107	Are pictures used in instructional materials reviewed to assure that the product and its use are correctly implied?		
108	Is technical data used in instructional material reviewed to assure that the product and its use are correctly implied?		
109	Is sales material easily understood by the users?		
110	Is instructional material easily understood by the users?		
111	Have you adequately considered translating promotional and instructional material into additional languages?		
112	Are verbal presentations by sales personnel periodically reviewed to assure that the product and its use are correctly implied?		
113	NO. OF 'YES' ANSWERS		12
114			
115	SERVICING PROCEDURES		
116	Is the product 's service limitation clearly defined and understood?		
117	Are service personnel thoroughly trained in servicing of the product?		
118	Are investigations made of product complaints?		
119	Are records maintained of communications with the product users?		
120	Are all service related communications documented either verbally or in writing?		
121	NO. OF 'YES' ANSWERS		1
122			
123	GENERAL		
124	Are vital records maintained for the expectant life of the product?		
125	Are limits of warranty and guarantee understandable?		
126	Have you accepted hold harmless agreements with your suppliers?		
127	Have you accepted hold harmless agreements with your customers?		
128	Do you have a recall procedure in writing?		
129	Is the recall procedure well-defined?		
130	Are the liability limits of your distributors adequate?		
131	Do you know the liability coverage of your distributors?		
132	Do you know the liability coverage of your suppliers?		
133	NO. OF 'YES' ANSWERS		9
134			
135			
136			
137			
138	SCORING		
139	1. Add the subtotals indicated for each section.		
140	2. Plot total on scoring chart below.		
141	3. Determine self evaluation rate.		
142	TOTAL NO. OF 'YES' ANSWERS	90	
143	100		
144	Excellent Control		
145	100		
146	99		
147	Control Established		
148	90		
149	89		
150	Acceptable but Below Average Control		
151	85		
152	84		
153	Improvement Required		
154	70 & Below		
155			
156	*Note: In isolated instances, a few answers may vary because of the nature of certain products or their characteristics. The above scoring chart has been weighted for these variations which, therefore, will not affect self-evaluations.*		
157			
158	Adapted from a publication by Fred. S. James & Co. Inc. ([illegible]) prior to its acquisition by Transamerica Inc.		
159			
160			
161			

Appendix J. Nomenclature

Abbreviation	Description
SPI	Stitches per inch
UMTRI	University of Michigan's Transportation Research Institute
DFMEA	Design Failure Mode and Effect Analysis
RPN	Risk Priority Number
SEV	Severity Value
OCC	Occurrence Value
DET	Detectability Value
NHTSA	National Highway Traffic Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
CPSC	Consumer Product Safety Commission
df	Degrees of freedom
SS	Sum-of-squares
MS	Mean Squares
F	F ratio