Road Traffic Safety Needs in Low-Resource Settings

Final Report

ME450 Fall 2021: Team 11
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December 15, 2021

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ABSTRACT

According to the WHO, road traffic incidents cause the deaths of 1.3 million people globally each year, with 93% of fatalities occurring in low- and middle- income countries and an additional 20-50 million people sustaining non-fatal injuries from incidents [1]. Specifically in Ethiopia and Ghana, pedestrians are most affected by traffic incidents in urban areas, with roadside crash barriers meant to protect pedestrians being sparingly used, ignored, expensive, and even stolen [2] [5] [22]. Our team hopes to determine a way to redesign crash barriers to reduce the impact of collisions and reduce the rate of crash barriers stolen in Ethiopia and Ghana.

EXECUTIVE SUMMARY

The general problem of road traffic safety needs in low income countries was broken down into different foci being: pre-accident prevention; mid-accident injury mitigation; post-accident care. These different foci allowed our team to break down the vast possibilities of traffic accidents to different areas of the problem. As a team we felt that the focus on pre-accident prevention had peaked the most interest as well as stayed the most true to the original understanding of the problem. We believe that the solution space for this problem is vast in needs with mechanical solutions which is something that our team wanted to be able to explore.

In order to find needs that fit our strategic focus we started with searching through M-Library and Google Scholar with a focus on issues in Ethiopia and Ghana. Through these searches we were able to find trends of what was most prevalent in causing traffic accidents as well as who was involved in them. We also were able to talk to different stakeholders of people who have lived in or are currently living in LMIC, specifically in the region of sub-Saharan Africa. From all these resources we were able to compile a list of 19 need statements that fit our interests and focus.

The needs selection process used two different filtering systems that cut our need statements from 19 to 10 to 5 and ultimately the chosen need. The first filter was focused on what the team deemed most important for the success of the project while the second was what we as a team wanted to see out of the project. The top ranking need had a substantial total compared to second, therefore the chosen need statement: A way to protect pedestrians from fatal and severe traffic injuries in cities in Ethiopia. Upon further review we realized that the scope of this need statement was too broad. Through stakeholder interviews we were able to find 5 different areas inside this need and ultimately chose to focus on crash barriers. Crash barriers are put along busy streets to separate pedestrians and vehicles around curves and intersections but are regularly stolen due to their high resale value. From this new scope we developed our final need statement: A way to redesign crash barriers to reduce the impact of collisions and reduce the rate of crash barriers stolen.

With the solidified need statement we developed 8 requirements with specifications to help guide and frame our solutions. The 8 requirements are impact lifespan, impact threshold, low light visibility, unappealing to steal, hard to steal, hard to climb over, low cost, and locally manufactured. These requirements were gathered through stakeholder interviews, crash barrier benchmarking, and in depth research which led to their respective engineering specifications.

As a team we generated concepts by means of individual and team brainstorming along with design heuristics which lead to a total of 140 concepts developed. We felt as though the design space had been reached at this point due to the repetitiveness of the concepts generated as well as the diversity. After, we performed screenings of concepts that were not feasible and reduced the concepts to 36. We noticed that the concepts could be clustered and morphed into 12 final designs. From these 12 we used a matrix of our requirements with the highest priority to leave us with 2 final concepts. These concepts then underwent analysis in jack software for their ability to be climbed over, as well as simple calculations for impact. In the end a roller barrier concept was chosen.

This concept is a modification of a barrier that is in use in Ghana and Ethiopia today. It comes with modifications in the form of no exposed metal and top rollers to make it difficult to climb. The roller barrier concept then underwent more indepth jack analysis in order to determine that the requirements were being met. We then followed up with making a prototype of the top roller section of the crash barrier. This allowed us to empirically test the ease of climbing the barrier. Impact testing was also performed on the pvc material chosen for the design but the tests did not come back with conclusive results. Moving forward we would redesign our impact testing to perform a scaled down version of a crash for a more completed high fidelity prototype.

Our final design has a lot of strengths. The rollers on top of the design function as intended and meets one of our most important requirements. Additionally, we are very proud of our stakeholder engagement throughout the project. Without stakeholder input, our design would not be as strong as it is now. However some pieces of our design that are weak are the retroreflectivity and plastic casing. With more time we would consider other ideas for retroreflectivity such as painting the barrier or testing different colors to see which one is most visible at night. Any future modifications would focus on ensuring that all requirements are covered through this design.

PROBLEM DESCRIPTION

According to the WHO, road traffic incidents cause the deaths of 1.3 million people globally each year, with an additional 20-50 million people sustaining non-fatal injuries from incidents. Additionally, road traffic injuries are the leading cause of death for people aged 5-29. Developing economies account for a vast majority of these incidents, with 93% of fatalities occurring in low- and middle-income countries (LMIC), with these incidents costing 3% of a country's gross domestic product each year [1]. As is evident from the research by the WHO, road traffic safety in LMIC is a significant problem, where improvements in the problem and solution space can have a large impact on the quality of life for residents of LMIC as well as helping to mitigate potential barriers to economic development and growth.

Given the information and statistics found from the WHO, our team was interested in breaking down this general problem further, so that we were able to have a more targeted process for research. As such, we distinguished three separate foci within the problem of road traffic safety: (1) pre-accident prevention; (2) mid-accident injury mitigation; (3) post-accident care. Expanding on these three potential foci, we chose to describe pre-accident prevention as a problem space that involved many current solutions - legislation for traffic safety, functional seatbelts in cars, and increased visibility among others - that were commonplace in our personal experiences traveling in high income countries (HIC), but are not as widely enforced or accepted in LMIC [2]. The focus that was most difficult to define for the team was the mid-accident injury mitigation, where we determined that for our purposes, this focus would include mitigating the impact of a road traffic incident once it was inevitable, or it had already occured. One of the best examples we used to define this focus was using airbags to attempt to limit severe and fatal injury during traffic accidents in HIC. Finally, our third potential focus was the problem space of post-accident care. This includes transportation to a medical center, emergency surgeries, and physical therapy for long-term injuries that resulted from a road traffic incident. After discussions within the team, we felt that a focus on pre-accident, severe and fatal injury prevention would be the most interesting for us to explore, and we believe that the solution space for this problem involves numerous spaces that are mechanically oriented, so that our team is able to produce a tangible solution at the end of the semester.

The problem definition provided to the team included road traffic safety for a population of all LMIC. As a team, we wanted to push on that provided population, so we worked again to give ourselves three different options for the population of our problem: (1) LMIC as provided in the original problem statement; (2) Ethiopia specifically; (3) HIC. As per the original problem, our team wanted to include some initial research into road traffic safety issues in LMIC in general, allowing for a broad scope of information gathering and need statement generation. On the other hand, we also felt that narrowing the population would give us sources that delved deeper into the issues of a specific country, in our case Ethiopia. We decided on Ethiopia as the specific LMIC to consider as our target population because there are numerous sources for Ethiopia that are recent and relevant, as well as potential need statements that had already been generated by the Global Health Design Initiative at the University of Michigan [3]. The final space our team considered was HIC as a target population, as we all thought that drawing from personal experiences in the United States would provide us with extensive background information, and being closer to the target population may help us during the design process. In the end however, we decided to move forward with Ethiopia as the target population for our strategic focus, the reasoning for which is detailed in the subsequent paragraph, and a diagram of our selection can be seen in Figure 1 below.

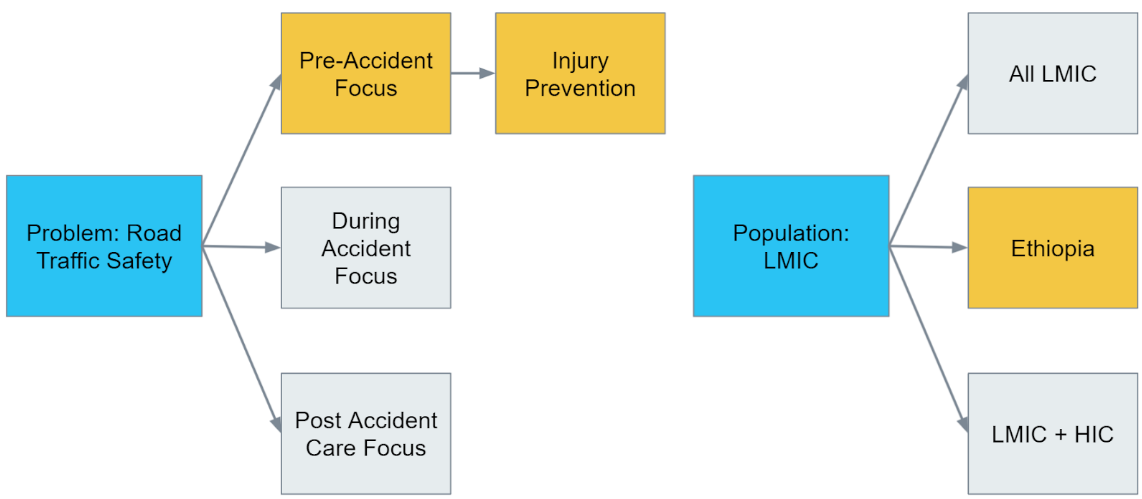


Figure 1. Flow diagram of the problem definition process

Our team chose Ethiopia as the target population for our strategic focus of injury prevention for multiple reasons. The first - and most important - reason being the clear need for road traffic safety innovation and improvement in the country. In Ethiopia, road traffic deaths have doubled between 2007 and 2018, with approximately 13 people being killed in road incidents each day. Road traffic safety education, accident tracking, enforcement bodies, and post-crash care are all under-resourced in Ethiopia, potentially explained by a low level of awareness, weak political leadership, and the challenge of obtaining sustainable funds to improve road traffic safety [2]. As is clear from the findings in the United Nations report, the need for road traffic safety improvements in Ethiopia is great, and potential solutions are wide-ranging, though some may be out of the scope of our team's abilities during the semester. Being able to look at a wide-ranging problem will allow us to understand all of the context surrounding road traffic safety issues in Ethiopia, and in turn will provide us with extensive information that can be used throughout the design process. In addition the clear evidence of road traffic safety issues in Ethiopia, we felt that the country was specifically well suited for a strategic focus in pre-accident injury prevention, as the UN identified issues within multiple areas of road traffic safety, most of which can be classified as pre-injury prevention - road safety management, safe infrastructure, safe vehicles, and safe road users are all problem spaces that lean towards pre-accident injury prevention. This leads to the second reason for the team's decision to focus on Ethiopia - road traffic safety in Ethiopia, especially within pre-accident injury prevention, has an abundance of resources as well as some prior research. In addition to the extensive UN Road Safety Performance Review for Ethiopia, the University of Michigan Global Health Design Initiative provided us with some benchmark needs to assist in our needs finding research. These needs had been developed by students who had travelled to Ethiopia previously, and had more first-hand experience with road traffic safety problems than our team is capable of [3]. For these reasons, our team decided that our strategic focus is pre-accident injury prevention for people in Ethiopia.

Within our selected population of Ethiopia, there are numerous potential stakeholders that may be affected by solutions that the team develops over the course of the semester. First and foremost, vehicle users have a large stake in a solution - this includes drivers as well as passengers, with 712 and 2,372 fatalities in 2018 respectively. In addition, pedestrians are also subject to the negative effects of problems with road traffic safety, accounting for 1,513 fatalities in 2018, mainly concentrated in urban areas [2]. Beyond those immediately affected by road traffic incidents, the Ethiopian Government has a large stake in the road traffic safety problem space, as many solutions include or may benefit from legislation and enforcement of stricter road traffic safety laws [2]. Doing so would require a significant undertaking and commitment from the government, which may be averse to pushing for significant change due to any number of factors. Additionally, the transportation industry in Ethiopia, one of the main methods of transportation for many residents, has a large stake in the problem because they account for a majority of the vehicles that are currently in use in the country [2]. Any potential vehicle modifications or upgrades would produce a significant financial burden on the industry at the outset, however in the long run it would most likely benefit from becoming a safer and more reliable business. Outside of Ethiopia itself, car manufactures also have a stake in the road traffic safety space, as most cars currently in use are second hand vehicles, that may have significant use, and potentially worn out systems [2]. If new regulations were installed that required vehicle upgrades or higher standards for imported vehicles, car manufacturers may benefit from an untapped market that previously relied on second hand vehicles rather than directly manufacturing or purchasing them in Ethiopia. The stakeholders mentioned here do not encompass all groups that may be affected by road traffic safety improvements in Ethiopia, however they do represent those who have the most influence or will feel the most immediate and significant impacts.

At this point in our design process and project arc, our team anticipates that we will accomplish multiple goals by the end of the semester. The first of which is determining a significant need within injury prevention in Ethiopia that has been reviewed and modified with input from stakeholder interviews and second hand observation, to allow us to use design ethnography to inform our process. We also anticipate delivering specific requirements and specifications that are solution-neutral and critical to solving our specified need. Finally, and most importantly for our team, we anticipate developing a functional prototype by the end of the semester, to allow us to complete part of the design process arc by finishing with a tangible, functional, potential solution. Using this prototype, we hope to be able to test its functionality as a team, as well as testing its usability with stakeholders we have connected with throughout the design process. The outcomes listed above are the goals that we anticipate meeting during the semester, and ones that we feel will lead us through the design process and towards a viable, potential solution.

NEEDS FINDING METHODS

To find needs and assess their feasibility, impact and severity, a cohesive search of the existing literature was needed. Initially, we started by looking into the existing database of need statements provided by Professor Sienko and the Global Health Design Initiative [3]. While most of these statements were centered around infrastructure and healthcare needs, the locations and regions that were listed in the database gave us a starting point for our review and research.

First, we ran an initial search through M-Library and Google Scholar, focusing on issues in Ethiopia. For example, some of our search terms were “road traffic safety Ethiopia”, “pedestrian safety Ethiopia”, “road traffic injuries Ethiopia” and “passenger injuries Ethiopia”. Slowly through these search terms we were able to begin finding specific interests and paths for each team member. Ekim focused on pedestrian safety, Peter and George focused on car passenger safety, and Marcela and Eric investigated protective equipment. Throughout these focused paths, we were able to form a cohesive base of academic journal articles that support our need statements and allowed us to get a collective view of the road traffic safety situation in Ethiopia. Additionally, through these searches, Peter spent a lot of time reading the United Nations Ethiopia Road Safety and Performance Review which gave us insight into the existing problems, suggested solutions, and the surrounding statistics to support our claims [2].

Through these searches we were able to establish trends for relevant disease state fundamentals, existing solutions, stakeholders, and the market. For the disease state fundamentals, injury severity and fatality, long-term impact of the accident, and victim type (pedestrian, passenger, cyclist) were important for all needs. Existing solutions typically had issues with cost and aesthetics, specifically issues with import taxes. The important stakeholders for the project were: pedestrians, vehicle occupants, cyclists, manufacturers, government and the 450 team. Finally, market analysis shows that there is a high potential population but there may be issues with education and training for the solution. Overall, the need finding results were consistent for all our needs.

Our current needs finding method is stakeholder and user interviews of people who have lived in or are currently living in sub-Saharan Africa. As of writing this report, two interviews have been conducted. Our first meeting was with Eva Dibong from Cameroon. She is a current Mechanical Engineering BSE at Rensselaer Polytechnic Institute and lived in Cameroon for ten years. As she had a driver and almost always travelled by car, she was able to give us insight into how car passengers feel and what made her feel safe in the vehicle. The main issue she had noticed was issues with lighting and not feeling safe while driving at night due to issues with illumination. Our second interview was with Augustine Appah from Ghana [4]. As he currently gives there, he was able to give us his view on existing issues that he notices on a day-to-day basis. His main complaint about the traffic infrastructure in Ghana was that the traffic lights function inconsistently which causes many head-on collisions and increases the likelihood of speeding [5]. Both meetings provided some solution ideas and painted a picture of what traffic looks like in the region. Additionally, we gained an additional perspective on our existing need statements and were able to establish connections which we will continue to utilize throughout the semester for further feedback.

NEED STATEMENTS

From the different methods described above for needs finding, we were able to compile a list of a lot of different needs to then access. Examples of five different need statements gathered and their background information are described below.

A way to produce low cost protective equipment for motorcycle passengers in Thailand to reduce fatal injuries in the event of an accident.

The team has decided that our first need is to produce low-cost protective equipment for motorcycle passengers in Thailand to reduce fatal injuries in the event of an accident. This is specifically because most of Thailand's population travel by motorcycle which is the largest, fastest, and most efficient way to travel around the city [6]. The main issue, however, is that people that ride motorcycles in Thailand get caught in accidents that could potentially kill them if not cause irreversible damage to their body. In a case study done from 1994 to 1997 there were 12,002 injured motorists with 129 death cases in Thailand simply because some of the motorists were riding without any protective gear or a helmet [6]. The Helmet Act that was established after this case study pretty much increased helmet wearers by five times the original amount of helmet users and decreased death by 20.8% but this still did not prevent those who do not wear helmets from being injured or killed in accidents [6].

A way to protect car passengers on interstate highways from fatal traffic injuries.

In investigating road traffic incidents in Ethiopia, our team took notice of the most vulnerable car occupants in Ethiopia. We came to the conclusion that car passengers account for the largest proportion of deaths on interstate highways in Ethiopia, and have relevant statistics to support our claim. Passengers of cars accounted for 51.6% of fatalities, 52.5% of serious injuries, and 63.6% of slight injuries [2]. There are existing solutions to protect passengers, such as seatbelts and airbags. However due to current policy, seatbelts are not enforced for passengers. Additionally, Ethiopia's vehicle market is dominated by second-hand import vehicles that lack modern airbag technology [7]. Vehicle occupants, particularly passengers, vehicle owners, vehicle manufactures, and the Ethiopian government are all relevant stakeholders in this case. Our team expects a large market demand for a solution to this problem due to the large number of occurrences.

A way to protect pedestrians from fatal and severe traffic injuries in cities in Ethiopia.

In our initial needs finding search on M-Library and Google Scholar, we noted that there were many articles pertaining to injury severity and the prevalence of pedestrian collisions in Ethiopia. In the major cities, collisions with pedestrians make up a large percentage of road traffic accidents and tend to have more severe injuries. We looked at regions with major cities and hospitals for accurate and relevant injury statistics. In Addis Ababa, 39.7% of road traffic incidents had a pedestrian victim in which 36% of those victims had severe injuries [8]. At a hospital in Mekele City, Northern Ethiopia, 32.14% of road traffic accident patients were pedestrians [9]. While there are some existing solutions such as reflective clothing and front bumper attachments, these solutions are usually too costly or unattractive to stakeholders. By creating a solution that will protect pedestrians by keeping them away from road traffic and visible to drivers or preventing more severe injury by altering the vehicle, we can reduce the injury severity and prevalence of pedestrian victims.

A way to maintain consistent lighting for nighttime travelers in Ethiopia.

While diving into the differing reasons for the large number of traffic incidents in LMIC the lack of good lighting seems to come up. Results from the studies have shown that lighting has a significant contribution to the amount and severity of accidents [11]. Especially in Ethiopia, 13% of their traffic accidents were being attributed to low lighting conditions [12]. In rural Ethiopia, a majority of the roads don't have lighting therefore leaving the only light to come from the headlights on vehicles. [13] But, due to poor vehicle lighting standards and low use from drivers there is usually no illumination from vehicles from the use of headlights [14]. The general solution to this need would be the installation of reliable street lights to illuminate the roads. This is an issue though because the installation of the street lights involves a large initial cost, a high operational cost and the use of electricity. Most of these cities have a larger priority for the use of their resources and electricity and therefore aren't putting in the effort to install street lights [14]. Other than the street lamps there were no other solutions to this need besides the headlights already installed on the vehicles. But as mentioned previously, these lights are usually in bad condition along with just not being used. The large lack of usage comes from a stigma that the headlights take up a lot of gas from the vehicle and therefore in order to save gas they choose to not turn on the headlights. Since it is a manual choice and something that doesn't help much to begin with, the driver will make the choice to forgo the use of their headlights.

A low-cost way to update outdated vehicles in Ethiopia with modern car safety features to reduce injury severity and frequency of accidents.

In our team's second round of needs finding, we investigated the modes of transportation most common in Ethiopia, and attempted to determine if they had an effect on road traffic safety and the number of incidents in the country. We found that Ethiopia's automotive market is dominated by second-hand imported vehicles [7] and confirmed our suspicions that the fact that motor vehicle defects contribute to crash occurrence is undisputed, even though its significance is difficult to estimate [2], with further confirmation from the Pan African Medical Journal that poorly maintained vehicles are one of the main reasons for road traffic incidents [15]. The existing vehicles are inadequate to solve this problem, as many of the second-hand cars have mechanical systems, such as steering, brakes, and suspension, are subject to wear through use and time, and the Government in Ethiopia has significant gaps in regulations and inspection programmes for vehicles [2]. The highest standard solutions include compulsory seatbelt usage, all-round airbags, as well as high quality of maintenance and repair for vehicles. In Ethiopia however, vehicles are required to have front and rear seatbelts with usage only compulsory for the driver, less than 20% of vehicles have front fitted airbags, and unlicensed car service centers provide low quality maintenance for vehicles [2]. It is clear that there is a significant gap between local solutions, or the lack thereof, and the solutions found in other countries. Vehicle owners, the general transportation business, the Ethiopian government, and car exporters are all potential stakeholders in this issue, with the main benefits occurring for vehicle owners/passengers, while high overhead costs for modifications are obstacles for the transportation business.

NEEDS FILTERING AND RESULTS

In order for a need to be considered it first had to pass two criteria. The first being that it had to focus on the pre-accident aspect of a traffic incident. This means that it is more of a preventative measure than a need after or during an accident. The criterion was set based on our team preferences and the direction that we wanted to head in. The second criterion was that it had to be a need coming from a LMIC. We noticed that there were very different needs in high income countries compared to LMIC when it came to traffic accidents. There was a larger interest in the needs coming from the lower income countries so we chose to make that a criteria. If a need met both of these then it was added to our list of potential needs. In the end we had a total of 19 needs that we needed to work through to decide the final need. The decision was made by making two different filters, the first filtering down to 10 needs, and the second filtering down to 5 and ultimately the chosen need. This can be seen depicted in Figure 2 on the next page. Two different filters were used because we wanted to capture different aspects of the projects with each filter. We worked through the two different ranking tables for the two filters together as a team to make sure that everyone was in agreement to the ranks given. As well, since all the ranks were chosen by the same people it made sure that there was no one person giving bias to a certain need.

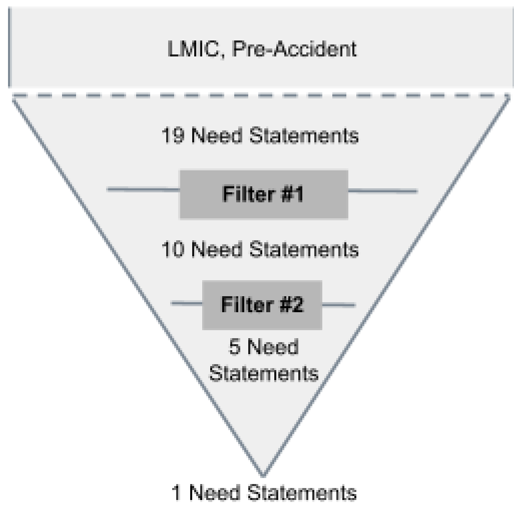


Figure 2. Depiction of Needs filtering stages

Filter #1
The first filter we used was prioritized based on what we thought was most important to the project. We had six different criteria, Feasibility Index, Injury Prevention, Tangible Solution, Market Size, Stakeholder Impact, and Personal Favorites. Each criteria was given a weight and then a unique ranking system of 1-3 to ensure consistency in the ranking process of the different needs for each criteria. A criteria could receive a 0 as a ranking for the need if the team deemed the need to be majorly lacking in said criteria and would be disqualified. Therefore a 0 in any criteria was an automatic disqualification of the need.

Feasibility Index. Feasibility Index we defined as how feasible is the project in terms of ME450 and what we are able to accomplish in one semester. This was something that we held to a high importance due to the fact that this is a limiting factor of the project, therefore we weighted this a 3. The ranking system for the feasibility index for filter #1 can be seen in Table 1.

Table 1. Ranking system 1-3 for the feasibility index for filter #1

	Feasibility Index
3	The need is definitely feasible in ME450
2	The need might be feasible in ME450
1	Not feasible in ME450

Injury Prevention. Injury Prevention was defined as the likelihood that a solution for this need would result in the lowering of injury due to traffic accidents. Since the main goal of the overall problem was to lower injury we also weighed this highly as a 3. The ranking system for injury prevention for filter #1 can be seen in Table 2 on the next page.

Table 2. Ranking system 1-3 for injury prevention for filter #1

	Injury Prevention
3	The need would definitely lower injuries due to traffic accidents
2	The need has the potential to lower injuries
1	No injuries due to traffic accidents would be prevented

Tangible Solution. Tangible solution was defined as the ability to make an actual product as the solution that we could hold. This is something that is not necessarily needed for the project to be completed well therefore only had a weight of 2. The ranking system for a tangible solution for filter #1 can be seen in Table 3.

Table 3. Ranking system 1-3 for a tangible solution for filter #1

	Tangible Solution
3	All solutions for need would be tangible
2	Some solutions for need would be tangible
1	No solutions for the need would be tangible

Market Size. Market size was defined as the number of people that the need would impact or potentially could effect. We weighed this as a 2 because we wanted to make sure that the need chosen would have a large potential market but it is not as important as the feasibility. The ranking system for the market size for filter #1 can be seen in Table 4.

Table 4. Ranking system 1-3 for the market size for filter #1

	Market Size
3	The need has a very broad and large potential market
2	The potential market could be large or small
1	The potential market for the need is very niche

Stakeholder Impact. Stakeholder impact was defined to mean how much would the user actually be impacted by the solution to this need. Meaning that if this solution was to be implemented how much would it change the lives of those people. This, like the market size criteria, also got a weight of 2 for similar reasons. The ranking system for the stakeholder impact for filter #1 can be seen in Table 5 on the next page.

Table 5. Ranking system 1-3 for the stakeholder impact for filter #1

	Stakeholder Impact
3	The user's life would be largely impacted by a solution to this need
2	The user's life could be impacted by a solution to this need
1	There would be no impact on a user

Personal Favorites. Personal favorites got the lowest weight of 1 because in this first filter we are really looking at lowering our needs to only ten specific needs that match the criteria listed out. The ranking of personal favorites was more to get an idea of the needs that people were being drawn to and less about impacting the results of the filter. There was no ranking system for personal favorites for this filter. Each team member was allowed to choose one need as their personal favorite and that need would get one extra point in the rank table.

Results. From the first filter the need statements were cut down to 10 from the original 19. The totals from the rank table ranged from a minimum of 19 to a maximum of 32 (not counting any of the ones that got disqualified meaning their total was 0). The ten need statements that passed all had a total of over 20 points. The complete tank table can be seen in Table 6 on the next page.

Table 6. Results from the first needs filtering with set top 10.

#	Need Statement	Feasibility Index	Injury Prevention	Tangible Solution	Market Size	Stakeholder Impact	Personal Favorite					Total	Rank
							EC	EK	ML	GM	PW		
		3	3	2	2	2	1	1	1	1	1		
1	A way to fix holes and cracks on paved roads in Ethiopia for a low cost in order to reduce traffic accidents	1	2	1	3	2						21	**10**
2	A way to produce low cost protective equipment for motorcycle passengers in Thailand to reduce fatal injuries in the event of an accident.	2	3	3	2	2						29	**2**
3	A way to ensure pedestrians in Ethiopia can see/anticipate oncoming traffic to prevent endangering themselves when crossing a road	1	3	1	2	3						24	**6**
4	A way to protect car passengers on interstate highways in Ethiopia from fatal traffic injuries	2	3	1	3	2						27	**3**
5	A way to protect motorcyclists in countires with high helmet use	0										0	
6	A way to protect pedestrains from fatal and severe traffic injuries in cities in Ethiopia, Columbia, and China	2	3	2	3	2	1	1		1		32	**1**
7	There is a need to prevent those using alcohol from driving	0										0	
8	A way to produce low cost driving safety equipment for people with disabilities to protect in the event of an accident	1	3	2	1	2						22	**9**
9	A way to protect an injured person involved in an accident from further injury in removal from a crushed vehicle	0										0	
10	A way to protect roadside pedestrians in Ethiopia from injury during an unaffiliated road traffic incident	0										0	
11	A way to indicate to drivers in Ethiopia the traffic patterns and warnings on secondary or rural roads	1	2	1	2	2						19	
12	A low-cost way to update outdated vehicles in Ethiopa with modern car safety features to reduce injury severity and frequency of accidents.	2	2	2	3	2					1	27	**3**
13	A way to maintain consitent street and intersection lighting for nighttime travelrers in Ethiopia	2	2	2	2	2			1			25	**5**
14	A way to protect passengers riding in the bed of a truck in Ethiopia	1	2	1	2	2						19	
15	A way to limit the speed on taxis, Bajas, and public transportation in Ethiopia	1	2	1	3	3						23	**7**
16	A way to be able to limit speeds on certain roads based on speed limits	0										0	
17	A way to redirect traffic in congested rural areas to prevent accidents and release congested traffic into more urban areas to travel a bit more freely	0										0	
18	A way to ensure that oversized loads on vehicles are identifiable by others and injury/death can be prevented from mishaps during transport	1	2	3	2	2						23	**7**
19	A way to make new, safe, and modern methods of transporatation affordable to citizens in Ethiopia	0	2	3	2	2						20	

Filter #2
We decided that the difference between the totals was not substantial enough to make more decisions on the filtering based on this same criteria. This led to the creation of a second filter in order to find out the top five need statements. This time only four criteria were used, Feasibility Index, Injury Prevention, Tangible Solution, and Personal Favorites. The definitions of the criteria stayed the same from the first filter but the weights and ranking systems changed. This time the criteria in the filter were based on team interest in regards to what we wanted to see most out of this project. The ranking system was switched to 1-5 for each criteria in order to allow for more range in the point totals at the end.

Feasibility Index. We decided to lower the weight of the feasibility index to 2 for this round. This was because we felt that all the projects coming into this filter had pretty similar results in the previous filter when it came to feasibility therefore it wasn't as important to consider. The ranking system for the feasibility index for filter #2 can be seen in Table 7.

Table 7. Ranking system 1-5 for the feasibility index for filter #2

	Feasibility Index
5	The need is definitely feasible in ME450
4	The need is most likely feasible in ME450
3	The need might be feasible in ME450
2	It is unlikely that the need is feasible in ME450
1	Not feasible in ME450

Injury Prevention. As a team we decided that injury prevention was still as important to the team's overall goal as it was for the problem statement. Therefore the weight was given a 3 just like in the first filter. The ranking system for injury prevention for filter #2 can be seen in Table 8.

Table 8. Ranking system 1-5 for injury prevention for filter #2

	Injury Prevention
5	The need would definitely lower injuries due to traffic accidents
4	The need would most likely lower injuries due to accidents
3	The need has the potential to lower injuries in traffic accidents
2	The need is unlikely to lower injury from traffic accidents
1	No injuries due to traffic accidents would be prevented

Tangible Solution. Tangible solution got the biggest change in weight for this filter. As a team with mechanical engineering as our main background we wanted to prioritize needs that would lead to most solutions having a tangible solution we could make. Therefore we gave it a weight of 4, making it the most important criteria in this filter. The ranking system for a tangible solution for filter #2 can be seen in Table 9 on the next page.

Table 9. Ranking system 1-5 for a tangible solution for filter #2

	Tangible Solution
5	All solutions for need would be tangible
4	Most solutions for the need would be tangible
3	Some solutions for need would be tangible
2	Very few solutions for this need would be tangible
1	No solutions for the need would be tangible

Personal Favorite. Personal favorites carried a heavier importance in the second filter compared to the first. This is because we were now focused on what the team wanted instead of filtering out bad need statements. The weight was bumped up to a 2 and every team member chose their top two needs, giving their top need a rank of 2 and their second favorite need a rank of 1. This was because the larger on the rank table is of more importance than the lower number.

Results. From the second filter the need statements were cut down to the top 5 from the 10 statements we had after the first filter. This time the totals from the rank table ranged from a minimum of 21 to a maximum of 51. The complete tank table can be seen in table 10 on the next page. From the top five gathered the difference between the first and second rank was 16 points. This was a significant difference when comparing the other top scores had a max difference of 2. Because of this, we decided that the filtering system of the first and second pass were enough to choose our final need statement. As well, the chosen need statement ranked in the top two of every team member's personal favorites.

Table 10. Results from the second needs filtering featuring a top 5 ranking.

#	Need Statement	Feasibility Index	Injury Prevention	Tangible Solution	Personal Favorites					Total	Rank
					EC	EK	ML	GM	P W		
		2	3	4	2	2	2	2	2		
1	A way to fix holes and cracks on paved roads in Ethiopia for a low cost in order to reduce traffic accidents	2	3	3						25	
2	A way to produce low cost protective equipment for motorcycle passengers in Thailand to reduce fatal injuries in the event of an accident.	4	3	4						33	**4**
3	A way to ensure pedestrians in Ethiopia can see/anticipate oncoming traffic to prevent endangering themselves when crossing a road	1	3	3						23	
4	A way to protect car passengers on interstate highways in Ethiopia from fatal traffic injuries	4	4	3				1		34	**3**
6	A way to protect pedestrains from fatal and severe traffic injuries in cities in Ethiopia	4	5	3	2	2	1	2	1	**51**	**1**
8	A way to produce low cost driving safety equipment for people with disabilities to protect in the event of an accident	2	3	2						21	
12	A low-cost way to update outdated vehicles in Ethiopa with modern car safety features to reduce injury severity and frequency of accidents.	2	3	4					2	33	**4**
13	A way to maintain consitent street and intersection lighting for nighttime travelers in Ethiopia	3	3	3	1	1	2			35	**2**
15	A way to limit the speed on taxis, Bajas, and public transportation in Ethiopia	2	3	2						21	
18	A way to ensure that oversized loads on vehicles are identifiable by others and injury/death can be prevented from mishaps during transport	3	3	4						31	

SELECTED NEED

A way to protect pedestrians from fatal and severe traffic injuries in cities in Ethiopia.
Through the filtering methods described above, our selected need focuses on pedestrian safety, or Need Statement #3. As mentioned previously, major cities make up a large percentage of road traffic accidents and tend to have more severe injuries. Pedestrians are more likely to be injured in traffic as they typically do not have any protective equipment or protective structure like vehicle occupants do. Additionally, it is 2.14 times more likely a pedestrian will be harmed severely by a large or heavy truck than by a light vehicle [8]. With higher severity levels, there can be longer and more severe lasting impact from the accident. Therefore, there is a large problem with injury severity associated with pedestrian accidents and we hope to find a solution for this need throughout the semester.

Narrowing Scope. As we began to research the different aspects of pedestrian safety we realized that there are many different aspects of this problem that we can tackle. While leaving it broad would allow more room to have many different problems that fit inside of pedestrian safety we decided that it was best to try to narrow down specific areas in pedestrian safety we wanted to focus on. This was done through stakeholder interviews with Dr. Bikila [22] and Augustine [5]. Through these interviews we were able to identify five different need areas within pedestrian safety that are prominent in Ethiopia and Ghana and are shown in figure 3 below. The five areas are alcohol level detection, speed humps. nighttime visibility, crash barriers, and truck converted busses. All of the areas have a space for us to work in therefore we chose to go solely with team preference when it came to making the decision on which to choose.

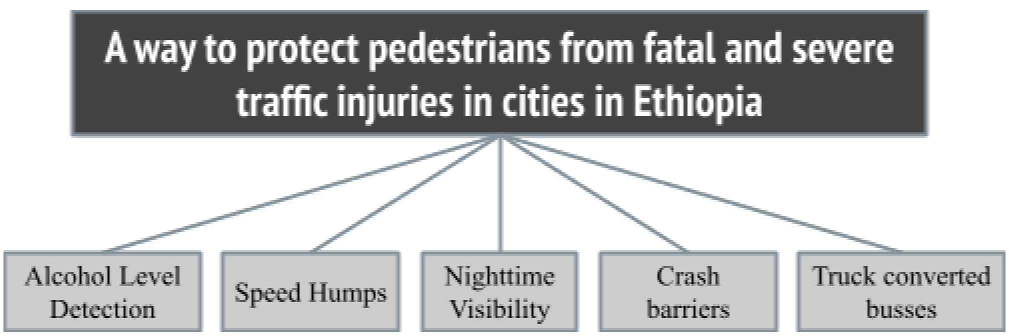


Figure 3. Breakdown of different need areas within pedestrian safety

Final Need. From the five areas we chose to go with crash barriers as our selected area. Crash barriers are put along busy streets to separate pedestrians and vehicles around curves and intersections. But these crash barriers are regularly stolen due to their high resale value in Ethiopia [22] as well as in Ghana [23]. As well, people are climbing over the barriers and are getting stuck in oncoming traffic [23]. The crash barriers can be effective in keeping pedestrians and motor vehicles separate and reduce injury but only if they remain on the roads. From this new scope we developed our final need statement.

A way to redesign crash barriers to reduce the impact of collisions and reduce the rate of crash barriers stolen.

Background Information. Once we decided our new need would focus on crash barriers, we held more interviews with our Ghanian expert, Augustine [23]. Through this interview he was able to provide us with news sources and videos in Ghana that showed the aftermath of the stolen barriers. One specific incident that was covered heavily in the news occurred about three weeks ago, on October 5th, 2021, in Pokuase [24]. About 40 meters of metal crash barriers were stolen, valued at $3500. 10 barriers were stolen, measuring around four feet long. The barriers were taken despite the fact that the fasteners had been welded [25]. The Resident Engineer of Pokuase Interchange and Local Roads Project, Kwabena Bempong, has stated that they will be looking into anti-theft bolts and nuts as this was a national issue [26].

Figure 4. An image of the stolen barriers in Pokuase [24]

As we are having interviews with a stakeholder in Ghana, we decided to add Ghana into the context of our project. Similarly, to Ethiopia, the rate of injuries and fatalities caused by road traffic accidents is increasing [27]. The most common risky behavior in Ghana is speeding [28]. Additionally, in 2013, 2249 fatalities were caused by road traffic incidents and has increased by about 63%, road traffic injuries by 49% and fatalities by 65% between 1994 and 2010. [27]. Both countries import second-hand or older vehicles as well [5]. We also have determined that the stakeholders, injury statistics, and market analysis is very similar for both countries and can be considered the same for both. Updates on these sections are listed below.

Injury Prevalence and Severity. Through the search listed above, we determined the severity of the injuries as well as the prevalence of those injuries. Typical patient demographics were similar across Addis Ababa and the three regions discussed. Across the literature, we noted that a traffic injury with a pedestrian victim typically occurred in urban settings with a higher rate of severe/fatal injuries. As pedestrians are not as well protected as those in vehicles, they are prone to more severe injuries and have more long-term impacts. Only in Southern Ethiopia was there a higher rate of incidents in a rural setting. Additionally, the patient demographics are usually 25- to 50-year-old males for all three regions [16]. The table below lists the injury statistics and severity for the regions and Addis Ababa. In the new context of Ghana, there was not as much readily available information about direct patient statistics for road traffic accidents. However, a study was conducted to analyze the pedestrian injury patterns in Ghana between 2002 and 2006, specifically on the Kumasi-Accra highway [29]. This highway links the national capital Accra and the second largest city Kumasi and is the most traveled road in Ghana. The trend of pedestrian injuries being the largest demographic of traffic injuries in an urban setting that we noticed in Ethiopia seems to be consistent for the Ghana context as well.

Table 11. Injury Statistics and Severity for Ethiopia

Region/City	Patient Statistics	Injury Severity	Source
Addis Ababa	39.7% pedestrian	36% severe	[8]
	-	18.4% fatal	[16]
		45.5% severe	
Northern Ethiopia	32.14% pedestrian	-	[10]
Eastern Ethiopia	35.07% collision patients	-	[15]
Southern Ethiopia	51.4% collision patients	68% severe	[17]
Ghana	-	33% fatal	[29]
		45% severe	

Note: Eastern and Southern Ethiopia were hospital-based studies so specific victim breakdowns were not listed.

Existing Solutions. There are a few existing solutions intended specifically for pedestrian safety and injury severity reduction. The major ones we decided to investigate were reflective clothing, car front bumper/hood attachments and lighting (headlights, streetlights, etc.) [18]. Reflective clothing will make a pedestrian more visible and is a low-cost solution, around 10 USD on Amazon [19]. However, it is typically unattractive to stakeholders which makes them less likely to accept and use clothing. For bumper and hood attachments and redesigns, while they are expensive, they can reduce the severity of the injury and the impact upon the pedestrian. Outside of cost, there are drawbacks for vehicle manufacturers and there will be barriers with implementation. Finally, our lighting solutions were discussed in a previous need statement but are also important for pedestrian visibility. Therefore, we have included them here as well. While most vehicles have headlights, there are issues with maintenance and ensuring a wide range of visibility with a lack of ambient street lighting. Additionally, street lighting can be inconsistent as the power grid is not as stable. We also discovered in our interview with Augustine that there is an ongoing problem in Ghana with robbers stealing the pieces of a streetlight as they have a high resale value [5].

Now that our scope has been narrowed, we have a more narrow list of existing solutions. The most common barrier types in Ethiopia and Ghana right now are metal railings and type F concrete barriers, shown in Figure 5 and 6 respectively on the next page. While these barriers do reduce impact upon collision and prevent severe and fatal injuries, there are some issues with these solutions. Metal railings are viewed as expensive in these areas as they have a high resale value. Augustine informed us that one of the largest industries in Ghana is metal and electronic recycling, so when someone brings in metal to recycle, they get paid [23]. Additionally, these metal barriers are very easy to climb over and pedestrians will hop over them when attempting to cross the road instead of walking to a far away pedestrian bridge or overpass. Therefore this solution is not fit for this context and needs to be improved. Type F concrete barriers are also functional in preventing injury and reducing impact in the case of a collision but they cannot easily be manufactured or brought to the region. In Ethiopia there is a shortage of cement and they are very heavy and expensive to import. So, even though they are not attractive to steal, they have issues for local manufacturing. Additionally, pedestrians can still climb over these barriers.

Figure 5. Metal Railing Barrier

Figure 6. Type F Concrete Barrier

Benchmarking. The solutions listed above can be used to benchmark scenarios in relation to Ethiopia and Ghana. We believe that these will be good validation points and benchmarks when we need to compare our design ideas and solutions in the design context. However, there are also some existing solutions in the United States and other regions that could also be useful to benchmark against. Plastic water filled barriers and foam filled anti crash barriers are also common types of barriers. Even though these solutions are not common in Ethiopia and Ghana, we can still consider them against the existing solutions. For example, plastic water filled barriers, shown in Figure 7 on the next page, would be cheaper to produce and easier to install. However, they are a similar shape to existing barriers and can still be climbed over by pedestrians. Additionally, they can be easily drained and stolen but they do not have the same resale value as metal so they might be less likely to be stolen. There are also new forms of metal railings that have foam cylinders in them to reduce the impact of the crash even further. An image of these barriers is shown in Figure 8 on the next page. While functional, these barriers have the same risk of being stolen as they have metal parts. However, further research will need to be done to determine how easily they can be stolen and how easily pedestrians can climb over these barriers. Overall, there are many existing crash barriers that can be used as a comparison point but none of them fully cover the needs of Ethiopian and Ghananian stakeholders. Therefore, our design needs to cover these gaps and ensure it fits the remainder of our requirements and specifications.

Figure 7. Plastic Filled Water Barrier

Figure 8. Foam Filled Anti-Crash Barriers

Stakeholders. As discussed before, the stakeholders are similar across all the needs we discovered. The most relevant stakeholders for this project are pedestrians, drivers, the government, and vehicle manufacturers are the most relevant. While pedestrians are the victim in this need, vehicle occupants have two roles. They are both victims in the case of a collision and influencers as some solutions are dependent on their acceptance as well. Additionally, manufacturers and the local government will influence the process further down the line in terms of implementation and maintenance. Through further interviews with stakeholders who live in the area, we will be able to learn more about the specific ways these stakeholders influence the design and solution. It can be assumed that these stakeholders will hold true for Ghana as well.

Market Analysis. Tulu, Washington, Haque, and King (2017) stated that walking accounts for 60% of daily trips in Addis Ababa. Applying this measure to the population of Ethiopia, it can be assumed that 67.26 million people use walking as their main mode of transportation in Ethiopia [16]. We also found that the average hospital stay in Ethiopia is around 22.25 USD [20]. Therefore, the possible market size is around 1.5 billion USD. However, there are variations in different regions of Ethiopia for both cost and percentage of people using walking as their main mode of transportation so this estimate may vary.

Currently, the pedestrian victim or other victims in the accident bear the most cost. The next step for market analysis would be to further research health care costs associated with these incidents in relation to the severity of the accident. The cost of an average hospital stay in Ghana is around 15 USD [30]. The population of Ghana is 31.7 million and around 80% of travel is conducted through road transport [31]. Therefore, the possible market size is 375 million USD. Altogether the possible markt size is around 1.875 million USD. This might vary depending on collision severity, hospital selection and population size as well as mode of transportation.

POTENTIAL STAKEHOLDERS AND UPCOMING INTERVIEWS

The next steps for this project involve conducting more interviews with stakeholders to gain further insight into the need and gain a new perspective on the problem. Our next two interviews are with Ropa Denga, a human factors professional from Zimbabwe and Dr. Bikila, a professor at the Addis Ababa Institute of Technology. As Dr. Bikila is a civil engineering expert, they will be able to provide feedback on our understanding of the infrastructure needs in Ethiopia as well as the perspective of an Ethiopian resident. Additionally, Augustine Acquah is an occupational and musculoskeletal researcher and lecturer at the University of Health and Allied Sciences in Ghana. He will be able to provide the view of a resident as well as an expert of human factor engineering.

Outside of personal connection stakeholders, which cover our pedestrian, cyclist, and vehicle occupant stakeholder interests, there is also a potential influence from the government and manufacturers. However, it is too early in our project to meet with these stakeholders so we will reach out to experts in this area when we have more concrete solutions. As interviews with potential stakeholders have been helpful for our project thus far, continuing these discussions with a variety of stakeholders will be beneficial when creating our final design.

REQUIREMENTS AND ENGINEERING SPECIFICATION

Our team was active in seeking firsthand stakeholder input for our requirements and specifications, and we successfully were able to have multiple discussions with current or former residents of sub-Saharan Africa. The two primary resources we used for developing our requirements were Dr. Bikila (Road and Transport Engineering Chair, School of Civil and Environmental Engineering, Addis Ababa Institute of Technology) as well as Augustine Acquah (Occupational and Musculoskeletal Researcher/Lecturer, University of Health and Allied Sciences, Ghana). Over the course of video interviews, Dr. Bikila and Augustine provided us with firsthand knowledge of crash barriers in Ethiopia and Ghana, and we were able to pull eight requirements from these discussions, which can be seen in Table 12 on page 21.

To develop the specifications for the requirements we utilized the crash barrier benchmarking the team had compiled after determining our selected need statement - an extensive discussion of this benchmarking can be found on page 18. This benchmarking provided us with a baseline reference for some crash barrier performance specifications, and our stakeholder interviews with Dr. Bikila and Augustine helped to flesh out the requirements and their applicability to the need in Ethiopia and Ghana.

In addition to the specific requirements and specifications listed in Table 12 on page 21, we classified the priority and current status of each requirement. The priority of a requirement was determined through the team's discussion with Dr. Bikila and Augustine, and denoted as low, medium, or high priority. Low priority requirements would be nice to have, medium priority requirements are preferred for the final design, and high priority requirements are critical for the final design. Along with the priority, the current status of each requirement is displayed below in the table, with a green requirement denoting that the team is very confident in the requirement and has significant resources for establishing specifications, a yellow requirement denoting that the team is mostly confident with the requirement, but will further develop the specifications with additional research, and a red requirement denoting that the team is not confident in the wording of the requirement or with the specifications established in Table 12. Our team will work quickly to move every requirement to the green status by digging deeper for specifications through research as well as stakeholder interviews.

Finally, Table 12 is split into two parts, to make the requirements and specifications easier to organize and understand. The first section relates to the performance of the crash barrier, while the second section deals with the characteristics of the crash barrier.

Table 12. Full table of requirements and specifications listing the requirement, specifications, and priority noted. The status is shown in the highlighting. The table is broken down into the performance and characteristics sections as discussed previously.

Requirement	Specifications	Priority
Performance Requirements		
Impact Lifespan	Compressive strength > 80% original strength throughout barrier lifetime Barrier lifetime of > 50 years	Med
Impact Threshold	Occupant impact velocity < 9 m/s Occupant ride down acceleration < 15G	High
Low Light Visibility	Retroreflectivity ≥ 93 mcd/m^2/lx	Med
Characteristic Requirements		
Unappealing to steal	0 m^2 exposed surface area of metal components	High
Difficult to Steal	Lifting index > 1 RWL > 86 kg If fasteners are needed, all external fasteners must be anti-theft	Med
Difficult to Climb Over	Grip strength on the top of the barrier > 0.107 MPa Height between potential foot and hand placement > 35 cm Height of barrier > 110 cm	High
Low Cost	Barrier costs < 10,000 USD/km	Med
Local Manufacturing	75% of all parts and processing must be of Ethiopian/Ghanaian origin	Low

Requirement #1: Impact Lifespan
After speaking with Dr. Bikila, it was evident to the team that a redesigned crash barrier needed to have a long lifetime, with the capability to survive multiple impacts [22]. The team took this knowledge and translated it into a requirement for the impact lifespan of the crash barrier - this involves the sustained strength of the material as well as the general barrier lifetime. To determine our current specifications, we benchmarked our redesign against standard concrete barriers and the specifications present from ASTM as well as general concrete performance compiled by the European Concrete Paving Association. This research resulted in two specifications, the first of which being that the compressive strength of the barrier is > 80% of the original compressive strength of the material, at all times when the barrier is in use [32]. This was determined as a specification because it is drawn from the standards used for precast concrete barriers, a benchmark for crash barriers, to which we will compare our redesigned barrier. The second specification was pulled from precast concrete characteristics, with the barrier lifetime > 50 years [33]. Our team included this specification to ensure that material degradation and weathering did not adversely affect the barrier early in its lifespan, so that our redesigned barrier could be used for decades. We have noted this requirement as a medium priority due to the more significant priority placed on Requirement #2: Impact Threshold, and this requirement is denoted as yellow status, as more work is needed to refine and finalize the specifications.

Requirement #2: Impact Threshold
One of the most important performance metrics of the crash barrier is the impact threshold, or the effects that an impact has on a vehicle occupant. A key to our selected need is to reduce the impact of collisions, and this requirement reflects that need. The team developed this requirement through the interview with Dr. Bikila as well as the statistics and analysis seen in the UN Road Traffic Safety Report for Ethiopia [22][2]. Researching this requirement resulted in performance metrics and standards for highway barrier safety that were used as a benchmark for the team's redesigned barrier. Specifically, the specifications include that the occupant impact velocity with the interior of the vehicle < 9 m/s and the occupant ride down acceleration < 15 G, taken from the National Cooperative Highway Research Program (NCHRP) in the United States [34]. These specifications relate to the effects of an impact on the occupant of a vehicle, and require a standard for safety in the performance of a redesigned crash barrier. To visualize the testing used by the NCHRP, an image of an impact test is shown below in Figure 9.

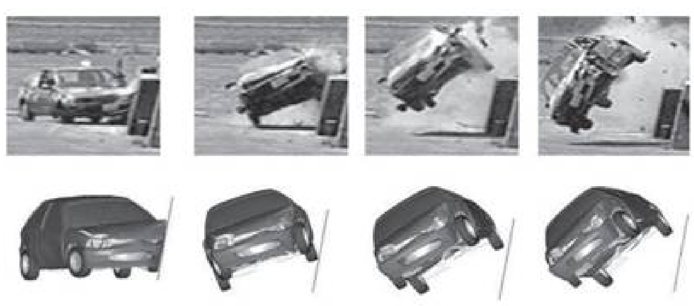


Figure 9. Image of an impact test used by the NCHRP

We have noted this requirement as a high priority due to the critical significance of safety to our selected need, and this requirement is denoted as green status, since the team is confident in the research and standards used to generate the specifications.

Requirement #3: Visible in low light
It is important that the crash barriers can be seen in low light because there isn't great illumination on

the streets due to lack of street lights. Because of this, a requirement for the crash barriers visibility was made. If it were not easy to see at night then the crash barrier could actually cause more accidents in people scraping their cars on its side or crashing into it. This is why this requirement was given a high priority ranking. The goal of this crash barrier is to prevent injuries due to crashes and therefore we need to make sure our solution isn't actually making the situation worse. In order to quantify how something can be seen in low light, its retroreflectivity can be measured. Retroreflectivity means how much light will be reflected at a given illuminance and is depicted in figure 10. We are specifically quantifying this requirement to be that the barrier retroreflectivity must be greater than or equal to 90 mcd/m^2/lx (read as millicandelas per square meter). This is due to case studying stating that values between 80 and 120 mcd/m^2/lx is the range of acceptable retroreflectivity values [35]. Another case study had 98% of subjects stating that 93 mcd/m^2/lx or greater was adequate leading to the conclusion that 93 mcd/m^2/lx should be considered the minimum level for retroreflectivity for low light conditions [36]. Using these two studies a value of 93 was chosen due to its convergence in both of the ranges.

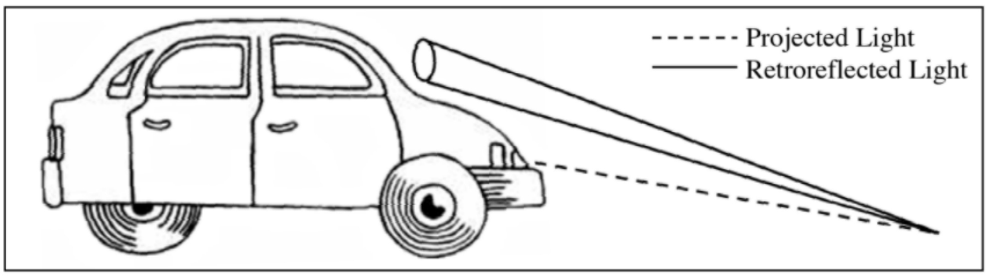


Figure 10: Visualization of retroreflectivity in regards to cars. [37]

Requirement #4: Unappealing to Steal
Plastic materials are much cheaper than metal parts with industries seeing savings of up to 50% on overall costs just by switching from metal to plastic [38]. Due to the time saved in being able to use plastic instead of metal in the overall production of the barrier, the overall costs of barriers would drastically decrease making the appeal of stealing them less likely. Plastic barriers can also include messages which could not be put on concrete or metal barriers therefore the barriers would be harder to use for resale if stolen and can be tracked more easily [39]. Additionally, through our second interview with Augustine, we learned that metal and electronic recycling is a large industry in Ghana [23]. Therefore, thieves mainly steal metal items as they can easily be resold. This in combination with the cost of plastic indicates that our design should not be metal. Based on a psychological test in 2010 that involved 20 Caucasian undergraduate students aged from 18-22, 6 men and 6 women were asked to wear six different colored t-shirts, blue, yellow, black,green , red, and white. In the order rating in colors from least to most attractive it would be red, black, blue, green, yellow and white [40]. Therefore a mixture between the lowest colors not only would allow easier visibility of the colors on the barrier but will also help in reference for people not to steal the barrier because the colors will not add to the value of the barrier. Based on this study it would probably be more expensive to have the barrier in red or green then in yellow or white which are more visible colors to the eye as is.

DR2 Update: Previously we did not have a quantifiable specification for this requirement and focused on ideas we had heard from our stakeholders. However, during our most recent meeting with Augustine, we realized that reducing the amount of visible and exposed metal on the design was very important to deter thieves [48]. Therefore, we adjusted the specification to be 0 m^2 exposed surface area of metal on our design so we have something to validate our requirement. Additionally, this quantifies the importance of reducing exposed metal on our design.

Requirement #5: Difficult to Steal
A large problem in Ghana and Ethiopia is that these crash barriers are being stolen and resold for large amounts of money. While Requirement 4 discusses how to make these barriers unappealing visually, we also have to consider making them difficult to remove once installed. Before our secondary interview with Augustine, we were considering quantifying this step by considering the weight and lifting index of the barrier. Using the NIOSH lifting equation for three people lifting a Type F crash barrier (shown in Figure 11), we were able to determine that our barrier's recommended weight limit should be over 86 kg and the lifting index (actual weight/recommended weight limit) should be over 1 [32, 41, 42]. This will be able to prevent it from being easily carried off by thieves. However, after our second meeting with Augustine, we were able to determine that there may be some other measures to consider outside of weight [23]. The metal barriers that were stolen in Ghana three weeks ago were simply removed from the posts on the side of the road and carried away in broad daylight [24-26]. After reading these articles, we will also be looking into specifications for anti-theft fasteners and awkwardly shaped barriers to make sure our specification for this requirement is fully thought through and matches what our stakeholders are saying.

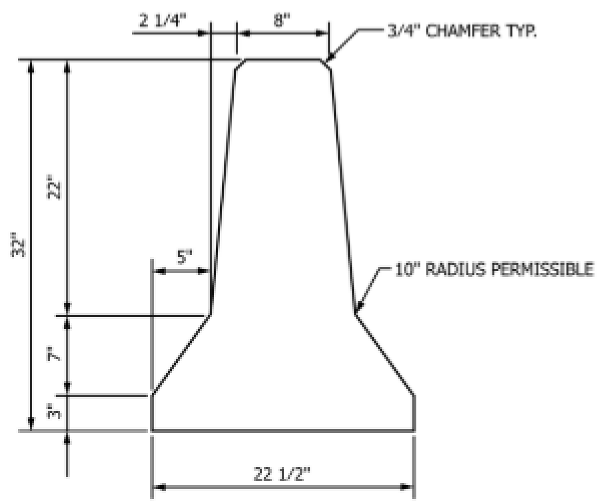


Figure 11. Type of F Barrier Standard Size

DR2 Update: Through discussions with stakeholders, we added an additional specification to this requirement in order to account for any outward facing fasteners [48]. While this requirement is not quantifiable, ensuring that any outward facing fasteners are anti-theft will make it more difficult to steal.

Requirement #6: Hard to Climb Over
Through our interviews with stakeholders, we learned that there is not an established infrastructure for pedestrians crossing high traffic roads. Specifically, Augustine was describing that some urban areas in Ghana have built pedestrian bridges and overpasses on the highway to help solve this issue [23]. However, as these bridges are far apart and aren't near the popular shops, pedestrians try to climb over them to get to the other side of the road. Therefore, these barriers need to prevent this and ensure pedestrians stay in the safety of the sidewalk. As discussed in our DR1 presentation, we initially considered the coefficient of friction between cement and a person's shoe. This would have to be greater than 0.75 for dynamic coefficient of friction and greater than 0.21 for utilized coefficient of friction [43]. However, after our conversations with Augustine, we noticed that this might not necessarily be the best way to quantify this requirement. Therefore, we are considering using usability tests and a peer-reviewed or established Likert scale to measure and validate this

requirement.

DR2 Update: As discussed above, through discussions with Augustine we know that this specification does not quantify the requirement in the way we intended. Therefore, we have updated it accordingly. First, we have added a grip strength specification so that the grip strength is above 0.107 MPa. This was derived from the average grip strength of a 35 year old male from a database [49]. Additionally, we added specifications for both the height between potential hand and foot placement and the overall height of the barrier. These specifications are over 35 cm and 110 cm respectively. We derived these values by looking at playground climbing equipment standards that were built around 5-12 year old children [50]. We then took anthropometric data for a 10 year old male boy and a 35 year old man in the 50th percentile and scaled up the values from the standard [51]. We then made sure that our design heights would be greater than these values as these values were created for safe climbing and we want to deter climbing. These new specifications better quantify this requirement as it matches what we were told by stakeholders and does not constrain our design.

Requirement #7: Low Cost
One of the largest obstacles to wide scale implementation of road barriers in Ethiopia and Ghana is their cost. Road barriers, while simple, can be extremely expensive to manufacture and install into existing road infrastructure. The cost to install road barriers up to European Union standards is 230,000 USD/km (10,867,500 Ethiopian Birr; 1,403,000 Ghana Cedis) [44]. This is extremely expensive, especially when considering the amount of road that needs to be retrofitted. Our team also evaluated the cost of commercially available road barriers, without construction/installation, to be 19,400 USD [45] (919,000 Ethiopian Birr; 118,100 Ghanaian Cedi) . We aim to produce a road barrier approximately ½ the cost of these commercially available barriers, costing about 10,000 USD/km (473,481 Ethiopian Birr; 60,878 Ghana Cedis). Our team believes this cost goal will allow more widespread adoption of road barriers.

Requirement #8: **Locally Manufactured**
During our discussion with Dr. Bikilia, one of the largest considerations was that the road barriers are locally manufactured. Due to large import taxes and barriers, locally manufactured barriers will be more cost effective, while also adding to the local economies of Ethiopia and Ghana [46]. In order to establish the definition of locally manufactured in this context, we interpreted the “Made in the USA” standards established by the Federal Trade Commission [47]. 50% of significant parts must be of Ethiopian or Ghanaian Origin, and all processes and manufacturing must be done in Ethiopia and Ghana. With local production and assembly, widespread implementation of road barriers will be more attainable for the Ethiopian and Ghanaian governments.

DR2 Update: Previously the specification for this was 50% of significant parts must be of Ethiopian or Ghanain origin. However, through further stakeholder discussions and research we have increased this value to be 75% of parts and processes [48][52]. This will ensure that both the majority of manufacturing and materials are sourced locally and make the barriers more accessible for the region.

CONCEPT GENERATION

Our concept generation plan began with individual brainstorming, moved to team brainstorming, and next involved utilizing Design Heuristics for iteration on concepts. The team began with this three-stage concept generation plan and then proceeded naturally from there to morphological analysis to generate 12 concepts that were then analyzed in the concept selection process. Each stage of the concept generation process is detailed below, with examples from the results from concept generation activities as well as concepts eliminated in preliminary screening.

The first stage in our concept generation process was an individual brainstorming session that was held for 15 minutes as a precursor to the team brainstorming session that would follow. We decided to allow this individual brainstorming time so that each team member would be able to "warm up" and have some time on their own to explore the solution space. This allowed every member to generate their own concepts and be comfortable sharing in the team brainstorming session that followed. This stage resulted in 36 concepts and some examples of concepts from this individual session are seen below in Figure 12.

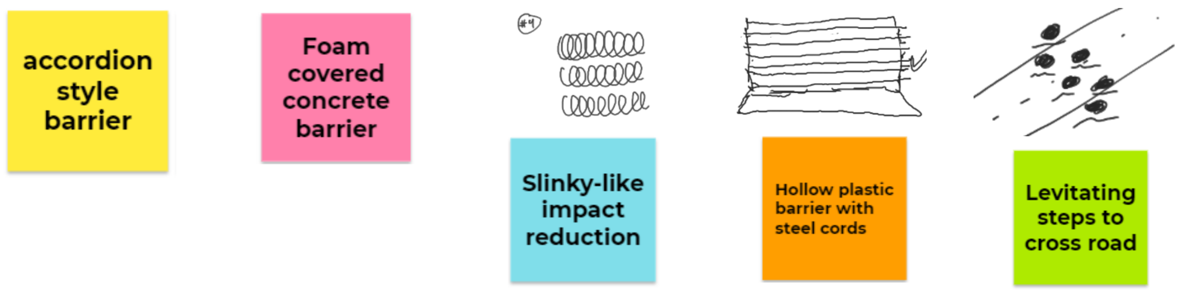


Figure 12. Example of 5 concepts from the individual brainstorming session

Following the individual brainstorming session, the next stage of our concept generation process was a 30 minute group brainstorming session. Within this session, the team was all together on a Zoom call, giving ideas to a scribe that were then placed on a shared Jamboard. The goal for the team brainstorming stage was to help the team gather a large pool of concepts, and explore the edges of the solution space with wild ideas to encourage an adventurous concept generation process. This stage resulted in an additional 33 concepts, with some example concepts from the team brainstorming session seen below in Figure 13.

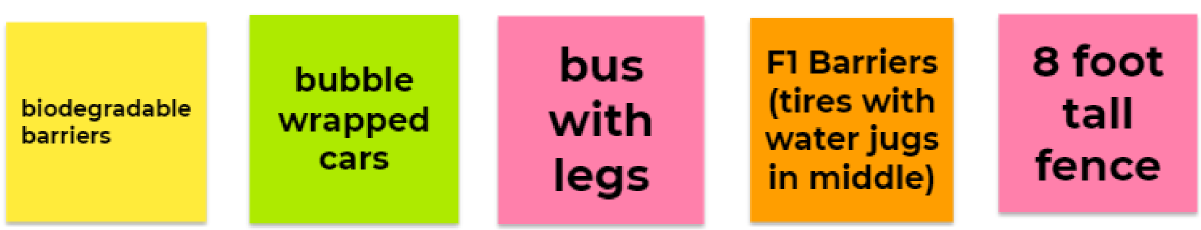
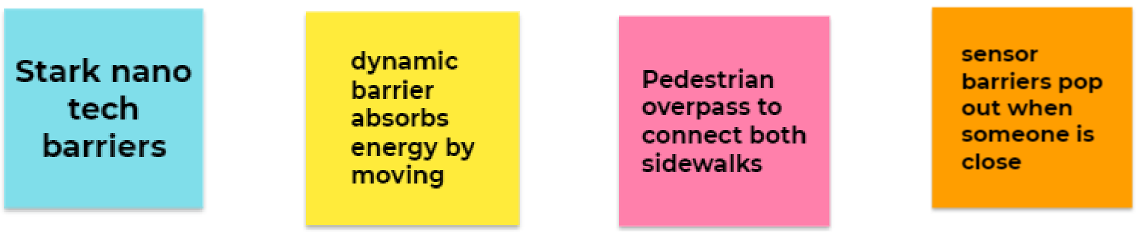


Figure 13. Example of 5 concepts from the team brainstorming session

The next stage in the team's concept generation process involved using a random number generator to determine Design Heuristics that we would use to iterate on the concept produced during the brainstorming sessions. The random number generator was used nine times and pulled up the following cards that were used for conception generation: #35 - Flatten, #3 - Add natural features, #50 - Provide sensory feedback, #8 - Allow user to assemble, #55 - Repurpose packaging, #29 - Create system, #2 - Add motion, #67 - Unify, and #31 - Elevate or lower. Using these nine Design Heuristic cards, the team generated an additional 71 concepts, bringing the total from brainstorming and Design Heuristics to 140 concepts. An example of one concept generated for each Design Heuristic card can be seen below in Figure 14.

#35 - Flatten | #3 - Add natural features | #50 - Provide Sensory Feedback | #8 - Allow user to assemble | #55 - Repurpose packaging



#29 - Create system | #2 - Add motion | #67 - Unify | #31 - Elevate or lower

Figure 14. Example of one concept from each Design Heuristic Card

With 140 concepts now generated in a shared Jamboard, the team decided that the solution space had been sufficiently explored, based on the number of concepts as well as the fact that there were multiple repetitive ideas. Because of this, the team decided to perform preliminary concept screening, first performing a "completely out there" gut check to eliminate wild, out-of-the-box ideas that would be physically impossible. Applying this screening process narrowed our number of concepts from 140 to 90. An example of concepts that passed this screening and concepts that failed are shown below in Figure 15.

<u>**Pass**</u> | <u>**Fail**</u>

Figure 15. Examples of concepts that passed/failed "completely out there" gut check screening

The team noticed that multiple concepts remaining in the current pool of 90 were physically possible, but not necessarily technically feasible and would not fulfill the requirements and specifications developed for a solution. Due to this, the team applied a second preliminary concept screening filter, looking at the technical feasibility of concepts against the requirements and specifications, eliminating concepts that we did not think could pass the specifications. After this second screening of concepts, we had eliminated 54 additional ideas and now had a concept pool of 36. Examples of concepts that both passed and failed this second screening are shown below in Figure 16 on the next page.

Pass **Fail**

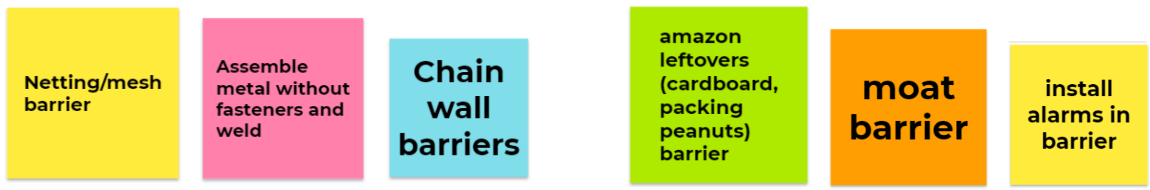
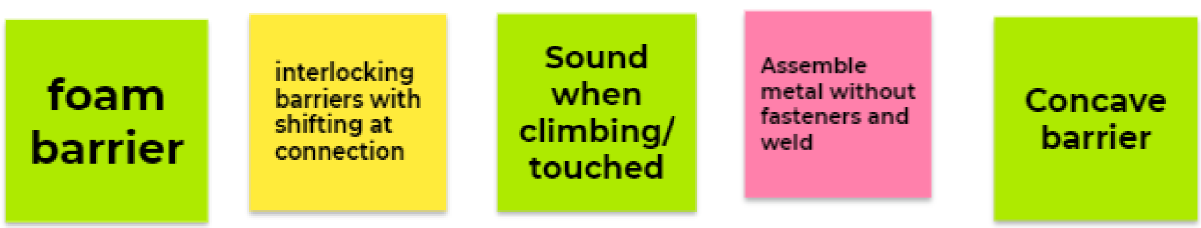


Figure 16. Examples of concepts that passed/failed technical feasibility screening

Morphological Analysis (+ solution space complete) - Once the concept pool had been narrowed to 36 ideas, the team went over all of them, and realized that many were partial concepts, characteristics of a solution, or ideas for creative functionalities that could be incorporated into a solution. After noticing this, the team decided to cluster the remaining ideas and then use those clusters to perform morphological analysis and generate fleshed-out concepts that could be used for concept evaluation. Discussing natural clusters for the ideas resulted in five clusters that each of the 36 ideas was placed into: 1 - Materials, 2 - Characteristics, 3 - Preventative functions, 4 - Assembly, 5 - Shape. Examples of ideas that were placed into each cluster can be seen in Figure 17 below.



1 - Materials 2 - Characteristics 3 - Preventative functions 4 - Assembly 5 - Shape

Figure 17. Example ideas in each of the five clusters used for morphological analysis

Each cluster contained at least four ideas from the previous concept pool, and utilizing morphological analysis with these clusters, the team generated 12 final concepts that we believed were novel, creative, functional, and capable of passing the requirements and specifications. After diving deeper into each of these 12 concepts, the team was satisfied with the exploration of the solution space. We felt that additional morphological analysis would result in repetitive or technically infeasible concepts. Five of the final 12 concepts are discussed and displayed in depth in the following paragraphs.

Concept #1: Formula 1 - Inspired Barrier:

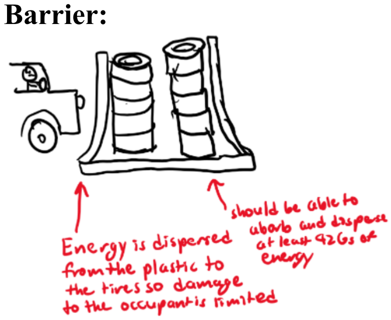


Figure 18. Formula 1 - Inspired Barrier concept drawing

This concept was inspired by the tire barrier used in Formula 1 motorsport. The main characteristics of this concept would involve stacks of tires housed within a plastic-walled enclosure that would be able to disperse energy and limit the effects of an impact. This would also utilize old tires that would otherwise be thrown away, considering the environmental implications of reusing old materials. This concept can be classified as a plastic barrier with similar benchmarking and high potential for feasibility.

Concept #2: Airbag-Deploying Barrier:

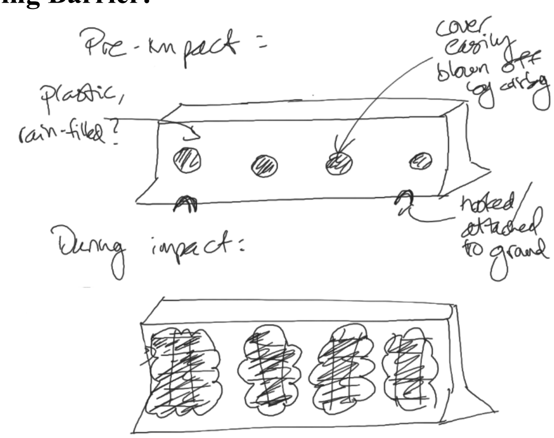


Figure 19. Airbag-Deploying Barrier concept drawing

This concept was inspired by the airbag deployment system in cars, and it involves a modified concrete barrier that houses multiple airbags in a 2 meter section that will deploy in impact. This will limit the effects of an accident and lessen the blow against the concrete while also directing debris and the vehicle away from pedestrians. Each concrete section would be anchored to the ground to render it immovable. This concept was classified as a concrete barrier with some benchmarking and medium potential for feasibility.

Concept #3: Woven-Mesh Structure:

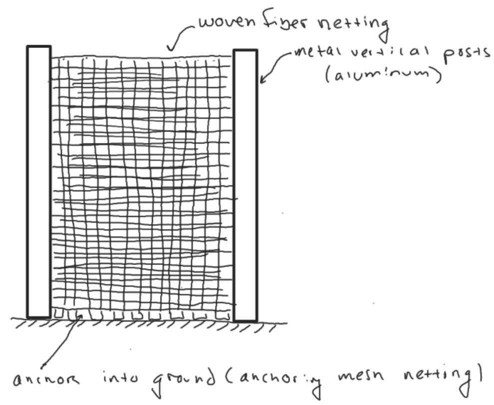


Figure 20. Woven-Mesh Structure concept drawing

The woven-mesh structure was inspired by the waving traditions in Ghana, and acts as a barrier for the roadside. Aluminum supports would tension a netting/mesh structure that is anchored to the ground to prevent cars or debris from entering the sidewalk. Each section would be ~2.5 meters tall to act as a deterrent to pedestrians looking to bypass barriers. This concept was classified as a woven barrier with low benchmarking analysis and low potential for feasibility.

Concept #4: Roller Barrier:

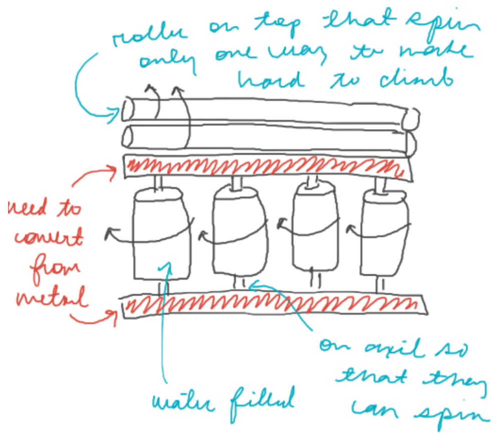


Figure 21. Roller Barrier concept drawing

The roller barrier concept is modified from a benchmarking solution during the early stages of the design process. The modifications made are specific to the requirements and specifications with metal rails replaced by plastic to deter people from stealing the barrier and roller wheels on the top of the barrier to prevent pedestrians from climbing over it. In the middle there are plastic, water-filled rollers to decrease the impact of a crash and divert energy to the rotational motion of the rollers. This concept was classified as a plastic barrier with high benchmarking analysis and high potential for feasibility.

Concept #5: Tectonic Barrier:

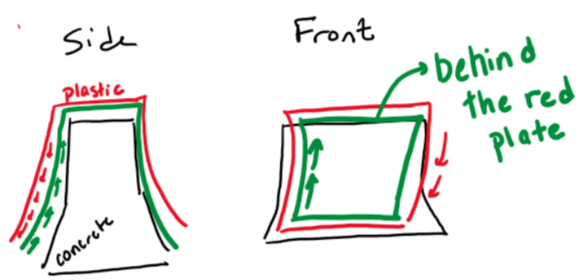


Figure 22. Tectonic Barrier concept drawing

The tectonic barrier concept is a modified concrete barrier that utilizes shifting plastic covers on the three exposed surfaces of the barrier (top and two sides). The shifting plates discourage and prevent climbing over the barrier, and they also provide an additional layer of energy absorption in the event of a crash. This concept was classified as a concrete barrier with high benchmarking analysis and high potential for feasibility.

A full documentation of all concepts generated at each stage of the process can be found in the appendix at the end of this report.

CONCEPT SELECTION PROCESS

Our team's concept generation process included a screening process which elminited any concepts that were deemed not feasible or did not pass a gut check. Following this screening process, we were left with

12 viable concepts to select from. Our selection process was done in two steps: a weighted pugh chart, and then engineering analysis to narrow down to one final concept. The 12 concepts that remained following the initial screening were placed into a concept selection matrix with four criteria: stakeholder input, unappealing to steal, hard to climb over, and locally sourced materials. These criteria are displayed below in Table 13.

Table 13. Criteria for concept selection matrix with rankings.

Rank	Stakeholder input	Unappealing to steal [1]	Hard to climb over	Locally sourced material [2]
0	Not supportive	≥ 25% exposed metal	Easy to climb over	0% locally sourced
1	Neutral	< 25% exposed metal	Most people can climb over	≤ 50% locally sourced
2	Somewhat supportive	< 10% exposed metal	Most people can't climb over	> 50% locally sourced
3	Strongly Supportive	No exposed metal	Cannot climb over	> 75% locally sourced

1. Exposed metal surface area
2. Volume of components that are locally sourced

Our team believes these criteria are the most important in selecting our final concept. Unappealing to steal, hard to climb over, and locally sourced material were all derived from our requirements and specifications for characteristics. Stakeholder input was also considered as our team has had multiple meetings with stakeholders from Ethiopia and Ghana which have provided us with valuable insights on our concepts. These criteria were then placed into a weighted matrix with the 12 remaining concepts, as shown below in Table 14.

Table 14. Concept selection matrix with 12 pre-screened concepts.

Concept	Stakeholder input	Unappealing to steal	Hard to climb over	Locally sourced material	Total
	2	1	1	1	
1	**3**	**3**	**2**	**2**	**13**
2	1	3	0	3	8
3	0	3	0	1	4
4	1	1	2	1	6
5	0	2	0	1	3
6	2	3	1	3	11
7	1	2	1	2	7
8	**3**	**2**	**3**	**2**	**13**
9	1	2	1	2	7
10	2	3	1	3	11
11	2	3	1	3	11
12	2	2	1	2	9

Stakeholder input was given a weight of 2, while the other criteria were all given a weight of 1. As our team has no experience designing in our target locations, stakeholder input was given a higher weight than the other criteria. The opinions of our stakeholders on each design was an important factor in deciding our final design.

Two concepts were selected from our concept selection matrix, as they both scored 13 total points. These concepts were concepts 1 and 8, the tectonic barrier and roller barrier. All other concepts were not considered going forwards in the selection process.

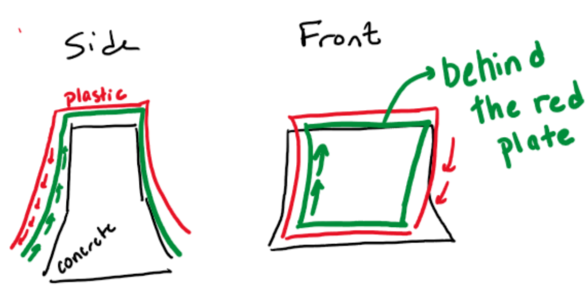
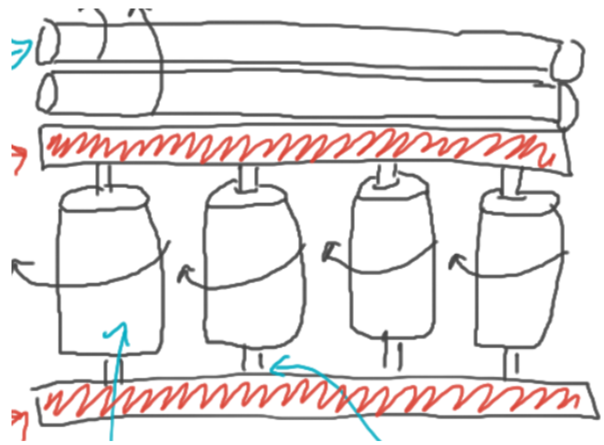
Concept 1- Tectonic Barrier	Concept 8- Roller Barrier
	

Figure 23. Final two concepts resulting from concept selection matrix.

Our team continued our concept selection process by conducting a preliminary engineering analysis of the two concepts shown above. The results for this analysis can be seen below in Table 15.

Table 15. Engineering analysis phase of concept selection to select the final concept.

Hard to climb over		**Impact force comparison**
Tectonic Barrier (1) Posture analysis was deemed overall moderately dangerous Force analysis showed a few moments where spine was dangerously impacted Overall: Some people can climb but it will not be comfortable	**Roller Barrier (8)** Never reached analysis as the pedestrian got stuck halfway through climbing	$Impulse = \Delta Momentum$ $F*t = m\Delta v$ $\boldsymbol{F_{IMPACT} = (m\Delta v) / t}$ (1) Assume $m_1 = m_8$ (2) Assume $\Delta v_1 > \Delta v_8$ (3) Assume $t_1 < t_8$ $\therefore F_{IMPACT-1} > F_{IMPACT-8}$

In our preliminary analysis, we chose to compare the two barrier designs on two characteristic requirements that we have defined: hard to climb over and impact force. Using Jack, an analysis was conducted on both the tectonic barrier and roller barrier in which a human model was analyzed as it climbed over each barrier. In the case of the tectonic barrier, the model was still able to climb over the barrier, however it did include moderately dangerous levels of stress in the body. However, in the case of the roller barrier, the human model was not able to climb over the roller barrier. As a result, the roller barrier better fulfilled the hard to climb over requirement. This can be attributed to the horizontal rollers that are placed on top of the barrier, which make it significantly more difficult for a pedestrian to climb the barrier. A rudimentary impact force comparison was conducted as shown in table X3 in which the change in velocity from impact was assumed to be less and the impact time was assumed to be greater in the case of the roller. This results in the roller barrier having a lower impact force, and thus outperforming the tectonic barrier. The roller barrier design allows for greater force dissipation through the rollers, thus better fulfilling our impact threshold requirement. Overall, the roller barrier better fulfills our requirements and is the superior concept. It is important to consider the potential disadvantages of the roller barrier: complexity of rotating assemblies, as well as large quantity of fasteners. Additionally, the tectonic barrier has some advantages in this aspect: less moving parts, less fasteners, and overall simplicity. However, the main goals of our project are to create a barrier that prevents pedestrians from entering the road, while also reducing the impact force of crashes, and the roller barrier better achieves these goals than the tectonic barrier.

CONCEPT DESCRIPTION

The final chosen concept can be seen depicted in Figure 24 as the first low stakes CAD model for the concept. This first iteration of the selected concept is a redesign of existing roller barriers with some added features. It serves to understand the functionality of the concept and begin to finalize the final concept design.

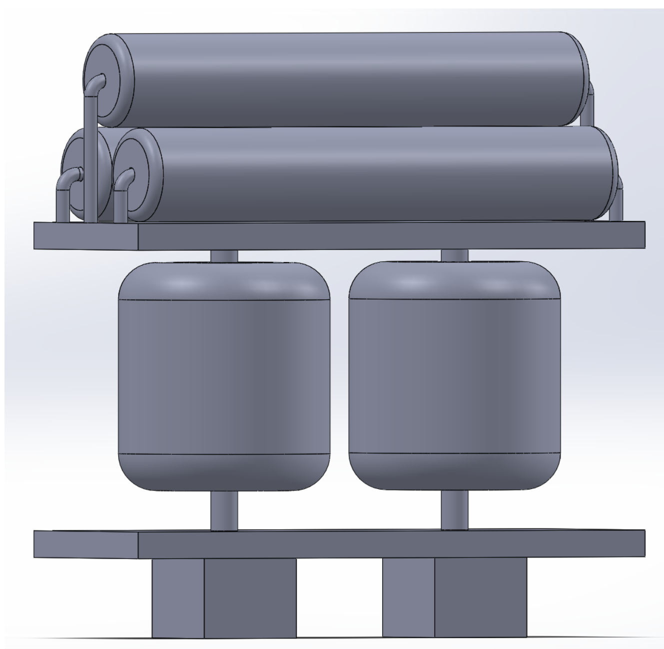


Figure 24. Preliminary CAD model for final concept

Redesigned Aspects of Original Roller Barrier

Roller barriers are currently becoming a popular type of crash barrier used in Ethiopia and Ghana. As seen in Figure 25, these barriers are made up of a lot of metal components. In trying to meet our requirement of appealing to steal we needed to redesign the barrier to not have any exposed metal. In Ethiopia and Ghana there is local plastic manufacturing of think water tanks, pvc pipes, and other types of bins. This allows for the options of the guard rail to be redesigned from metal to some strong plastic material. More research is needed to figure out the correct materials to use for the rail since the guard rail on the bottom and top is meant to take most of the initial impact of a car when hit. Therefore this plastic needs to be able to withstand a majority of the impact.

Figure 25. Current roller barriers being used in Ghana today [52]

New Features
The main feature added to the roller concept is sets of horizontal rollers on top of the barrier to make it hard to climb over. These rollers are set at different heights on top of the barrier to make it even harder to get over. The rollers free spin and the easier that the rollers spin the harder it is to grip them in order to climb over them. The top rollers also add a height feature to the concept. The original concept was shorter in nature and therefore allowed pedestrians to climb over easier. Since the main focus of the group was pedestrian safety, we honed in on making sure that the final design met the hard to climb over criteria. The hand drawn final concept can be seen in Figure 26 below. The figure depicts the orientation of movement of the rollers, both top and bottom.

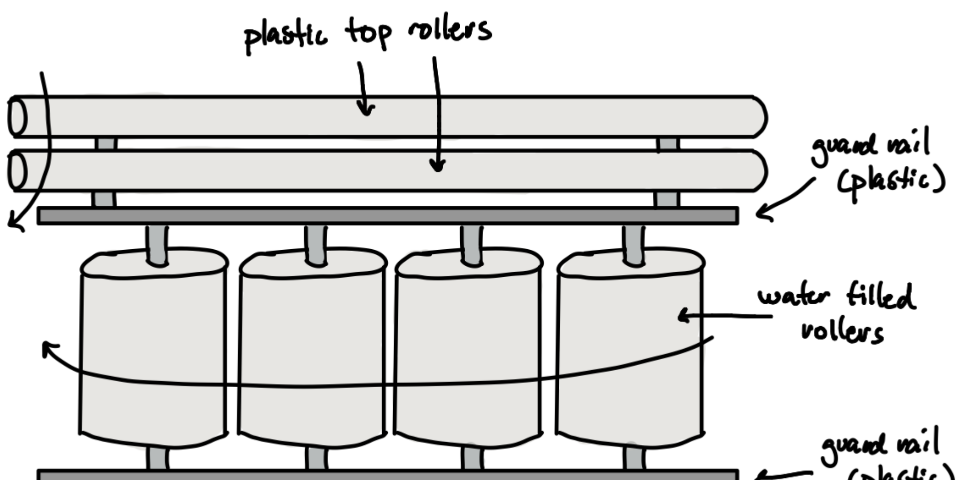


Figure 26. Hand drawn depiction of final concept design with included call outs of features.

CONCEPT ANALYSIS

As described above, our final concept is based on existing roller barriers with an additional roller on top to prevent pedestrians from climbing over it. Even though this design is still being improved through conversations with stakeholders, engineering analysis has been conducted to gauge what needs to be adjusted in our final design. Based on feedback from our stakeholders, we have decided the most important requirements to analyze for iterations of our design are: difficult to climb over, difficult to steal, and impact. We are also prioritizing local manufacturing but we are waiting on information from our stakeholders and a final bill of materials to validate this specification. Therefore, only our three most important technical requirements will be discussed for our current design.

Difficult to Climb Over

This requirement has quantifiable specifications involving grip strength and various height measurements on the design. To analyze this requirement we have mostly used theoretical and software analysis based on human factors and occupational biomechanics. Additionally, we have plans to run some empirical testing once we have a few complete prototypes. While the height measurements are easily validated by using the Solidworks measure tool for iterations of our design, the grip strength and overall climbing requirement needed more in depth analysis.

Grip Strength. In order to calculate the grip strength needed to hold onto the top rollers, we used a quick back of the envelope style calculation with a low level of detail. Because of the format of this analysis, a few assumptions were made. First, we had to assume that the rollers would be stationary as accounting for the rolling motion would complicate our equation. Assuming stationary rollers does decrease the confidence we have in this analysis but for a quick understanding of this specification we determined that this analysis would be sufficient. Additionally, we assumed that the pedestrian would be able to reach and easily hold onto the top rollers and did not account for any potential awkward arm/hand positioning to reach the top rollers. We also considered one singular roller and not the entire chain of rollers for a one handed grip. The equation for this analysis was found in a journal article and related grip strength to the ratio of the diameter and length of a cylindrical object [53]. However, the grip strength was calculated in Newtons and our specification was based on MPa. To ensure we could properly validate this specification, we assumed a palm down grip on half the surface area of the roller which was then divided by the Newton value calculated in the equation shown below. Grip strength is measured in Newtons, D is diameter of the object in mm, and L is the length of the object in mm.

$$Grip\ Strength\ =\ -\ 0.45(\frac{D}{L})^2\ +\ 30.80(\frac{D}{L})\ +\ 342.50$$

The surface area of the cylindrical object was calculated by measuring the cylindrical piece of the rollers and ignoring the two circular caps. This value was then divided in half to account for the palm grip. All of these calculations in combination ended up that the Grip strength required to hold one roller is 0.006983 MPa. This value is much smaller than the specification we had listed above. Some design changes such as increasing the diameter or decreasing the length of the roller may need to be considered to ensure that this specification is met. However, as the roller will be moving as the pedestrian is attempting to grip it, this will increase the grip strength required. Therefore, we can predict that our design will still be functional with a few minor adjustments. We will need to determine if adding rolling to our calculations will increase this value as well. Our next steps for this analysis include some empirical testing when we obtain a prototype of our top rollers. We can use force sensors on a team member's hand and see how much strength is required to get a comfortable grip on the rollers as they are moving. Hopefully these analyses in combination will allow us to tweak and adjust this design in order to match this specification.

Jack. To visualize how a pedestrian would approach climbing our design, we ran a simulation in Jack software. This is more complex and contains a medium level of detail for an initial iteration. While the CAD used was highly detailed a few assumptions were made about the pedestrian that reduced the complexity of this software. We assumed that the pedestrian would be a 50th percentile male in both weight and height. Additionally, we considered the ground below the pedestrian to be flat and only used one approach of climbing for the initial analysis in this software. The climbing approach we used was the same way that Peter had approached the climbing while we were selecting our concept. This is a right foot placement on the barrier while using both hands to attempt to pull oneself up over the barrier. We were also limited in some of the movements the pedestrian was making as the software was not as fluid as a typical human would be while climbing. We also faced some limitations with tolerance issues while determining the hand placement and grasp on the top rollers of the barrier. However, even with all of these limitations and assumptions, we are fairly confident in our Jack simulation as it is a commonly used tool in industry to determine biomechanical movement and we will be more confident as more iterations are conducted. The results from this simulation showed that with this method of climbing, the pedestrian gets stuck once they have their hands and feet on the barrier as there is not an easy way to pull oneself over the top. This was caused by the large rollers in the middle of the design and the large gap between potential foot placements (i.e. the two white PVC pipes). The final frame of the climbing attempt is shown in Figure 27 below.

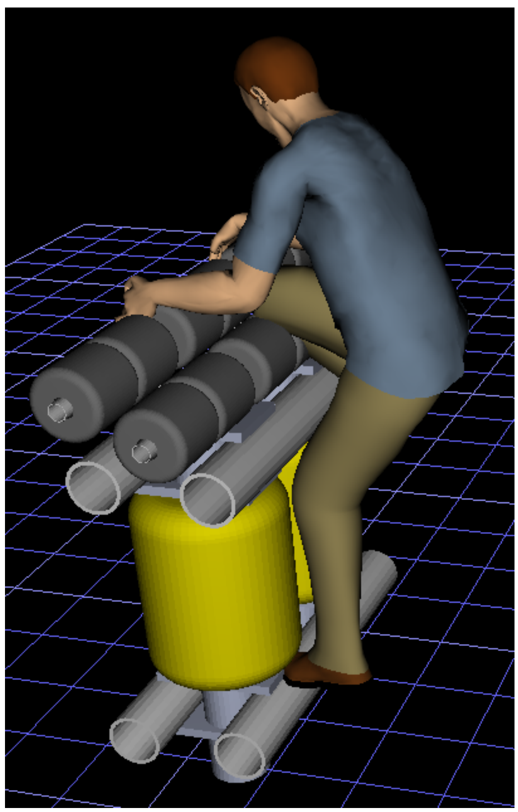


Figure 27. Final frame of climbing attempt that shows a pedestrian being stuck at the top.

As seen in the Figure, any attempt to pull oneself up and reposition their foot at the top of the barrier is not possible. The figure in Jack was able to put their foot there but only if their knee was in the barrier, which is not physically possible in real life. Therefore, we are confident that it would be very easy to get over this barrier and would discourage most of the pedestrians who attempted. Additionally, the lower back analysis that was running during the simulation showed that this final position would result in harmful levels of damage to the pedestrian's spine. Therefore, it would also likely be painful for those attempting to climb this barrier. These factors together would hopefully reduce those who can and would attempt to climb this barrier and validate that the design is functional in preventing people from easily climbing this barrier and discouraging those who try as we cannot assume it will prevent every single pedestrian from climbing. While we are confident in this specific iteration of analysis, we will need further iterations to feel confident about the design as a whole. Our intended next steps with the Jack software would be to run males in the 5th and 95th percentile as well as females in the 5th, 50th and 95th percentile. We would also test different climbing methods in all of these percentiles and see if another approach or foot/hand placement would actually allow someone to successfully climb over this barrier. Again, a completed prototype of our top rollers would help us get a better idea of climbing methods.

Difficult to Steal

This requirement has specifications involving the lifting index and recommended weight limit to pick up and carry the full assembly. To analyze this requirement, we have currently used theoretical software based analysis in Jack. The software analysis was able to give us information about the lifting specifications however the fastener specification will be analyzed once we have a full bill of materials and a finalized design as it is not quantifiable.

Jack. In order to understand the biomechanical consequences of attempting a two person lift on a 1 meter section of our complete assembly, we ran a lifting simulation in Jack. Similar to the difficult to climb requirement, this is a complex and medium detail iteration of this simulation. The same highly detailed CAD model was used but assumptions about the human lifting impacted the overall complexity and detail of this iteration. We assumed that the lifter is a 50th percentile male in both weight and height. We also considered the ground below the lifter would be flat and only considered a bottom grasp lifting method. There were some limitations with the Jack software as the movements are not as fluid as a typical human lift and we ran into issues while running two humans at once. Therefore, to account for the two person lift, we divided the weight of the barrier in half and put the center of mass closer to the lifter to account for the additional upward force that would be holding the other end of the barrier. The mass of the barrier was calculated in Solidworks using the mass properties tool. As with the climbing analysis, we had issues with the precision of the humans grasp on the barrier. However, even with all of these limitations and assumptions, we are fairly confident in our Jack simulation as it is a commonly used tool in industry to determine biomechanical movement and we will be more confident as more iterations are conducted. The results from this simulation showed that a lift is possible but would have a highly increased risk of lower back injury. This would make the lift highly uncomfortable and painful for the lifter. Figures 28 and 29 show both the pose chosen for the bottom grasp lift and the results from the lower back analysis.

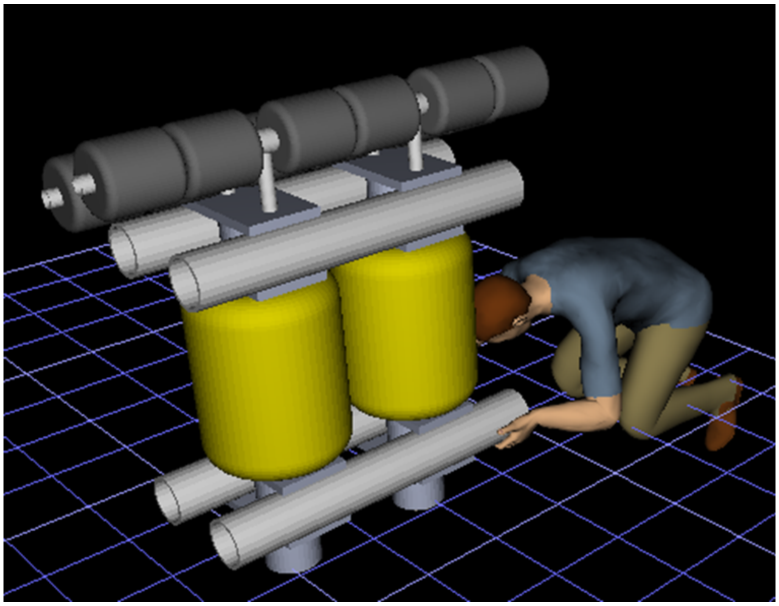


Figure 28. Lifting position for one half of a two person lift.

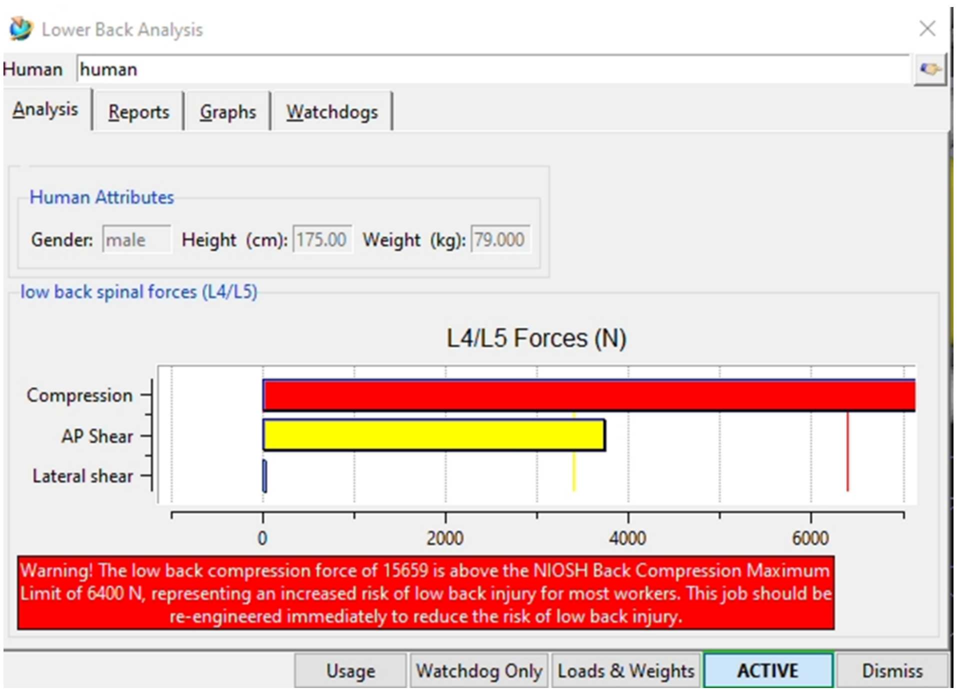


Figure 29. Results of a lower back analysis at the peak of the lift.

As seen in the figures above, this lift would be uncomfortable and painful for the lifter even though it is a possible lift. Additionally, this simulation shows the lifting index of 1 is exceeded. Solidworks calculated that the mass of a 1 meter section of our barrier design is around 177.38 kg and half of this is around 89kg. This also exceeds the recommended weight limit of 86 kg per person stated in our specification. While our specifications have been validated through this simulation, further iterations are needed to fully understand this specification. We have considered only one type of lift with one human model. Therefore, similarly to the climbing requirement, we will reiterate this analysis using a 5th and 95th percentile male model and a 5th, 50th and 95th percentile female model as well. Additionally, different types of lifts such as grabbing the middle rollers or the top rollers instead will be considered. Even though it is possible that the thieves would be able to dismantle the barrier and carry the pieces away individually, we are limiting our analysis for that scenario as we assume that all the outward facing fasteners would be anti-theft and require special tools that might not be readily available. Therefore, we are confident that it would be not easy to lift sections of our barrier and carry them away but further iterations and conversations with stakeholders are integral to fully exploring the scenarios. Hopefully with additional simulations and stakeholder interaction we will feel more confident that our barrier is less easy to steal than the existing barriers in Ethiopia and Ghana.

Impact Threshold and Lifespan
This requirement has specifications involving the occupant impact velocity and ride down acceleration during a crash. Additionally, it also considers the lifetime and compressive strength of the barrier. To analyze this requirement, we have initially considered using a form of finite element analysis software to validate the impact threshold and lifespan of the barrier. However, through a meeting with Professor Hulbert we learned that this simulation is too advanced for the scope of this class and would involve a high level of expertise [54]. Therefore, he suggested a small scale empirical test using very simplistic replications of our design. The section below contains the plan of action that we intend to implement for this empirical testing.

Empirical Testing. As discussed before, we have determined that empirical testing is the best way to validate these requirements and specifications. As this was recommended by a stakeholder we believe that this would be a sufficient and appropriate analysis for this design. The main parts of the design that will be taking impact are the yellow rollers and the PVC piping. Therefore, our plan is to obtain PVC piping at different wall thicknesses and create a simple prototype for the yellow rollers. As we will be scaling the impact for a full size prototype, we do not need 1 meter section of all the PVC nor do we need the yellow rollers to be exact. PVC piping is easily obtainable through the machine shop or a hardware store so our main concern is replicating the yellow rollers. A suggestion by Professor Hulbert was to fill a gallon or liter plastic bottle with water to replicate the rollers and then scale the results to our design [54]. As we will be using quick prototypes rather than a complete assembly, there is a low level of detail for this analysis. This also ensures that we can iterate through different materials quickly and not worry too much about maintaining a certain level of detail or complexity throughout our testing. We believe that these assumptions for our prototypes are appropriate as they were validated by an expert in the field and we will be more confident in this as we hear from more experts in the machine shop and civil engineering department. Through these contacts, we will be able to concretely define our empirical testing and begin running through various iterations of materials in order to adjust our design accordingly. Our current plan for empirical testing as discussed with Professor Hulbert is to research typical impact forces during an accident and scale the forces down based on how big our prototypes are comparatively to our design [54]. Then using weights, we can apply a force to our design and observe how various materials react. Our observations in combination with knowledge from statics and physics can be used to determine which material and combination will be the most appropriate and effective for our design. Then we can repeat these experiments until we are able to validate our requirements and specifications with our scaled down prototypes. Hopefully in the next week we will have heard back from experts in civil engineering and the machine shop and can begin the iterative process of empirical testing.

FINAL DESIGN DESCRIPTION

The final chosen concept can be seen in Figure 30. This selected concept design is a redesign of existing roller barriers with some added features. The completed final design is still evolving and improving as analysis and stakeholder meetings take place.

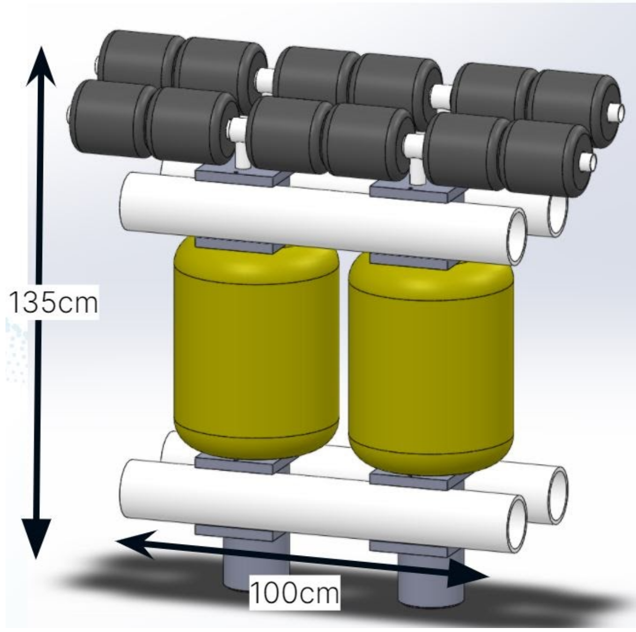


Figure 30. First iteration of the roller barrier selected concept

Materials and Dimensions of Design
Roller barriers are a popular type of crash barriers but these barriers are made up of a lot of metal components.With our requirement of appealing to steal having the specification of having no exposed metal we needed to redesign the barriers guard railings. We chose to make the bottom and top railing portion out of pvc pipes. PVC pipes are a strong plastic material that is manufactured locally in Ghana and Ethiopia making it an accessible material to use. This guard rail on the bottom and top is meant to take most of the initial impact of a car if it were to hit the crash barrier.

The design does feature a steel pipe running through the middle of the rollers which can be seen in Figure 31. This adds strength to the rollers and allows for the barrier to hold its place upon impact. The metal pipe is covered by plastic covers on the top and bottom in order to hide it from view and give the appearance of non-metal. The top and bottom plastic covers are made of polyethylene and hold the pvc guardrail.

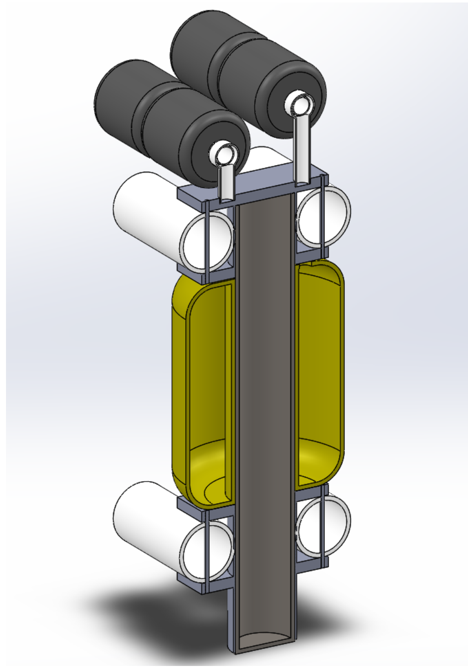


Figure 31. Cross section view of the roller barrier concept

The roller parts are hollow plastic containers made out of an EVA and polyurethane mixture that will be filled with water. The dimensions of the rollers can be seen in Figure 32. These rollers are meant to deflect the car's impact and allow it to have a larger area of impact and therefore reducing the impact force over the area. The rollers also feature a bright yellow color to allow for higher visibility.

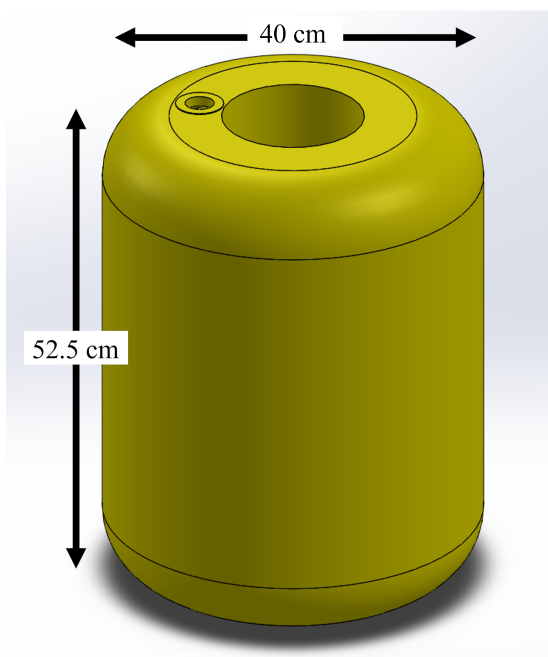


Figure 32. Dimensioned view of the roller containers

The main feature added to the roller concept is sets of horizontal rollers on top of the barrier to make it hard to climb over. The rollers are made out of polyethylene with their dimensions shown in Figure 33.

There are two rows of the rollers at two different heights to make it even harder to get over. The original preliminary CAD featured three rows but it was decided that there was no need for an extra set of rollers on the road side of the barrier. The rollers free spin on pvc pipes with small spacers between the rollers. This helps to reduce the friction between the separate rollers to allow them to spin easily. The easier that the rollers spin the harder it is to grip them in order to climb over them. The rollers not only make it hard to grip when trying to climb over, they also add height to the barrier making it even tougher.

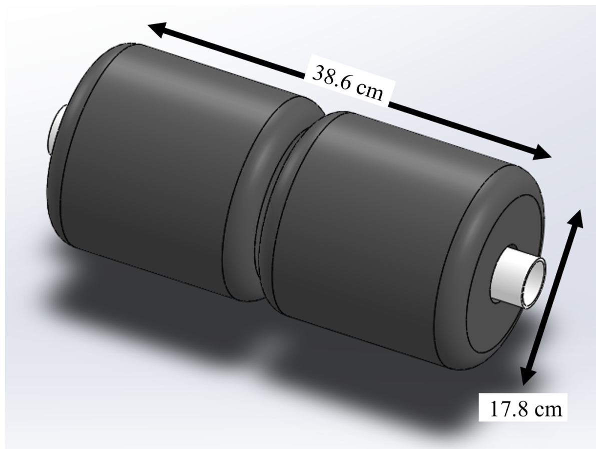


Figure 33. Dimensioned view of the top rollers

The overall design of the roller barrier plays heavily off of the existing roller barriers currently in use. This allows for the main focus to be the top rollers added to the design to reduce climbing over as well as the redesign of the metal portions. The water filled rollers have been proven to be effective crash barriers and function as intended.

Build Description

As a team we wanted to be able to be able to model some aspects of the design in order to help validate their functionality. The main part of the roller barrier, being the vertical rollers meant to take the impact as well as the pvc pipe, is something that has already been tested since it is (partially) a currently used solution. The pvc pipes still need further testing on their strength functions but it isn't feasible to have a car crash into our prototype, therefore it isn't modeled. However, the new addition of the top rollers could be modeled in order to physically test how hard it would be to climb over the barrier. We designed a prototype of the barrier that included the correct height as well as the top most rollers and can be seen in Figure 34. The top most roller is the hardest one to get over and allows for good testing without having to model the shorter top roller as well.

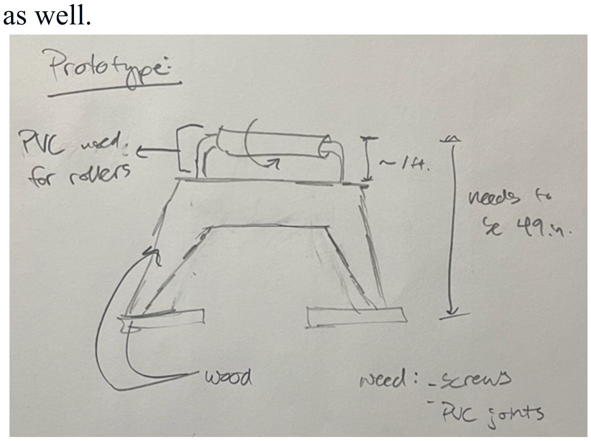


Figure 34. Sketch of prototype build

Materials and Parts. For the base of the barrier we decided to use wood to construct it to allow us for a sturdy base that would be affordable and easy to manufacture. The top rollers would be made out of pvc, the largest available that is close to the seven inches of the final design, and would be mounted on with more pvc. The pvc on pvc would allow for less friction as well as the correct shape. This can be seen in the full bill of materials found in Appendix B. When going to purchase the materials, we found pre-made sawhorses available at the hardware store. These provided the necessary shape and stability we needed. This allowed us to simplify the build process as well as save on money. The only thing needed to be fixed was making two stands for the sawhorse in order to meet our desired height.

Manufacturing Plan.
Materials List:

- 1x 4”x2’ PVC pipe
- 2x 1.5”x2’ PVC pipe
- 1x 29” sawhorse
- 2x 1.5” PVC elbow
- 2x 1.5” PVC end cap
- 18x 4” woodscrew
- 1x 2”x10”x12’ lumber

Assembly:

1. Place 2x PVC elbows on ends of a single length of the 1.5”x2’ PVC pipe
2. Mark distance from each center of elbow on top of sawhorse
3. Using 2x wood screw, drill end caps into marked points on sawhorse using electric drill
4. Cut the remaining length of 1.5”x2’ PVC pipe in half using hacksaw
5. Place each half of 1.5”x2’ PVC pipe into the PVC end caps attached to the saw horse
6. Place 4”x2’ PVC pipe around 1.5”x2’ PVC pipe with elbows attached
7. Attach each PVC elbow to the vertical PVC pipes
8. Cut the 2”x10”x12’ lumber into 6 equal lengths of 2’ each using a handheld electric circular saw
9. Using 6x wood screw, fasten horizontal piece of 2’ lumber to two vertical pieces (3 screws along each side)
10. Repeat step 9 for second base
11. Place sawhorse on top of wooden bases
12. Using 4x wood screw, fasten the sawhorse to the bases from the underside of each base

Figure 35. Fully built prototype for testing.

Relationship to Final Design. As mentioned previously, as a team we decided that the highest importance of the project was ensuring that the barrier meets the requirement for hard to climb over. Therefore the build is meant to allow us to test just that. It has the same height as the final design concept with only the roller concept on the top being modeled. The vertical rollers as well as the pvc are meant for the impact of the car which wouldn't be able to be tested in the time frame of the project. So focusing on the top rollers and being able to empirically test the ease of climbing was the main priority. As a team we are all of different body types and therefore tested the build ourselves to see how hard we thought it would be to climb over. With the data collected from us attempting this, it will help validate the design's intention of being hard to grip and get over. The engineering value that the team added was the enginuity of the rollers being but horizontally on the top, which is exactly what this build shows. The parts that are not modeled in this build are already in use today as roller barriers and therefore weren't our main focus.

Contextual Factors for Final Design

The final design concept along with all the parts of this project were heavily influenced by contextual factors. Focusing on a country that is not our own requires us to have them very present when making decisions. The most valuable tool when looking into the social impacts of our need and final design was being able to meet and talk with stakeholders that are from Ethiopia and Ghana. Dr. Bakila and Augustine currently reside in those two countries and helped to guide us in the right direction. They helped fill the gaps with understanding the different regions and helping us contextualize our designs.

Public health, safety, and welfare. Safety was a big factor when it came to the design of the final concept. Going back to the original theme of our project, we were focused on reducing pedestrian injuries in car crashes. This took form in trying to reduce the ability for pedestrians to put themselves in greater risks. The aspect of making the design inherently very hard to climb over would help keep pedestrians out of busy streets where cars don't stop. This goes hand in hand with public health and trying to prolong the lives of people in these areas. Unlike the US, in Ethiopia and Ghana there are little to no traffic regulations put in place. That is the reason people don't think twice about climbing over the barriers and walking into oncoming traffic. So reducing that or atleast adding an obstacle to getting on the street would help to add more thought into intentionally getting past the barrier and into the street.

Global context. In doing our research on pedestrian safety in other low income countries, we realized a trend that a lot of them do not have traffic regulations. Therefore there is room for these new crash barriers to be implemented elsewhere to clearly define where cars won't stop for pedestrians. The aspect of reducing the metal is currently specific to Ethiopia and Ghana since both of the countries have access to metal recycling industries that they can sell stolen metal to. Other countries with this access could also benefit from a more plastic based design that would help reduce the rate the barriers are stolen.

Social Impacts. Since the country that we are designing for is not our own or what we are familiar with, it was very important for us to keep the social implications in mind. Something that we think will work in the United states is not necessarily something that will be in Ethiopia and Ghana. For this reason we made sure to keep very good connections with our stakeholders and looked to talk to people currently in these regions. Dr. Baklia and Augustine were crucial in allowing us to keep the social factors in mind and run our ideas and requirements by them. We got a lot of input on our specifications and what would work in their countries, as well as on our final chosen design. A big example of this was in making the specification for unappealing to steal to have no exposed metal. This is not the specification we were thinking about at all through scientific research, but in talking with our stakeholders we realized that it was the best way to quantify this requirement to fit the area.

Economic Impacts. The economic impact of the design was not a factor that was specifically thought about when created but ended up being tied to lowering the cost. Since the cost of manufacturing and obtaining materials highly increases with imported goods, we wanted to reduce that by concentrating on the design being from the specific countries. The design was crafted to be at least 75% locally manufactured material from Ethiopia and Ghana. As a result this will help keep business in the respective countries and help develop more income. Therefore the factor became a good incentive to keep this specification in the forefront when finding materials and coming up with the design.

DESCRIPTION OF VERIFICATION AND VALIDATION APPROACHES

Verification: Difficult to climb over
As discussed in previous sections, the first requirement to be validated was one of the most important requirements for the project - a solution that is difficult to climb over. After completing a Jack simulation as engineering analysis, the team wanted to validate the results given by the software and decided to use a low-fidelity prototype of the alpha design concept. This prototype focused on the height of the barrier and the top rollers meant to prevent climbing as the team felt that these two aspects of the barrier were the most important to validating the difficult to climb requirement. An image of the finished prototype - next to George for reference - can be seen below in Figure 36.

Figure 36. Assembled prototype next to George for size reference

Once the prototype had been assembled, three team members each attempted to climb over it, allowing us to personally validate the difficulty of climbing over our alpha design. Every team member had significant difficulty while attempting to climb over the prototype, and each time was unsuccessful or involved uncomfortable physical effort that would highly discourage users from continuing to climb the barrier. Our team picked this method to validate the difficult to climb over requirement because it allowed us to physically attempt to climb a prototype of the alpha design for us to have the firsthand experience to validate the requirement. Additionally, using team members as users in this case was efficient for the short time that the team had to validate requirements. If given more time and resources, the team would manufacture a higher fidelity prototype with more aspects of the alpha design incorporated. Then, for testing, we would ask non-team members and if possible, potential users in Ethiopia and Ghana. This would allow us to test and validate our design in the location where it would actually be deployed.

Verification: Impact threshold
The next requirement that the team attempted to validate was the impact threshold requirement. To classify the occupant impact velocity and ride-down acceleration accurately, a full crash test would be required. Due to the significant costs and time involved, the team decided that classifying the maximum impact force on the PVC pipes that would be used for the main rails of the design was a sufficient alternative for this semester. To do this testing, a 30lb dumbbell was dropped onto a section of PVC that was stationary on a concrete sidewalk. The height from which the dumbbell was dropped started at 3ft. and increased 1ft. with each test until the PVC failed after the 5 ft. drop. Images of the dumbbell impacting the PVC from 4 ft. (Figure 37a) and 5 ft. at failure (Figure 37b) can be seen below.

Figure 37a. Impact of dumbbell dropped from 4 ft. **Figure 37b.** Impact of dumbbell dropped from 5 ft.

The impact velocity of the dumbbell at failure of the PVC was calculated using the mass of the dumbbell, gravity, and the height from which the dumbbell was dropped. Then, the time of impact was calculated using the slow-motion recording of the impact. These variables were then used to classify the impact force of the PVC pipe, resulting in F_{IMPACT} = 1.01kN. This result was less than the impact force necessary for a car crash [34].

Although this result produced a quantification of the impact force that caused failure in the PVC pipe, the team felt that this did not adequately evaluate the impact threshold requirement. This was due to the fact that a car impact is a force applied over a distance whereas the dumbbell drop was closer to a force at a point. Additionally, the team felt that testing just one section of PVC did not allow for the full structural integrity of the alpha design that would help divert the impact force of a car crash. Due to this, the team is not comfortable classifying the success or failure of the design when it comes to the “impact threshold” requirement. Ideally, we would be able to fully manufacture a high-fidelity prototype of the alpha design with all intended components to size, however if simply given additionally time, the team would follow the procedures set forth in the “Recommended Procedures for the Safety Performance Evaluation of Highway Features” report released by the National Cooperative Highway Research Program to perform a scaled-down version of car crash testing [34].

Verification: Cost + Local manufacturing

Our team was able to verify two additional requirements with assistance and feedback from Dr. Bikila, namely the cost and local manufacturing requirements. After completing research and using feedback from discussions with Dr. Bikila, the team determined the materials used for the main parts of the alpha design, and he was able to provide a cost analysis of this initial Bill of Materials (BOM). This BOM can also be found in Appendix B of this report. Seen in Table 16 below is the Bill of Materials with rough pierce estimates and comments from Dr. Bikila and his contact in Ethiopia for a 1 meter section of the barrier alpha design.

Table 16. Rough price estimate for initial BOM of 1 m section of barrier alpha design

Number	Name	Material	Dimensions	Amount	Unit Price	Total Price	Remark
1	Main rollers	EVA + polyurethane	ID = 150mm, OD = 400mm, L = 525mm	2	100USD	200	USD, to be imported or communicate and fabricate with foam factories
2	Top rollers	Polyethylene	ID = 50mm, OD = 178mm, L = 190mm	12	25USD	300	USD, to be imported or communicate and fabricate with foam factories
3	Interior rod	Steel	D = 130mm, L = 1045mm	2	15000	15000	Birr
4	Bottom rail	PVC	D = 140mm, L = 1000mm	4	4500	4500	Birr, imported, standard dimension is Dia.160mm
5	Top rail	PVC	D = 45mm, L = 440mm	6	800	800	Birr, imported, standard dimension is Dia. 50mm
					Sub Total	838.33	
					Contingency	83.83	
					Total (USD)	922.17	

All major components of the alpha design are included in the cost analysis, and extrapolating the costs for a 1 meter section of barrier to 1 km, the total costs including 10% contingency will be approximately \$9,221.70. This verifies that the alpha design concept completes the cost requirement of <\$10,000.

In addition to verifying the cost requirement, the notes from Dr. Bikila's contact also helped to verify the local manufacturing requirement. As seen in the comments, all rollers as well as the steel rods can be manufactured in Ethiopia while the PVC components would need to be imported. When taken as a percentage of all significant parts in the apha design, the rollers and steel account for 16 parts while the PVC accounts for 10 parts, meaning that 16/26 or 61% of significant parts are able to be locally sourced. This falls below the local manufacturing requirement of 75% of parts being locally manufactured. Unfortunately given the time constraints, the team was unable to perform further research and have additional discussion with Dr. Bikila to help increase the number of locally sourced parts. For future design iterations however, the design will need to be evaluated with local manufacturing in mind to potentially lower the number of PVC parts or change the material of those parts to one that can be locally sourced.

DISCUSSION

Overall, we are proud of our work on this project and what we were able to accomplish within the semester. In this section, we will discuss the strengths and weaknesses of sections of this project and any future improvements.

Problem Definition

While a large section of our project was focused on defining our problem and narrowing the scope of the project, with more time and resources, we would hope to be able to talk with more locals in the region that we were focusing on. Additionally, our resources for this project were focused on what we could access through M-Library and Google Scholar. Interviewing locals or getting a hold of local data might have allowed us to define the project with our own conclusions through primary sources. This could have made our project stronger as it would focus on what is currently a problem in the region and ensure that it would actually be helpful without imposing our own bias onto the issue. While we were able to ensure that our project was fitting for the region we were designing for with some stakeholder interviews, further research with primary sources would have strengthened our project definition.

Design Critique

Our final design has a lot of strengths. The rollers on top of the design function as intended. As one of our most important requirements from our stakeholders was to prevent pedestrians from climbing over the barrier, we made sure to test this requirement as thoroughly as we could. It is very difficult to get around the rollers as they add both height and difficulty in grip to the design. Additionally, we are very proud of our stakeholder engagement throughout the project. Without stakeholder input, our design would not be as strong as it is now. However some pieces of our design that are weak are the retroreflectivity and plastic casing. We were informed by a stakeholder that the typical retroreflective tape that is used on barriers is often stolen and we weren't able to fully reconsider other options. Therefore with more time we would consider other ideas for retroreflectivity such as painting the barrier or testing different colors to see which one is most visible at night. Next, through discussions with our stakeholders we learned that maintenance on roadside barriers is not as high as it is in America. Therefore, we are concerned that over time the plastic casing might crack and expose the metal structure underneath. This would violate our "Unappealing to Steal" requirement and might cause some sections of the barrier to be stolen over time. With more time and resources, we would want to test the plastic materials on the outside of the barrier and ensure that the barrier could take a few small crashes and the metal structure would remain hidden. A future modification for this issue could be exploring other material options to cover or even replace the metal structure. Overall, our design addresses most of our requirements and prioritizes the issues discussed with our stakeholders. Any future modifications would focus on ensuring that all requirements are covered through this design.

RECOMMENDATIONS

A whole new setup is recommended with more expensive equipment including actual steel and pvc components fully assembled. The team was not able to work on this specifically due to budgeting, however, if the project continues it could be possible to increase the budget for materials to be able to test the product in an actual environment similar to Ethiopia and Ghana.The wood that is used in the prototype setup is not built to scale and will fail under actual environmental use.The screws installed in the prototype will also not be the screws used in the actual setup.A new setup would allow for scaling to be done to ensure that each component is worthy of actual environmental use and that the barrier will be the correct size to absorb damage from car crashes. Testing of the material is also needed to understand how an actual car would affect the barrier and how the barrier would actually operate in a country like Ghana or Ethiopia. Based on conditions in Ghana and Ethiopia the team would also recommend that a list of companies that can produce the materials locally be contacted to not only determine the cost of production for each barrier but also determine what parts could be officially locally manufactured versus having to ship parts overseas.

BLOCK CONTENT CONNECTIONS

Design Process

DR0. For our design process for DR0 the team focused on collecting needs relative to the problem at hand but not limiting our thought process on what could be done towards helping to improve traffic safety. After collecting a good amount of needs we filtered needs through need filtering criteria and eliminated certain needs as need be. Radical ideas were eliminated immediately while more mundane ideas were considered and filtered through. The team was able to limit the number of needs down to five specific needs that would satisfy the criteria for our project and after filtering through those 5 needs we found that one specific need scored a lot higher than any of the other needs therefore that need was chosen to be our topic criteria for our project.

DR1. Using the information collected we were able to filter our need statement down to a single need statement that embodied the scope of our project without limiting the creativity in a possible solution. After completing DR0 we focused specifically on narrowing down our focus which required stakeholder involvement therefore we met with Dr. Bikila and Augustine to discuss possible solutions. Based on the information we receive from these stakeholders we were able to narrow our focus specifically on traffic barriers due to their major importance in the safety of drivers in urban countries and the issues connected with their feasibility to be stolen and resold to other markets. Now we are in the process of finalizing our requirements and specifications for these traffic barriers to be able to have a clear view of how we should design and build our project to the best of our ability.

DR2. The core stages of the design process utilized for DR2 included concept generation and evaluation, which are detailed later in this section. Additionally, the team continued to connect with stakeholders and get first hand information about the concepts, requirements, and specifications.

Final Report. As highlighted in the DR0, DR1, and DR2 summaries, the design process that was the most useful to our team in the context of our project was a detailed problem exploration, need identification, concept generation and concept selection. This allowed our team to have a deeper understanding of the problem, and generate/select a concept that will have the greatest impact on solving the problem.

Problem Definition

DR0. This block was very important for our section since defining the problem was the main goal of DR0. The lecture on problem definition and solving the right problem helped frame the way we thought about the different needs we were gathering. We also began having interviews in which we used C-SED interview protocol documents to help develop our own interview protocol.

DR1. The small dive into specifications and requirements in this block allowed for the team to be on the same page as far as what each of those meant for this course. We also continued to build our interview protocol as the meetings changed from need finding to specifying scope and requirements.

DR2. The dive into specifications and requirements continued to be useful, as we have developed each set further to a green status with stakeholder input and additional research. The block allowed us to understand the process for iterating on requirements and specifications while keeping the same principles.

Final Report. If our team was given more time and resources to collect data to further define the problem, we would explore past actions taken by the Ethiopian and Ghanain governments and attempt to understand why the governments have failed to protect road users. Continuing meetings with Dr. Bikila from Addis Ababa Institute of Technology would aid us in further understanding and defining the problem.

Social Context

DR0. Considering the context of the cultures we will be designing for is very important for this project as we live outside of the region. We made sure to meet with stakeholders from the area to get an accurate understanding. Additionally, when considering potential stakeholders for our various needs, we wanted to account for people as well as various companies/industries that may also impact our design choices.

DR1. As we continue through the project and settle on a final solution, we want to ensure that our current potential stakeholder list is accurate and we understand their relationship to our project. We want to create a potential stakeholder map for our current need as well as our last few design ideas to make sure we understand the full impact of our design. Keeping contact with our experts will ensure that this map and the relationships with the region are accurate.

DR2. As the team generated and evaluated concepts, we continued to involve stakeholders to provide us with firsthand social context for the problem and potential solution. Throughout the development of the final concept and any prototyping or engineering analysis, we will also speak with stakeholders and continue to consider the social impact of the final design and any significant changes that are made to it.

Final Report. The stakeholders that will benefit the most from our project are road users in Ethiopia and Ghana. The introduction of a low cost road barrier will improve upon the existing road conditions in our target locations and reduce the amount of traffic fatalities for both vehicle occupants and pedestrians. It is possible that the use of plastics in our barrier design may negatively impact those whe reside close to the roads, as microplastics can be emitted into the environment through the abrasion of the barrier over time.

Libraries

DR0. Having the broad problem statement of road traffic safety in low income settings the MLibrary databases were critical in finding specific needs that could be addressed. After meeting with Joanna, we were able to navigate through the different databases and find most of the 19 initial need statements we had before we filtered down to our last need. We would use keywords like “pedestrian”, “pedestrian safety”, “traffic”, “road traffic accidents”, “developing countries”, “resource limited setting”, and “low resource setting” in order to find the different articles we used to find our needs.

DR1. After finalizing our need statement and the direction which we wanted to take the project we headed into developing requirements and specifications. This led us through searching through the MLibrary databases for sources in order to inform our specifications. We used databases like INSPEC to search for relevant information on current requirements for crash barriers.

DR2. In order to get a good understanding of past crash barriers as well as some methods used for testing, we used MLibrary as a resource to find primary resources to back up our development. In trying to find materials and plastics of different strengths, different articles with research on plastics strengths were compiled and used to make our selections for our realized chosen concept.

Inclusivity

DR0. As our project was originally for low middle income countries, we made sure that as a team our various social identities were discussed. We wanted to make sure our biases as people living in a high income country and being unfamiliar with the culture would not impact the choices we were making in our design. Additionally, to ensure we were not making any unjust assumptions and had accurate information about the issues in road traffic safety, we made sure to have interviews with stakeholders to gain an accurate perspective.

DR1. Not much has changed since our project definition in DR0, but we made sure to keep in touch with our stakeholders and ensure no bias from our social identities was a part of our project. Continuing to keep track of these identities and being aware of our potential biases throughout this project will be just as important as keeping in touch with stakeholders.

DR2. The team has continued to keep in regular contact with the stakeholders, and during concept selection, stakeholder input was taken into account and weighted above other characteristics of a concept. This allows us to provide real, potential end-users with an opportunity to provide feedback on the design and any potential issues it may cause in Ethiopia or Ghana.

Final Report. Our team members share many cultural similarities, and most importantly, none of us have ever been to Ethiopia, Ghana, or sub-saharan Africa. Due to this, our team approached our design process with heavy emphasis on stakeholder input from those in our target area. Input from stakeholder interviews of Dr. Bikila Teklu Wodajo as well as Acquah Augustine Appah were heavily weighted during our concept selection process. Dr. Bikila conducts research on road traffic safety and is located at Addis Ababa Institute of Technology in Ethiopia. Due to our cultural differences with our stakeholders, and their connection to Ethiopia, Ghana, they provided us with valuable insights on how to optimize our final concept for use in these locations.

Ethics

DR0. In the scope of the project we expanded our research to include multiple countries and multiple varieties of problems however the main stem of the problem in general involves ethics. The team created a list of this collection of problems to be able to create safer environments not only for people pertaining to the need we specifically chose but for people around the world who may have a similar problem or issue.

DR1. Our project primarily is based on road traffic safety which is already ethical within itself, however the team plans to make sure that we are engaged in the community through stakeholders and know what will be needed to fully understand the project at hand and how to create the most optimal solution for the project. The team also plans to, if possible, pay stakeholders for their efforts to help the team in our endeavor to come up with a solution to this problem.

DR2. The team has determined compensation to give stakeholders for their involvement throughout the design process, demonstrating ethical handling of continued stakeholder involvement. This feedback has been valuable to us as well in a sense that it provides us with firsthand knowledge of the problem and potential ethical issues stemming from concepts, so that the team can consider and eliminate these issues without having to make significant assumptions from secondhand research

Final Report. In the design of our project, we faced ethical dilemmas in the selection of materials for our final concept. Our team wanted to minimize the amount of exposed metal to satisfy our requirement and specification, and decided on a largely plastic final concept. This introduced an environmental concern in the production, lifespan, and disposal of the barrier. As the barrier is mostly plastic, its disposal can have a negative impact on the environment, and abrasion throughout its lifespan will introduce microplastics into the environment. We analyzed the cost/benefit of this choice, and ultimately the benefits that plastics introduce far outweigh the concerns our team has. Additionally, we are looking into the possibility of reusing plastics in the manufacturing process.

Our personal ethics are largely similar to the professional ethics we are expected to uphold by the University of Michigan. However, we are more conscious of how our final concept will affect Ethiopia and Ghana, which introduced a more specific element of ethics. This is more similar to professional ethics of a future employer, in which the wide ranging effects of a specific product or project will have to be considered in the design process.

Environmental Context

DR0. As DR0 was early in our design process, the main focus was fully defining our team's need. Due to this, our team was not concerned with any solution specific environmental or cost impacts. The learnings from the block were not fully applied in this iteration of the report, but our team was considering the environmental impacts and context as we iteratively selected our need statement.

DR1. As detailed in the project plan in DR1, concept generation is the next phase of our project. In conducting concept generation, our team will need to consider the environmental impacts and context of our selected road barriers. The tools that we have used in the block, such as EcoAudit, will be extremely useful in meeting our requirements for the road barrier. Specifically the block will aid in addressing our low cost requirement, as well as our need for local material use.

DR2. During concept generation and evaluation, the team used the knowledge from the Environmental Context block to consider the impact of various concepts. For our final concept, we will use EcoAudit to approximate the cost of the barrier as well as the environmental impact of manufacturing, delivering, and installing the barriers in Ethiopia and Ghana.

Final Report. Our final project design is largely made of plastics, which presents the opportunity for plastic reuse. In both Ethiopia and Ghana, plastic waste is abundant, and our barrier design can be a method for plastic waste to be repurposed in a way that benefits the public. When the plastic barriers reach the end of their life cycle, they can be recycled for other plastic purposes, or simply remolded to form new barriers. The production of the plastic barrier does consume finite resources in plastics and metals, however our team is exploring the possibility of using repurposed plastics and metals in the production process. Due to the conditions that the barrier will be exposed to, microplastics may be emitted into the environment throughout the barrier's life cycle.

Our barrier can be made more sustainable by exploring the use of compostable plastics as our main material. However, compostable plastics may not satisfy our lifespan requirements.

Concept Generation

DR1. Concept generation appeared in our project plan for the days following DR1, and for this process, our team pulled various strategies from the learning block. Our current plan is to hold a brainstorming session that will have 10 minutes of individual time and 30 minutes of group time, with the goal of 100 concepts. Then, we will use randomized design heuristics to further iterate and develop additional concepts. Finally, we will coordinate with stakeholders to have short interviews and show multiple concepts to gauge their reaction and receive feedback on our concept generation results.

DR2. Concept generation and evaluation were the core of DR2 and our team followed best practices with an individual brainstorm, team brainstorm, Design Heuristics, and morphological analysis. In between stages of concept generation, we also performed concept screening with gut checks and preliminary filtering. To evaluate concepts, the team was able to do rough engineering analysis in a first round of selection, and then continued to complete more refined analysis for the final selection process. We are further evaluating the performance of the selected concept and materials at this time.

Final Report. Due to our brainstorming approach to concept generation, we began the project with a wide range of concepts, many of which were not feasible in the time frame of ME 450. Compared to our final concept, a large portion of the first round concepts were much less realistic and not similar. Due to the detailed concept generation and selection process, we do not see any evidence of fixation on this early idea or an existing idea in the market.

Engineering Analysis
DR2. As engineering analysis was a core piece of DR2 and of the iterative concept generation process, our team used ideas laid out in the block to perform the relevant analyses. The main concepts that were introduced in the learning block which were most important to us were the differences between simple and complex analysis. This includes back of the envelope style physics checks of the impact as well as complex simulations of human interaction with the barrier. Additionally, human factors analysis was also very important as we had specifications based on human behavior. We will be using the empirical analysis methods throughout the final weeks of the course.

Verification and Validation
DR2. Since the concepts we were generating had to be verified against our requirements and specifications. Therefore, we used methods laid out in the analysis learning block to ensure these were being met. In order to validate our design, we decided to reach out and discuss this through further meetings with our stakeholders. By showing them our design and adjusting our requirements and specifications, we were able to affirm our design met the intended design they had discussed with us earlier in the semester.

CONCLUSION

We began our project by collecting inspiration from the Global Health Design Initiative database and slowly reduced our project boundaries to only cover injury prevention, specifically in Ethiopia. Injury prevention was the most interesting sector for the team and also contained needs that had feasible tangible solutions. Additionally, we chose Ethiopia as the number of fatalities from road accidents has doubled in the last decade and hopefully through this project we can attempt to cover some of the gaps in road traffic safety there. Once the project was well defined, we began an in depth search on a variety of databases to gather information. Through these searches, we generated multiple need statements. We then consolidated them into 5 high profile need statements through a broad rank table filter. From there we were able to filter our needs using criteria such as a feasibility index, injury prevention, and tangible solution to which we created weights for how much of an impact each filter would carry. We took each need statement and ranked them based on our need criteria and we found that the need statement with the highest priority was "A way to protect pedestrians from fatal and severe traffic injuries in cities in Ethiopia" which ranked almost 20 points above the next highest scoring need statement. This was specifically because this specific need rated high in both the ranking criteria and the personal favorites category for being broad and allowing the team to expand their ideas on project ideas while focusing on a specific country. The selected need analysis showed that pedestrians are more likely to have severe injuries as an accident victim when compared to vehicle occupants. As existing solutions are unattractive or costly, we hope to find a solution that is both low cost and aesthetic to fill that gap. After meeting with multiple stakeholders about the issue we decided to narrow our scope specifically to traffic barriers specifically because it seemed to be an occurring problem that the countries we researched were either lacking roadside barriers due to theft or there weren't any barriers separating roadways whatsoever allowing drivers to switch into oncoming traffic causing head on collisions. Pedestrians will also climb over these barriers to reach the other side of the road, which is unsafe for both the vehicle occupants and the pedestrian. The team was able to come up with specific requirements and specifications that covered the basics of what we would need to be able to create a solution to the problem as well as hopefully create a more efficient way of moving and placing traffic barriers within urban areas. With the requirements in mind, the team performed concept generation using brainstorming, design heuristics, morphological analysis and explored the fullness of the design space before narrowing down to 12 final concepts. These concepts were then analyzed against the team's high priority requirements through engineering analysis in order to make the final selection. A concept based around roller barriers was chosen as the concept to be explored as the solution. The design modifies existing roller barriers by adding rollers on top to make it hard to climb over and reduce the amount of pedestrians on the roads. The concepts underwent multiple analyses, both empirical and theoretical. Empirically we build a prototype of the top roller portion to try and climb over. Theoretically we used software such as jack. We also performed impact testing on material intended to be used for the design but the results were inconclusive. Therefore if we had more time to do testing we would perform different impact testing to get better results on our chosen materials. Overall our final design did meet a lot of our requirements and had high praise from our stakeholders. There are things to improve upon the design and more iterations to be made. We are happy with the results of this project and proud of what was completed this semester.

ACKNOWLEDGEMENTS

We want to thank Professor Sienko, Augustine Appah, Dr. Bikila, Dr. Gregory Hulbert, and Dr. Paul Green for helping us throughout this project.

REFERENCES

[1] “Global Status Report on Road Safety.” World Health Organization, 2018. http://apps.who.int/iris/bitstream/handle/10665/277370/WHO-NMH-NVI-18.20-eng.pdf?ua=1.

[2] United Nations Economic Commission for Europe. Road Safety Performance Review - Ethiopia. United Nations, 2021. https://doi.org/10.18356/9789210055482.

[3] Global Health Design Initiative. “Need Statements,” n.d. https://globalhealthdesign.engin.umich.edu/need-statements/.

[4] Dibong, Eva. Eva Dibong + 450 Team Meeting, October 8, 2021.

[5] Appah, Augustine. Augustine + 450 Team Meeting, October 9, 2021.

[6] Ichikawa, Masao, Witaya Chadbunchachai, and Eiji Marui. “Effect of the Helmet Act for Motorcyclists in Thailand.” Accident Analysis & Prevention 35, no. 2 (March 2003): 183–89. https://doi.org/10.1016/S0001-4575(01)00102-6.

[7] Schiller, Dr Thomas. “Africa Automotive Leader Deloitte Africa,” n.d., 52.

[8] Baru, Ararso, Aklilu Azazh, and Lemlem Beza. “Injury Severity Levels and Associated Factors among Road Traffic Collision Victims Referred to Emergency Departments of Selected Public Hospitals in Addis Ababa, Ethiopia: The Study Based on the Haddon Matrix.” BMC Emergency Medicine 19, no. 1 (December 2019): 2. https://doi.org/10.1186/s12873-018-0206-1.

[9] Hassen, Abrahim, Ameyu Godesso, Lakew Abebe, and Eshetu Girma. “Risky Driving Behaviors for Road Traffic Accident among Drivers in Mekele City, Northern Ethiopia.” BMC Research Notes 4, no. 1 (December 2011): 535. https://doi.org/10.1186/1756-0500-4-535.

[10] Woldu, Awtachew Berhe, Abraham Aregay Desta, and Tewolde Wubayehu Woldearegay. “Magnitude and Determinants of Road Traffic Accidents in Northern Ethiopia: A Cross-Sectional Study.” BMJ Open 10, no. 2 (February 2020): e034133. https://doi.org/10.1136/bmjopen-2019-034133.

[11] Haji, Seifeddin. “Traffic Safety Evaluation on Urban Road Intersection Using Proactive Approach: A Case Study in Adama City,” 2018, 21.

[12] Jones, Steven, Kenneth Odero, and Emmanuel Kofi Adanu. “Road Crashes in Namibia: Challenges and Opportunities for Sustainable Development.” Development Southern Africa 37, no. 2 (March 3, 2020): 295–311. https://doi.org/10.1080/0376835X.2019.1659131.

[13] Tulu, Getu Segni, Simon Washington, Md. Mazharul Haque, and Mark J. King. “Investigation of Pedestrian Crashes on Two-Way Two-Lane Rural Roads in Ethiopia.” Accident Analysis & Prevention 78 (May 2015): 118–26. https://doi.org/10.1016/j.aap.2015.02.011.

[14] Tulu, Getu Segni, Simon Washington, Mark J King, and Mazharul Haque. “Why Are Pedestrian Crashes so Different in Developing Countries? A Review of Relevant Factors in Relation to Their Impact in Ethiopia,” 2013, 19.

[15] Bulto, Lemma Negesa, Yadeta Dessie, and Biftu Geda. “Magnitude, Causes and Characteristics of Trauma Victims Visiting Emergency and Surgical Units of Dilchora Hospital, Eastern Ethiopia.” Pan African Medical Journal 30 (2018). https://doi.org/10.11604/pamj.2018.30.177.10969.

[16] Tulu, Getu Segni, Simon Washington, Md. Mazharul Haque, and Mark J. King. “Injury Severity of Pedestrians Involved in Road Traffic Crashes in Addis Ababa, Ethiopia.” Journal of Transportation Safety & Security 9, no. sup1 (March 30, 2017): 47–66. https://doi.org/10.1080/19439962.2016.1199622.

[17] Negussie, Abel, Andarge Getie, Elias Manaye, and Tamrat Tekle. “Prevalence and Outcome of Injury in Patients Visiting the Emergency Department of Yirgalem General Hospital, Southern Ethiopia.” BMC Emergency Medicine 18, no. 1 (December 2018): 14. https://doi.org/10.1186/s12873-018-0165-6.

[18] Bhalla, Kavi, Dinesh Mohan, and Brian O’Neill. “How Much Would Low- and Middle-Income Countries Benefit from Addressing the Key Risk Factors of Road Traffic Injuries?” International Journal of Injury Control and Safety Promotion 27, no. 1 (January 2, 2020): 83–90. https://doi.org/10.1080/17457300.2019.1708411.

[19] Amazon.com. “GripGlo Reflective Safety Vest,” n.d. https://www.amazon.com/GripGlo-Reflective-Safety-Bright-Strips/dp/B00N39F7TE/ref=sr_1_5?dchild=1&keywords=reflective+vest&qid=1634003661&sr=8-5.

[20] Teni, Fitsum Sebsibe, Begashaw Melaku Gebresillassie, Eshetie Melese Birru, Sewunet Admasu Belachew, Yonas Getaye Tefera, Befikadu Legesse Wubishet, Bethelhem Hailu Tekleyes, and Bilal Tessema Yimer. “Costs Incurred by Outpatients at a University Hospital in Northwestern Ethiopia: A Cross-Sectional Study.” BMC Health Services Research 18, no. 1 (December 2018): 842. https://doi.org/10.1186/s12913-018-3628-2.

[21] The James and Anne Duderstat Center. “Fabrication Studio,” n.d. https://www.dc.umich.edu/partners-2/ground-connections-dmc/fabrication-studio/.

[22] Wodajo, Bikila. Dr. Bikila + 450 Team Meeting, October 14, 2021.

[23] Appah, Augustine. Augustine + 450 Team Meeting, October 30, 2021.

[24] “Pokuase Interchange Burglary: Contractor Liable to Replace Stolen Crash Barriers.” NEWS360, October 6, 2021. https://www.youtube.com/watch?v=8TFmj08P5ig.

[25] Bonney, Emmanual, and Emelia Abbey. “Pokuase Interchange Burgled: Newly Installed Crash Barriers Stolen.” Graphic Online, October 5, 2021. https://www.graphic.com.gh/news/general-news/ghana-news-pokuase-interchange-burgled-newly-installed-crash-barriers-stolen.html.

[26] Bonney, Emmanual. “Stolen Crash Barriers to Be Replaced - Resident Engineer.” Graphic Online, October 6, 2021. Bonney, Emmanual, and Emelia Abbey. “Pokuase Interchange Burgled: Newly Installed Crash Barriers Stolen.” Graphic Online, October 5, 2021. https://www.graphic.com.gh/news/general-news/ghana-news-pokuase-interchange-burgled-newly-installed-crash-barriers-stolen.html.

[27] Chen, Greg. “Road Traffic Safety in African Countries – Status, Trend, Contributing Factors, Countermeasures and Challenges.” International Journal of Injury Control and Safety Promotion 17, no. 4 (December 2010): 247–55. https://doi.org/10.1080/17457300.2010.490920.

[28] Siaw, Nicholas Apreh, Emmanuel Duodu, and Samuel Kwakye. “Trends in Road Traffic Accidents in Ghana; Implications for Improving Road User Safety,” n.d., 5.

[29] Damsere-Derry, James, Beth E. Ebel, Charles N. Mock, Francis Afukaar, and Peter Donkor. “Pedestrians’ Injury Patterns in Ghana.” Accident Analysis & Prevention 42, no. 4 (July 2010): 1080–88. https://doi.org/10.1016/j.aap.2009.12.016.

[30] Aboagye, Aqq, Ank Degboe, and Aad Obuobi. “Estimating the Cost of Healthcare Delivery in Three Hospitals in Southern Ghana.” Ghana Medical Journal 44, no. 3 (August 22, 2011). https://doi.org/10.4314/gmj.v44i3.68890.

[31] Konlan, Kennedy Diema, Abdul Razak Doat, Iddrisu Mohammed, Roberta Mensima Amoah, Joel Afram Saah, Kennedy Dodam Konlan, and Juliana Asibi Abdulai. “Prevalence and Pattern of Road Traffic Accidents among Commercial Motorcyclists in the Central Tongu District, Ghana.” The Scientific World Journal 2020 (June 1, 2020): 1–10. https://doi.org/10.1155/2020/9493718.

[32] ASTM, 2019, “Standard Specification for Precast Concrete Barriers,” ASTM C825 – 19

[33] “Concrete Safety Barriers: A Safe and Sustainable Choice.” European Concrete Paving Association, 2018. https://www.eupave.eu/wp-content/uploads/Brochure-Concrete-safety-barriers-a-safe-and-sustainable-choice.pdf.

[34] Ross Jr., H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., 1993, “Recommended Procedures for the Safety Performance Evaluation of Highway Features,” National Cooperative Highway Research Program, Washington, D.C., 1993

[35] Loetterle, F. E., Beck, R. A., and Carlson, J., 2000, “Public Perception of Pavement-Marking Brightness,” Transportation Research Record, pp. 51–59.

[36] Shklyan, R., “Enhancing Concrete Barrier Reflectivity With A Focus On Recycled Glass Aggregate Replacement,” p. 127

[37] Graham, J. R., and King, E., “Retroreflectivity Requirements for Pavement Markings,” TRANSPORTATION RESEARCH RECORD, p. 6.

[38] *The cost and performance benefits of switching from metal to plastic parts*. ManufacturingTomorrow. (n.d.). Retrieved November 2, 2021, from https://www.manufacturingtomorrow.com/article/2018/11/the-cost-and-performance-benefits-of-switching-from-metal-to-plastic-parts/12494.

[39] *Water-filled barriers vs concrete barriers: Pros & cons*. OTW Safety. (2020, June 19). Retrieved November 2, 2021, from https://otwsafety.com/blog/water-filled-vs-concrete-barriers/.

[40] *Antonio*. Real Men Real Style. (n.d.). Retrieved November 2, 2021, from https://www.realmenrealstyle.com/attractiveness-confidence-color/.

[41] Waters, Thomas R., Vern Putz-Anderson, and Arun Garg. "Applications manual for the revised NIOSH lifting equation." (1994).

[42] Cornell University Ergonomics Web. "Biomechanics of Safe Lifting," n.d. https://ergo.human.cornell.edu/DEA3250Flipbook/DEA3250notes/lifting.html.

[43] Fong, Daniel Tik-Pui, Youlian Hong, and Jing-Xian Li. "Human walks carefully when the ground dynamic coefficient of friction drops below 0.41." Safety science 47.10 (2009): 1429-1433.

[44] Cafiso, Salvatore, and Carmelo D'Agostino. "Evaluating the Safety Benefit of Retrofitting Motorways Section with Barriers Meeting a New EU Standard: Comparison of Observational before–after Methodologies." Journal of Traffic and Transportation Engineering (English Edition) 4, no. 6 (December 2017): 555–63. https://doi.org/10.1016/j.jtte.2017.05.012.

[45] "What Is the Highway Guardrail Cost per Foot?," May 11, 2020. https://guardrailsupplier.com/what-is-the-highway-guardrail-cost-per-foot/.

[46] Gelb, Alan, Christian Johannes Meyer, Vijaya Ramachandran, and Divyanshi Wadhwa. "Can Africa Be a Manufacturing Destination? Labor Costs in Comparative Perspective." SSRN Electronic Journal, 2017. https://doi.org/10.2139/ssrn.3062914.

[47] "Complying with the Made In USA Standard." Federal Trade Commission, December 1998, 42.

[48] Appah, Augustine. Augustine + 450 Team Meeting, November 13, 2021.

[49] Thorngren, K.-G., and C. O. Werner. "Normal Grip Strength." *Acta Orthopaedica Scandinavica* 50, no. 3 (January 1979): 255–59. https://doi.org/10.3109/17453677908989765.

[50] *Handbook for Public Playground Safety*. US Consumer Product Public Safety Commission. Retrieved November 10, 202, from https://files.eric.ed.gov/fulltext/ED427507.pdf

[51] McDowell, Margart A., Cheryl D. Fryar, Cynthia L. Ogden, and Katherine M. Flegal. "Anthropometric Reference Data for Children and Adults: United States, 2003-2006: (623932009-001)." American Psychological Association, 2008. https://doi.org/10.1037/e623932009-001.

[52] Wodajo, Bikila. Dr. Bikila + 450 Team Meeting, November 19, 2021.

[53] Rossi, Jérémy, Eric Berton, Laurent Grélot, Charlie Barla, and Laurent Vigouroux. "Characterisation of Forces Exerted by the Entire Hand during the Power Grip: Effect of the Handle Diameter." *Ergonomics* 55, no. 6 (June 1, 2012): 682–92. https://doi.org/10.1080/00140139.2011.652195.

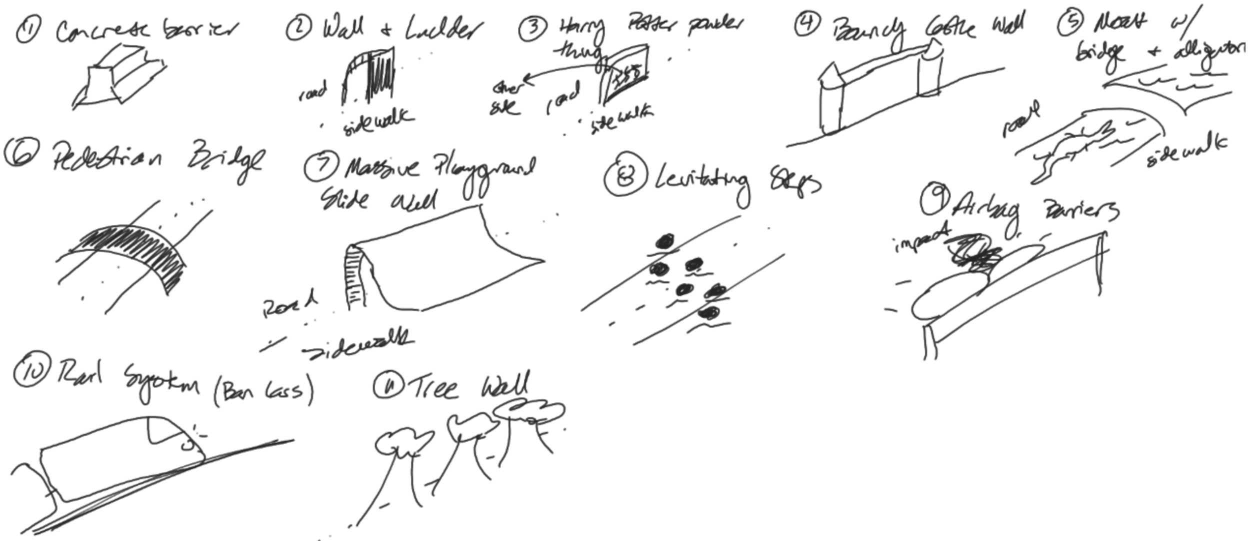
[54] Hulbert, Greg. Prof. Hulbert + 450 Team Meeting, November 22, 2021

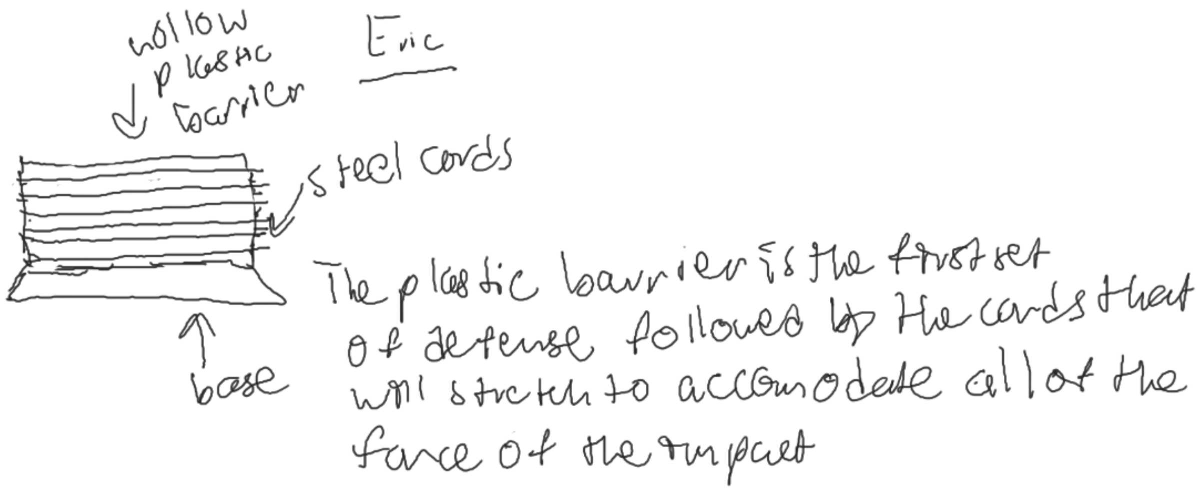
[55] PVC Pipe & Pipe Nipples - Grainger Industrial Supply

APPENDIX A - CONCEPT GENERATION RESULTS

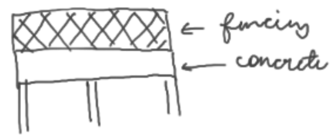
Displayed below are all of the results from the concept generation process, with each stage labelled above the array of concepts for that respective stage.

Individual Brainstorming Results:





#1



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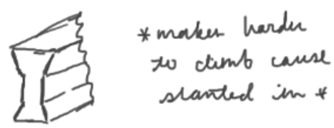

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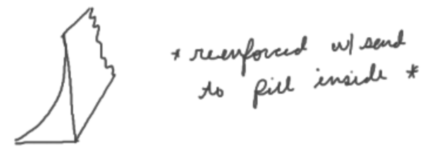

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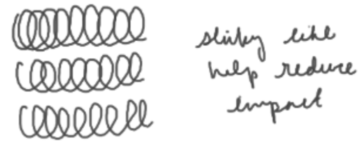

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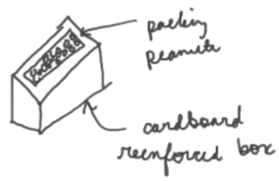

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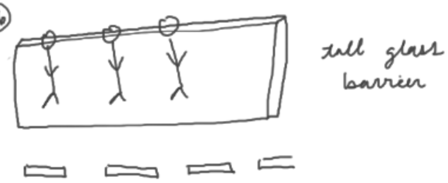


1. Foam covered Concrete barrier
2. Concave concrete barrier

3. magnetic wire (repulsion of cars)
4. high shock absorbant (jello-like, not edible though)
5. Concrete barrier with controllable electric fence
6. Recyclable cardboard barrier (high absorption)

life size shaq statutes

accordion style barrier

foam barrier

barbed wire on concrete barrier

plastic water filled barrier bolted into the ground

invisible fences (ala dogs)

interlocking wooden fences (log cabin)

stamped dirt walls

boulders on the side of the road

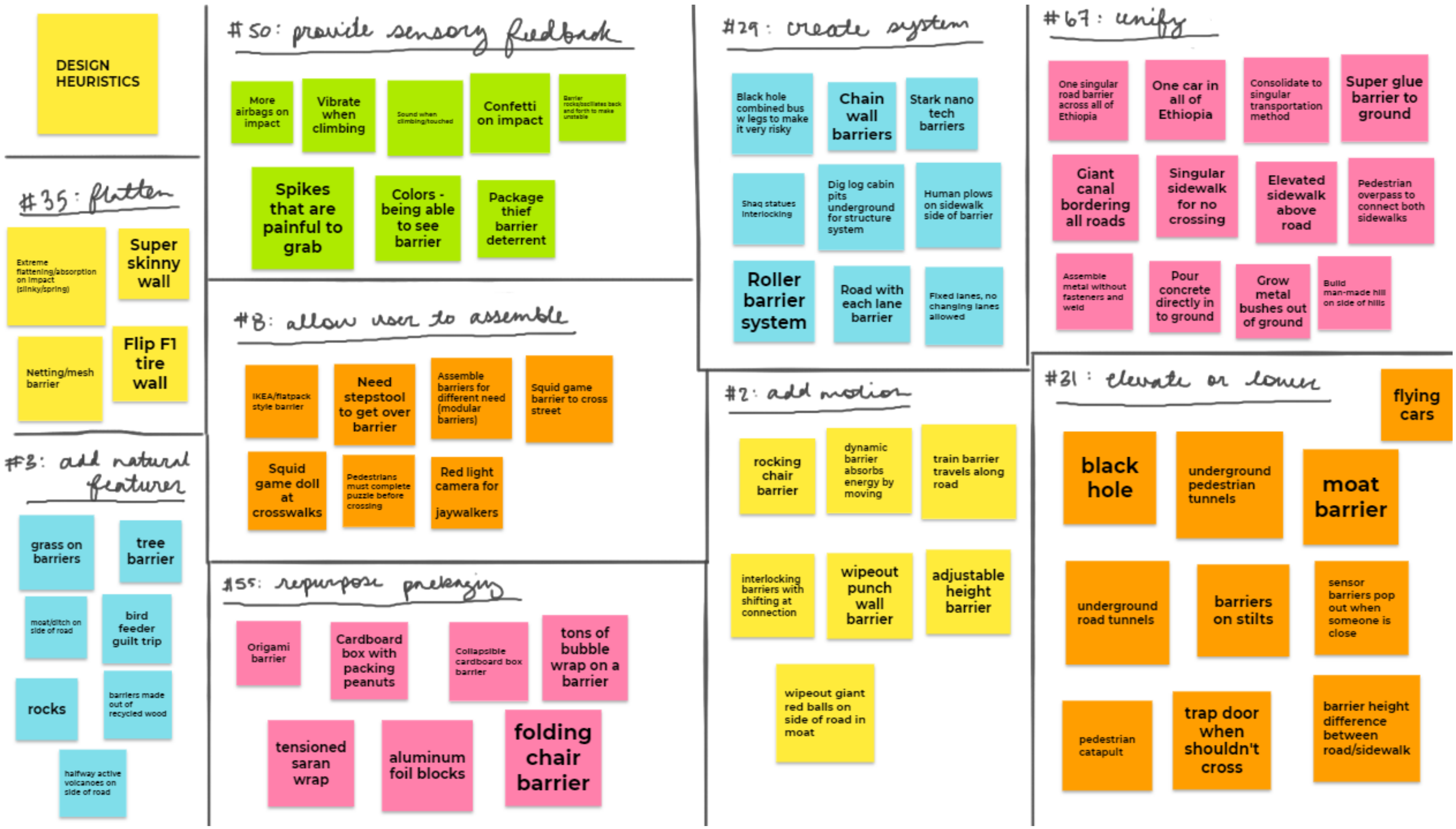
piles of dirt

concrete barriers with reinforced steel

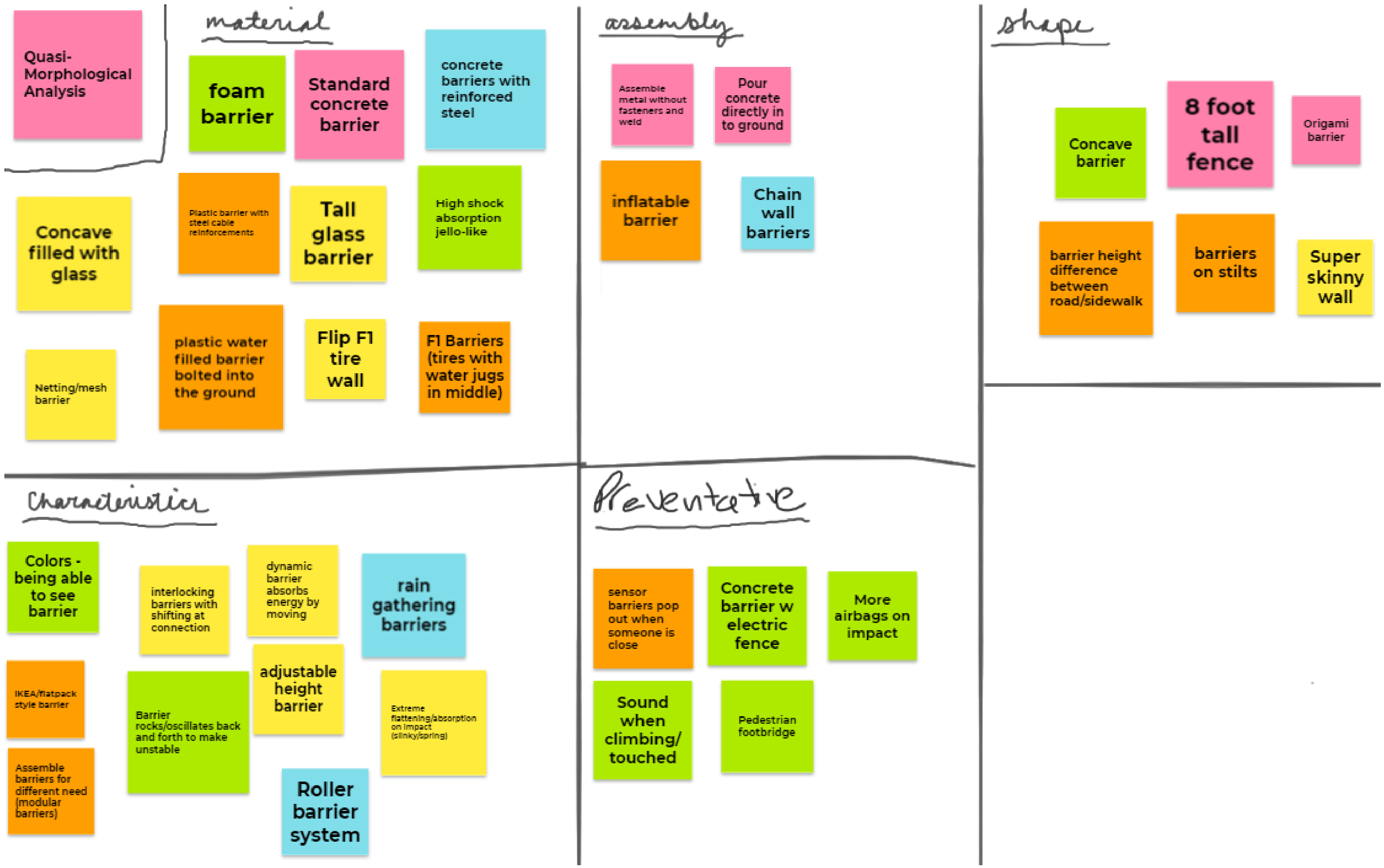
old mattresses (mattress style barrier?)

Team Brainstorming Results:

Design Heuristics Results:



Clustering Results:



Morphological Analysis Results:

#1

metal/concrete barrier with internal plastic pieces that shift around each other and lock like tectonic plates

#2

Top funnel/inlet that collects rain to store inside barrier

#3

barrier with rows of impact activated foam/soft material

#4

Foam outer layer with origami/meshed interior/water to reduce material

#5

Plastic barrier with retractable airbags

#6

Plastic filled with water/sand with pedestrian facing side concave

#7

Springs/cords embedded into plastic/concrete barriers for flexibility

#8

plastic/water-filled/foam rolling barrier inside metal rails

#9

Mesh/netting/woven fiber structure replacing the barrier

#10

Look into Formula One barriers/protection methods

#11

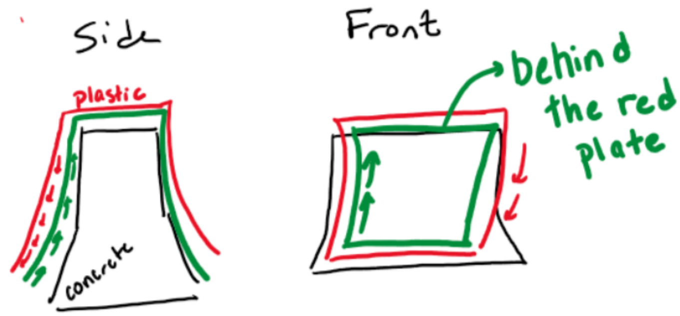
Weld custom metal pieces together on site

#12

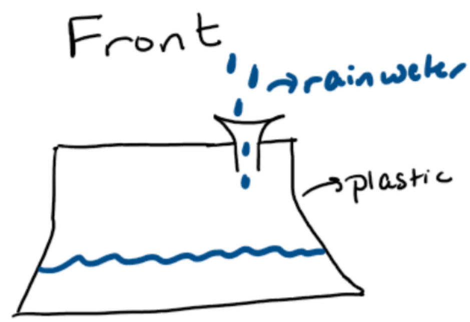
Fastener to interlock concrete or plastic barriers (clicks into each other)

Final 12 Concepts from Morphological Analysis:

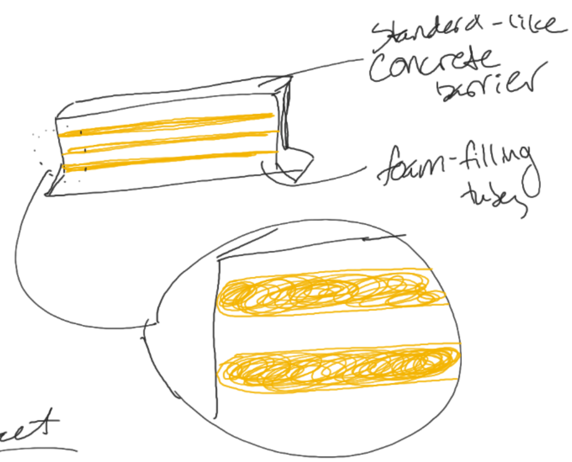
metal/concrete barrier with internal plastic pieces that shift around each other and lock like tectonic plates

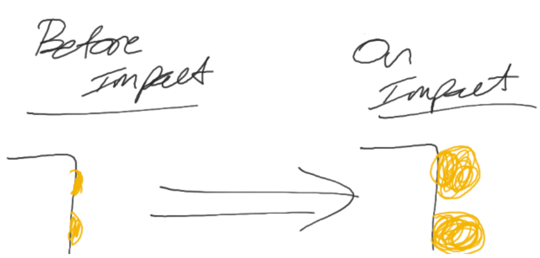


Top funnel/inlet that collects rain to store inside barrier

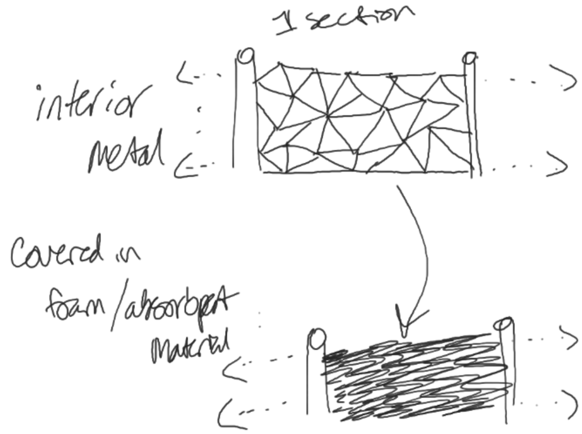


barrier with rows of impact activated foam/soft material

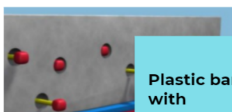




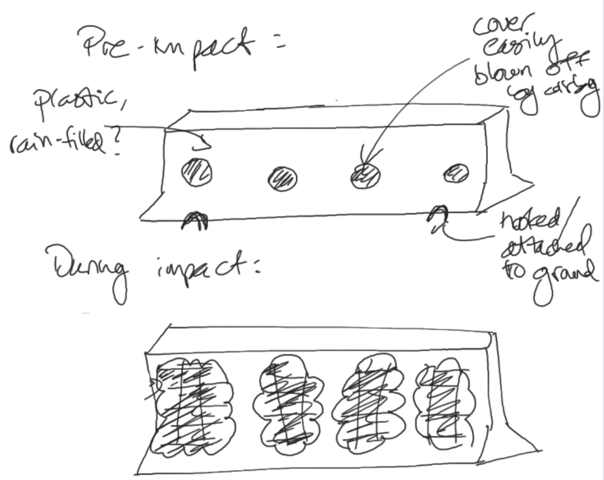
Foam outer layer with origami/meshed interior/water to reduce material



- barrier too tall to climb
- sections > 4 ft to be harder to carry



Plastic barrier with retractable airbags



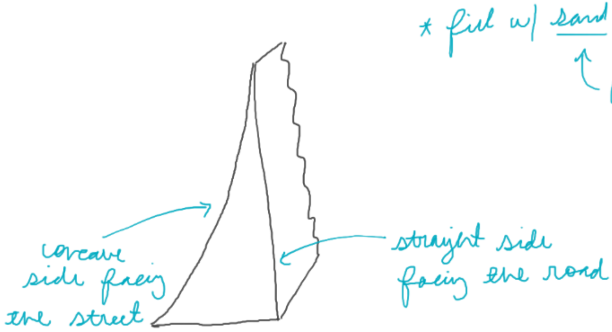
- barrier is plastic
- multiple cavities to house airbags
  - airbags deploy on impact

Plastic filled with water/sand with pedestrian facing side concave

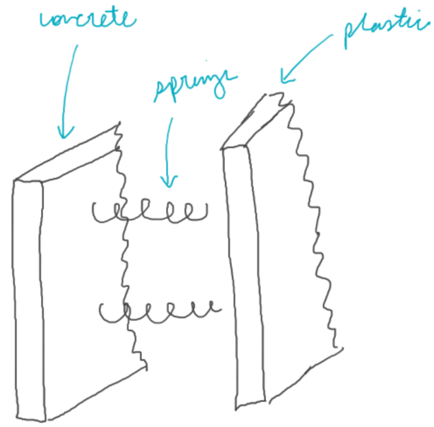
made from same material

* fill w/ sand or water *

how accessible is sand?



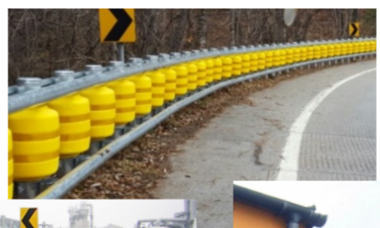
Springs/cords embedded into plastic/concrete barriers for flexibility

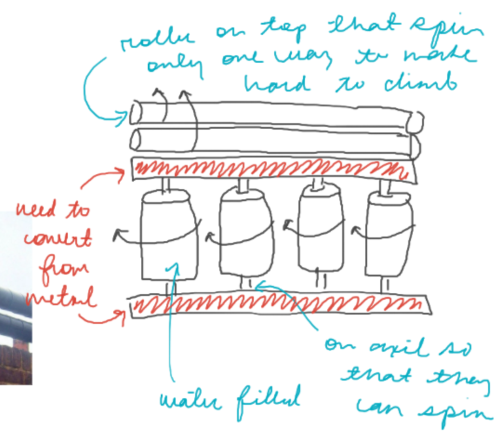


* help cushion impact *

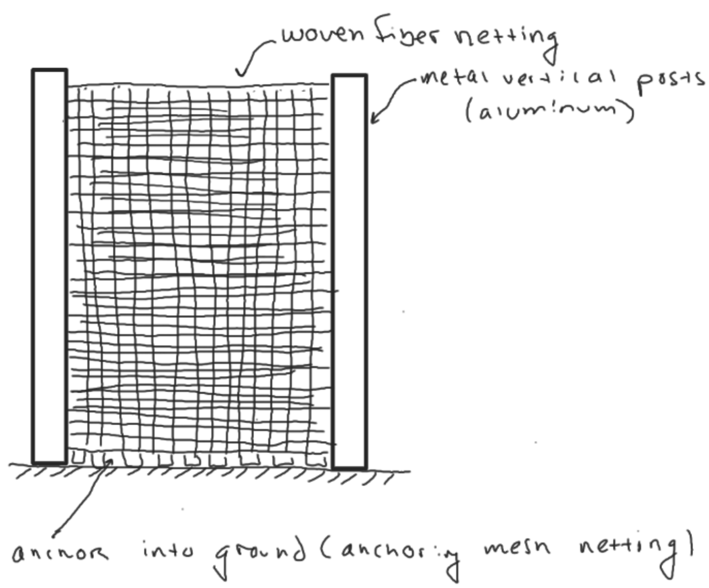
* not enough force to push car back *

plastic/water-filled/foam rolling barrier inside metal rails

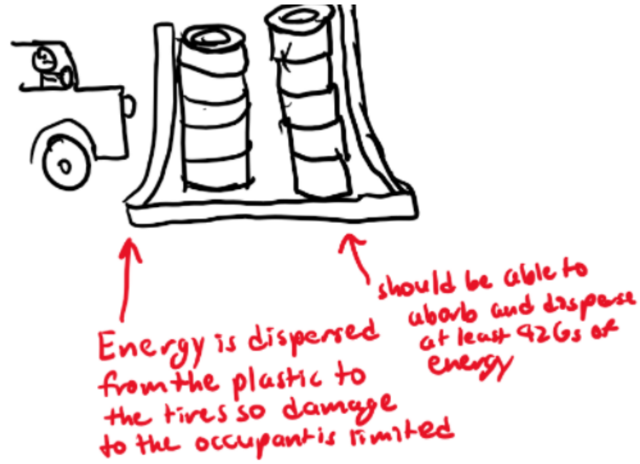




Mesh/netting/woven fiber structure replacing the barrier



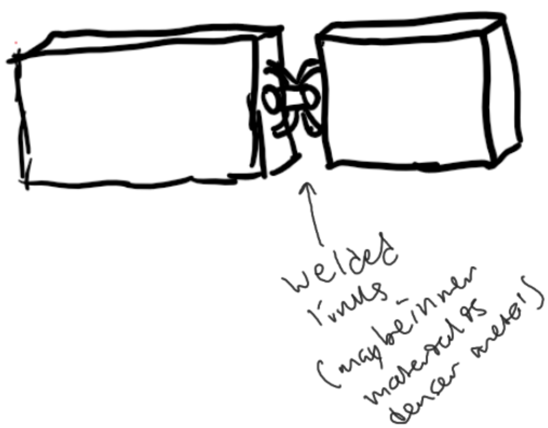
Look into Formula One barriers/protection methods



barrier links

Fastener to interlock concrete or plastic barriers (clicks into each other)

Weld custom metal pieces together on site



APPENDIX B - PROTOTYPE BILL OF MATERIALS AND MANUFACTURING PLAN

Table B1. Prototype Bill of Materials

Item	Quantity	Source	Prod. Num	Cost	Notes
29” Contractor Sawhorse	1	Home Depot	090489476014	\$30.72	N/A
2x10-12ft lumber	1	Home Depot	715216068026	\$16.62	Cut to 6x 2 ft. sections
4”x2’ PVC pipe	1	Home Depot	611942112760	\$16.21	N/A
1-½”x2’ PVC pipe	2	Home Depot	611942109456	\$4.48@	1x cut in half to 1 ft. sections
1-½” PVC hub cap	2	Home Depot	039923361103	\$2.56@	N/A
1-½” PVC elbow	2	Home Depot	039923215529	\$0.94@	N/A
#10x4”wood screw	18	Home Depot	887480019025	50PC \$7.51	N/A

Manufacturing Plan.
Materials List:
- 1x 4”x2’ PVC pipe
- 2x 1.5”x2’ PVC pipe
- 1x 29” sawhorse
- 2x 1.5” PVC elbow
- 2x 1.5” PVC end cap
- 18x 4” woodscrew
- 1x 2”x10”x12’ lumber

Assembly:
13. Place 2x PVC elbows on ends of a single length of the 1.5”x2’ PVC pipe
14. Mark distance from each center of elbow on top of sawhorse
15. Using 2x wood screw, drill end caps into marked points on sawhorse using electric drill
16. Cut the remaining length of 1.5”x2’ PVC pipe in half using hacksaw
17. Place each half of 1.5”x2’ PVC pipe into the PVC end caps attached to the saw horse
18. Place 4”x2’ PVC pipe around 1.5”x2’ PVC pipe with elbows attached
19. Attach each PVC elbow to the vertical PVC pipes
20. Cut the 2”x10”x12’ lumber into 6 equal lengths of 2’ each using a handheld electric circular saw
21. Using 6x wood screw, fasten horizontal piece of 2’ lumber to two vertical pieces (3 screws along each side)
22. Repeat step 9 for second base
23. Place sawhorse on top of wooden bases
24. Using 4x wood screw, fasten the sawhorse to the bases from the underside of each base

APPENDIX C - ALPHA DESIGN BILL OF MATERIALS

Table C1. Bill of Materials and rough cost estimate of significant parts in alpha design for 1 meter of barrier

Name	Material	Dimensions	Amount	Unit Price	Total Price
Main rollers	EVA + polyurethane	ID = 150mm, OD = 400mm, L = 525mm	2	\$100	\$200
Top rollers	Polyethylene	ID = 50mm, OD = 178mm, L = 190mm	12	\$25	\$300
Interior rod	Steel	D = 130mm, L = 1045mm	2	15000 ETB	15000 ETB
Bottom rail	PVC	D = 140mm, L = 1000mm	4	4500 ET	4500 ETB
Top rail	PVC	D = 45mm, L = 440mm	6	800 ETB	800 ETB
				Sub Total	\$838.33
				Contingency	\$83.83
				Total (USD)	\$922.16

APPENDIX D - BIOS

Eric Carter. I am from Laurel Maryland and was born and raised in Silver Spring Maryland and still live in the Silver Spring area. I am pursuing a degree in Mechanical Engineering and I will be graduating with this degree in December of 2021. I chose mechanical engineering specifically because as a young kid I wanted to start a car company. Normally people that start companies would take the route for a business degree, however, I really wanted to know the ingenuity as well as the time and effort it took to build a car completely from the ground up. Coming out of high school I got accepted into Morehouse College where I stayed for 3 years to pursue an Applied Physics degree that I will not receive until I complete the degree for the University of Michigan. After receiving these two degrees I plan to start up a job, hopefully at a car company, and understand every component that goes into making a car possible. From there I hope to eventually start up a car company by 30 and see where life takes me. Right now I am involved in the NSBE (National Society of Black Engineers) chapter on campus as well as the NBSP (National Society of Black Physicists) chapter. In my spare time I enjoy learning about new technologies and how to make a better, more enjoyable car.

Ekim Koca. I am from Troy, Michigan and I am currently pursuing a Mechanical Engineering BSE with the International Minor for Engineers. I will be graduating in December 2021. I chose mechanical engineering because I wanted to establish a strong foundation in engineering and through this degree program I was able to explore a variety of disciplines. I have been working in the Driver Interface Safety Lab at the University of Michigan Transportation Research Institute since September 2018 and I have been involved with driver performance, safety and human factors projects with Paul Green. Through this lab, I found human factors could combine my interest in engineering while establishing human connections and keeping people safe. Currently, I am funded through an individual fellowship to run a project measuring the impact of interface lighting on night time driving. My research interests revolve around inclusive design, usability, driver performance, human machine interaction, and human cognitive perception. I hope to pursue a PhD in Human Factors Engineering and work as a professor or researcher. I also work as a ME 235 IA to explore my interest in teaching. Additionally, I am involved with the Turkish Student Organization, Nordic Ski Team and Society of Women Engineers. In my spare time, I enjoy reality TV, board games and crocheting.

Marcela Lebrija. I am originally from Monterrey, Mexico but currently live in Houston, Texas. I am pursuing a Mechanical Engineering BSE with a minor in Computer Science. I have always been very hands on since I was a child and wanted to know how everything worked. Once something would break I would ask my parents if I could have it and I would take it apart to see the inner workings and try to understand the item better. This was done to computers, calculators, game controllers, you name it. This led me straight to mechanical engineering and has proven to be the right path for me. I will be graduating in May of 2022 and will be working full time at Texas Instruments in Dallas, Texas as an equipment engineer in their wafer manufacturing facilities. I am involved in Engineering Honors as well as IPE (International Programs in Engineering) and SHPE (Society of Hispanic Professional Engineers). I am also a DA (departmental advisor) for ENGR110 meaning I teach two discussion sections for the class. It is really fun because I really enjoy teaching and helping the freshman learn how to succeed as engineers at Michigan. And in my spare time I mainly enjoy reading, watching movies, and (when I am home) spending time with my little brother who is six.

George Misthos. I am from Dix Hills, NY, a suburb on Long Island. I am pursuing a B.S.E. in Mechanical Engineering and will be graduating in May 2022. Engineering and Mechanical Engineering specifically attracted me from a young age as I was always engaged in hands-on projects with my Dad, whether it was working on our cars or our fishing boat. I originally came to Michigan to be a Naval Architect and Marine Engineering major, but I switched my second semester of my Sophomore year as Mechanical Engineering touches a wider range of topics than NAME. However, I still have interest in the marine field, and have interned for Gibbs and Cox, a marine engineering firm, for the past two summers. I specialized in Survivability engineering my first summer, where I developed software to analyze the equipment lost in the event of a ship being damaged. My second summer I specialized in Shock engineering where I was involved in multiple shock qualification projects for the Navy's newest surface ship, FFG-62. Outside of Engineering, I am a member of the Michigan Men's Rowing team where I spend many of my hours on the water at Bandemer Park. Some of my hobbies in my spare time include tuning cars, building computers, and making Spotify playlists.

Peter Wacnik. I am from Libertyville, IL (about an hour north of Chicago) and I am currently pursuing a B.S.E in Mechanical Engineering with a minor in Computer Science, graduating in May 2022. I was drawn to mechanical engineering through multiple avenues, from building LEGOs to my high school physics class. Now, I enjoy the broad scope and wide applicability of a degree in mechanical engineering, but more specifically I am fascinated and extremely excited by consumer product design. I was able to intern at Bosch over the summer of 2021 with the Dremel brand, working on product design and development, including user research, concept generation, rapid prototyping, and other front-end design activities. This internship as well as my experience with Dr. Daly in ME499 truly has me excited about user-centric design, as I had always thought innovation was the "light bulb moment" - but after ME499 and my internship, I love how involving the user extensively can provide a designer with insights that would never have been known before. I've always enjoyed talking to people and learning about their experiences, and I feel that user-centric product design allows me to do just that, while also solving people's everyday problems using my degree, so I hope to find a job in industry that matches that description. Beyond classes, I'm a member of the Men's Rowing Team at UM as well as Pi Tau Sigma, and outside of extracurriculars, I love football, F1, movies, and classic rock (especially Tom Petty).