From Idea to Prototyping A hands-on engaging undergraduate design experience

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Abstract

This paper describes an undergraduate-level problem-based design project that relates to easing a real annoying experience for most drivers: the speed bump. It focuses on an engaging, mentoring-based learning process from inception to prototyping, while bearing in mind aspects of commercialization.

The process starts with observation – an essential first step in problem solving – of what we take for granted, in this case, the solid, static, annoying speed bump. The next step is discussing and thinking critically, identifying pros and cons of existing solutions. It is followed by a more broad definition of the problem as a “vehicular speed reducer” instead of “speed bump,” focusing on the *real* problem. This is followed by a re-representation of the problem, performing inquiry-based focused research, thinking divergently to generate multiple alternatives, experimenting, testing, and evaluating multiple relevant solutions. In addition, non-technical aspects of the project were considered such as sustainability, commercialization, as well as political and environmental friendliness.

The problem with existing speed bumps is multi-faceted: they cause vehicle damage, driver discomfort, and interfere with emergency response vehicles just to name a few. Most importantly, the design of the speed bump has remained unchanged for over half a century, and for the most part it is an ad-hoc design. Redefining the problem allows for innovative ideas to flow, taking off from the current inside-the-box thinking. Students who have been involved in this on-going project have gained experience in multiple non-technical soft skills such as communication, time management, problem-solving, and the ability to benefit from constructive criticism.

The status of the project sits in the middle of testing our latest prototype which utilizes springs as a mechanism to make the speed bump more dynamic. The idea is to have the mechanism impact fast vehicles while having no impact on vehicles abiding by the speed limit.

1. Introduction

Ever since the first means of speed reduction were implemented their designs have remained unchanged and have stagnated. They’ve become more of a nuisance to drivers than a safety feature. Looking at available products¹, their designs are unimaginative, lacking creativity, and have no modern appeal and functionality. This observation alone could be a reason for their dislike.

Focusing on speed bumps and humps, both are rounded mounds of asphalt/concrete. What is limiting the adoption of a different shape? Both are left unpainted or are painted with stripes. Why are more unique color schemes and patterns, which would increase visibility and attention, not considered? Letting one's imagination roam free can lead to more ideas. The process for developing and creating observations similar to these will be outlined later in this paper.

There are many different forms of speed reduction in use today: Chokes, chicanes, roundabouts, traffic circles, and speed bumps, humps, and tables are some speed reducer implementations one would be familiar with. The U.S. Department of Transportation (DoT) Federal Highway Administration (FHWA) refers to these devices and techniques as traffic calming measures². In reality, the opposite of calming is what the driver feels.

Of course, these speed reducers are used for a reason: they still work. The FHWA compiled a list of various speed reduction designs and their measured effectiveness on urban and rural roadways³. The results from this analysis showed that roundabouts and speed bumps/humps were the most effective non-electrical method of speed reduction. Positive attributes of installing existing roundabouts and speed bumps/humps is that they are physical modifications/additions utilizing the same materials as the roadway, asphalt and/or concrete⁴, making them durable, able to withstand harsh traffic wear for years, and minimize costs by not using more remote materials.

However, the drawbacks outweigh the benefits. Speed bumps and humps have a list of issues and concerns⁵:

- Causes traffic jams/backups in high volume traffic
- Drivers will go into bike lanes to avoid them
- Interferes with snow plows, with a chance of damaging plows by being obscured in snow
- Can be difficult to see, surprising drivers and damaging their vehicles; lawsuits have been filed due to this⁶
- The force on the vehicle can make a driver hit their head on the roof, spill drinks and/or food, and can damage a fragile item being transported
- Lifting of the front end of on-coming vehicles at night causes temporary blindness
- Fast drivers are not affected or do not care; slow, obedient drivers are punished
- Patients inside an ambulance can be injured

Likewise, roundabouts have their share⁷:

- Large area to modify, take several days/weeks to plan and build, and require partial/complete intersection closure for construction
- Unfamiliar drivers can be confused and enter/exit incorrectly, causing an accident and/or traffic jam
- Fast drivers are only limited by how much rubber they want to wear off their tires while turning
- If improperly designed/marked, a driver could enter too fast and lose control

2. Motivation and Goal

From a hands-on perspective, the goal of this project is to create, design, and test *dynamic* speed bumps. The dynamic speed bump is a contrivance that responds differently to various vehicular speeds. This ‘response’ could be, for example, a temporary physical deformation if the driver goes over the speed bump slow enough for it to react, should the material implemented possess such characteristics. The dynamic speed bumps will reward slow drivers by allowing them to pass with less feedback (the force the bump exerts on the drivers vehicle) while remaining the same as it is now for fast drivers. This will be the foundation leading to our ultimate goal of producing and marketing a finalized design that meets our evaluation standards which will be covered under our summary of the Design Process.

From an academic perspective, the goal of this project is to provide the students with a real-world learning experience and have them gain or improve upon skills not normally taught in a typical engineering classroom environment. These skills include:

- **Creativity:** disregarding physical, political, and financial limitations to come up with as many different methods of speed reduction possible.
- **Innovation:** thinking outside-the-box and coming up with as many different methods of emulating the same effect of the target problem, with and without physical, political, and financial limitations to justify the practicality of the idea.
- **Hands-on building skills:** taking our thoughts and ideas, putting them down on paper, gathering/selecting materials, and troubleshooting and correcting any flaws in assembling the final design.

The students will also continue to be tested in the following soft skills already present in their engineering curriculum:

- **Communication:** Conveying messages and ideas between mentor and student.
- **Time management:** Students practice prioritizing tasks associated with the project and their coursework.
- **Problem-solving:** Overcome obstacles in design and implementation of ideas.
- **Accepting constructive criticism:** Being open to and learning from input received from others.

The technical motivation behind our efforts stem from the current state of speed reduction needing to remain equally effective but become less penalizing to the vehicle operator. Currently, speed bumps are neutral, treating all drivers, fast and slow, equally. We define fast drivers as the ones that drive above the speed limit, quickly slow down to go over the speed bump, then accelerate off. A slow driver obeys the speed limit in the area, slows down for a speed bump, and gradually goes back to their normal driving habit.

3. Summary of the Design Process

The manner used to come up with our ideas is being called the *creativity and innovation process* which consists of six steps:

1. **Observation:** A look at the present; what is currently being used; observe it in action.
2. **Discussing and thinking critically:** From what was observed determine the strengths and weaknesses of the design. What can be improved? What can change?
3. **Redefinition and re-representation:** Given the more broadly-understood real problem, we can now redefine and re-represent the problem, so it can be later solved in a broader sense.
4. **Ideation:** Thinking divergently to generate multiple alternatives; the most promising ideas continues to the next step.
5. **Prototyping and Testing:** Experimenting with materials to determine which is best suited for each idea, designing and building the prototype, and testing the prototype.
6. **Evaluation:** Through the observation and collection of data from testing, the design will be determined whether it is effective or not. This will be done using the following criteria:
 - I. **Identify potential problems:** Determining possible faults or design flaws that could, for example, result in damage to the driver's vehicle, leading to lawsuits.
 - II. **Manufacturing complexity and cost effectiveness:** Is the speed reducer more complex to make and install compared to the target speed reducer? If it costs less it might be an acceptable trade off. Speed bumps and humps cost hundreds to thousands of dollars to install depending on the size and materials used.
 - III. **Measured feedback:** If a fast driver receives the same amount of feedback the target speed reducer produced and a slow driver is satisfied with the amount of feedback received it would be logical the dynamic speed reducer is effective in its application.

In addition, several non-technical aspects are considered for our ideas:

- **Sustainability:** If implemented, how long will the speed reducer remain effective? Will someone find a way to abuse the design to their advantage?
- **Commercialization:** In comparison to the speed reducer it is replacing, how does it compare aesthetically? What would be the advantage of promoting our design?
- **Political:** Are there any liability considerations that need to be taken into account? What is the requirement to petition the testing and evaluation by the local authorities?
- **Environmental:** Does our design have a larger carbon footprint than existing speed reducers? Are the materials recyclable?

4. Detailed Design Process

In this section we will walk the reader through our design process, focusing on speed bumps and speed humps.

4.1 Observation

Our process began with observing the speed reducers located around our neighborhoods and on our University campus. We watched cars drive over them to see the effects produced on a compact car versus a larger vehicle like a truck or van. We drove over them ourselves to get an idea of what level of feedback we should be aiming for.

4.2 Discussing and thinking critically

With this information we sat down and discussed the changes that could be made to what we observed:

- The material used most commonly was asphalt. What other materials be used?
- The shape of each bump/hump was inconsistent. Some were oval, producing less feedback, and others were circular, forcing us to go well below the speed limit to stay within our comfort zone. What other shape can be used?
- A majority of bumps/humps were black or dark grey (natural asphalt or painted rubber) with and without white/yellow lines. Why can't the overall color be brighter, increasing visibility at night, or have a larger variety of colored lines and patterns to make them easier to spot?

4.3 Redefinition and re-representation

Taking our original target problem, the speed bump and speed hump, we can redefine them to be vehicular speed reduction devices. With this, we can represent the speed bump/hump with an empty box, in which we can put anything that we can imagine inside that could emulate the original effect of the speed bump/hump. From here, our imagination can run wild.

4.4 Ideation

In this section we have taken several of our ideas and organized them into their own subsections. The pros and cons of each idea are presented and whether or not we feel it is promising enough to begin prototyping and testing.

A. Utilizing a Fire Hose

This idea consists of placing a zigzagged fire hose back and forth on the road similar to what is shown in Figure 1 below. While the shape does not have to be exactly as depicted, the idea is to make a speed reducer that is more spread out so faster drivers might slow down more to driver comfortably.

Figure 1: Fire hose zigzagged across the road.

There are several ways the fire hose can be utilized:

- a. Filling and pressurizing the hose with water using a fire hydrant, elevated water tank, or a generic garden hose adaptor. While the pressure within the hose will be different for each method, the idea is to have the water act as our dynamic variable. If a driver goes quickly over the hose the water won't have enough time to flow out from under the tires. For a slower driver, the water will spread out giving them less feedback.
- b. Filling the fire hose with cement. This option is less dynamic and will treat fast and slow drivers alike. However, it will be more durable.
- c. Filling the fire hose with sand/dirt. This option, while it would be more dynamic than cement, would have trouble regaining its shape. This method would most likely be suited for temporary speed reduction, such as at a concert or sporting event for a day.

The concept we're working with here is sound, but the physical limitations for this idea would be too costly to overcome. This idea was not developed further due to the fact that its vulnerability to being punctured is too great. While filling the fire hose with cement will alleviate this problem, it would not meet our requirement for measured feedback during evaluation.

B. Utilizing a Generic Garden Hose

This idea utilizes several generic garden hoses cut into pieces and arranged in a Pascal's triangle configuration as shown in Figure 2. Using the elastic and flexible characteristic of the rubber used in a garden hose when a vehicle drives over it the entire arrangement should compress under the weight. For a fast driver this would punish them greatly because it would create a bouncy bump that would produce a greater amount of feedback. For a slow driver it should have reduced feedback versus a traditional speed bump/hump, but there is a chance the bouncy nature of the elastic material would undermine our efforts.

Figure 2: Hoses stacked in a Pascal triangle arrangement.

Thoroughly discussing the pros and cons of this idea lead to the conclusion it has promise. Currently another on-going idea, discussed later, is being evaluated. Once that one is done this is one of the ideas we would pursue.

C. Mesh Designs

This subsection consists of several mesh designs depicted in Figure 3. These different designs showcase the direction we took when considering the implementation of surface area based speed reducers. While they are not dynamic the fact the surface area has increased will only slow drivers down with minimal feedback; if anything the ride will get a little shaky.

Figure 3: Mesh designs that increase surface area.

The three designs are outlined as follows:

- On the left of Figure 3: Grooves across the roadway to shift/alert drivers to slow down. This is similar to what is implemented on the side of roadways to alert drivers they're not in the center of their lane.
- In the middle of Figure 3: Bumps; hubcap-sized or another small raised surface.

- c. On the right of Figure 3: This mesh implementation would be emulating a rocky road or rough surface.

These designs were not pursued, not because they wouldn't be effective, but because we feel it would resemble too closely with what's already available today, as well as lacking appeal for commercialization due to that fact.

D. Unorthodox Methods

These ideas are a bit more exotic in their execution. The first idea is more or less a scare tactic, and the second is the same old speed bump we know but made out of an unconventional material.

- a. Placing traffic spikes across the road but with dull teeth so as to not cause damage. Scares the driver into slowing down and be cautious. To induce the desired effect a sign can be placed next to the speed reducer to warn drivers if they go too fast their tires will be damaged even though it wouldn't happen due to dull teeth. While this would be a very effective method of reducing the speed of fast and slow drivers the possibility of lawsuits arising cannot be taken lightly.
- b. Replace speed bump/hump material with D3O impact protection dilatant non-Newtonian fluid. This material hardens upon impact, but remains malleable when lightly manipulated. The major drawback to this idea is that costs could be prohibitively high.

E. The Dynamic Diamond

The diamond idea would be a completely mechanical speed reducer. There will be an undetermined mechanism that measures how fast the vehicle is going, most likely based off the pressure your vehicle exerts on the mechanism (no electrical components), and then using that pressure to activate a hydraulic piston which will move the PVC segments making the speeding vehicle hit them to slow down, or if the driver goes slowly enough, the speed reducer will do nothing. Refer to Figure 4 below.

Figure 4: An overview of the dynamic diamond speed reducer.

Because this system will be purely mechanical, the complexity of the entire system will be greater than if it were combined with an electrical control system. If the driver drives at the desired speed limit, or below, the device should not trip because the force from the vehicle will not be high enough to activate the system. This idea is promising and will be pursued once the current on-going evaluation is completed.

F. The Dynamic Windshield Wiper

This speed reducer idea is based on the windshield wipers used on a vehicle. This speed reducer will be completely mechanical, using an undetermined mechanism to measure the speed of the vehicle that would use the energy gathered from the vehicle passing over it to make the speed reducer activate if the amount of energy received meets the activation threshold. Refer to Figure 5 below.

Figure 5: Overview of the dynamic windshield wiper speed reducer.

Because this system will be purely mechanical, the complexity of the entire system will be greater than one using an electrical control system. If you drive at the desired speed limit, or below, the device should not activate because the force from the vehicle will not be high enough to trigger the system. Similar to the dynamic diamond from the previous subsection this idea is also promising and might be pursued in the future.

G. The Snake

The snake idea will utilize at least one garden hose, fire hose, or thick rope, and several pieces of smaller rope. The idea is to snake the material back and forth by tying the material down with rope and shaping it to a desired pattern that the driver of the vehicle can follow without hassle at the desired speed for the area it will be placed in.

Figure 6: An overview of the snake speed reducer.

If the driver goes too fast they will either put more wear on their tires trying to avoid hitting the material, or they will hit the material and, depending on the height of the bump, will put unnecessary stress on their vehicles suspension. If the driver obeys the speed limit they will be treated to a smooth ride with some slight turning. For more durability, the material setup can utilize lawn protectors (pyramids or domes) to increase the consequence of hitting the speed reducer.

4.5 Prototyping and Testing

We went forward with prototyping the snake idea since it could easily be tested using pieces of rope. Although we are aware of the consequences this would present to drivers on two-way roads (the possibility of head-on collision), our curiosity got the best of us as we wanted to see what would happen if we made the *driver* the dynamic variable. Going too fast or too slow in this situation could produce interesting observations.

For testing the snake idea we needed the distance between the two front tires (Width) along with the distance between the front and rear tires (Base). Measurements were taken from several vehicles of varying size since we want the speed reducer to accommodate all non-commercial and non-emergency vehicles.

Chevy Silverado 2007:	Width: 80"	Base: 148"
Honda Accord 1999:	Width: 69"	Base: 112"
Chevy Malibu 2010:	Width: 69"	Base: 112"

The Width of the vehicles was measured from the outermost point of the left tire to the outermost point of the right tire. The Base of the vehicles was measured from the middle of the front tire touching the ground to the middle of rear tire touching the ground.

Although these measurements do not represent all vehicles, it will suffice for our initial testing. The speed reducer should be wide enough so that no noncommercial or nonemergency vehicle can drive over it without having to turn. So, from the measurements gathered, 80" should be a suitable test Width and 148" for Base. These numbers both reflect the measurements of the Chevy Silverado because it is the largest consumer vehicle that we measured. Since our example target for the speed reducer will be 25 miles per hour we can convert this to feet per second to determine the distance for each turn:

$$\frac{25 \text{ miles per hour} * 5280 \text{ feet}}{60 \text{ minutes} * 60 \text{ seconds}} = 36.67 \text{ feet per second}$$

Now that we know the distance a vehicle will cover in one second, roughly 37 feet, how can we use this?

Figure 7: An overview of the snake speed reducer with measurement and calculated distance information.

From Figure 7 above, using a sine wave as our snaked material, we can look at several use-cases to determine the best-suited amount of turning the driver will have to perform while driving over the speed reducer:

1. One period of the sine wave can be the same length as the distanced traveled by the vehicle in one second.
2. A half period of the sine wave can be the same length as the distance traveled by the vehicle in one second.
3. A quarter period of the sine wave can be the same length as the distance traveled by the vehicle in one second.

From the three above cases which one would be best for punishing the fast drivers while rewarding the slower drivers? We began testing using option 2.

Figure 8: Rope being laid out for testing the snake speed reducer.

In Figure 8 the initial layout of the pattern based off the calculations on the previous page is shown. We used yellow nylon rope and duct tape to make the testing layout easy to see on the asphalt.

Testing the snake idea proved to give positive results: Driving at the planned speed limit was nearly flawless. When we drove at 30 mph we couldn't maintain it because the turning made us slow down. Giving the vehicle more gas only made the drive more uncomfortable and our sense of control diminish. Driving below the speed limit was comfortable and we were only more surprised to find ourselves wanting to drive faster due to the fun go-cart feeling.

A. Material Testing

Since our feedback from testing a generalized prototype of the snake idea was mostly positive we looked into different materials that could be suitable for use. For our first stage of testing materials to be used we got PVC pipe in sizes of $\frac{3}{4}$ ", 1", 1- $\frac{1}{2}$ ", and 2". We tested each one individually but eventually settled on cascading them like a staircase because it gave greater feedback when driven over and lowered the fatigue the PVC pipe would be exposed to; shown in Figure 9.

Figure 9: The cascaded PVC arrangement we determined was most effective. The vehicle approaches from the smaller PVC side first.

Our second material test consisted of a 2" wide, 100' long exercise/boat rope shown in Figure 10 below. Although the PVC pipe we tested before was durable enough, we wanted to explore other materials to see whether there would be another that would be easier to manipulate and move around.

Figure 10: Boat/exercise rope in comparison to the cascaded PVC arrangement.

After testing the boat/exercise rope we determined it was less effective than the cascaded PVC pipe setup. As of now, the testing of the snake idea has been put on hold due to one of our ideas currently undergoing evaluation which we feel has greater potential.

4.6 Evaluation

As mentioned several times earlier, we have another on-going speed reducer idea currently undergoing evaluation. What can be said of the idea is that it is utilizing springs as a variable for creating a dynamic system. As it stands, the idea is considered intellectual property and will the patent process soon.

5. Conclusion

In this paper we have described our desire to challenge the established system for speed reduction, i.e. speed bump, speed humps, roundabouts, etc. We started small, focusing on speed bumps/humps, but will soon expand our ideas to reach into larger scale speed reduction systems.

Working on this project, and seeing what was accomplished in the amount of time we were available to meet, has shed light on the fact that, in many courses, the design process for going from idea to market, or prototype, is mostly left up to the student to decide which method is best. Yet, from our individual experience, the unguided nature of these courses tends to lead to disorganization and wasted time on trial and error methods of design. For this project we were guided and mentored using the *creativity and innovation process* outlined in this paper. We are taught to observe and interpret the things we take for granted around us and see them as a source of inspiration and lay a foundation for creative thinking.

Upon the start of this project the authors had their sureness and doubts as to what to expect as an outcome of their time and effort. As there are many different speed reduction methods on the market today, a quick internet search shows how much already exists. However, the existence of these ideas only obscured our vision initially.

The preliminary expectation of this project had the authors thinking only one or two small changes could be made to existing designs. This included using different materials that were more environmentally conscious, or moving to advanced electronic systems. The fact that several pages in this paper were dedicated to ideas and concepts we consider viable, in one way or another, goes to show that the grass is greener on the other side, so to speak.

We have laid out our creativity and innovation process for any other interested parties to use themselves. There is no single best way to come up with ideas, but we feel where we are heading is an excellent start and should be included in any capstone design course. For us, future plans include taking our on-going speed reducer idea to market. Demonstrating to, and working with, local authorities to begin real-world integrated testing and showing people that there is a better solution for speed reduction.

If the reader were to ask “what were we suppose to learn from this paper?”, the answer is to encourage students to think creatively; to not ask the same questions over and over again, but to find another way to ask the same question... challenge the established methods of thinking and create new designs.

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