Multidisciplinary Senior Design
Kate Gleason College of Engineering
Rochester Institute of Technology
Rochester, New York 14623

Project Number: P13675

Bicycle Helmet Mirror System

Zachary Kirsch (ME)
Olivia Scheibel (ME)
Martin Savage (ME)
Henry Woltag (ISE)

Abstract
One cause of motor vehicle and bicycle collisions is cyclists making turning maneuvers while unaware of road conditions behind them. Currently, riders have the option to use a side mounted helmet mirror system to aid in their vision to the rear. However, this mirror arrangement has several drawbacks: distorted vision, front view obstruction, and difficult adjustment. A dual mirror system was proposed to address these issues. This system is mounted over the top of the helmet to provide a wide angle view behind the cyclist while not obstructing the forward line of sight. The team designed, prototyped, and tested a system resulting in a final product that can be adapted for use with multiple helmet styles currently on the market, and increases cyclists' awareness of road conditions, thereby increasing the cyclist's safety.

Introduction
In the United States, 48,000 cyclists were injured in motor vehicle related traffic accidents in 2011 (NHTSA's National Center for Statistics and Analysis, 2013). Pai (2011) found that 38.8% of these bicycle accidents were caused by vehicles attempting to overtake a cyclist. It was noted by Cross and Fisher (1977) that cyclists were executing turning maneuvers while unaware of traffic conditions behind them, leading to increased chance of collisions between cyclists and motor vehicles.

Helmet mounted bicycle mirrors are currently available to help increase cyclists' awareness of road and environmental conditions behind them and thereby prevent the aforementioned collisions. However, the currently available mirrors have several drawbacks that discourage their use. Current mirror systems often obstruct cyclists' forward line of vision and have a limited rear viewing angle. As 20% of bicycle related traffic accidents are frontal collisions (Pai, 2011), it is important to insure that the cyclist forward line of vision remains unimpaired.

The concept for a dual mirror bicycle helmet rear viewing system was proposed by Robert Fish, an industrial design student at the Rochester Institute of Technology. The concept was transformed into a design, prototyped, and tested using an iterative process to optimize the design while ensuring that the final design was durable, safe and easy to use, and more effective than currently available products.

Design Process

Concept Development
The bicycle helmet mirror system is comprised of two subsystems: the optical system and support system. It was determined that the optical system had the smallest degrees of freedom for design and

should therefore be designed first and then the support system should be optimized based on the optical design.

Establishment of Customer Needs and Engineering Specifications

The first step in the design of the bike helmet mirror system was to develop and evaluate customer needs and their related engineering specifications. The team interviewed stakeholders and identified a customer proxy in order to establish key engineering specifications. A benchmarking analysis was performed to ensure that the quality standards of the proposed design would meet or surpass those of currently available bicycle mirror systems. The established set of engineering specifications can be seen in Table 1.

Table 1. Engineering Specifications

Specification	Unit of Measure	Marginal Value	Ideal Value	Comments/Status
Power required for operation	Watts	-	0	No power input
Number of tools required for adjustment	Quantity	1	0	
Estimated Sales Cost	Dollars	30	20	Market value projection, no restriction on prototype beyond budget
Number of helmet styles system can attach to	Quantity	-	3	Minimum value
Durability - survive drop from height	ft	-	6	Dropped with mirror system attached to helmet
Weight	lbs	0.775	0.18	
Survive wind speeds	mph	45	60	Mirrors maintain desired position and orientation up to these speeds
Breakaway force (if snagged on object)	lbs	-	45	Based on NHTSA neck injury criteria
Rear image angle	degrees	10	25	Based on benchmarking
Projected area of main mirror in direction of motion	in^2	18	8	
Recyclability of materials used	%	-	100	Exceptions: mirrors, adhesives
Mirrors and supports removable from helmet	Yes/No	-	Yes	Interface between helmet and supports need not be removable
Lateral forward viewing angle	degrees	-	180	Does not block lateral vision when looking straight ahead
Distance behind at which vehicles are visible	ft	130	200	Based on calculations
Image oriented properly	Yes/No	-	Yes	

Geometric Optical Analysis

The team performed a fundamental geometric optical analysis to ensure that a dual mirror system would be best suited for the system. Although the dual mirror system offered the benefit of having fewer mirrors, a triple mirror system offered a less complicated manufacturing process as curved mirrors would not be needed. The team used a model of a 50th percentile male head to determine design parameters for each proposed design. A schematic of the geometric optical analysis performed on a proposed dual mirror system design can be seen in Figure 1.

Once an initial design had been proposed for each concept, a sensitivity analysis was performed. The sensitivity analysis involved moving the position of the mirrors until the system no longer performed to the specifications seen in Table **1**. The goal was to identify the system that was the least sensitive to variations in position which may occur as a result of impacts due to wind gusts or cycling on an uneven road. It was found that the dual mirror system's performance superseded that of the triple mirror system in the sensitivity analysis. The team concluded that a dual mirror system would be better suited for the intended application.

Structural Design

Once an initial design had been proposed for the support system an iterative process was used to optimize the design. It was determined that the static stress the system could experience would be small compared to the impact stress the system would be exposed to. To simulate the impact stresses that the system may be exposed to, a drop test analysis was performed using SolidWorks Simulation package. The helmet-mirror assembly was dropped from a height of three feet in various orientations to simulate the system falling while not in use by the user, such as a fall off of a shelf. The collision was assumed to be inelastic in order to simulate a worst case scenario.

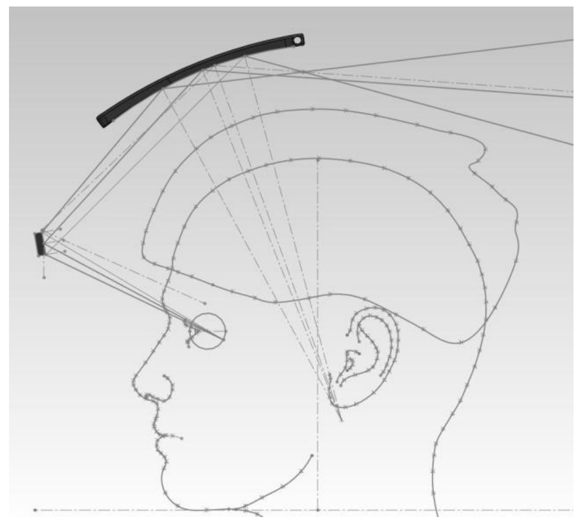

Figure 1. Schematic of geometric optical analysis performed on a proposed dual mirror system.

This analysis provided the location of stress concentrations and areas of high stress within the system. Adjustments were made to the design to optimize the system. The adjustments included adding fillets and increasing dimensions in the front supports, as seen in Figure 2, such that the part had enough strength to survive the simulated impacts.

Material Selection

Multiple factors were considered when proposing possible mirror materials; clarity of the image, ease of manufacturing, and durability. For safety, glass was not considered for use. The proposed options were reflective Mylar film, chrome window tint, Krylon Looking Glass®- Mirror Like Paint, and acrylic mirror. After testing, it was found that the mirror like paint was not reflective and the Mylar film and chrome window tint had insufficient surface quality. It was therefore decided that acrylic mirror would be used for the mirror system.

The support system was designed so that it was made of two materials: flexible gooseneck tubing and ABS plastic. ABS plastic was chosen for material properties including resistance to water, heat, and UV, and for its ability to be both 3D printed and injection molded. Gooseneck tubing was chosen as it is flexible enough to allow the system to attach to multiple helmet styles. An impact analysis was performed to ensure that the gooseneck would withstand impacts resulting from cyclists riding over drops of 3 inches to simulate the effect of a rider going over a curb. It was found that the gooseneck would deform, but, based on a geometric optical analysis, not to the point where the optical system was no longer effective.

Manufacturing

The bike helmet mirror system is designed to be packaged in individual components and assembled by the user. There are a few reasons for this decision. The first is that the assembled product occupies a very large product volume. By shipping in components to be assembled by the user, the total packaging material and shipping volume is minimized. Secondly, the time that is saved in the manufacturing process reduces manufacturing costs by increasing output per shift. The final reason for the components to be assembled by the user is that it accommodates for individual flexibility. The mirror system is designed to be used by any user and attached to any style of helmet. Allowing the user to assemble the unit allows them to find the optimal location for the dual lock pads to attach to their helmet for proper optical alignment.

Manufacturing the components for the mirror system is a multistep process. The front mirror is manufactured by having an acrylic mirror placed into a mold cavity. ABS plastic is then over molded to the back of the acrylic mirror through an injection molding process. ABS has a melting temperature 100°F lower than acrylic; therefore, there is no concern of the ABS melting the acrylic on contact. The mold would have two side pulls to create the threading necessary for the screw fasteners.

The top mirror follows a similar manufacturing process to the front mirror. The one difference occurs before the injection molding process. The acrylic mirror starts by being placed on a hot plate to be raised to a plastic temperature. The acrylic is then placed into a clamp mold to form the shape of the curved surface. Once cooled, the part is placed into the injection mold to be over molded by the ABS.

Many of the parts in the mirror system are formed solely through injection molding. The front supports, snap fits, and the gooseneck inserts are all formed in this process and are made of ABS.

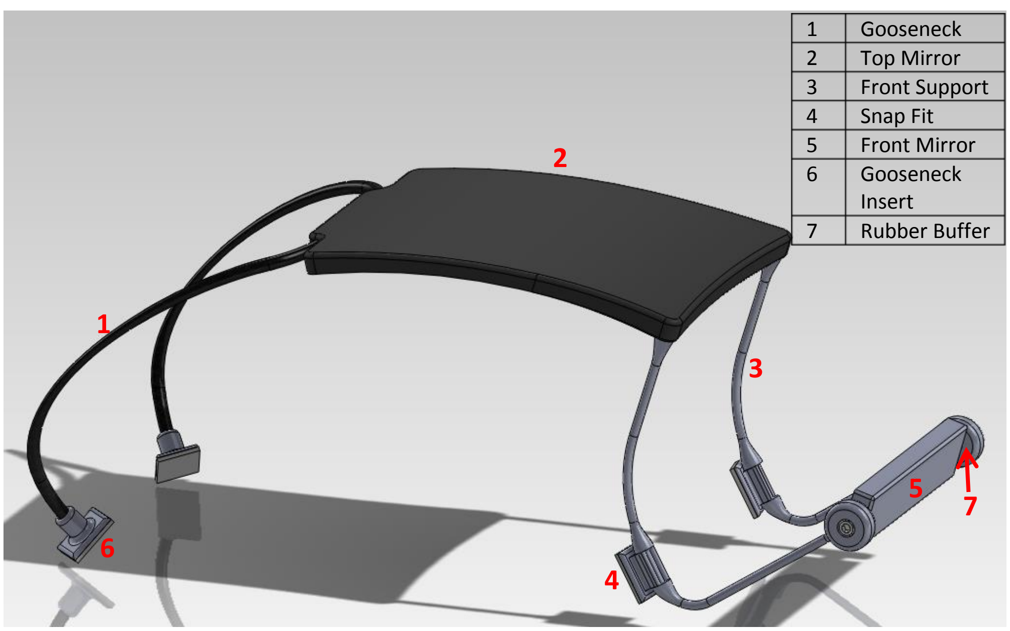

Figure 2. Annotated system assembly.

The buffer is the last piece that is produced in house. These parts are formed from Neoprene rubber and are formed through a stamping process of sheet rubber.

The following parts are ordered in through outside vendors. Gooseneck material connects the rear of the top mirror to the helmet, and is ordered from Uniprise. 3M Dual lock is used to connect the snap fits and the gooseneck inserts to the helmet. Screws are used to connect the front mirror to arms. The screws used are 6-32 screws and can be purchased from most hardware suppliers.
Once manufactured, some assembly is completed in house. The gooseneck is inserted into the top mirror and secured via adhesive. Attached to the ends of the gooseneck through adhesive are the gooseneck inserts.

Once a customer acquires the parts, the following assembly steps need to be completed. The arms are attached to the top mirror. The front mirror and buffers are attached to the arms with the 6-32 screws (which can be inserted with a standard hex wrench that many cyclists already own). The customer then attaches the dual lock to the attachment points and the helmet to fit their desired mounting.

The cost breakdown of manufacturing is shown in **Error! Reference source not found.**. The total manufacturing costs of materials are $5.28. Following the standard procedure of doubling and doubling to determine customer price yields a cost of $21.13.

Table 2. Estimated manufacturing costs

Part	Material	Qty	Critical Dimension		Unit Cost		Part Cost ($)
Arm	ABS	2	0.007	lb	1.18	$ / lb	0.02
Buffer	Neoprene	2	0.025	in^3	0.30	$ / in^3	0.02
Dual Lock	Dual Lock	8	0.300	in^2	0.17	$ / in^2	0.41
Front Mirror	ABS	1	0.037	lb	1.18	$ / lb	0.04
	Acrylic	1	0.400	in^3	0.42	$ / in^3	0.17
Gooseneck	Coated Steel	1	13.250	in	0.25	$ / in	3.31
Gooseneck Inserts	ABS	1	0.001	lb	1.18	$ / lb	0.00
Screws	6-32 Screws	2	1	ct	0.15	$ / ct	0.30
Snap Fits	ABS	2	0.001	lb	1.18	$ / lb	0.00
Top Mirror	ABS	1	0.148	lb	1.18	$ / lb	0.17
	Acrylic	1	2.000	in^3	0.42	$ / in^3	0.84

Total Manufacture Cost ($)	5.28
Purchase Price ($)	21.13

Testing and Validation

In creating this product, certain design specifications were created and can be seen in Table 1. In order to ensure that the products meet the specifications, a rigorous test plan was created for the prototype to complete.

Test 1 measures the rear viewing angle of the mirror system. Specification S9 requires that the system must show a marginal value of 10 degrees behind the rider and ideally 25 degrees. To test this, a team member will stand a measured distance away from a white board and another member will mark the extent of their rear horizontal vision. Using these calculations and basic trigonometric calculations, the lateral rear viewing angle can be measured.

Test 2 measures the distance behind the user that a vehicle is visible. Specification S14 requires vehicle visibility of at least 130 feet and ideally 200 feet. A team member will wear a helmet with the mirror attached and attempt to view vehicles at increasing distances until the vehicle is no longer visible. The farthest distance at which a vehicle is visible will be recorded and compared against the specification.

Figure 3. System prototype

Test 3 measures the wind speed resistance. Specification S7 requires that the mirror system must resist deformation under riding wind speeds - 45 miles per hour nominal, and 60 miles per hour ideal. The helmet and mirror system will be attached to a Styrofoam mannequin head and placed in the wind tunnel. The speed will be increased in 5 mile per hour increments until the ideal wind speed is reached or until the mirror system deforms under the loading.

Test 4 measures the system break-away force. To meet highway safety standards, the mirror system must break away before a load of 45 pounds is applied. This is addressed in specification S8. A force gauge will be attached to the front of the mirror mount system. Force will be applied until the system is removed from the system. The maximum force reached will be the force compared against the specification.

Test 5 is used to determine if the helmet mirror system can survive a drop from three feet onto concrete. This is addressed in specification S5 and covers the situation where the helmet falls off of a set of handlebars or off a shelving unit and onto the ground. The helmet is dropped in the following configurations: upright, inverted, nose, back, and side. The test is scored on a pass/fail criterion.

Results and Discussion

It can be noted in Table 3 that the performance of the bike helmet mirror system exceeded the engineering specifications in many areas. The system performed particularly well in the wind speed resistance and the rear viewing distance tests, exceeding the specifications by 211% and 108%, respectively. Although the system weight and estimated sales cost exceeded the ideal values, they did fall within the marginal values.

Due to time and budget constraints, destructive testing (Tests 4 and 5) were postponed. It is anticipated that the system break-away force would meet the required value of 45lbf based on initial testing and theoretical analysis. It is important however that the break-away force is tested before the system is sold as it is required by NHTSA's safety standards. The system was designed to reduce and eliminate high stress and stress concentrations, respectively. This should result in a durable system although it is recommended that the drop test be performed to confirm this.

A $500 budget was allotted to create the system prototype. In total, $471.81 was spent to produce the final prototype, including several prototype iterations. The budget analyses can be seen in Table 4. It is estimated that the final product could have a sale cost of $21.13 which is beneath the marginal engineering specification of $30.

Conclusions and Recommendations

The final prototype met or exceeded most of the engineering specifications with the exception the breakaway force and the durability tests which have yet to be tested. As these aspects were ranked highly in the customer specifications, it is recommended that future work include testing and making appropriate changes in the design, if necessary, to ensure that the engineering specifications are met.

Table 3. Testing results and their related engineering specifications and customer needs. A green check indicates that the performance of the system exceeded the specifications. A purple question mark indicates that the test has yet to be performed.

Customer Needs	Rating	Related Engineering Specifications		Test Results		
Safe to wear	9	Breakaway force	45 lbs	To be tested as part of future work		?
Provides a wide angle view behind the cyclist	9	Rear Image Angle:	25 degrees	Rear Image Angle	40°	✓
Holds mirror orientation as set by user	9			Mirror position is controlled		✓
Minimizes obstruction to the cyclist's forward field of vision	9	Lateral forward viewing angle	170 degrees	Front mirror is positioned such that it does not affect the lateral view		✓
Attaches to a typical helmet without compromising the helmet's integrity	9			Attaches to helmet via Dual Lock		✓
Is lightweight and omfortable to wear	9	Marginal Weight	0.775 lbs	Weight	0.4 lbs	✓
Is durable	9	Survives drops from:	3 ft	To be tested as part of future work		?
Provides a clear, correctly oriented image	9	Distance behind which vehicles are visable	130 ft	Distance Behind which vehicles are visable	270 ft +	✓
Is adjustable to provide optimal view for the rider	9			System is adjustable to accomadate a wide demographic of users		✓
Is inexpensive ($10-$20) for the consumer	3	Marginal Cost	$30	Estimated sale cost	$21.13	✓
Detaches from the helmet	3			Can detach from the helmet		✓
Can be adjusted without the use of tools	3			Does not require tools		✓
Requires no power input	3			Does not require power		✓
Is aesthetically pleasing	3					
Refrains form significantly increasing wind resistance	1	Survives wind speeds	45 mph	Survives wind speeds	140 mph +	✓
Is fabricated in an environmentally friendly way	1	Recycleability of materials used	100%	All materials (with the exception of the adheasive) are recyclable		✓

Table 4. Budget used to develop final prototype.

Ordered	Delivered	Item	Vendor	Status	Total Cost
2/1/2013	-	Helmet	Berts bikes	Acquired	54.99
2/19/2013	3/4/2013	Sample Mylar	Nielsen	Requisition - Acquired	5.00
2/19/2013	3/4/2013	Dual Lock	McMaster	Requisition - Acquired	34.72
2/19/2013	3/7/2013	Adhesive	JoAnn	Requisition - Acquired	9.84
2/21/2013	3/5/2013	Flex Tubing	Uniprise	Requisition - Acquired	38.20
3/18/2013	4/2/2013	Mylar sheet	Nielsen	Requisition - Acquired	37.00
4/11/2013	-	ZCorp prototype	Brinkman lab	Acquired	20.00
4/15/2013	-	Spray adhesive, coating	Loews	Acquired	16.00
4/17/2013	-	Scrapers	Harbor Tools	Acquired	3.98
4/19/2013	-	FDM model 1, 2	Brinkman lab	Acquired	101.55
4/19/2013	4/30/2013	Acrylic mirror	Home Depot	Requisition - Acquired	48.98
4/29/2013	-	FDM model 3	Brinkman lab	Acquired	101.55
					471.81

Although the weight of the system was beneath the marginal value, it did exceed the ideal value. It is recommended that future iterations of the prototype focus on weight reduction through redesign of the system components or the use of alternative materials.

Although the system surpassed the ideal value for the rear viewing distance, the prototyping process of the curved mirror was difficult and time consuming. Often the mirror would have surface defects or unwanted deformations as a result of the heating process. Although these defects did not appear to significantly affect the viewing distance, it is recommended that alternative manufacturing processes or materials be investigated to improve aesthetics and simplify the manufacturing process.

Acknowledgments

Support for this work was provided by the Multidisciplinary Senior Design Project Office at the Rochester Institute of Technology.

The authors would like to express their appreciation to Dr. Richard Lux, Mr. Michael Buffalin, Dr. Dennis Cormier, Dr. Mario Gomes, Mr. Dave Hathaway, Dr. Marca Lam, Mr. Travis Newberry, and Mr. John Wellin for providing invaluable guidance, advice, insight, and assistance throughout the course of the project.

References

Cross, K., & Fisher, G. (1977). A study of Bicycle/Motor Vehicle Accidents: Identification of Problem Types and Countermeasure Approaches. *National Highway Traffic Safety Administration*.

NHTSA's National Center for Statistics and Analysis. (2013, April). *Traffic Safety Facts: Bicyclists and Other Cyclists.* Retrieved from National Highway Traffic Safety Administration.

Pai, C.-W. (2011). Overtaking, rear-end, and door crashes involving bicycles: An empirical investigation. *Accident Analysis and Prevention*, 1228-1235.