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Safety Concerns and Design Challenges of Side-Saddle Pillion Riders of Motorized Two-Wheelers in India: A Case Study Designing a Saree Guard and Footrest

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Abstract

Before designers develop a product for a distinctive market (e.g., India) they must understand what makes that market unique and how that society will influence their design. This paper outlines the distinctive features of motorized two-wheelers (e.g., Harley Davidson® motorcycles) in India and a design approach to address the individuality of the market and its societal influences. A literature review provides basic background of the economic, environmental, policy, cultural, and physical influences on the Indian two-wheeler, and how they relate to safety concerns specific to pillion passengers. Members of the research team (cross section of engineers and research psychologists) emulated the behavior of users in order to develop their design; interviews with users in India also informed prototypes and models. The team was able to design a product where the drive train and rear wheel could be protected, decreasing the likelihood that sarees (a traditional long dress worn by Indian women) would become caught, while increasing anticipated comfort of the side-saddle pillion rider and the driver. By employing these market-focused methods, other designers can identify unique safety, comfort, and/or convenience issues in other types of transportation and develop concepts and products to meet those needs.

Keywords: Automotive Engineering; Seat Design; Ergonomics; India; Pillion; Two-Wheelers

Statement of Purpose

As in most rapidly-growing economies, India's citizens are commuting longer distances to their workplaces [1,2]. The way millions in India are choosing to do this is via motorized two-wheelers (scooters, motorcycles and mopeds) [3]. As more two-wheelers are on the roads, safety concerns increase, including some that are exclusive to the Indian culture. Two-wheeler designers and manufacturers have an opportunity to include safety features specifically intended for Indian two-wheeler drivers and pillion passengers (those who ride on the seat behind the driver either side-saddle or straddling/cross the saddle) in their products. Harley Davidson® has recently expanded to the Indian market; the research team, composed of students and faculty in the fields of automotive engineering, human factors, and industrial/organizational psychology, sought to develop a product specific to the Indian market. This paper outlines some of the factors that make riding a two-wheeler in India unique and the design approach used to address a subset of these needs.

Introduction

Motor vehicle sales and ownership are growing rapidly in India and other developing Asian countries [4]. The most affordable motorized mode of transport in India is the two-wheeler. In India, two-wheelers dominate the market, representing 76% of vehicle sales in 2011-2012 [5]. Passenger vehicles comprise 15%, while the remaining 8% is made of three-wheelers and commercial vehicles (4% each) [5]. As of 2006, India was the second largest market in the world for two-wheelers, behind China [4,6].

These increases in ownership of two-wheelers, and specifically motorcycles, are believed to be due to increases in urban incomes since the 1980's [1,7]. Urban India has growing numbers of young professionals and college students with disposable incomes [8]. Two-wheelers offer reliable door-to-door service, requires little parking space, can be parked securely inside a residential complex, and can carry pillion passengers and luggage. Motorcycles have become the motorized two-wheeler of choice-valued for their rugged appearance, higher road speeds compared to scooters, and appeal to the younger generation.

With these increases in two-wheelers on the road, the safety of the vehicles becomes very important. In 2011, approximately 27% 19.2% of people killed in crashes in India were on two-wheelers, compared to the 17.6% fatally injured in cars, jeeps and taxis; 27,290 people were killed and 115,047 people were injured in two-wheeler crashes [9]. India's National Institute of Mental Health and Neuroscience (NIMHANS) stated that brain and limb injuries were the most frequently occurring injuries for two-wheeler drivers and riders [10].

While much of the safety and design research conducted on two-wheelers has been done in the United States and Europe, it may not all apply globally. In India and other countries, cultural factors play a large role in the safety of riding two-wheelers. Some researchers have focused on the safety of the two-wheeler in terms of licensure, helmets, or road conditions, but few have focused on the opportunities for the two-wheeler designers to meet the unique design needs of the specific user populations.

Literature Review: Understanding the Motorized Two-Wheeler in India

Before designers can begin to develop a new product for a distinctive market such as India, they need understand what makes

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that market unique and how life in that society should be taken into consideration to influence the design. India offers a number of unique challenges that should be considered prior to starting the design process for a two-wheeler; a review of the Indian market place and its motorists would make these challenges apparent. The topics covered in this section focus on those the team members from India view as most relevant to understand the Indian culture relevant to two-wheeler pillion passengers which include two-wheeler use, environmental effects that impact safety for two-wheeler operators and passengers, and design influences that affect safety, including anthropometry and traditional clothing.

India and the two-wheeler

There are a number of differences between urban and rural populations in India --the major ones are education and the economy. There is a large divide in income levels between urban and rural populations, where urban Indians have higher incomes than rural Indians [11,12]. Children in rural areas are less likely to be educated [12,13].

Because of these lower levels of income and education in rural India, the lower purchase price and fuel efficiency of two-wheelers, compared to passenger vehicles, allow more families to own them. Two-wheelers are used for commuting to work, completing household errands and shopping, transporting passengers, as well as for delivering and selling merchandise via attachments for wagons [6,14]. Improved roads, increases in gas prices, traffic congestion, and lack of parking are cited as reasons for increases in two-wheeler use [6]. Additionally, as Indian cities continue to grow, they also continue to sprawl, increasing the need for motorized transportation, because many distances are now too great for walking and cycling [15]. Also, when compared to a passenger car, a two-wheeler is more fuel efficient and thus more economical, offering transport across almost any Indian terrain at the most minimum cost of ownership.

Personal/household transport of goods: Because the two-wheeler is the primary vehicle for many Indians, they use it for all the activities that take them beyond walking distance of their homes, be it commuting to school, going to social events, or shopping for groceries or other household items. Often, these activities require the riders to transport items, such as school books, supplies for dinner, or new purchases. If no storage locations exist within or on the two-wheeler, the cargo must be held either by the driver or the pillion passenger. If required to be held by the driver, this likely means that the driver will have less control over the vehicle. If items are held by pillion passengers, they are unable to hold on with both hands, decreasing their balance and stability. Many scooters and mopeds have storage built in under the seats; however, motorcycles require the storage to be added-on. Common methods of doing this are by adding pannier boxes, saddle bags, or tank bags.

Figure 1: Image of traffic congestion in Mumbai, India.

The discomfort of commuting to work: When commuting to work, Indians travel an average of 29 minutes each way, with 12% of commuters traveling over an hour [2]. With increases in the number of commuters, the amount of time that riders spend on their two-wheelers makes comfort increasingly important for both drivers and pillion riders. While not always the case, the entry-level two-wheelers often do not have the features of the more expensive commuter two-wheelers, including wider and more comfortable seating, a more relaxed posture position, back rest, and storage locations.

Environmental influences affecting safety

Road conditions: India has about nine million kilometers of roads, of which only 50% are paved, and only 20% are considered in "good" condition [16]. Urban roads contribute to about 14% of the total network as of 2008 [16]. Recent hazards of road travel have come from these improvements to the infrastructure (i.e., road construction) [17]. The construction adds additional road hazards by narrowing the available drivable space, increasing the number of pedestrians in or extremely close to the roadway, and allowing for construction vehicles to move in and out (often with minimal warning).

Forty percent of rural villages are not connected to an "all-weather road network" [17]. Additionally, most roads, including the national highways, are narrow and not well-maintained. Road warning markers are minimal, and visibility is often poor due to pollution. A report for travelers to India about the road conditions stated that "most roads are only adequate for animal-drawn and pedestrian traffic" [17].

Additionally, as stated previously, increases in disposable income and the low cost of purchase for many two-wheelers in India have made them increasingly more popular and prevalent on the roads. The result of this is a rise in congestion, especially in urban areas, thereby increasing the number of crashes [17]. In both rural and urban areas, roads are bustling (Figure 1) with pedestrians, animals, other motorized vehicles and non-motorized vehicles, such as bicycles and rickshaws [17]. As would be expected, this congestion is worse in cities, and the number of crashes, almost 65%, happen on city or municipal roads, while 15% occur on highways [10].

Although the road system in India is expanding, it is not growing sufficiently to meet the user demands. As the roads become more congested, road traffic injury rates have surged, becoming a public health concern as the number of deaths related to crashes increases. In 2011, there were a total of 497,686 crashes and 118,089 (24%) involved two-wheelers [9]. This was the highest of any category (i.e., cars/jeeps/taxis, buses, trucks). Of those crashes involving two-wheelers, 20% were fatal crashes, with over 27,000 deaths [9]. It was found that over half of all fatal crashes occurred at high speeds [10]. When the types of crashes were classified for two-wheelers, rear end collisions accounted for approximately 40%, side angle collisions for 15%, head-on collisions for 13%, while skids and falls accounted for 12% [10].

Weather conditions: Despite the increased risks for crashes, two-wheelers are the dominant mode of transportation in India. Indians use them for their day-to-day activities throughout the year, regardless of season or weather. Monsoon season lasts from June to September on the west coast of India and from mid-October through December on the east coast [18]. During the monsoon season, flooding is extremely common. Potential hazards brought on by the rain and flooding include: slick roadways (concrete, oil on surface) and surfaces (metal of bridges or hole coverings, rubber added to decrease noise, painted line

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Figure 2: Image of two-wheeler passengers riding in rain with an umbrella.

Figure 3: Image of a female wearing a traditional Indian saree while sitting side-saddle.

markings on the roadway), as well as large puddles and potholes filled with water [19].

Rainy weather can lead to two-wheeler crashes in a number of ways. For example, single riders can lose their balance, as there is a weight transfer to the rear wheel when the front brakes are depressed, which in turn causes the rear wheel to slip. Furthermore, passengers on the two-wheelers frequently use an umbrella to prevent the driver (or themselves) from getting wet (Figure 2). Not only is the use of an umbrella impractical but also it may distract or impair the driver's vision, thereby causing a crash.

Helmet legislation: The Motor Vehicles Act of India states that every person riding a two-wheeler must wear a helmet [20,21]. The use of helmets is thought to be the single most effective safety measure available to motorcycle riders [22]. However, in India each state is responsible for transportation within their boundaries [20,21], but in many Indian states, the law is not enforced [22]. In general, the challenge has been to convince two-wheeler riders to wear protective clothing and gear of any type [6,23]. The mortality rate for drivers without helmets is approximately six times higher than drivers with helmets [24]. A fact sheet for two-wheeler safety, produced online by NIMHANS [10], reflects that the institute has called for an increase in enforcement of helmet laws, stating that "more than half of the injured and killed motorcyclists had not worn helmets, indicating need for up scaling enforcement."

Design influences affecting safety

Anthropometry: Anthropometric data of a country is a vital database for automotive design and other design applications [25]. Anthropometrics can affect many aspects of a two-wheeler design, including steering handle placement, seat design and size, and foot pegs. The Indian population is anthropometrically different compared to the populations of many leading two-wheeler manufacturing countries (e.g., the United States).

In 1999, Shamasundara and Ogale [26] conducted an anthropometric study, following the Automotive Industry Action Group (AIAG) guidelines, to compare the Indian population with that of the North American population. They concluded that the average Indian was shorter than the average North American by 63 mm, mostly due to the leg height. However, the arm lengths were similar (although shoulder-elbow height and elbow to fingertip distance were both smaller for Indians). Additionally, the authors found that Indians had wider waists and foot breadths. The differences in waist and foot circumferences are surprising, and may be related to differences in measurement methodology or changes in secular trends, for example in recent decades, the weight (and thereby waist circumference) of North Americans has increased [27]. When the Civilian American and European Surface Anthropometry Resource (CAESAR) database [28] and SIZE INDIA database (an anthropometric database created for automobile manufacturers of the Indian population) [25] are compared, similar results are seen. This also agrees with the Shamasundara and Ogale [26] study, which states that North Americans are taller (stature) than Indians, although it found Indians weigh almost 14 kgs less for females, and 22 kgs less for males when compared to North Americans. Two-wheel manufacturers need to take these anthropometric differences into account and design vehicles that fit the intended user population.

Impacts of women's traditional clothing: Market dynamics and the customer demographics are changing as more and more women in India are using motorbikes and scooters. As the prevalence of two-wheelers increases, so does the number of females who will be driving or riding as pillions. Marketers and industry experts say the Indian retail landscape is being radically transformed as more women have jobs and see a surge in the average household income, thus increasing the market share of women riders by 40% [29].

Women who drive two-wheelers typically wear pants; however, women who ride as passengers wear a wider variety of clothing. While clothing styles for females are starting to shift in India, traditional dress consists of a saree or salwar suit (Figure 3). Sarees are typically long pieces of cloth that are worn as a dress. Salwar suits have two pieces; the pants are worn very loosely along with a long, loose shirt.

Both styles of dress have fabric that hangs loosely off the shoulder or arm, which makes for a snag hazard, easily getting pulled into the wheel or drive train of a two-wheeler. Additionally, neither of the garments allows for modest or comfortable straddling of the seat, so, it is common for women in traditional dress to ride side-saddle. Conventional two-wheeler pillion seats, often designed primarily for the US and/or European markets, are not designed to be sat upon in a sideways position.

Clothing snags: When women wearing traditional dress ride as a pillion on a two-wheeler, they must hold the loose ends of their clothing or sit on the loose ends. Both of these options still leave many opportunities for the clothing getting caught in the two-wheeler. Two-wheelers in India are required to have a guard for the rear wheel,

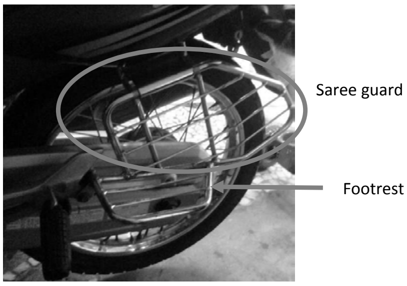

Figure 4: Example of a Saree guard, installed on two-wheeler with an integrated footrest.

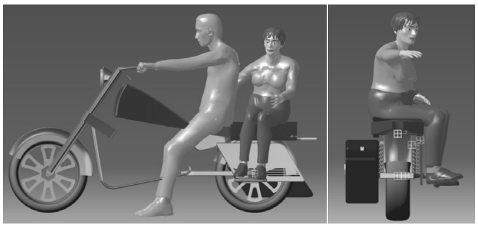

Figure 5: Image generated to show position of a female when riding side-saddle on two-wheeler.

Figure 6: Example of a side seat handle.

typically known as a "saree guard"; however, because this guard is unique to the Indian market, it is not part of the initial design of the vehicle. An image of a saree guard can be seen in Figure 4. It should be noted that while the guard offers some protection, loose clothing can still be pulled into the wheel and drive train. A study found that women were more likely to be burned when wearing a saree; saree material (often cotton) catches fire easily and spreads quickly, compared to tighter fitting clothing [30].

In addition, when a piece of long dress fabric gets caught in the saree guard, it can cause a variety of potential crashes by jamming the drive train. This will immediately stop the two-wheeler, possibly throwing both the driver and the pillion from the two-wheeler. Another possibility is that the female wearing the fabric could become attached to the drive train (due to the jam). Crash data from India do not include details such as this to determine the number of crashes clothing causes but anecdotes from news stories and medical case studies underlie the possible dangers.

Comfort: Comfort can also become a major safety concern. Pillion riders frequently do not have a backrest or have a backrest with minimal support (especially females sitting side-saddle); therefore, their back and shoulders become strained when riding for extended lengths of time. The pillion riders have limited vision of the road in front of them. (Discomfort becomes worse when the pillion rider is seated side-saddle and has to turn her head to the side to see forward). When pillion riders are not able to see the road in front, they are unable to anticipate turns and other driving maneuvers, and may potentially throw off the balance of the two-wheeler or the driver. Another problem for riders (especially side-saddle pillion passengers) whose anthropometrics are not accommodated and therefore do not have a proper fit on the two-wheeler, is that their muscles and joints (shoulders, hips, and knees) are put into positions that cause strain and discomfort. When passengers on the pillion seat become less comfortable, they are more likely to move to adjust their position, throwing off the balance of the two-wheeler. All of these concerns have the potential to be addressed and relieved via design changes to the two-wheelers themselves. Designers need to be aware of the problems and design the vehicle for the appropriate user population (i.e., Indian two-wheeler users).

Side-saddle posture: When women sit side-saddle as the pillion rider, it introduces a number of concerns. The primary safety concern is balance. In order for a woman to get onto the two-wheeler in the side-saddle position, the driver has to be seated with the two-wheeler balanced between his/her legs. Then the pillion rider has to put one hand over the driver's shoulder, while the other hand holds onto the seat. Next, the rider places one foot on the footrest, and pushes her body up. When high enough, the passenger places her buttocks on the seat. When in this position, both legs hang over one side. Figure 5 shows an approximation of a woman's seating position when riding side-saddle on the pillion seat of a two-wheeler. The pillion rider has been scaled to represent the mean size of an Indian woman (stature and waist circumference), using the RAMSIS (Human Solutions GmbH, Kaiserslautern, Germany). Note that in Figure 5, the two-wheeler is designed using prototype components, so the seat is flat; a saree guard covers the drive train; and a footrest that supports both feet is included.

Sitting side-saddle does not allow the pillion rider to balance body weight evenly across both sides of the two-wheeler, thereby requiring the driver to have to work harder to control and balance the two-wheeler, especially during turns. Additionally, the standard seat's curvature and shape are not matched to the passenger's body, especially in the side-saddle position. Most two-wheeler pillion seats, designed for the cross-saddle seated passenger, are narrow towards the back end, while sloping toward the front end. The seat slopes forward to help the cross-saddle rider's balance and to keep the center of gravity close to ground. However, these seats do not support the lower body (hips) of women pillion riders when they sit side-saddle. Additionally, when backrests are available, they are designed to support a passenger sitting cross-saddle; therefore, when passengers sit side-saddle, the backrest pushes awkwardly into the pillion passenger's side, as opposed to allowing them to lean against and support themselves and their weight.

The women also have minimal options for where to place their hands for support. When pillion riders do place their hands for support on the driver, they often hold on to the driver's shoulders or hips; however, in the side-saddle position, only one hand has easy access to this support. Some two-wheeler owners have added handles for additional support; typically to the side of the pillion seat (Figure 6). These handles are often not positioned in a natural ergonomic position, and they require a side-saddled rider to bend her shoulder and twist at the waist (especially taller women). This position may cause stress in the shoulder and lower back and is often uncomfortable.

All of these two-wheeler seat design features cause discomfort for women pillion riders who sit side-saddle, making them more likely to move around and adjust their position during extended rides. When a female rider moves around and repositions herself, it requires the driver to counteract that shift in balance, thereby increasing the potential for a crash. A further cause of discomfort that interferes with balance is the design of the toe/footrest, which in most cases is a foot peg designed to hold a single foot. When women ride side-saddle, they have no place to put their other foot or alternatively, place one foot on top of the other, both of which cause muscle fatigue and/or discomfort.

One advantage of this side-saddle seat position is that it easily allows pillion riders to jump off in case of a crash, in some instances limiting their injury. Alternatively, if the two-wheeler crashes or falls in the opposite direction, the woman pillion rider has a high likelihood of hitting her head on the road, potentially causing severe or fatal injuries. Unfortunately, crash data does not include specifics that would allow interpretation of rates of side-saddle pillion riders in crashes, so the exact impact of side-saddle position in crashes is unknown.

Case Study: A Design Process to Address Safety Concerns of Women who Sit Side-Saddle

Investigation of problems

An all-male team of engineering students, mentored by female research psychologists, investigated possible seating improvements for motorcycles for the Indian market. Harley-Davidson® was selected, due to the recent introduction of their motorcycles in India. The team started the project by investigating the current problems that exist with the motorized vehicles in India (described above). Furthermore, members of the team (many of whom had grown up in India) documented their anecdotal experiences and observations regarding the role of two-wheelers in India, including how through their lifetimes two-wheelers had become more common and the design problems they had experienced or friends/relatives had experienced.

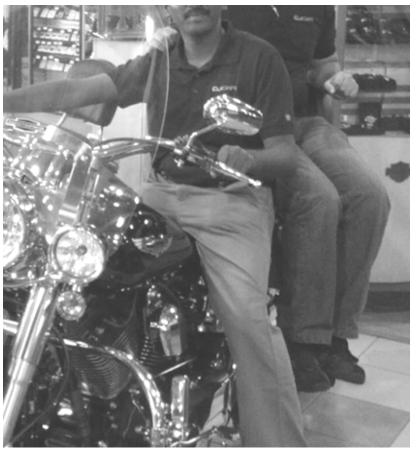

Figure 7: Team recreating driver and side-saddle seated pillion passenger to understand challenges and safety issues facing two-wheeler riders in static environment.

The team focused their efforts to improve the comfort of the side-saddle pillion rider. The problem of women who sit side-saddle was chosen also because it was one of the problems which may be improved via an engineering solution. However, it should be noted that while the side-saddle pillion position was the focus, many of the other issues noted in the previous section were also taken into consideration, for example, the anthropometry of the user population, legislation which require some type of saree guard, and comfort of seated body position. Once the target product had been determined, the team started their development process, including gaining firsthand experiences with the problem through personal experiences, user interviews, a house of quality analysis, physical prototyping, and modeling.

Direct experience: To better understand the safety design issues that affect side-saddle pillion riders, the team visited a motorcycle dealership that sold many of the same two-wheeler models also sold in India. While many team members had first-hand knowledge about driving a two-wheeler and/or riding on the pillion in India, none had experienced riding on the pillion seat in the side-saddle position. At the dealership, they sat on the different models of two-wheelers in the side-saddle position and experienced what many Indian women are already intimately familiar with. The team quickly realized that current two-wheeler pillion seat designs are not ideal for those who required side-saddle seating. For example, as the mean waist circumference of Indian females (826 mm) is greater than that of the American females (778 mm) [26], the narrow design of the seat made it difficult for many of the students to fit comfortably. Additionally, none of the team members felt safe when sitting in the side-saddle position, even when stationary, because they had no way to secure themselves. None of the two-wheelers available at the dealership offered handles or other types of handholds for pillion riders to hold on to. Based on the team's personal experiences, they knew that many Indian women would hold onto the driver's shoulder or torso (chest or waist). By sitting on the pillion seat in the side-saddle position, the team appreciated that the footrests do not accommodate both feet, and when team members tried to position two feet on the footrest, they were forced into an uncomfortable position because they had to put additional pressure on their heels to keep them affixed to the footrest. These issues can all be observed in Figure 7, where the pillion passenger is seen holding onto the driver's shoulder, while his other hand has nothing to hold on to. Additionally, the figure shows the pillion passenger's feet as the passenger tries to fit them onto the footrest and the awkward body position that the rider is put into. (Note that the rider is not seated at a 90 degree angle to the driver, which makes it harder for the rider to place both feet on the footrest). Most of the team members realized that the footrest is key in pillion riders' ability to position them onto the pillion seat in the saddle-seat position. When trying to raise themselves up onto the seat, team member's feet often slid off those footrests because of the material the footrests were made of did not have strong traction.

By putting themselves into this side-saddle position, the team also appreciated that the passenger seat was much higher than the driver seat, requiring pillion passengers to apply an increased level of force on the driver when transitioning themselves from standing on the ground onto the pillion seat. A further consequence of this pillion seat position was that it would raise the center of mass of the two-wheeler and passengers, increasing the challenges of balancing the two-wheeler when turning.

All members of the team took turns getting into the side-saddle pillion seated position. When the team discussed their individual experiences, they found that the slender members had an easier time getting on the two-wheeler, although it was not clear if this was only due to their size or also their physical strength. All the members of the team were relatively young men (in their 20's), indicating that many of the women in India who would be sitting in this position would have similar problems, if not more difficulty.

In addition to investigating the experience with the standard equipment on the two-wheeler, the team also investigated the differing effects of using several custom seats and footrests. The custom seats investigated tended to have additional lower back support and were wider and longer, while the custom footrest did accommodate pillion riders placing two feet on the footrest, but only the heels could be placed on the footrest, and not the full foot.

This first-hand opportunity allowed the team to feel the physical discomfort that many side-saddle pillion riders experience. This experience helped the group brainstorm potential design modifications. The team appreciated their experience was a best case scenario since they were indoors, wearing pants instead of sarees, wearing sneakers or similar shoes with a snug fit and soles designed to decrease slippage, and were not riding through the busy streets of India. In order to further understanding of these challenges, the team needed to continue to investigate the design problem.

Determining the test platform and assessment of design components: In order to design a safety product, the team determined that they would need a two-wheeler to use as a platform for their design. The team used a Harley Davidson Iron 883 for the project, along with a saree guard designed specifically for the bike, as well as multiple footrests, pillion seats, and backrests that were available for the Iron 883. By having both the Iron 883 and these additional components at the team's disposal, the team was able to conduct further investigation, including the current mountings and how the components were attached to the Iron 883.

The team completed a market survey of saree guards, footrests, pillion seats, and backrests. For each aftermarket product, team members completed an informal heuristic review and assessed the impact (both positive and negative) for the side-saddle pillion riders. For example, the team quickly realized that even when handles are added, their size and placement often make them difficult and uncomfortable to hold on to. The Harley-Davidson® saree guard did not have an integrated footrest and was minimalistic, as are many of the other saree guards. The current Harley Davidson saree guard did not cover or conceal the open shock springs, allowing for the potential for the pillion riders' calves to be pinched.

Age	Male			Female		
	Driver	Passenger	Driver & Passenger	Driver	Passenger	Driver & Passenger
≤ 30	5	-	3	-	6	2
≥ 40	8	-	1	-	9	-

Experience varied mostly by age, although females tended to have slightly less experience with two-wheelers than males [≤ 30 females: M=6.25 (SD=3.85), males: M=7.33 (SD=4.47); ≥ 40 females: M=12.89 (SD=9.93), males: M=14.22 (SD=9.56)].

Table 1: Summary of participants (n=35).

1	Females: ≤ 30 Yrs old	Females: ≥ 40 Yrs old
Jeans/Trousers	1	1
Saree	2	6
Salwar Suit	-	2
Skirt	-	-
Jeans/Trousers &Saree	2	-
Salwar Suit & Skirt	2	-
Salwar Suit, Skirt &Saree	1	-

Table 2: Clothing styles worn by female respondents based on age.

Seating clinic (pressure maps and motorcycle seats): In order to understand the impact of various sitting positions for the side-saddle riders, a seating clinic was conducted with eight individuals, in addition to the members of the design team. The seating clinic illustrated the impact when pressure is applied at different areas of the seat. Participants sat on a Vista Medical Pressure Mapping System (Winnipeg, Canada) pressure sensor mat that was placed onto a variety of seats. The team was able to see how each individual's buttocks, thighs and weight varied between the combinations of individuals and seats. This activity helped the all-male team understand the differences in the shape and pressure of the load between genders, different body styles, and different seating preferences. This activity consistently demonstrated how the females' hips showed a larger uniform distribution of pressure on a greater amount of surface.

After sitting still on the seat, the individuals repeated the task when rocking back and forth in the seat to demonstrate getting on/off the two-wheeler as well as the movement that occurs while riding. The pressure map showed how the individual's movement quickly transitioned between lower levels of pressure to extreme "hot spots", indicating high levels of pressure on the seat. By observing a variety of individuals in the same seated configurations, the team was able to note the vast differences in pressure areas based on the individuals' seated position/posture and their body shape/size. This information assisted the team in understanding the thickness of the cushion needed for a potential seat and the ribbing structure for the design of the seat.

User interviews

The team conducted a series of structured interviews with two-wheeler users in India. The interviews were all individual interviews conducted either in-person, over the telephone, or via internet audio/video communications lasting 30-60 minutes. The interview consisted of a combination of short answer, Likert, and demographic items regarding their experience, preferences, and dislikes.

Interview responses and results

Participants: A total of 35 male and female Indian participants were interviewed. They all had experience as either a two-wheeler driver with a passenger, or as a passenger sitting side-saddle or cross-saddle. A convenience sample was used consisting approximately of half males and half females, and all participants provided consent prior to the interview. While all participants were over the age of 18, two age groups were used: 30 years of age or under (≤ 30) and 40 years of age or older (≥40) (Table 1). These age groups were selected to ensure a range of female clothing styles, as younger women are more likely to wear western-style clothing (i.e., trousers) while women over the age of 40 are more likely to wear more traditional Indian clothing (i.e., salwar suits and sarees).

Gender, clothing, and saddle posture: Of the females 30 years old and under, one participant "always" rides side-saddle as a passenger, and the other seven female participants ride side-saddle "sometimes". Alternatively, of the female participants age 40 and over, seven "always" ride side-saddle and two "sometimes" ride side-saddle. Table 2 shows the clothing styles that female participants reported; in some cases respondents wore multiple styles of clothing.

Citation: Shroff N, Mitchell KB, Vallabhaneni T, Deshpande P, Kazan H, et al. (2014) Safety Concerns and Design Challenges of Side-Saddle Pillion Riders of Motorized Two-Wheelers in India: A Case Study Designing a Saree Guard and Footrest. J Ergonomics S3: 004. doi:10.4172/2165-7556.S3-004

Rate your concern related to balance when….	Rating* (frequency)					Mean (SD)
	1	2	3	4	5	
As a driver						
…passenger gets **on to** the two-wheeler	6	5	6	2	1	2.4 (1.18)
…passenger gets **off** the two-wheeler	10	4	3	-	1	1.8 (1.12)
…going **straight** with passenger	15	3	-	-	1	1.4 (0.96)
…turning **right** with passenger	2	6	6	5	-	2.9 (1.09)
… turning **left** with passenger	4	4	9	2	1	2.6 (1.10)
As a passenger						
…getting **on to** the two-wheeler	3	4	6	4	-	2.6 (1.06)
…getting **off** the two-wheeler	8	4	3	1	-	1.8 (0.97)
…going **straight**	10	2	2	2	1	1.9 (1.34)
…turning **right**	5	4	8	-	-	2.2 (0.88)
…turning **left**	5	5	4	2	1	2.4 (1.22)

* Level of concern: 1= lowest and 5= highest

Table 3: Frequency of ratings by interview participants' responses about balance.

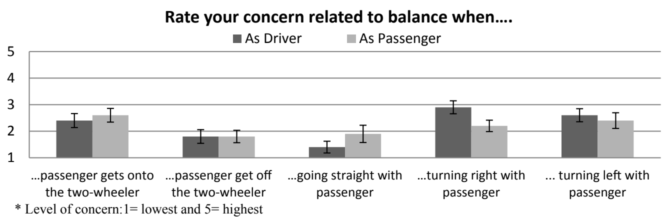

Figure 8: Comparison of passengers' and drivers' views of balance on a two-wheeler for a variety of activities, with standard error bars.

Overall, 78% of the females ≥40 years old typically wear a saree (which requires sitting side-saddle on a two-wheeler), whereas for the females ≤30 years old, only 44% wear a saree. Salwar suits are worn by 22% of females ≤30 and ≥40 and allow users to sit either cross-saddled or side-saddled. The other dressing styles included jeans worn by 33% of females ≤30, and skirts, which were worn by 33% of female's ≤30 years of age. However, jeans and skirts were not popular among the females' ≥40 years of age.

Use of two-wheelers: Eighty-nine percent of the male and female participants reported that their primary purpose for riding a two-wheeler is for commuting to work. The average duration of the commute is 57 minutes (SD=44.1 min), with an average reported speed of 43 km/h (SD=8.7) and a reported maximum speed of 66 km/h (SD=12.5). About 51% of the participants encountered high density traffic during their daily commutes. Two participants stated that they normally experience low density traffic during their commute, only because they use alternate roads to avoid the busy main roads. Due to the extended length of most of the participants' commutes, many noted that a comfortable seat is necessary in order to avoid fatigue.

Balance and comfort: When the participants were asked about balance when riding, eighty-five percent (85%) of the driver participants said that they drive more cautiously with a heavy passenger, and 90% of the drivers said that they drive more cautiously with a passenger 60 years of age or above. When the drivers were asked if the passenger ever pushes them forward, 70% of the drivers said that they have been pushed forward by the passenger, which occurred mostly frequently during sudden braking. (This was an expected response, as inertia and pillion seat inclination causes the pillion passenger's weight to shift forward quickly). Thirty percent (30%) of the drivers claimed that they are never pushed forward by the passenger. This may be due to a flat seat design where the driver and the passenger are seated at the same height. Ninety-five percent (95%) of the drivers prefer that passengers sit cross-saddle because of better weight balancing while turning and to improve the passenger's safety.

Eighty percent (80%) of the drivers said that their passenger holds on to their shoulder in case of bumpy driving conditions or sudden braking. Thirty percent (30%) of the drivers stated their passenger would hold on to their waists or hips (but it is important to note that participants mentioned that passengers hold on to them in different ways depending on the passenger and/or the conditions). Only one driver participant stated that his or her passengers hold on to an aftermarket handle. When passengers were interviewed, results were similar: 82% stated that they held onto the driver's shoulders or arms; 12% stated that they held onto the driver's stomach or waist; one (or 5%) preferred to hold on to the handle/seat; and one individual (or 5%) preferred to hold on to the luggage rack. When pillion riders were asked if there was a way to hold on that they disliked, three riders (14%) stated that they did not like to hold onto the handle. One female specified that she disliked holding on to the handle because it got hot during the summer, got cold during the winter, and was often slippery.

In general, balance is an important issue for the participants who were drivers of two-wheelers who must keep control over the vehicle as it stands still, moves along the roadways at a variety of speeds, and as it turns. Most interview participants' two-wheelers weigh at least 100 kg (many over 150 kgs). Driver participants were asked specifically about the effect of passengers on their balance as the passenger got on and off the two-wheeler, as the two-wheeler moved along straight roadways, and when turning right and left (Table 3).

Figure 8 shows participants' mean ratings (as a driver and as a passenger) for the balance questions. The mean ratings for getting onto the two-wheeler and turning (both right and left) are all high; however, of special interest is the difference in opinion regarding the effects of turning right, where the driver had a higher level of concern about balance than the passenger did (rating of 2.9 for driver versus 2.2 for the passenger).

Comfort also plays a large role in balance, especially during longer rides. As either the driver or the passenger become fatigued, they likely adjust their body position to become more comfortable, thereby throwing off the balance of the two-wheeler. In order to understand riders' comfort levels, interview participants were asked about neck, back, knee, and leg problems when they rode for a long duration in the side-saddle position. Mean commute times were almost one hour for participants. More than half of the passenger participants noted they experience problems with at least one of these areas of the body when they ride for extended periods. Furthermore, participants reported that discomfort increased with the length of the journey. Passengers were asked how long they are able to sit on a pillion seat at a single stretch; responses ranged from 15 minutes to 3 hrs, although it should be noted that most gave a time limit of 1 hour. When asked about discomfort, one participant noted that she twists her knees forward toward the driver to allow the seat to accommodate more of her hips in an attempt to relieve discomfort. Other comfort issues that were noted by participants were: strain on the lower back from twisting in the seat, strain on the neck from keeping the head turned, and a pressure point in the thigh thought to be from one foot hanging without a place to rest it. Additional comfort problems occur during the monsoon season when a passenger has to duck and hide behind the driver and tuck the chin down to avoid the rain, while at the same time lifting the legs to avoid the mud and water splashing from the potholes in the road.

Eighty-five percent of the drivers said that they normally have only one passenger riding along with them, and the remaining 15% of the drivers said that they occasionally have more than one passenger on their motorcycle. In these cases, the additional passengers were typically their children. As more passengers are added to the pillion seat of the two-wheeler, participants noted additional comfort problems with the neck, back, and legs, due to the decrease in individual space.

Seat design: Participants' most frequent complaint was related to the seat design. This was true for both the drivers and the passengers. The current seat designs tend to become narrower towards the rear end of the motorcycle, allowing even less support for the pillion rider. Additionally, this design sometimes causes the pillion rider to need to sit further forward on the seat, putting additional pressure on the driver. When asked how they would modify or improve the design of two-wheelers, interviewed drivers wanted to see seats that are wider, softer and flatter. Passengers had similar comments.

Passenger participants were asked to rate the level of issues with their seat (on a scale of 1-5, where 1 was *no issues,* and 5 was *critical concern*); 59% of participants selected 3 or greater on the rating scale. Fifty-nine percent (59%) stated that they thought the seats should be longer to better accommodate the driver and the passenger, and 82% felt the seat should be wider. Participants felt the seat length is not adequate to support both the driver and the side-saddled pillion comfortably. Ninety-four percent (94%) of passenger participants felt that the seat should either have less of a slope or should be completely flat (with most preferring a flat seat). For the material of the seat, driver and passenger participants noted that they want seats that are soft, but not slippery; one participant also commented that he or she wants something that would not get hot. It was noted by one participant that due to the slope of the seat and the slippery material covering the seat, pillion riders would often experience balance issues, requiring them to continuously re-adjust their position by applying force onto the shoulders of the driver.

Passenger participants were also asked about the need for of some type of backrest or other support. Seventy percent (70%) stated that they prefer back support for their lower back; however, the other 30% of passenger participants stated that the support is not needed. One participant noted that they would only want back support when traveling for extended distances, while another noted that they do not want back support because it would interfere in the ability to change positions. These comments would suggest that some type of removable back support would be ideal.

Footrest design: Participants were also asked about their experience using a footrest. Fifty-one percent (51%) of the female pillion riders typically wear flat bottom shoes without heels, while 41% wear heels. None of the participants reported wearing pointed heels while riding as a passenger on a two-wheeler. When asked to rate the level of issues with foot placement (on a scale of 1-5, where 1 was *no issues* and 5 was *critical concern*), 24% stated they have no issues, while 35% gave ratings of 3 or greater. Passenger participants' comments focused on the design of the footrest not being large enough to support both feet, the placement of the footrest being too far back on the two-wheeler to comfortably position the body, and the surface of the footrest being too slippery, which causes their feet to slide off.

Handle design: Passenger participants were asked about the comfort of the handles (on a scale of 1-5, where 1 was *extremely comfortable* and 5 were *not comfortable, critical issues*). Twenty percent (20%) of participants rated it as 1 (*extremely comfortable*), 36% as 2, 14% as 3, and 29% as 4. (No participant rated the hand hold as 5 and 1% did not respond.) These responses suggest that hand holds may be unique across different two-wheeler platforms and/or are a personal preference. Comfort issues that participants noted were related to the placement on the seat of the handle and the overall size, which they would prefer to be larger. According to the passenger participants, holding onto the driver's shoulder often causes strain in the arm muscle after extended periods; therefore, some type of handle is desired: ideally, one that they could lean on. An additional problem noted during extended rides, in the cases where a handhold was available, was that sweat would cause the handle (which was usually some form of metal) to become slippery.

Storage design: When the drivers were asked an engineering feature in their vehicle that they would like to change, 20% of them said that they would like to have some storage space in their two-wheeler, and they felt it should be provided as a stock option from the manufacturer. None of the participants in this survey had a two-wheeler with a factory-fitted storage space. Participants noted they most frequently carried backpacks, laptop bags, grocery bags, tools, etc., when traveling. Due to the unavailability of storage space, they either ask the passenger to carry a bag on his or her lap, or if they are driving alone, they keep the bags on the fuel tank and try to balance them while driving, which pose a road hazard. Some of the two-wheeler users indicated that they had installed an aftermarket tank bag or a pannier box to have some storage space. Seventy-five (75%) of the drivers who participated in this survey said that they do not have any kind of storage space in their two-wheeler.

Summary: By interviewing a variety of users, the team was able to get a better understanding and a broader perspective of the problems these users have with their two-wheelers. While safety and crashes were not specifically discussed during the interviews, the problems that were noted by the participants give clues to why some crashes may be occurring. Specifically, the team noted the discomfort that pillion riders have to experience often for an hour or more, multiple times per week. This discomfort can cause the passenger to attempt to shift position, potentially throwing the two-wheeler off balance, making it difficult for the driver to handle, and possibly causing a crash. The feedback from these users' experiences was used by the team to guide the designs of final components, such as the saree guard and footrest.

House of quality (HOQ) analysis

Based on the information gathered to this point, the team decided to focus their design efforts primarily on the saree guard with an integrated footrest. As the team members started to work on the actual design product, they needed to find a way to match and trade-off between the engineering requirements and the user needs. They did this by using a house of quality analysis (HOQ) [31]. The team determined both the engineering and user characteristics that they wanted to incorporate into their design. Figure 9 is an example of a HOQ for this project with a subsection of characteristics. The engineering characteristics comprised the "how" the design would work, and the user characteristics comprised the "what" that was needed by the users. For each of the engineering characteristics, objective target values were established to guide the design with specific measurements. For each of the user characteristics, the team determined a rating of the importance on a scale of 1-10, where 10 were the items that were the *most important*. Each intersection of the characteristics was also rated as either strong, medium, or weak based on their relationship with each other. If there was no relationship between the two characteristics, the cell was left blank. This same rating scale was also used to show the

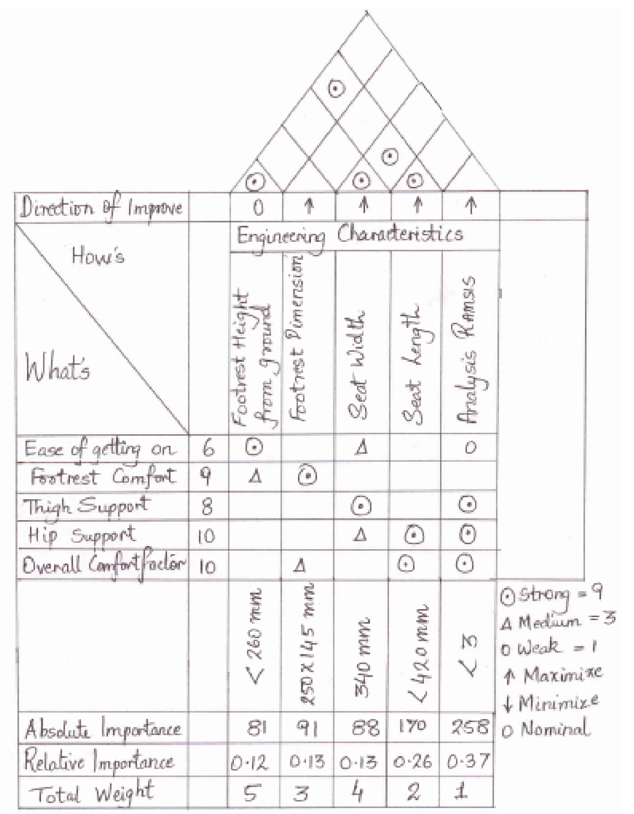

Figure 9: House of quality (HOQ) analysis for the footrest design component.

relationship between the different engineering characteristics with each other. From this, the direction of improvement was determined (maximized, minimized, or nominal).

After the relationships were determined, scores were calculated for each engineering characteristic (multiplying the strength score by the importance, and summing those totals for each engineering characteristic column). The relative importance was then calculated by dividing that engineering characteristic absolute importance score by the sum of the absolute importance for all the engineering characteristics. The relative importance scores were then rank ordered to indicate which engineering characteristics are the most important, based on the user's needs and desires. While most of these ratings are subjective, they all rely on the information that was gleaned from users during the interview process as well as the design team's first hand experiences when they sat on the two-wheelers themselves. After the design item (saree guard and footrest) is fully developed and used by the public, the customer ratings portion of the HOQ can be used to see how accurately the team's ratings aligned with their customers' perceptions of their product. This knowledge can then help with future designs.

By using the HOQ, the team was able to identify what is most important for the user (in this case the pillion passenger). The most critical design constraints were developed from the customer's perspective towards the seat comfort, namely hip support and thigh support. As can be seen in the example in Figure 9, the HOQ allowed the designers to see how the user would perceive these designs as safe and comfortable while stating specific characteristics (i.e., the seat width, seat length). The team was then able to correlate this information to the other engineering and user characteristics to complete the analysis. From the information on the HOQ, the team learned that in order to influence and assist with the overall comfort of the pillion passenger, the design and position of the footrest would need to be modified by positioning it higher, allowing users to comfortably step onto the footrest and position themselves on the seat in the side-saddle position.

Decision matrix: From the HOQ, the critical elements for design release included the seat and footrest length and width, along with the seat and footrest height from the ground. The next step was to create a decision matrix for the saree guard. It was decided to develop saree guard prototypes and evaluate them via real-time user experience. Thus, a decision matrix was created as shown in Figure 10. Each of the criteria listed would be evaluated through user interviews with the prototypes created by the design team.

Physical prototype mockups

After exploring the relationship between the users' needs and the engineering requirements in the HOQ, the team began brainstorming. The team met and discussed different alternatives for the saree guard design and the problems they knew existed currently – either from their own first-hand experiences or from the user interviews. The team discussed ways that they could modify a design to fix these problems, while still keeping intact the requirements for the guard – namely, that it protect the passenger (especially those sitting side-saddle and wearing sarees) from the drive train.

After having created the decision matrix, the next step was to create the prototypes, complete the decision matrix and weigh the designs against each other to create the optimum saree guard. The team needed to quickly and easily develop prototypes of their ideas, assess them and see how well they worked. They were interested in creating two types of prototypes – physical and virtual.

Physical prototypes: In order to make physical prototypes, the design team decided to limit their prototype materials to cardboard, aluminum foil, and cardboard tape. These materials be modified easily as both problems and ideas emerged. The foil was bent or curved in any shape with minimum time. Cardboard tape was used to reinforce edges, attach different components to each other, and create the illusion of details for things such as air vents. Each member of the team was charged with developing his own physical prototype of the saree guard. Measurements of the Iron 883 (wheel, drive train, light locations, etc.) were taken so that the physical prototypes would be appropriately sized (Figure 11).

Each of the physical prototypes was mounted onto the Iron 883 and assessed for compatibility with the two-wheeler. Team members were able to quickly determine what was working and what was not working. The easy nature of the aluminum foil allowed the designers to make changes on the fly and re-work whatever was needed. For example, when they realized that the sizing of their prototypes did not cover as much of the wheel as they desired, additional aluminum foil could be added to increase its size, and when it was found that the tail light interfered with their designs, space could be opened and cut out of the design to accommodate it.

From this exercise, team members were able to get a rough design, mounting point locations and dimensions for the saree guard. Additionally, they were able to get a better understanding of the different design ideas that were brainstormed and were able to physically feel and see each of these concepts. The team was able to do this development in less than two days and at a cost of under $100.

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Decision Matrix for Saree Guard

Criterion	Weight	CONCEPTS									
		Alternative A		Alternative B		Alternative C		Alternative D		Alternative E	
		Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Percentage Diameter of Wheel Covered	5	9	45	7	36	7	35	9	47	6	31
Heat Dissipation Effectiveness	3	8	23	8	25	8	25	8	23	9	28
Passenger Ergonomic Comfort Level	5	9	46	8	41	7	34	8	39	9	44
Aesthetics/ Style	5	8	40	8	38	8	40	7	35	7	36
Ease of Installation/ Servicing	5	9	45	7	33	8	39	6	30	8	41
Overall Weight of Assembly	5	7	35	8	39	5	27	8	38	9	43
Ease of Manufacturing	3	8	24	8	24	6	18	8	23	9	26
Overall Cost	5	7	36	7	37	6	29	6	29	7	37
Groung Clearance	5	7	34	10	48	8	40	7	35	8	41
Footrest Integration	1	8	8	8	8	6	6	6	6	7	7
Reuse of Exisiting Harley Products	1	7	7	7	7	5	5	5	5	7	7
Total	**43**	**86**	**342**	**86**	**337**	**74**	**298**	**77**	**310**	**86**	**340**
Scoring	1	Low									
	3	Medium									
	5	High									
Rating	1	Low									
	10	High									

Similar Concepts Scored Highest - Combined into 1

Figure 10: Decision matrix for saree guard.

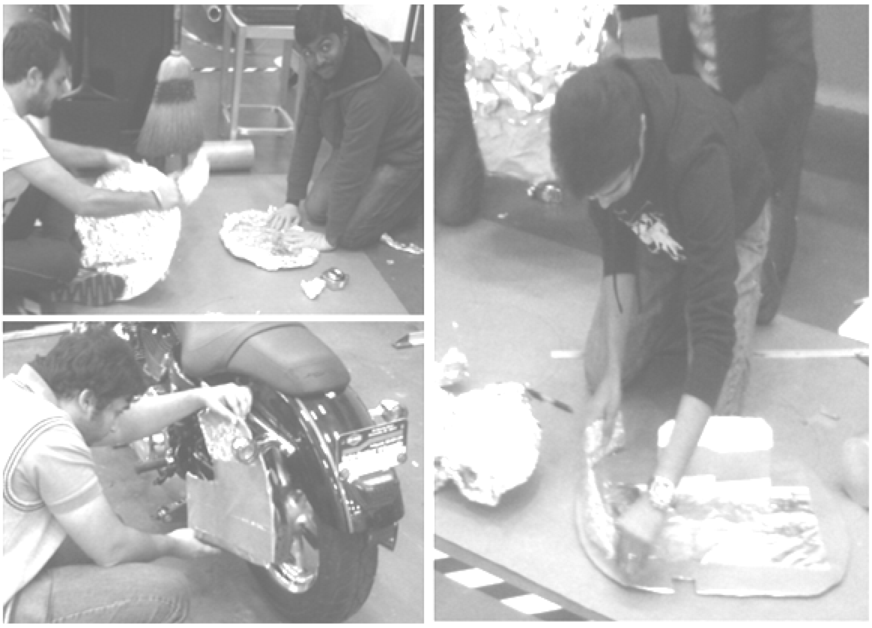

Figure 11: Team developing physical prototypes for assessment.

Figure 12 shows the design concept alternatives that were developed by each of the five team members.

Once the physical mock-ups of the devices were made, they could be assessed in two ways: 1) with potential users and 2) using the decision matrix. During the user testing, the team members as well as persons outside the team acted as test participants for each of the designs. Each test participant sat on the two-wheeler in both the driver and pillion passenger position. Each test participant was asked about his or her posture, comfort, and safety for each of the designs they assessed; this included how they felt about the direction their body faced, if their legs touched the saree guard or any part of the two-wheeler, how their feet were positioned, etc.

One participant commented that in order to feel safe when riding in the pillion passenger position, it was important for the saree guard to cover a large portion of the drive train, thereby not allowing the saree to be sucked into it. Some designs had openings to allow for the two-wheeler suspension and shock absorbers. A participant noted that these openings could be a potential for skin pinches and the ability of the saree to get entangled in the shock as the spring compressed and uncompressed. The test team learned from these comments that ventilation needed to be added to the design in the form of slits and a smaller overall form to decrease the likelihood of overheating, and the shock absorbers needed to be covered as well.

By looking at some of the designs on the Iron 883, the design team realized that they should not block the airflow to the drive train

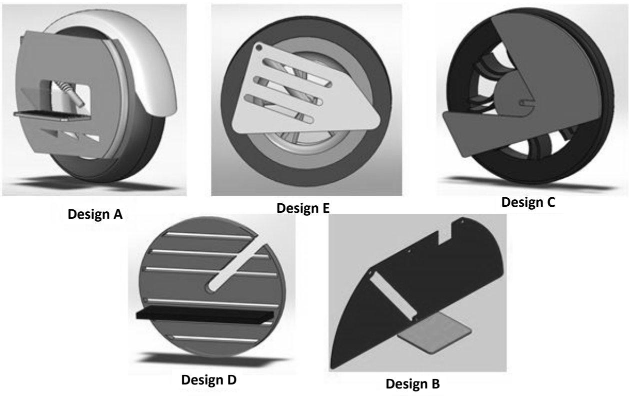

Figure 12: Design concept alternatives.

completely, and that users would need to be able to clean behind the saree guard (e.g., from the mud from the tires in the monsoon season). The design team took these needs into consideration for the next step of their designs.

After the feedback was collected from the participants, the team input the information into a decision matrix they had developed (Figure 10). A list of design criteria variables was re-evaluated; these ranged from engineering criteria to user acceptability requirements, e.g., heat dissipation and user comfort. Weights were given to each criteria variable, where higher weights equated to more importance. Each one of the designs was given two columns, one for rating and one for the score. The ratings were given on a score of 1-10, where 10 equated to the best design. Scores were determined based on the rating and the weight for each criteria variable. Each group member rated each of the designs independently, and then a mean score was calculated for the final score. Each column was totaled from those final scores, and those concept alternatives with the highest scores were determined to be the best concepts. In the case of this project, alternative A had the highest, with alternatives B and E scoring very closely (Figure 12). Instead of using just one of the designs, the team decided they could merge the best components from each of the three concepts and make an even better design. After analyzing these prototypes, the physical prototypes chosen were used to create a virtual prototype, and the engineering and industrial design features continued to be fleshed out.

Making physical prototypes allowed the team to see and try out firsthand what their design concepts were. They were able to get feedback (both from other team members and from test participants) almost immediately, and as potential modifications came up, they had the ability to change them within a few minutes and continue to collect feedback with regard to the changes. The team had specific goals for their designs that included increasing the safety and comfort of the side-saddle pillion passenger, so they were able to focus their designs and testing. Using the decision matrix, they were able to quantitatively score each of the prototype designs and see not only overall but also in what particular areas each design excelled and failed. Using this knowledge, the team was able to incorporate the ideas that worked best, creating a new hybrid prototype that performed better than any of the original prototypes.

Design concept development & modeling in computer-aided design (CAD)

Based on the information gathered from the HOQ and the decision matrix, a number of the design parameters were set, and the team started development of a model in CAD software program. Initial CAD work was completed using Solid Works, while the final design was done in CATiA (both from Dassault Systèmes, Waltham, MA). CATiA allowed for validation using RAMSIS. This process took the five team members approximately three weeks during the semester's course. The final modeling in CATiA and work with RAMSIS took approximately one week.

Initially, the main focus was to design the saree guard to suit customer needs and have aesthetic appeal, while incorporating all the features of the decision matrix. Further, it was understood that the saree guard and footrest designs are interdependent, as the footrest mount can be integrated with the saree guard. As seen in the design progress (Figure 13), the saree guard design evolved with several iterations until the final design. Some of the designs in the design tree show newly designed saddle bags with an integrated backrest for the pillion in the side-saddle position, while in other images the backrest is integrated with the saree guard. The latter was developed specifically for a cross-saddle position. The first design in the design progress tree was analyzed, and results showed that it was disproportionate in dimensions as compared to the rear end of the Iron 883. It would be very expensive to create a cost-effective solution to mount the flip-down footrest on a 3 mm thick saree guard. Thus, in the following design the flip down footrest was replaced with a fixed footrest, which was thought to be more stable. Another change was improving the aesthetics of the design by incorporating a backrest for the pillion which matched the style of the Iron 883 better. Additionally, the size and location of the air vents were modified and placed parallel to the disc brake.

The team continued to assess and modify their design. The team decided that the backrest in the second design would not assist but may impede a pillion passenger sitting side-saddle; therefore, in the next design the integrated backrest was eliminated. The saree guard design also continued to be tweaked, and the team modified it to give a streamlined look and flow. The backrest was also integrated with the saddle bag in order to attempt to provide additional back support for side-saddle seated pillion passengers.

Along with the saree guard and footrest, the seat also had to be modified as the seat height, cushion thickness and seat mounts would

Figure 13: Design progress (early designs on the left and later designs on the right).

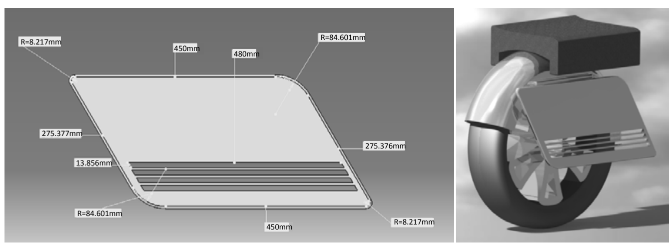

Figure 14: Final CAD designs.

be tailored for the pillion seat. As can be seen in Figure 14, the saree guard incorporates features from the three physical prototype designs that were chosen as the best designs by the decision matrix. The corners are rounded off for more dynamic appeal to the Iron 883 and also for safety. Three slits were added for the disc brake heat ventilation. Initially, it was thought the material would be aluminum, due to its light weight; however, aluminum (as well as many other metals) becomes very hot when in the sun for extended periods of time (such as in India when the motorcycle is parked outside all the day). The design team realized from their interviews and from sitting on the two-wheelers in the side-saddle position, that this would be uncomfortable and could potentially cause burns for passengers; thus, other materials were considered. The team decided to use a hard plastic, similar to the plastic used to make saddle bags, because it is still lightweight, yet would not get as hot as the aluminum, therefore increasing comfort for the passenger.

The team found multiple advantages to using and creating their products in a virtual environment. The primary advantages were that by modeling their saree guard in the virtual environment they would be able to save time, costs, and mistakes. The use of a virtual model allowed the team to visualize the product in a higher fidelity form than was allowed with the cardboard and aluminum foil, wood, or metal. Furthermore, the modeling enabled the team to learn about anything they had initially planned on that may have needed changing.

By modeling in CAD, the team was also able to analyze the costs that would be associated with different methods for manufacturing, thereby allowing them to choose the method with the best return on investment. As part of this process, the team was able to modify the product with a goal of reducing costs, while using specific manufacturing processes. Both the design and manufacturing modifications were made at minimal cost in terms of labor hours, materials, and overall program time.

By using a model, the product can be imported into other programs to assess the impact of other influences on the product. For example stress, strain, and dynamic analysis could have been performed on this saree guard model at relatively low cost. The model also allowed the team to perform a system integration check, ensuring that the saree guard interfaced with other parts of the Iron 883 (e.g., the mounting points for the saree guard and the drive train interface with the footrest).

Validation in RAMSIS

To check the product interface with customers/passengers virtually, a Human Solutions software, RAMSIS, was used in conjunction with CATIA. RAMSIS allows for the integration of a variety of human anthropometric models with automotive engineering. The comfort potion of RAMSIS was originally validated in a study where 21 test participants were placed in a mock-up vehicle, and rated their perceived comfort, and then the vehicle was replicated in CAD and RAMSIS showed similar comfort ratings [32]. Additionally, RAMSIS with CATIA was used to develop a rear seat module for a vehicle prototype program. The seating comfort and headroom analysis was done using RAMSIS for the new vehicle build. Although RAMSIS gave accurate results in the virtual environment, results were validated during production. Using RAMSIS allows one to position and test a 95th percentile in the rear seat of the vehicle [33]. The avatar can be manipulated in both its physical dimensions and its posture. The design team used the RAMSIS software to assess the posture and integration of a variety of sizes of an Indian woman sitting side-saddle on the Iron 883. Incorporated into the software is a tool that assesses the physical comfort of the avatar, based on the body position and the design of the software model (in this case the seat and the saree guard). The comfort ratings are calculated by the software, based on each body part's physical fatigue and level of discomfort. Using this software, the design team was able to adjust the posture and position of the avatar to determine minimum and maximum discomfort. This information was used to aid in the design specifications for the saree guard. For example, the team was able to determine the ideal height of a footrest (from the ground) for an individual of a certain height, and how that measurement changed as the user's height changed.

The RAMSIS model was also used to assess the interaction between the driver and the side-saddle seated pillion passenger (Figure 15). For example, as the shoulder position of the pillion passenger changes based on the height of the driver's torso, the comfort and positioning of the pillion passenger could be observed. The design team was able to see how this would cause additional fatigue, as the pillion passenger would have to reposition himself/herself while finding something to hold onto (e.g., luggage rack). Additionally, the software was used to assess the amount of force that the pillion passenger needed to put onto the driver when using him/her for support to get onto the two-wheeler in the side-saddle position. From the model the comfort was calculated, and the fatigue on the lower limbs was found to be acceptable. Therefore, it was determined that the footrest was an acceptable height from the ground.

By using the software, the team was able to quickly and easily manipulate the design of the saree guard and footrest to allow for optimum positioning and comfort for a wide variety of user body shapes and sizes.

Unfortunately, for the saree guard, the development process ended here with the end of the semester, but the next steps would have been to manufacture a high fidelity product (ideally using a 3D printer or some type of metal or wood). By performing all the previous design steps, the team likely would have had fewer modifications to make and would have been able to reduce costs by producing few versions. This prototype would need to have been able to be attached to the Iron 883. Following this, extended user trials would have been conducted, likely in two phases. In the first phase, test participants would ride for extended periods of time (hrs) around a track. Ideally, these test participants would be individuals experienced in riding side-saddle in India, but at a minimum, participants would have been dressed in a saree. In the second phase of testing, test participants would be given the Iron 883 with the saree guard to ride for their daily activities in India

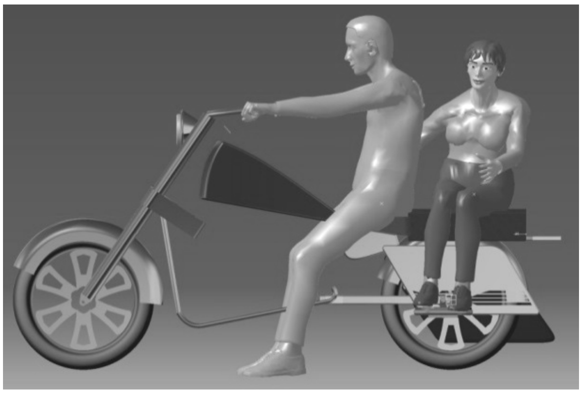

Figure 15: RAMSIS screenshot of 5th percentile Indian woman holding onto driver.

for one week or more. After each user trial, feedback would be collected from the test participants, and modifications could be made to the final product. Following the production of the developed saree guard for the Iron 883, the design could be modified for other and assessed in similar ways (i.e., user trials) to determine the effectiveness of the design. Small modifications, such as attachment points, may need to be modified.

Summary and Conclusions

As companies expand into new countries and cultures, it is important for them to have a good understanding of the local user population and their needs. In this case, the side-saddle seated pillion passenger is a niche market scope; however, it is an important one in the Indian culture. As the number of two-wheelers in the Indian economy increases, so does the size of this user group (although as western dress becomes more common, it may be less of an issue). Because of this population, India has a unique safety concern. Adding the product that the design team developed to the Indian two-wheeler, the drive train and rear wheel can be protected, decreasing the likelihood that sarees will become caught in them. Additionally, the team was able to increase the anticipated comfort of the side-saddle pillion rider and, potentially, the driver. A strong understanding of the user population and its unique characteristics was necessary to develop a product to meet their needs, in terms of safety, comfort and marketability. The team was able to address the design problem in a relatively short amount of time (3-4 months on a part-time basis in a graduate course) and in a relatively low cost manner (less than $500, not including labor and with access to already purchased software). They were able to gain an understanding of the problem space through literature reviews, personal experiences, and user interviews, taking what they learned in these activities and translating them into a number of different potential prototype designs. The team was constantly designing, assessing, and modifying their designs throughout all the different stages of the product development. These designs could be used by the designers and test participants, and modifications were able to be made quickly and easily with low cost prototypes. Once components of the design were settled on, the team was able to make virtual models, assess the design for compatibility with the platform they were designing for, and conduct engineering analyses and human modeling analyses. The methods outlined in section four (understanding the user opinions and needs, prototyping, and modeling), show a detailed example of how engineering students took a unique problem set and engineered a potential solution. By following similar methodologies, and by keeping the end user and their influences in mind, designers working on other design problems may also be able to identify safety issues in other types of products, and improve their designs to better meet the users' needs.

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