Chapter 4
Technology Assessment: Evaluating Personal Transportation Technologies

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Abstract A hierarchical decision model was applied to the problem of consumer choice among single-person transportation technologies. Criteria and sub-criteria were pulled from literature and similar studies to objectively compare the vehicles. Pairwise comparison was used to rank the weights of each criteria and sub-criteria across four different cultural states: the USA, South Africa, India, and Kenya. For the USA the highest ranked criteria were economic and practicality, for South Africa safety and economic, for India safety, and for Kenya practicality. The lowest weight for all countries was for public use regulations. All countries preferred the simple human-powered bicycle to any more advanced technology. This data could be used to inform product development or marketing decisions within each country.

4.1 Introduction/Problem Statement

As the world's population continues to increase, transportation continues to be a significant source of energy consumption [1]. The transportation of people has greatly contributed to the shape of the modern world; as rural populations have gradually moved to urban environments their logistical needs have evolved as well. For instance, in 2009 the average American wasted 25 entire hours simply waiting in traffic, along with a corresponding increase in fossil fuel consumption and pollution [2]. Recent technological advances such as the Segway [3, 4], as well as more commonplace, "low-tech" devices such as the simple bicycle, are at the forefront of this technological shift.

Our paper sets out to use a hierarchical decision model (HDM) model to analyze consumer preferences concerning single-person transportation options. By

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T.U. Daim (ed.), *Hierarchical Decision Modeling*, Innovation, Technology, and Knowledge Management, DOI 10.1007/978-3-319-18558-3_4

analyzing the preferences of a small panel of consumers between several independent criteria and factors we hope to develop a model which can be used not only to predict which vehicles are preferred but also to address which criteria are most important to the consumer and so influence future product development.

4.2 Literature Review

4.2.1 Introduction to HDM Model

We opted to use an HDM model, which is used to break down a complex decision problem into smaller, less complex, subproblems [5]. HDM models have been used by many authors to compare between multiple technological options [6–8].

A hierarchical decision model has a goal, criteria that are evaluated for their importance to the goal, and alternatives that are evaluated for how preferred they are with respect to each criterion [5]. The goal, the criteria, and the alternatives are all elements in the decision problem, or nodes in the model. Depending on the complexity of the problem more levels can be added in a tree between goal and alternatives. The lines connecting the goal to each criterion mean that the criteria must be compared pairwise for their importance with respect to the goal. Similarly, the lines connecting each criterion to the alternatives mean that the alternatives are compared pairwise as to which is more preferred for that criterion.

An abstract view of such a hierarchy is shown in Fig. 4.1.

To identify the best alternative which will most satisfy the goal, the first step is to identify the criteria, sub-criteria, and alternatives. The second step is to create the hierarchical model and identify the relative priorities using pairwise comparisons. The third step is to determine the best alternative and analyze the weight. The steps are described in more detail below.

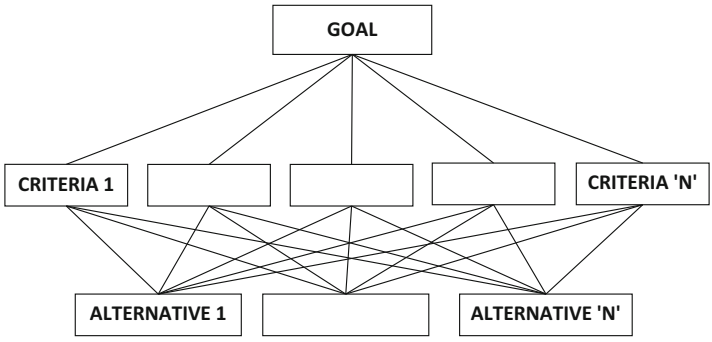

Fig. 4.1 HDM in abstract

4.2.1.1 Identify Criteria, Sub-criteria, and Alternatives

In this step different criteria, the technological factors (sub-criteria) under each criteria, and different alternatives are identified which specifically satisfies organization's objective. Technological factors can be either quantitative or qualitative. Brainstorming, interview, group discussion, and Delphi technique are some of the methods which can be used for identifying criteria and factors under each criterion.

4.2.1.2 Hierarchical Modeling

In this step a hierarchical model is developed by identifying the relative priority of each criteria and determining the relative importance of factors by calculating weights.

4.2.1.3 Weight Evaluation

In this step the best alternative is identified which contributes most to the organization's goal after evaluating the weight of all the technologies.

4.3 Hierarchical Decision Model

4.3.1 Criteria and Sub Criteria

To identify the criteria and sub-criteria, we searched many websites and discussed within our team in order to understand the important aspects that one should consider in comparing different types of single-person transportation vehicle. Since it was difficult to obtain quantitative objective values for some subcriteria, a 5-point scale was used. Other criteria needed to be inverted to reflect their appropriate value; for instance a high-cost score is a negative thing; these criteria are shown along with their proportional weighted curves. The criteria and sub-criteria used in our model are the following:

Safety [6]

1. Safety features: This is the safety equipment installed on the vehicle (e.g., braking system). The 5-point scale used for this sub-criterion is described in Appendix 2.
2. Stability: This is how steady the vehicle is when operating (i.e., turning corners, changing between different surfaces). The 5-point scale used for this sub-criterion is described in Appendix 2.

3. Weight restriction: This is the maximum weight of the person operating the vehicle that is specified by the manufacturer.
4. Recommended age: This is the lowest recommended age for a person operating the vehicle, as specified by the Department of Motor Vehicles or equivalent.
5. Maximum speed: This is the absolute maximum speed at which the vehicle can travel.

Practicality [6, 8]

1. Equipment weight: This is the weight of the vehicle (e.g., how heavy it is to pick up in the train, into your car).
2. Equipment size: This is the length of the longest dimension of the vehicle.
3. Charge time: This is how long an electric vehicle takes to fully charge before it can be used. The linear curve for charge time is shown in Fig. 4.2, which ranged from the best case (zero hours) for charging to the worst case (12 h). Twelve hours and above was seen as an unacceptable charging time since it is no longer practical for everyday use.
4. Maximum speed: This is the maximum speed at which an average user can travel using the vehicle. The sub-criterion is not just repeated; however, it is looking at how practical it is to use the vehicle and not the safety as under the safety criteria.
5. Range per charge: This is the maximum distance that the vehicle can travel on one charge. This assumes that the vehicle is being used economically and not at maximum performance.

Economics [6–9]

1. Purchase cost: This is the initial cost to purchase the vehicle. The linear curve shown in Fig. 4.3 was used, which ranged from the best case ($0) to the worst case ($7,000). To calibrate the scale, one dollar above the Segway price was

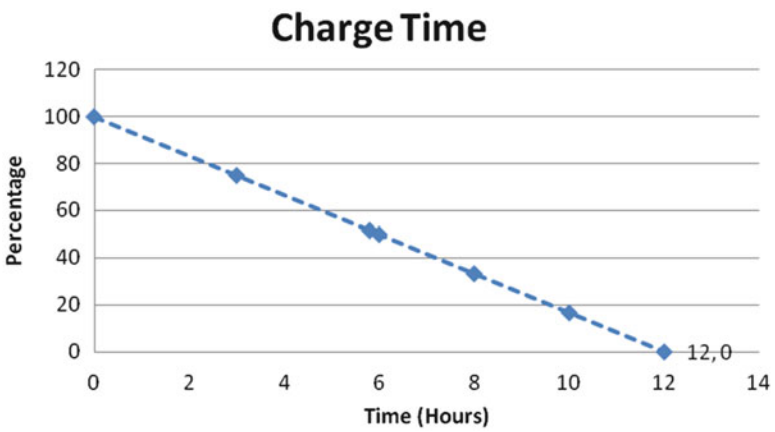

Fig. 4.2 Linear curve (charge time)

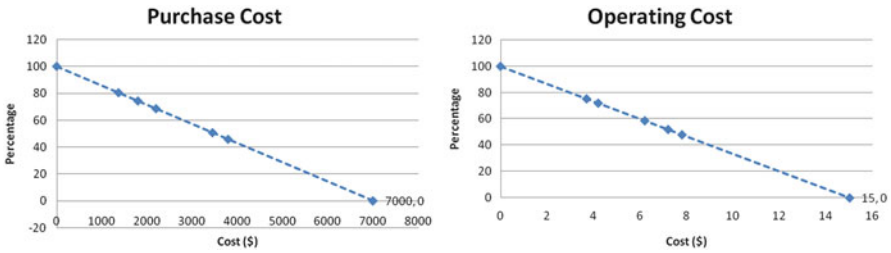

Fig. 4.3 Linear curves (purchase cost and operating cost)

chosen as the limit to the purchase cost, with any amount above this making the purchase impractical.

2. Operating (charging) cost: This is the cost to use the vehicle per month (i.e., charging cost for an electric vehicle). The linear curve shown in Fig. 4.3 was used, which ranged from the best case ($0) to the worst case ($15). The charging cost was calculated using the kWh usage per charge of the vehicle and a $0.2 per kWh rate, multiplied by 30 days of the month. This assumes that the vehicle will be charged once per day. The Segway for example uses 1.04 kWh per charge [8]; therefore taking 1.04 kWh per day multiplied by 30 days per month, multiplied by $0.2 per kWh, results in $6.24 per month. Although different countries have different kWh rates, this will not affect the outcome since all alternatives will be adjusted equally.
3. Maintenance cost: This is the cost to maintain the vehicle (e.g., replacing tires, batteries). The 5-point scale used for this sub-criterion is described in Appendix 2.

Service and Support [6, 8]

1. Warranty: This is the length of the warranty for the vehicle in years.
2. Ease of maintenance: This is how easy the vehicle is to maintain yourself. The 5-point scale used for this sub-criterion is described in Appendix 2.
3. Reliability: This is how reliable the vehicle is generally perceived to be. The 5-point scale used for this sub-criterion is described in Appendix 2.

Ease of Use

1. Physical exertion: This is how much effort goes into using the vehicle. The 5-point scale used for this sub-criterion is described in Appendix 2.
2. Comfort: This is how comfortable the vehicle is (e.g., standing vs. sitting, seat comfort). The 5-point scale for this sub-criterion is described in Appendix 2.
3. Storage: This is how practical the vehicle is to store away (e.g., in a cupboard). The 5-point scale for this sub-criterion is described in Appendix 2.
4. Handling: This is how easy the vehicle is to operate (e.g., turning, balancing). The 5-point scale for this sub-criterion is described in Appendix 2.
5. Appearance: This is the general perception on what the vehicle looks like. The 5-point scale for this sub-criterion is described in Appendix 2.

Public Use Regulations [10]

1. Sidewalk restrictions: This is whether the vehicle is allowed to be used on sidewalks or not. A binary "Yes or No" is used to quantify this sub-criterion.
2. Road restrictions: This is whether the vehicle is allowed to be used on the road or not. A binary "Yes or No" is used to quantify this sub-criterion.
3. License/permit requirements: This is whether you require a license or permit to use the vehicle on public roads and sidewalks. A binary "Yes or No" is used to quantify this sub-criterion.

4.3.2 Alternatives (Technologies)

Our team decided to choose technologies which are used as single-person transportation vehicles, with an average speed less than 30 miles per hour, which leads us to evaluate the following six technologies (the values for the sub-criteria of these technologies can be found in Appendix 3):

1. Human-powered (standard) bicycle: This is a standard bicycle with the highest physical exertion and lowest price among all the technologies selected. The bicycle is easy and inexpensive to maintain, has no public use restrictions, and has no charge time and cost. The bicycle used in the model was the Trek Soho Deluxe [9, 10].
2. Electric-assisted bicycle: This is a bicycle with an additional electric motor to assist the user when he/she pedals. The electric-assisted bicycle is considered as a standard bicycle with respect to public use regulations, except with an additional restriction for use on sidewalks. The bicycle has much less physical exertion than the standard bicycle with a relatively low charge time and cost; however the price is more than double. The bicycle used in the model was the Kalkhoff Sahel Pro [11–13].
3. Electric Trikke: This is a three-wheeled vehicle that is propelled by the user shifting his/her body weight, with assistance from an electric motor. The Trikke has a low charge time and cost, has relatively low purchase cost, and is foldable and easy to store away. The vehicle used in the model was the Trikke Tribred Pon-e 48V [14, 15].
4. Electric kick scooter: This is a two-wheeled vehicle with a small platform to stand on and propelled by an electric motor. It is approximately the same price as the electric-assisted bicycle (for similar performance to the other technologies), has a relatively low charge time and cost, and is also foldable and easy to store away. However the safety features and stability of the vehicle are considered to be poor. The vehicle used in the model was the Go-Ped ESR750 Li-ion 32 [16–18].
5. Segway: This is a two-wheeled self-balancing electric vehicle. The Segway has a very high cost and lower speed compared to the other technologies, but has

good safety features and is relatively easy to store away. The vehicle used in the model was the Segway i2 [19–21].

6. Electric scooter: This is a type of motorcycle with an electric motor for propulsion. The vehicle is heavy with a low speed, is not easy to maintain, and has high maintenance costs. The vehicle used in the model was the X-Treme XB-420M Electric Scooter [22–24].

4.3.3 Decision Model

The HDM model shown in Fig. 4.4 is structured with an objective, criteria, sub-criteria, and alternatives. The model attempts to include as many objective sub-criteria that could be obtained from the manufacturers' websites, manuals, and alternative sources. Some subjective sub-criteria however were included that were quantified by a 5-point scale, as described in Appendix 2. The alternative technologies were chosen all with a maximum average speed below 30 mph, over a varying price range, and with different benefits, however all performing the same purpose of single-person transportation.

4.3.4 Expert Responses

The experts for the model were the consumers, the people who would be making the decision of which vehicle to purchase for single-person transportation. The survey shown in Appendix 1 was sent out to possible consumers in four countries, namely India, Kenya, South Africa, and the USA. In total 16 complete responses were received, consisting of 5 from the USA, 4 from India, 4 from South Africa, and finally 3 from Kenya.

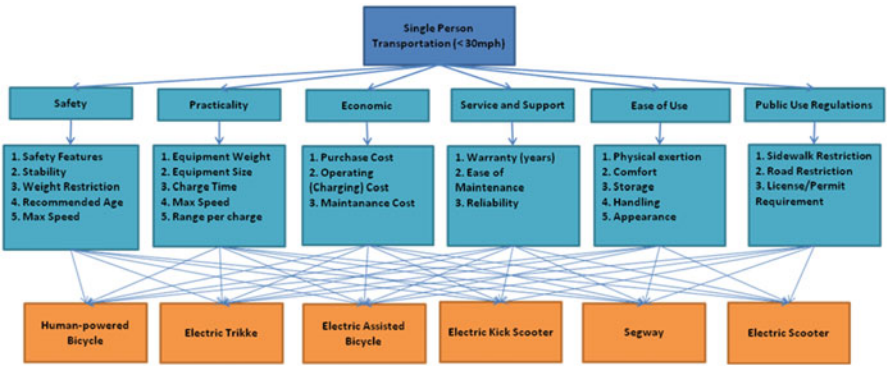

Fig. 4.4 Hierarchical decision model

4.3.5 Calculating Weights

The survey in Appendix 1 was used to obtain the pairwise comparisons from the consumers in the different countries. The comparisons were manually entered into the Pairwise Comparison Method (PCM) software [25] and the respective weights for the criteria and sub-criteria were obtained. The technology rankings were then obtained using these weights and the objective values per vehicle.

4.4 Results

The weights for the criteria and sub-criteria per country are shown in Appendix 4, with very few inconsistencies above 0.1. Using these weights the technology rankings per country were obtained.

4.4.1 Criteria and Sub-criteria Weights

Figure 4.5 illustrates the weights for the six criteria per country. It can be seen that the criteria with the highest weights for the USA was economic and practicality, for South Africa was safety and economic, for India was safety, and for Kenya was practicality. The lowest weight for all countries was for public use regulations.

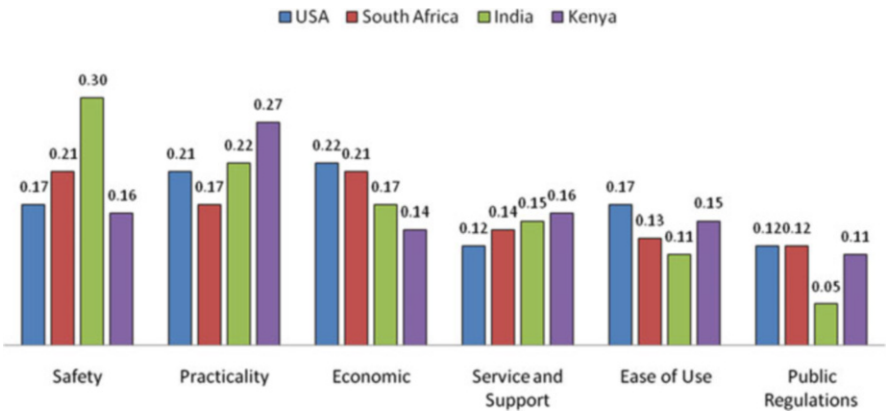

Fig. 4.5 Criteria weights per country

4.4.2 Sub-criteria Weights

4.4.2.1 Sub-criteria Weights Under Criteria

The weights for the sub-criteria per country under each criterion can be found in Appendix 4. These weights can be used to evaluate the importance of each sub-criterion to each criterion; however it was determined that it would be more beneficial to evaluate the sub-criteria to the overall objective.

4.4.2.2 Sub-criteria Weights to Objective

The weights for the sub-criteria to the objective (i.e., criteria weight multiplied by the sub-criteria weight) are shown under Appendix 5. The results are summarized in Table 4.1, which includes the highest and lowest weights for each country.

4.4.3 Technology Ranking

Figure 4.6 illustrates the outcome of the decision model, showing the rankings of each technology per country. The human-powered bicycle was ranked the highest for all four countries, while the electric scooter was ranked the lowest. The ranking of devices from all countries is in the same order.

Table 4.1 Sub-criteria weights to objective

Country	Highest weights	Lowest weights
USA	• Equipment weight • Purchase cost • Operating cost • Maintenance cost • Road restrictions	• Weight restriction • Sidewalk restriction
South Africa	• Purchase cost • Operating cost • Stability	• Weight restriction • Recommended age • Equipment weight • Equipment size • Storage • Appearance
India	• Safety features	• License/permit requirement
Kenya	• Range per charge	• Recommended age • Physical exertion • Storage • Appearance

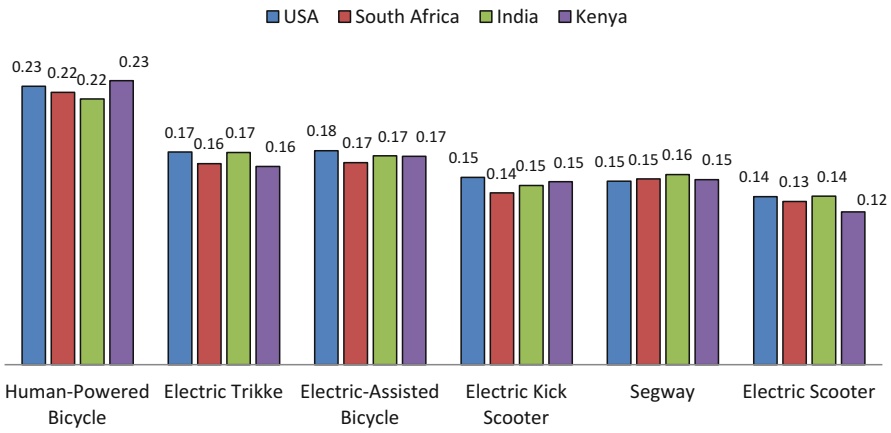

Fig. 4.6 Technology ranking per country

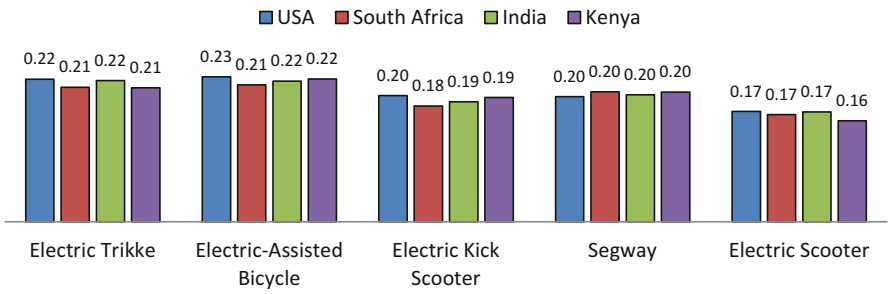

Fig. 4.7 Technology ranking per country (without human-powered bicycle)

Figure 4.7 illustrates the technology ranking with the human-powered bicycle removed. The ranking order remains the same among the electric vehicles. The electric Trikke and electric-assisted bicycle are ranked slightly higher than the remaining vehicles.

4.5 Discussion

As shown in Fig. 4.5, each country roughly agreed in terms of overall criteria, with a few exceptions. Indian respondents gave more emphasis to safety factors than the other countries, and less importance to regulations. Kenya ranked practicality the highest, while the USA and South Africa spread their weights across safety, practicality, economics, and ease of use.

We felt that this response made sense because of the perception of heavy traffic conditions in India which lead people to fear for their personal safety when using

transportation in public. It was also noted that there are no strict rules regarding vehicle licensing and no significant punishment for infractions which explains the low rank given to the regulation criteria.

For South Africa one of the highest weights was for purchase cost, which may be due to the fact that products in South Africa are generally more expensive, and the general income is lower. As an example, the Segway i2 is approximately 16 % more expensive than in the USA [26]. Additionally, the operating (charging) cost may have one of the highest weights because of the high increase in electricity costs over the previous years [27]. The lower weights (equipment weight, size, and storage) could be because bicycles are generally used for recreational or sporting activities in South Africa and lifting the vehicle is not a common requirement, neither is storing it away an issue.

For the Kenyan responses, practicality rose to the top largely due to the "range per charge" factor which makes sense given the local infrastructure and relative lack of urban development. One surprise was that the USA gave such a high ranking to economic concerns, being the richest country surveyed. There was also widespread agreement on the service and support criteria.

As shown in Table 4.1, each country also applied factor weights differently within each criteria group. It can be seen that for the USA the economic factors are the highest overall although there were other factors which achieved equal weight. It is also easy to see the rank of safety for Indian respondents, with "safety features" having the highest individual weight across all countries overall.

One surprising aspect of this table is the relatively low weight applied to "appearance." It is known that vehicle appearance can be quite important to consumers, but the team believes that the placement of this factor within the criterion of practicality may have led to its being overlooked by our survey respondents. Despite the different weights applied across all the criteria and factors, each country chose the simple human-powered bicycle as the best technology for transporting a single person. The actual scores are shown in Fig. 4.6. However, it appeared that, due to overwhelming weights applied such categories as "range per charge," "cost per charge," and "time to recharge," the bicycle was masking the differences between the other electric vehicles. Therefore we ran the weights again without the bicycle and achieved the answer shown in Fig. 4.6. The next preferred vehicle is the electric-assist bicycle followed closely by the Trikke and Segway. The least preferred vehicle was the electric scooter in all cases.

4.6 Future Work

As mentioned earlier, this chapter used a simple HDM model to compare across different transportation alternatives. However, when we began this project we attempted to apply a more advanced model using technology valuation (TV) factors to further refine the weights of each technological attribute. However, upon discussion with our advisor we opted to forgo this step since it would be too

time consuming to obtain appropriate desirability information from each respondent country. Future work could look into this TV methodology and attempt to refine the scores of our vehicle alternatives.

We hope that this methodology could also apply across different transportation sectors beyond single-person and low speed. For instance, knowing that safety is so important to Indian consumers could inform the marketing or even product development of transportation projects in that country. To further this research it would be good to offer the same survey to both consumers and product development personnel in each country to compare and contrast the weights applied by each group.

4.7 Conclusion

We have used a simple HDM model to compare consumer preferences for transportation alternatives across four very different countries and shown that while each country has preferred characteristics, they all prefer the common bicycle to any newer, more highly featured alternatives.

Appendix 1: Survey

Single-Person Transportation Survey

The purpose of this survey is to establish the importance of different criteria and factors that a person takes into account when deciding to purchase a vehicle for single-person transportation. These are devices such as bicycles, electric-assisted bicycles, and electric scooters. A full list of vehicles can be seen at the end of this survey. Throughout this survey "vehicle" refers to any one of these options.

Section 1: Comparisons

Introduction

The comparisons in this section are done by a method called pairwise comparison. This is when you have 100 points available and you assign them between two options. For example, the following is comparing safety against practicality:

Pairwise comparison			
Safety	70	30	Practicality

Since I see safety as more important than practicality I assign more points to safety than practicality. If I see them as equal I assign 50 to practicality and 50 to safety. If I see safety as substantially more important than practicality I assign 99 points to safety and 1 point to practicality. Do not assign 100 points to one option only. Also make sure that the values add up to 100 points for each comparison.

Comparison 1

The first comparison is between the following criteria when purchasing a vehicle for single-person transportation:

1. Safety—This is how safe the vehicle is to use (e.g., safety features, stability, weight restriction, maximum speed).
2. Practicality—This is how convenient the vehicle is to use (e.g., the weight and size of the vehicle, charging time, distance per charge).
3. Economic—This is the costs involved with purchasing, operating, and maintaining the vehicle.
4. Service and support—This is the length of the warranty and the reliability of the vehicle.
5. Ease of use—This is how much effort goes into using the vehicle (e.g., physical exertion, comfort, storage,).

6. Public use regulations—This is the restriction when using the vehicle (e.g., license requirements, sidewalk and road restrictions).

Please complete the comparison below:

Pairwise comparison			
Safety			Practicality
Safety			Economic
Safety			Service and support
Safety			Ease of use
Safety			Public use regulations
Practicality			Economic
Practicality			Service and support
Practicality			Ease of use
Practicality			Public use regulations
Economic			Service and support
Economic			Ease of use
Economic			Public use regulations
Service and support			Ease of use
Service and support			Public use regulations
Ease of use			Public use regulations

Comparison 2

The second comparison is between factors under safety, which are as follows:

1. Safety features—This is the safety equipment installed on the vehicle (e.g., braking system).
2. Stability—This is how steady the vehicle is when operating (i.e., turning corners, changing between different surfaces).
3. User weight restriction—This is the maximum weight of the person operating the vehicle.
4. User recommended age—This is the youngest recommended age for a person operating the vehicle.
5. Max speed—This is the maximum speed at which the vehicle can travel.

Please complete the comparison below:

Pairwise comparison (safety)			
Safety features			Stability
Safety features			User weight restriction
Safety features			User recommended age
Safety features			Max speed
Stability			User weight restriction

(continued)

Pairwise comparison (safety)			
Stability			User recommended age
Stability			Max speed
User weight restriction			User recommended age
User weight restriction			Max speed
User recommended age			Max speed

Comparison 3

The third comparison is between factors under practicality, which are as follows:

1. Equipment weight—This is the weight of the vehicle (e.g., how heavy it is to pick up in the train, into your car).
2. Equipment size—This is the longest length of the vehicle.
3. Charge time—This is how long an electric vehicle takes to fully charge before it can be used.
4. Max speed—This is the maximum speed at which the vehicle can travel.
5. Range per charge—This is the distance that the vehicle can travel on one charge.

Please complete the comparison below:

Pairwise comparison (practicality)			
Equipment weight			Equipment size
Equipment weight			Charge time
Equipment weight			Max speed
Equipment weight			Range per charge
Equipment size			Charge time
Equipment size			Max speed
Equipment size			Range per charge
Charge time			Max speed
Charge time			Range per charge
Max speed			Range per charge

Comparison 4

The fourth comparison is between factors under economic, which are as follows:

1. Purchase cost—This is the initial cost to purchase the vehicle.
2. Operating cost—This is the cost to use the vehicle (e.g., charging cost for electric vehicle).
3. Maintenance cost—This is the cost to maintain the vehicle (e.g., replacing tires, batteries).

Please complete the comparison below:

Pairwise comparison (economic)			
Purchase cost			Operating cost
Purchase cost			Maintenance cost
Operating cost			Maintenance cost

Comparison 5

The fifth comparison is between factors under service and support, which are as follows:

1. Warranty length—This is the length of the warranty for the vehicle.
2. Ease of maintenance—This is how easy the vehicle is to maintain yourself.
3. Reliability—This is how reliable the vehicle is perceived to be.

Please complete the comparison below:

Pairwise comparison (service and support)			
Warranty length			Ease of maintenance
Warranty length			Reliability
Ease of maintenance			Reliability

Comparison 6

The sixth comparison is between factors under ease of use, which are as follows:

1. Physical exertion—This is how much effort goes into using the vehicle.
2. Comfort—This is how comfortable the vehicle is (e.g., standing vs. sitting, seat comfort).
3. Storage—This is how practical the vehicle is to store away (e.g., in a cupboard).
4. Handling—This is how easy the vehicle is to operate (e.g., turning, balancing).
5. Appearance—This is your perception on what the vehicle looks like.

Please complete the comparison below:

Pairwise comparison (ease of use)			
Physical exertion			Comfort
Physical exertion			Storage
Physical exertion			Handling
Physical exertion			Appearance
Comfort			Storage
Comfort			Handling

(continued)

Pairwise comparison (ease of use)			
Comfort			Appearance
Storage			Handling
Storage			Appearance
Handling			Appearance

Comparison 7

The seventh comparison is between factors under public use regulations, which are as follows:

1. Sidewalk restrictions—This is whether the vehicle is allowed to be used on sidewalks or not.
2. Road restrictions—This is whether the vehicle is allowed to be used on the road or not.
3. License requirement—This is whether you require a license or permit to use the vehicle on public roads and sidewalks.

Please complete the comparison below:

Pairwise comparison (public use regulations)			
Sidewalk restrictions			Road restrictions
Sidewalk restrictions			License requirement
Road restrictions			License requirement

Thank you for your patience and time for completing this survey!!!!

Section 2: Single-Person Transportation Vehicles

Human-powered bicycle
- Price—$1,369
- Shimano mechanical disc front brakes

(continued)

	Electric Trikke • Price—$2,200 • Weight—46 lb • Range—24 miles per charge • Max speed—16 mph • Foldable • Dual disk brakes • Charge time—3 h
	Electric-assisted bicycle • Price—$3,449 • Weight—47 lb • Range—40 miles per charge • Warranty—2 years • Shimano hydraulic disk brakes
	Electric kick scooter • Price—$3,795 • Weight—46 lb • Range—28 miles per charge (econ) • Max speed—20 mph • Foldable • Mad Dog Disc braking system
	Segway i2 • Price—$6,999 • Weight—105 lb • Range—24 miles per charge • Max speed—12.5 mph

(continued)

	Electric scooter • Price—$1,799 • Weight—265 lb • Range—15 miles per charge • Max speed—15 mph • Warranty—6 months • Charge time—8 h • Front and rear drum brakes

Appendix 2: Description of 5-Point Scale for Sub-criteria

Table 4.2 Sub-criteria 5-point scale description

Factor	5-point scale	Description
Factor 11: Safety features	Excellent (E)	Safety features are above all other vehicles in the same category.
	Good (G)	Safety features are equivalent to the leading vehicles in the same category.
	Average (A)	Safety features are equivalent to competing products in the same category.
	Poor (P)	Very basic safety features installed that are not up to the standards of competing vehicles in the same category.
	Unacceptable (UA)	No safety features installed on the vehicle.
Factor 21: Stability	Excellent (E)	The vehicle can handle corners and changes in surface safely at the maximum speed.
	Good (G)	The vehicle can handle corners and changes in surface safely at the average speed of the vehicle.
	Average (A)	The vehicle handles corner sufficiently, and can handle changes in surface; however there is still a possibility of the vehicle losing control.
	Poor (P)	The vehicle turns corners with difficulty or unsafely. It is recommended to turn corners at very low speeds.
	Unacceptable (UA)	The vehicle cannot turn corners or handle changes in surface; it can basically not be used for any purpose.
Factor 33: Maintenance cost	Very Low (VL)	The cost to maintain the vehicle is less than 10 % of the purchase cost of the vehicle.
	Low (L)	The cost to maintain the vehicle is between 10 and 30 % of the purchase cost of the vehicle.
	Acceptable (A)	The cost to maintain the vehicle is between 30 and 60 % of the purchase cost of the vehicle.
	High (H)	The cost to maintain the vehicle is between 60 and 90 % of the purchase cost of the vehicle.
	Very High (VH)	The cost to maintain the vehicle is above 90 % of the purchase cost of the vehicle.
Factor 24: Ease of maintenance	Excellent (E)	It is possible to maintain all parts of the vehicle without assistance.
	Good (G)	It is possible to maintain small parts (tires, chains, etc.) and medium parts (batteries, wheels, etc.) without assistance.
	Average (A)	It is possible to maintain small parts (tires, chains, etc.) and medium parts (batteries, wheels, etc.) with assistance.
	Poor (P)	It is possible to maintain small parts (tires, chains, etc.) of the vehicle with assistance.
	Unacceptable (UA)	It is impossible to maintain the vehicle. The vehicle needs to be sent into the repair shop.

(continued)

Table 4.2 (continued)

Factor	5-point scale	Description
Factor 34: Reliability	Excellent (E)	The vehicle is reliable 100 % of the time.
	Good (G)	The vehicle operated acceptably with a very small possibility of failure.
	Average (A)	The vehicle operates acceptably with a small possibility of failure.
	Poor (P)	The vehicle is operational but there is a consistent possibility of failure.
	Unacceptable (UA)	The vehicle cannot be operated without a failure occurring.
Factor 15: Physical exertion	Very low (VL)	No effort is required when operating the vehicle.
	Low (L)	Slight amount of effort is required while operating the vehicle (e.g., standing).
	Acceptable (A)	Some effort is required while operating the vehicle (e.g., pushing, assisted cycling).
	High (H)	Equivalent effort to the average pace of walking is required while operating the vehicle.
	Very high (VH)	Equivalent effort to the average pace of running or cycling is required to operate the vehicle.
Factor 25: Comfort	Excellent (E)	The vehicle has no discomfort and can be used continuously without any issues.
	Good (G)	The vehicle is comfortable to operate for the duration of a long daily commute.
	Average (A)	The vehicle is comfortable to operate for the duration of an average daily commute.
	Poor (P)	The vehicle is uncomfortable to operate but can still be used for short durations.
	Unacceptable (UA)	The vehicle is extremely uncomfortable to operate. The vehicle should not be used.
Factor 35: Storage	Excellent (E)	The vehicle can be stored in a small-size closet, trunk of a car, etc.
	Good (G)	The vehicle can be stored in a standard-size storage closest.
	Average (A)	The vehicle can be stored in a small open area (e.g., balcony, storage room).
	Poor (P)	The vehicle can be stored in an open area such as a garage and small yard.
	Unacceptable (UA)	The vehicle cannot be stored anywhere except in a large open area.
Factor 45: Handling	Excellent (E)	The vehicle can handle all possible conditions
	Good (G)	The vehicle can handle different road surfaces and most weather conditions and is extremely easy to maintain balance on.
	Average (A)	The vehicle can handle slight changes in weather conditions and road conditions and is easy to maintain balance on.
	Poor (P)	The vehicle can only operate in standard weather conditions and flat paved roads.
	Unacceptable (UA)	The vehicle is very difficult to balance on, and does not handle any conditions and cannot be used.

(continued)

Table 4.2 (continued)

Factor	5-point scale	Description
Factor 55: Appearance	Excellent (E)	The vehicle would be appealing to all consumers in the market.
	Good (G)	The vehicle would be appealing to the current market of single-person transportation vehicles and will attract current motor vehicle users.
	Average (A)	The vehicle would be appealing to the current market of single-person transportation vehicles.
	Poor (P)	The vehicle would be acceptable to a very small amount of consumers in the market.
	Unacceptable (UA)	The vehicle is not appealing to any consumer and will not be purchased.

Appendix 3: Technologies

Table 4.3 Technology data

		Units	Limiting values		Human-powered bicycle	Electric Trikke	Electric-assisted bicycle	Electric kick scooter	Segway i2	Electric scooter
			Worst	Best						
Criteria 1: Safety										
Factor 11	Safety features	5-point scale	UA	E	G	A	G	A	E	G
Factor 21	Stability	5-point scale	UA	E	A	A	A	P	G	A
Factor 31	Weight restriction	lb	0	300	300	250	300	250	260	350
Factor 41	Recommended age	Years	0	21	8	16	16	16	16	16
Factor 51	Max speed	mph	30	0	40	12	20	20	12.5	15
Criteria 2: Practicality										
Factor 12	Equipment weight	lb	100	0	30	46	47	49	105	265
Factor 22	Equipment size	Inches	80	0	70	55	70	48	51	63
Factor 32	Charge time	Hours	12	0	0	3	6	5.8	10	8
Factor 42	Max speed	mph	0	30	25	12	25	20	12.5	15
Factor 52	Range per charge	Miles	0	100	100	24	40	28	24	15

(continued)

Table 4.3 (continued)

		Units	Limiting values		Human-powered bicycle	Electric Trikke	Electric-assisted bicycle	Electric kick scooter	Segway i2	Electric scooter
			Worst	Best						
Criteria 3: Economic										
Factor 13	Purchase cost	$	7,000	0	1,369	2,200	3,449	3,795	6,999	1,799
Factor 23	Operating (charging) cost	$/month	15	0	0	4.2	3.7	7.2	6.2	7.8
Factor 33	Maintenance cost	5-point scale	VL	VH	L	A	A	A	H	H
Criteria 4: Service and support										
Factor 14	Warranty	Years	0	10	2	1	2	2	1	0.5
Factor 24	Ease of maintenance	5-point scale	UA	E	G	A	A	A	P	P
Factor 34	Reliability	5-point scale	UA	E	E	G	G	A	G	A
Criteria 5: Ease of use										
	Physical exertion		VL	VH	VH	A	A	L	L	L

(continued)

Table 4.3 (continued)

		Units	Limiting values		Human-powered bicycle	Electric Trikke	Electric-assisted bicycle	Electric kick scooter	Segway i2	Electric scooter
			Worst	Best						
Factor 15		5-point scale								
Factor 25	Comfort	5-point scale	UA	E	A	P	A	P	P	G
Factor 35	Storage	5-point scale	UA	E	A	E	A	E	G	P
Factor 45	Handling	5-point scale	UA	E	G	A	G	P	G	G
Factor 55	Appearance	5-point scale	UA	E	A	P	A	P	A	A
Criteria 6: Public regulations										
Factor 16	Sidewalk restriction	Y/N	Y	N	N	Y	Y	Y	N	Y
Factor 26	Road restriction	Y/N	Y	N	N	N	N	N	N	N
Factor 36	License/permit requirement	Y/N	Y	N	N	N	N	N	N	Y

Appendix 4: Criteria and Sub-criteria Weights

1. India

Table 4.4 Criteria and sub-criteria weights (India)

	Person 1	Person 2	Person 3	Person 4	Mean
Criteria					
Safety	**0.19**	**0.43**	**0.31**	**0.26**	**0.30**
Practicability	0.16	0.24	0.26	0.22	0.22
Economic	0.23	0.11	0.15	0.19	0.17
Service and support	0.2	0.12	0.1	0.17	0.15
Ease of use	0.12	0.07	0.14	0.11	0.11
Public use regulations	0.1	0.03	0.04	0.04	0.05
Inconsistency	0.053	0.11	0.049	0.086	0.056
Safety sub criteria					
Safety features	**0.25**	**0.26**	**0.51**	**0.41**	**0.36**
Stability	0.37	0.29	0.18	0.21	0.26
Weight restriction	0.11	0.14	0.08	0.11	0.11
Recommended age	0.13	0.14	0.05	0.1	0.10
Max speed	0.15	0.17	0.18	0.17	0.17
Inconsistency	0.041	0.017	0.039	0.039	0.069
Practicability sub-criteria					
Equipment weight	0.17	0.19	0.15	0.18	0.17
Equipment size	0.25	0.18	0.17	0.14	0.19
Charge time	**0.2**	**0.29**	**0.23**	**0.23**	**0.24**
Max speed	0.23	0.13	0.21	0.18	0.19
Range per charge	0.15	0.21	0.23	0.27	0.22
Inconsistency	0.048	0.063	0.014	0.038	0.041
Economic sub-criteria					
Purchase cost	**0.43**	**0.33**	**0.25**	**0.33**	**0.34**
Operating cost	0.29	0.33	0.38	0.33	0.33
Maintenance cost	0.29	0.33	0.38	0.33	0.33
Inconsistency	0.000	0.000	0.000	0.000	0.052
Service and support sub-criteria					
Warranty length	0.65	0.17	0.09	0.16	0.27
Ease of maintenance	0.24	0.3	0.3	0.3	0.28
Reliability	**0.11**	**0.53**	**0.61**	**0.54**	**0.45**
Inconsistency	0.032	0.022	0.026	0.01	**0.198**
Ease of use sub-criteria					
Physical exertion	0.17	0.39	0.14	0.25	0.23
Comfort	**0.27**	**0.18**	**0.31**	**0.2**	**0.24**
Storage	0.2	0.08	0.21	0.21	0.17
Handling	0.18	0.21	0.21	0.2	0.20
Appearance	0.18	0.15	0.14	0.14	0.15

(continued)

Table 4.4 (continued)

	Person 1	Person 2	Person 3	Person 4	Mean
Inconsistency	0.003	0.015	0.072	0.024	0.065
Public use regulations sub-criteria					
Sidewalk restrictions	0.49	0.41	0.08	0.36	0.33
Road restrictions	**0.31**	**0.41**	**0.52**	**0.47**	**0.43**
License requirement	0.2	0.18	0.4	0.18	0.24
Inconsistency	0.059	0.000	0.021	0.005	**0.132**

2. Kenya

Table 4.5 Criteria and sub-criteria weights (Kenya)

	Person 1	Person 2	Person 3	Mean
Criteria				
Safety	0.16	0.16	0.16	0.16
Practicality	**0.24**	**0.25**	**0.33**	**0.27**
Economic	0.21	0.11	0.11	0.14
Service and support	0.12	0.18	0.17	0.16
Ease of use	0.14	0.19	0.12	0.15
Public use regulations	0.12	0.11	0.09	0.11
Inconsistency	0.081	0.076	0.05	0.038
Safety sub-criteria				
Safety features	**0.31**	**0.34**	**0.3**	**0.32**
Stability	0.26	0.21	0.26	0.25
Weight restriction	0.11	0.19	0.2	0.17
Recommended age	0.11	0.1	0.09	0.10
Max speed	0.21	0.16	0.14	0.17
Inconsistency	0.035	0.07	0.016	0.032
Practicality sub-criteria				
Equipment weight	0.15	0.13	0.14	0.14
Equipment size	0.2	0.2	0.2	0.20
Charge time	0.19	0.19	0.19	0.19
Max speed	0.19	0.21	0.2	0.19
Range per charge	**0.27**	**0.27**	**0.27**	**0.27**
Inconsistency	**0.102**	0.08	0.09	0.006
Economic sub-criteria				
Purchase cost	0.33	0.33	0.24	0.30
Operating cost	0.33	0.29	0.28	0.30
Maintenance cost	**0.33**	**0.38**	**0.48**	**0.40**
Inconsistency	0.000	0.021	0.006	0.056
Service and support sub-criteria				
Warranty length	0.18	0.33	0.38	0.30
Ease of maintenance	**0.41**	**0.33**	**0.37**	**0.37**

(continued)

Table 4.5 (continued)

	Person 1	Person 2	Person 3	Mean
Reliability	0.41	0.33	0.25	0.33
Inconsistency	0.000	0.000	0.05	0.081
Ease of use sub-criteria				
Physical exertion	0.16	0.15	0.15	0.16
Comfort	0.33	0.24	0.32	0.30
Storage	0.11	0.13	0.13	0.12
Handling	**0.3**	**0.33**	**0.3**	**0.31**
Appearance	0.11	0.15	0.1	0.12
Inconsistency	0.034	**0.108**	**0.182**	0.062
Public use regulations sub-criteria				
Sidewalk restrictions	0.32	0.29	0.26	0.29
Road restrictions	0.24	0.28	0.19	0.24
License requirement	**0.43**	**0.43**	**0.55**	**0.47**
Inconsistency	0.023	0.049	0.029	0.05

3. South Africa

Table 4.6 Criteria and sub-criteria weights (South Africa)

	Person 1	Person 2	Person 3	Person 4	Mean
Criteria					
Safety	**0.18**	**0.26**	**0.29**	**0.13**	**0.21**
Practicability	0.16	0.13	0.14	0.26	0.17
Economic	**0.24**	**0.19**	**0.19**	**0.23**	**0.21**
Service and support	0.23	0.08	0.19	0.07	0.14
Ease of use	0.11	0.13	0.1	0.2	0.13
Public use regulations	0.07	0.21	0.09	0.12	0.12
Inconsistency	0.051	0.005	0.016	0.059	0.06
Safety sub-criteria					
Safety features	0.23	0.36	0.41	0.11	0.28
Stability	**0.3**	**0.38**	**0.33**	**0.23**	**0.31**
Weight restriction	0.12	0.09	0.04	0.16	0.10
Recommended age	0.1	0.05	0.12	0.17	0.11
Max speed	0.25	0.13	0.09	0.34	0.20
Inconsistency	0.053	0.005	0.073	0.065	0.09
Practicability sub-criteria					
Equipment weight	0.1	0.16	0.2	0.12	0.14
Equipment size	0.09	0.06	0.1	0.12	0.09
Charge time	0.33	0.17	0.23	0.2	0.23
Max speed	0.21	0.22	0.13	0.34	0.22
Range per charge	**0.27**	**0.4**	**0.34**	**0.22**	**0.31**

(continued)

Table 4.6 (continued)

	Person 1	Person 2	Person 3	Person 4	Mean
Inconsistency	0.068	0.013	0.028	0.017	0.064
Economic sub-criteria					
Purchase cost	**0.38**	**0.5**	**0.25**	**0.38**	**0.38**
Operating cost	0.33	0.33	0.38	0.33	0.34
Maintenance cost	0.29	0.17	0.38	0.29	0.28
Inconsistency	0.021	0.000	0.000	0.005	0.078
Service and support sub-criteria					
Warranty length	0.21	0.42	0.36	0.14	0.28
Ease of maintenance	0.37	0.21	0.18	0.41	0.29
Reliability	**0.42**	**0.37**	**0.47**	**0.45**	**0.43**
Inconsistency	0.006	0.006	0.005	0.029	**0.103**
Ease of use sub-criteria					
Physical exertion	0.26	0.35	0.15	0.08	0.21
Comfort	**0.24**	**0.19**	**0.23**	**0.35**	**0.25**
Storage	0.1	0.12	0.13	0.11	0.12
Handling	**0.15**	**0.29**	**0.27**	**0.3**	**0.25**
Appearance	0.24	0.04	0.23	0.16	0.17
Inconsistency	0.021	0.008	0.023	0.017	0.078
Public use regulations sub-criteria					
Sidewalk restrictions	0.26	0.38	0.33	0.25	0.3
Road restrictions	**0.54**	**0.38**	**0.33**	**0.43**	**0.42**
License requirement	0.2	0.25	0.33	0.33	0.28
Inconsistency	0.005	0	0	0.005	0.071

4. USA

Table 4.7 Criteria and sub-criteria weights (USA)

	Person 1	Person 2	Person 3	Person 4	Person 5	Mean
Criteria						
Safety	0.22	0.23	0.19	0.1	0.13	0.17
Practicality	0.18	0.14	0.23	0.35	0.14	0.21
Economic	**0.17**	**0.17**	**0.26**	**0.16**	**0.31**	**0.22**
Service and support	0.18	0.2	0.07	0.05	0.08	0.12
Ease of use	0.17	0.12	0.22	0.15	0.18	0.17
Public use regulations	0.08	0.14	0.04	0.18	0.15	0.12
Inconsistency	0.026	0.05	0.033	**0.156**	0.049	0.065
Safety sub-criteria						
Safety features	0.37	0.27	0.25	0.1	0.3	0.26
Stability	**0.37**	**0.25**	**0.25**	**0.31**	**0.21**	**0.28**
Weight restriction	0.05	0.16	0.06	0.26	0.06	0.12

(continued)

Table 4.7 (continued)

	Person 1	Person 2	Person 3	Person 4	Person 5	Mean
Recommended age	0.09	0.15	0.25	0.14	0.14	0.16
Max speed	0.13	0.16	0.18	0.19	0.28	0.19
Inconsistency	0.015	0.023	0.003	0.01	0.101	0.075
Practicality sub-criteria						
Equipment weight	**0.27**	**0.19**	**0.09**	**0.26**	**0.77**	**0.32**
Equipment size	0.25	0.13	0.06	0.19	0.08	0.14
Charge time	0.15	0.22	0.26	0.14	0.02	0.16
Max speed	0.18	0.12	0.26	0.27	0.11	0.19
Range per charge	0.15	0.34	0.34	0.14	0.03	0.20
Inconsistency	0.006	0.016	0.019	0.056	0.068	**0.147**
Economic sub-criteria						
Purchase cost	0.29	0.38	0.27	0.23	0.46	0.33
Operating cost	**0.43**	**0.29**	**0.57**	**0.23**	**0.17**	**0.34**
Maintenance cost	**0.29**	**0.33**	**0.16**	**0.54**	**0.36**	**0.34**
Inconsistency	0	0.005	0.004	0	0.038	**0.133**
Service and support sub-criteria						
Warranty length	0.38	0.38	0.09	0.11	0.14	0.22
Ease of maintenance	0.25	0.29	0.55	0.5	0.28	0.38
Reliability	**0.38**	**0.33**	**0.36**	**0.39**	**0.58**	**0.41**
Inconsistency	0	0.005	**0.186**	0.005	0.035	**0.131**
Ease of use sub-criteria						
Physical exertion	0.11	0.14	0.09	0.17	0.28	0.16
Comfort	0.27	0.34	0.15	0.25	0.15	0.23
Storage	0.16	0.17	0.17	0.22	0.06	0.16
Handling	**0.25**	**0.22**	**0.43**	**0.19**	**0.33**	**0.28**
Appearance	0.2	0.13	0.17	0.18	0.17	0.17
Inconsistency	0.024	0.035	0.014	0.054	0.03	0.071
Public use regulations sub-criteria						
Sidewalk restrictions	0.31	0.38	0.05	0.12	0.02	0.18
Road restrictions	**0.21**	**0.38**	**0.68**	**0.66**	**0.85**	**0.55**
License requirement	0.48	0.25	0.27	0.22	0.14	0.27
Inconsistency	0	0	0.051	0.019	**0.123**	**0.19**

Appendix 5: Sub-criteria Weights to Objective

		USA	South Africa	India	Kenya
Criteria 1: Safety					
Factor 11	Safety Features	0.04	0.06	0.11	0.05
Factor 21	Stability	0.05	0.07	0.08	0.04
Factor 31	Weight Restriction	0.02	0.02	0.03	0.03
Factor 41	Recommended Age	0.03	0.02	0.03	0.02
Factor 51	Max Speed	0.03	0.04	0.05	0.03
Criteria 2: Practicality					
Factor 12	Equipment Weight	0.07	0.02	0.04	0.04
Factor 22	Equipment Size	0.03	0.02	0.04	0.05
Factor 32	Charge Time	0.03	0.04	0.05	0.05
Factor 42	Max Speed	0.04	0.04	0.04	0.05
Factor 52	Range per charge	0.04	0.05	0.05	0.07
Criteria 3: Economic					
Factor 13	Purchase Cost	0.07	0.08	0.06	0.04
Factor 23	Operating (Charging) Cost	0.07	0.07	0.06	0.04
Factor 33	Maintenance Cost	0.07	0.06	0.06	0.06
Criteria 4: Service and Support					
Factor 14	Warranty	0.03	0.04	0.04	0.05
Factor 24	Ease of Maintenance	0.05	0.04	0.04	0.06
Factor 34	Reliability	0.05	0.06	0.07	0.05
Criteria 5: Ease of Use					
Factor 15	Physical exertion	0.03	0.03	0.03	0.02
Factor 25	Comfort	0.04	0.03	0.03	0.05
Factor 35	Storage	0.03	0.02	0.02	0.02
Factor 45	Handling	0.05	0.03	0.02	0.05
Factor 55	Appearance	0.03	0.02	0.02	0.02
Criteria 6: Public Regulations					
Factor 16	Sidewalk Restriction	0.02	0.04	0.02	0.03
Factor 26	Road Restriction	0.07	0.05	0.02	0.03
Factor 36	License/Permit Requirement	0.03	0.03	0.01	0.05

Fig. 4.8 Overall factor weights per country

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