

DETC2017-67584

TOWARDS A UNIVERSAL SOCIAL IMPACT METRIC FOR ENGINEERED PRODUCTS THAT ALLEVIATE POVERTY

Phillip D. Stevenson

Graduate Research Assistant
Department of Mechanical Engineering
Brigham Young University
Provo, Utah 84602
Email: phillip.stevenson@byu.edu

Christopher A. Mattson

Department of Mechanical Engineering
Brigham Young University
Provo, Utah 84602
Email: mattson@byu.edu

Kenneth M. Bryden

Department of Mechanical Engineering
Iowa State University
Ames, Iowa 50011
Email: kmbryden@iastate.edu

Nordica A. MacCarty

Dept. of Mechanical, Industrial and Manuf. Engineering
Oregon State University
Corvallis, Oregon 97331
Email : nordica.maccarty@oregonstate.edu

ABSTRACT

More than ever before, engineers are creating products for developing countries. One of the purposes of these products is to improve the consumer's quality of life. Currently, there is no established method of measuring the social impact of these types of products. As a result, engineers have used their own metrics to assess their product's impact, if at all. Some of the common metrics used include products sold and revenue, which measure the financial success of a product without recognizing the social successes or failures it might have. In this paper we introduce a potential metric, the Product Impact Metric (PIM), which quantifies the impact a product has on impoverished individuals – especially those living in developing countries. It measures social impact broadly in five dimensions: health, education, standard of living, employment quality, and security. The PIM is inspired by the Multidimensional Poverty Index (MPI) created by the United Nations Development Programme. The MPI measures how the depth of poverty within a nation changes year after year, and the PIM measures how an individual's quality of life changes after being affected by an engineered product. The Product Impact

Metric can be used to predict social impacts (using personas that represent real individuals) or measure social impacts (using specific data from products introduced into the market).

1 INTRODUCTION

In 2014, nations around the world collectively provided \$161 billion in development assistance and aid for developing countries [1]. This amount has increased progressively throughout history. Moreover, engineering work in developing countries is also increasing. It is believed that this work has changed the lives of people around the world, but measuring its impact has been difficult – yet needed to improve the engineer's ability to positively affect society [2].

Aside from the use of engineering safety factors, traditional product evaluation tools are not designed to measure the social impact of engineered products, and there is no established methodology or tool that does [3]. As a result, engineers often describe a product's impact in financial terms [4–6]. This method does allow the engineer to optimize and improve products, but the social impact of these products is still unknown. The pur-

pose of this paper is to introduce a metric to quantify the social impacts of engineered products.

The metric presented in this paper is called the Product Impact Metric (PIM). It quantifies an engineered product's impact on impoverished individuals. It organizes multiple dimensions of impact, and compiles them into one score that can be compared for a variety of products or design alternatives. The dimensions included are health, education, standard of living, employment quality, and security. The PIM is meant to measure the social impact on people who are deprived of these necessities. It is important to recognize that the social impact measured by the PIM is a function of both the product and the consumer [7]. Thus, a social impact of the same product can vary for people in different life situations. For example, a device that gives people clean water will have a greater impact on people who do not have clean water than for people who already do.

It is also important to recognize that not all products need to maximize social impact. The difference between products that do and do not benefit from a PIM analysis can be observed when comparing products launched by traditional versus social entrepreneurs. Traditional entrepreneurs use tools that maximize profits, where the impact of these products is often measured in financial terms such as, how many units are sold, the market share, or the revenue generated. While these products will have a social impact, it is not usually the primary basis for decision making, and therefore would not benefit significantly from a PIM analysis.

In contrast, the social entrepreneur seeks social change, where the impact of their products is often evaluated by how they affect their consumers and other people involved in their business [8]. Although having a sustainable revenue is still an important factor, the primary basis for decision making is driven by changing underdeveloped social conditions. The types of assessment tools for these products are often more subjective and less usable by people trained in engineering. Therefore engineers designing products of this nature would benefit significantly from the PIM. Additionally, the impacts of these products become evident only after they have been distributed and sufficient measurements from the consumers have been taken. As such it would benefit engineers to be able to use the PIM analysis as a way to predict product impact before it has been introduced to the market.

The need for a social impact measure is essential, yet not trivial because of its multidimensionality. Knowing what to measure is complicated because a product can influence more aspects of a consumer's life than what it affects directly and obviously. For example, when people gain access to clean drinking water, the prevalence of disease tends to decrease [9]. Likewise, when people gain access to better cooking and heating fuels, respiratory illness occurrence decreases [10, 11]. Additionally, the more education a woman receives, the better off her children will be [12, 13]. Contrarily, negative impacts (such as decreas-

ing crop yields) can result when products disregard religious and community rituals [14]. These indirect impacts can be missed if the correct indicators are not chosen or if data is collected improperly.

Another source of difficulty comes from cultural differences. When the engineer is from a different culture, understanding the consumer's point of view can be difficult. Culture influences people's perception of a product's value. For example, someone might buy a product simply because it is a "cool, American invention" [15]. This can skew impact results that are based on the number of users and revenue from a product. Metrics that track how the consumer is affected by a product are less likely to be influenced by culture as they are related to the product's capabilities more than consumer perception and marketing activities.

In addition to the factors already explained, engineers are typically untrained and unfamiliar with assessing the social impacts of a product or program [16]. Though emerging engineering topics, such as energy justice, are beginning to acknowledge the relationship that products have with important social issues, engineers still tend to focus on product capabilities to identify a product's success or failure [17]. A product's impact and success cannot be determined by its functional capabilities alone (many products with promising functionality have been abandoned by consumers) [16]. Similarly, success cannot be evaluated based on social impact alone. Other impact areas, such as financial and environmental, should also be considered when developing a product [18–20]. Managing the tradeoffs between these impact areas adds to the complexity of the engineer's job.

In order to enhance the abilities of engineers, new strategies for measuring product social impacts are needed. These metrics may be specific to a single product, or abstract in order to measure various types of products. The PIM is meant to be a universal metric so that it can be used for all products. By taking this approach, the accuracy of the PIM is knowingly decreased (it is less likely to show all of the impacts of every product), but the usability of the metric is increased because it may be used for all products without modifications. These metrics must be easy to use because the data may be unusable if product and consumer data is collected incorrectly [21].

In this paper, the PIM is introduced as a way for engineers to assess the impact of the products they develop. We believe that the PIM has the potential to – as a first step – assist engineers in developing products that are meant to create a social impact.

2 Multidimensional Poverty Index

The PIM is inspired by the Multidimensional Poverty Index (MPI). The MPI was created by the United Nations Development Programme (UNDP) and was first part of the Human Development Report in 2010 [22]. The MPI measures a population's level of poverty. This is done by analyzing survey data in three dimensions: health, education, and standard of living.

The UNDP chose these dimensions because they are widely accepted as measures of poverty, but also because these are the only dimensions that had sufficient data for the underdeveloped countries that the MPI measures. Data for the MPI comes from household surveys conducted around the world by several national and global organizations (the UNDP does not conduct their own surveys) [23, 24]. The Product Impact Metric does not have this same data restriction because it uses new data that will be collected for each product. For this reason, any dimensions could have been included in the PIM.

While the MPI may use sufficient data for its purposes, the PIM benefits from using additional dimensions. The first three dimensions of the PIM are the same as the MPI: health, education, and standard of living. The last two dimensions of the PIM, employment quality and security, are among those that the Oxford Poverty & Human Development Initiative believe are missing from poverty data [24–26]. Other similarly missing dimensions of poverty data are agency and empowerment, psychological and subjective wellbeing, and ability to go about without shame [27–29]. Employment quality and security were selected because they can be measured with quantitative data, while the others rely heavily on subjective qualitative data. It is plausible that a product can directly impact health, education, and standard of living simultaneously, but it is less likely that a product will directly influence all five of the chosen dimensions. The addition of these dimensions enables the PIM to account for indirect impacts that the engineer might not notice otherwise.

In order to allow the PIM to more accurately track impacts, some calculation methods are changed from the MPI. The indicators in the MPI are binary, in that they are either satisfied or not. The indicators in the PIM are normalized between zero and one, zero meaning completely deprived and one being above the poverty line. In this way, when a product causes indicator values to change the PIM score reacts accordingly.

The MPI was an essential building block for creating the PIM. We started with it because it is globally recognized, debated, and refined. We have confidence that this makes the PIM a metric that can be used by people familiar and unfamiliar with social impact because interpreting MPI scores does not require training or significant explanation. By learning from the MPI and other insight gained from literature and our experience, we believe the PIM captures a necessary multidisciplinary perspective.

3 Proposed Metric

The equations that make up the PIM follow here accompanied with clarification of the calculation methods. The calculations are organized by measurement dimension as well as the consumer's characteristics.

3.1 Mathematical Relationships

The equation for the Product Impact Metric,

$$PIM = M_i - M_{i-1} \quad (1)$$

includes the multidimensional poverty level before (M_{i-1}) and after (M_i) the introduction of the product. In this way, the PIM measures how the product affects the consumer by determining the difference in a consumer's level of poverty. Two additional aspects of the PIM score are time with the product and the poverty increase of consumers independent of the product. Some impacts may only become evident after the consumer has the product for a long period of time and even without the engineered product their level of poverty might increase. These are further discussed in Sections 3.2 and 3.4.

Being multidimensional, this measure can reveal impacts a product has on many aspects of the consumer's life, both positive and negative. The multidimensional poverty level,

$$M = \frac{1}{5}(H + E + L + Q + Y) \quad (2)$$

includes the following measurement dimensions: health (H), education (E), standard of living (L), employment quality (Q), and security (Y). All of the dimensions (H, E, L, Q, Y) are scaled to be between zero and one, thus making them equally weighted, similar to the MPI. To preserve universal comparison from product to product across many researchers, we strongly discourage weighting these factors differently without explicitly acknowledging it to be a weighted PIM. An M score of zero indicates that the person is completely deprived in all dimensions. When using a geometric mean, if the person is deprived of one dimension, the entire M score is zero, regardless of the other dimensions. An arithmetic mean allows a dimension to equal zero without forcing M to be zero. If a product has some negative impacts but the total PIM score is positive, the negative impacts will be evident in the difference of each dimension and can be conscientiously assessed individually.

The Product Impact Metric accounts for impacts in these five dimensions of measurement (H, E, L, Q, Y) because they are simple to measure and indicative of a person's level of poverty [23, 24]. Each dimension is made up of sub-dimensions, marked with upside down hats ($\hat{}$), that include standard measurements and field measurements. Standard measurements, such as the national poverty line, can be collected from online databanks or other legitimate sources of national and regional data. The standard measurements used in the PIM are in Table 1. Field measurements are collected directly from the consumer, such as their weekly working hours. The field measurements that are necessary to calculate the PIM are in Table 2. Each sub-dimension

follows the form,

$$[\check{\cdot}] = \begin{cases} \frac{\text{Num}}{\text{Den}}, & \text{Num} < \text{Den} \\ 1, & \text{Num} \geq \text{Den} \\ 0, & \text{Num or Den} \leq 0 \end{cases} \quad (3)$$

so that it cannot equal more than one. The calculation of each dimension is completed by finding the average of the sub-dimensions

The first dimension, health, is measured with the sub-dimensions of nutrition ($\check{N}$), and child mortality ($\check{B}$). The equation for health is,

$$H = \begin{cases} \frac{1}{2}(\check{N} + \check{B}), & \text{Has children dependents} \\ \check{N}, & \text{Has no children dependents} \end{cases} \quad (4)$$

where,

$$\check{N} = \frac{s_{\text{BMIV}} - |s_{\text{BMIV}} - s_{\text{BMIR}}| - s_{\text{BMIA}}}{s_{\text{BMIV}} - s_{\text{BMIA}}} \quad (5)$$

$$\check{B} = \frac{n_c - n_{cb}}{n_c} \quad (6)$$

$$n_c = n_{cz} + n_{cb} \quad (7)$$

It includes field measurements for the body mass index (s_{BMIR}), number of children (n_c), number of child deaths in the family (n_{cb}), is the number of living children (n_{cz}), and standard measurements of average healthy BMI score (s_{BMIV}), and malnourished BMI score (s_{BMIA}). A BMI score includes measurements of height, in meters, and mass, in kilograms. The equation for calculating BMI is, $s_{\text{BMI}} = \text{weight}/\text{height}^2$. In $\check{N}$, the BMI scale is the same for all adults but changes throughout a child's life. Children have lower BMI scores than adults and so their healthy and malnourished BMI scores are also lower. The values of (s_{BMIV}) and (s_{BMIA}) can be found in growth charts produced by the World Health Organization [30]. The healthy BMI score, (s_{BMIV}), is the 50th percentile on the growth chart and the malnourished BMI score, (s_{BMIA}), is the 5th percentile on the growth chart.

The second dimension, education, has sub-dimensions for education are child schooling ($\check{S}_c$) and the individual's level of schooling ($\check{S}_I$). The the equation for education is,

$$E = \begin{cases} \frac{1}{2}(\check{S}_c + \check{S}_I), & \text{Has children} \\ \check{S}_I, & \text{Has no children} \end{cases} \quad (8)$$

TABLE 1. Standard measurements used in the calculation of the PIM.

Standard Measurements	Values
Health (H)	
Average good BMI (s_{BMIV})	21.75*
Malnourished BMI (s_{BMIA})	16*
Education (E)	
Acceptable years of schooling ($n_{l\alpha}$)	8*
Standard of Living (L)	
Water distance maximum ($d_{w\alpha}$)	200 m
Acceptable sanitation facilities per family ($n_{tf\alpha}$)	1
Hours maximum of electricity ($h_{e\alpha}$)	168 hrs
Monthly income poverty line ($m_{y\alpha}$)	Regional
Employment Quality (Q)	
Average regional working hours ($h_{k\alpha}$)	Regional
Security (Y)	
Total number of protection parameters ($n_{p\alpha}$)	5
Total number of exposure parameters ($n_{x\alpha}$)	5

* For adults

where,

$$\check{S}_c = \frac{n_{cl}}{n_{clg}} \quad (9)$$

$$\check{S}_I = \frac{n_{ql}}{n_{l\alpha}} \quad (10)$$

The field measurements are the number of children in school (n_{cl}), the number of school aged children (n_{clg}), the years of schooling of the individual (n_{ql}), and a standard measurement for the acceptable years of schooling ($n_{l\alpha}$). The children are the children of the consumer being measured.

The third dimension, standard of living, contains sub-dimensions for household cooking and heating fuels used ($\check{F}$), sanitation access ($\check{T}$), clean water access ($\check{W}$), electricity usage ($\check{E}$), and income ($\check{I}$). For this dimension the equation is,

$$L = \frac{1}{5}(\check{F} + \check{T} + \check{W} + \check{E} + \check{I}) \quad (11)$$

where,

$$\check{F} = \frac{n_{y\alpha}}{n_{y\alpha} + n_{y\beta}} \quad (12)$$

TABLE 2. Field measurements used in the calculation of the PIM.**Field Measurements****Health (*H*)**

Height

Mass

Measured BMI ($s_{\text{BMI}r}$)Total number of children (n_c)Number of living children (n_{cz})Child deaths (n_{cb})**Education (*E*)**Children in school (n_{cl})School aged children (n_{clg})Individual's years of schooling (n_{ql})**Standard of Living (*L*)**Clean Fuels ($n_{y\alpha}$)Dirty Fuels ($n_{y\beta}$)Sanitation facilities per family (n_{tf})Water distance (d_w)Hours with access to electricity (h_e)Monthly income (m_y)**Employment Quality (*Q*)**Weekly working hours (h_k)Weekly work hours lost due to injury (h_{kj})

Independents

Security (*Y*)Number of protection parameters (n_p)Number of exposure parameters (n_x)**Calculated Measurements**Measured BMI ($s_{\text{BMI}r}$)

Multidimensional Poverty Level (M)

Product Impact Metric (PIM)

$$\check{T} = \frac{n_{tf}}{n_{tf\alpha}} \quad (13)$$

$$\check{W} = \frac{d_{w\alpha} - d_w}{d_{w\alpha}} \quad (14)$$

$$\check{E} = \frac{h_e}{h_{e\alpha}} \quad (15)$$

$$\check{I} = \frac{\log m_y}{\log m_{yo}} \quad (16)$$

The field measurements used are the number of clean fuels used in the home ($n_{y\alpha}$), the number of dirty fuels used in the home ($n_{y\beta}$), the number of sanitation facilities per family (n_{tf}), the distance to an improved water source in meters (d_w), the number of hours of electricity per week (h_e), and the monthly income per capita of the family (m_y). Standard measurements are the acceptable number of sanitation facilities per family ($n_{tf\alpha}$), the maximum acceptable distance to an improved water source ($d_{w\alpha}$), the maximum hours of electricity per week ($h_{e\alpha}$), and the national poverty line (m_{yo}).

In $\check{F}$, dirty fuels are those that produce large amounts of smoke, like biomass, coal, and others. Clean fuels are those that do not have high emissions such as kerosene and propane. Electricity is also considered a clean fuel because there are no household emissions. Dirty fuels burnt in improved cookstoves designed to reduce in home emissions may be counted. For $\check{T}$, an acceptable sanitation facility is one that can be visited in private, is free of feces, and has few flies. This follows the standards set out by the United States Agency for International Development (USAID) and other organizations [31]. Facilities that are in the open and bucket latrines do not count as sanitation facilities unless they are maintained by a sanitation service and not the user. Approved water sources, in $\check{W}$, also follow guidelines set by USAID [31]. If a water source is a maintained source of clean water, like a well, piped water, or a public fountain, then it should be counted as a water source. Unimproved water sources include rivers, streams, and lakes and are not counted. If an improved water source is know to be contaminated, it is not counted as a water source. Hours of electricity, h_e in $\check{E}$, is the hours of plug-in electricity that the home receives. This can include power from a battery or generator if it is a reliable source and can produce power sufficient for more than just lighting. The monthly income, m_y in $\check{I}$, is the per capita income of the family. The incomes of all members of the family are included. The national poverty line should be taken from a reliable source such as a government or employment website and should be on a monthly scale.

Employment quality's sub-dimensions are hours of employment ($\check{R}$) and work related injuries ($\check{J}$). As this dimension is not included in the MPI, a new equation for employment quality was created, and is,

$$Q = \frac{1}{2}(\check{R} + \check{J}) \quad (17)$$

where,

$$\check{R} = \begin{cases} \frac{h_k}{h_{k\alpha}}, & \text{Independent or Dependent, Able} \\ \frac{h_{k\alpha} - h_k}{h_{k\alpha}}, & \text{Dependent, Not able, Working} \\ \frac{h_{kl}}{h_{k\alpha}}, & \text{Dependent, Not able, Not Working} \end{cases} \quad (18)$$

$$\check{J} = \begin{cases} \frac{h_k - h_{kj}}{h_k}, & \text{Independent or Dependent, Able} \\ \frac{h_k - h_{kj}}{h_k}, & \text{Dependent, Not Able, Working} \\ \frac{h_{kl} - h_{kjl}}{h_{kl}}, & \text{Dependent, Not Able, Not Working} \end{cases} \quad (19)$$

Employment quality includes field measurements for the weekly income-generating hours (h_k), weekly hours of lost employment due to work injury (h_{kj}), and the independent providers weekly income generating hours (h_{kl}), the independent providers weekly hours of employment lost due to work injury (h_{kjl}), and one standard measure, the regional average income-generating hours per week ($h_{k\alpha}$). In Equations 18 and 19, someone who is able, is physically and mentally able to work. This does not include children (within the regional age of minors) or the elderly (past the regional age of retirement). Weekly working hours, should represent a normal work week schedule and not account for holidays or injury time off. The independent provider's numbers are used when the consumer is completely dependent on their provider.

Similar to employment quality, the equation for security was created for the PIM. Security is broken into two sub-dimensions, protection ($\check{P}$) and exposure ($\check{O}$) and its equation is,

$$Y = \frac{1}{2}(\check{P} + \check{O}) \quad (20)$$

where,

$$\check{P} = \frac{n_p}{n_{p\alpha}} \quad (21)$$

$$\check{O} = \frac{n_{x\alpha} - n_x}{n_{x\alpha}} \quad (22)$$

Measurements needed are the number of protection parameters (n_p) and the number of exposure parameters (n_x), as well as the maximum protection parameters ($n_{p\alpha}$) and maximum exposure parameters ($n_{x\alpha}$). Literature on crime was examined and five factors of both protection against and exposure to crime were extracted [32–36]. The protection parameters are a local police

force, ability to lock the entire house, organized after school activities for children in the neighborhood, no criminal past, and that the consumer lives with trusted people. The exposure parameters consider if a person is a drug or alcohol user, a business owner, must leave the house at night, if there is criminal activity in the neighborhood, and if the neighborhood is resource poor.

To increase the metric's consistency, clarification of these parameters is necessary. The protection parameter "ability to lock the entire house" can only be satisfied if every door and window can be shut and tightly locked or if a secure wall or high fence circles the home and can be locked. Organized after school activities for children must be organized by a school or other community organization and be supervised by adults. Simply having places where children can participate in activities, such as parks, does not qualify. In order for someone to be a trusted roommate, the consumer has to have known them for at least one year. Living alone is counted as not living with a trusted roommate. In order to have the exposure parameter for leaving the home at night, the reason to leave must be for a necessity and not for pleasure or leisure. Such necessities include traveling to and from work, getting to a sanitation facility, and fetching water or other resources. The trips out of the house must occur at least once a week in order to qualify. Finally, resource poor neighborhoods are those where a majority of the community does not have sufficient food, water, energy, or other resources. This does not have to include the consumer who might have sufficient resources but refers to the conditions of the community. These guidelines are meant to clarify the measurements that will need to be taken and assist those who use the PIM.

3.2 Counterfactual

In order to attribute an impact to a single product, the impacts of other products, projects, and social influences acting on the consumer can not be ignored. These external factors, which also contribute to the social progression of consumers, are called the counterfactual [37]. A common approach of determining the counterfactual is by taking measurements from a control group concurrently with the measurements of the impacted group. If the PIM results are not compared to a counterfactual, then all the social improvement the consumer has attributed to the product, which may or may not be true. Especially in developing countries, there are other factors and groups that are trying to improve peoples lives, such as government programs. Thus, alongside the measurements that are taken for the group of impacted consumers (PIM_ϕ), measurements must be taken of a control group (PIM_τ). Using a method called difference-in-differences, the PIM of the control group is subtracted from the impacted group

$$PIM_\delta = PIM_\phi - PIM_\tau \quad (23)$$

to determine the true impact (PIM_δ) [38]. Measuring both a control group and an impacted group can be expensive and difficult to manage for many engineering groups. A method to reduce the cost of these measurements is by using personas.

3.3 Personas

Field survey data collection is very expensive and out of the scope of many engineering projects. When the engineer is far from their consumer, travel costs are high and time with consumers is limited. In order to reduce the costs and complexity of impact assessment, personas based on actual data may be used to simulate people who would use the product. Personas are a design tool used in human centered design [39]. They are a representation of a possible consumer and used to focus product design efforts. In the PIM, they are used to predict possible impacts on the consumer. Databanks such as World Bank, have data similar to the PIM indicators, only they are on a national scale. Indicator values can be generated from this data to create a persona that can be used to assess the impact of a product on a consumer. Additionally, control groups of personas can be produced that mimic actual populations for creation of the counterfactual. By collecting data over a similar time period as the data collected from the impacted consumers, a PIM_τ can be created. This way, the counterfactual can be created at a low cost.

Personas should be analogous to the projected consumer group. Only when personas closely match the consumers, will their PIM score be accurate. The PIM relies on the depth of poverty of the consumer, if the poverty level of the persona does not match the consumer's, then the PIM will be wrong even if indicators are changed in the same manner. Also, more research than retrieving indicators is necessary. The type of work, family structure, environment, and other social factors should be known while creating a suitable persona. This research also prepares the engineer to knowing how the product will affect that consumer. An example of a persona and product assessment is in the Section 4. Additionally, it is beneficial to observe the impact on men, women, and children. Deprivation among women and children is known to be higher than men, especially in low income countries [13,40]. Also, women and children are more impacted by products meant to reduce poverty [41]. Both of these factors offer evidence that the PIM score has potential to be higher for women and children than for men. This information should be factored into the decision of who the persona is.

3.4 Time

Long term analyses of products in the developing world are not common practice, though they should be. Unfortunately, it is more common to publish results of a product or project soon after launch. Without periodically tracking the impacts of a product it is difficult to ascribe them to the product alone. Long term analyses give more information on how the product is accepted

and if it is useful to the consumers. In order to motivate more long term product assessments, the PIM includes indication of the time attributed with the data collected. A subscript of the number of months of use the product has is added to the PIM score. If a product has a PIM score of 0.56 after 20 months of use, then the score should be displayed as 0.56_{20} . PIM scores that have more time demonstrate the sustained impact and are vital to learning more about product social impacts. Using this time element will make the PIM more transparent and scores that have more time will receive higher praise and recognition.

4 Examples

The PIM can be applied to either a persona that represents the target market or an actual person who is affected by the product. While personas can be used to predict an anticipated product impact, using a real person has a greater potential of finding a more meaningful PIM score. In this paper, personas are used for demonstration. The product chosen to model is the Village Drill. It is a human powered drill for digging bore holes for water wells in developing countries [42]. It was first launched in Tanzania, but has since been used across Africa and into South America and Asia. In this paper, the persona created is not a person who purchases the drill, but someone who purchases a bore hole, the consumer. Many products made for developing countries are sold to non-governmental organizations or have the purpose of creating businesses. In cases like these, creating a persona for the consumer might be more beneficial.

4.1 Adia the Farmer

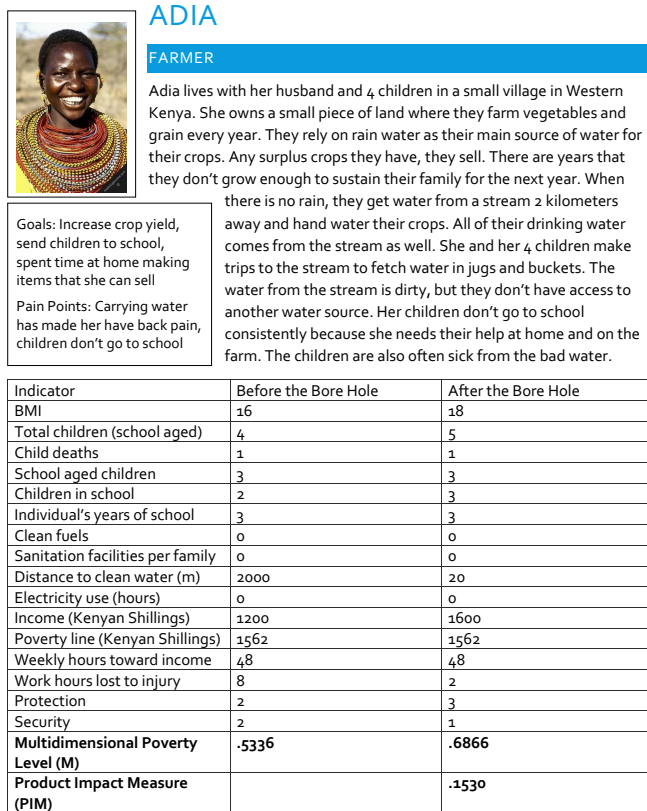
A persona, named Adia, was created to assess the impact of the Village Drill, see Figure 1. She lives with her husband and children in western Kenya. They own a piece of land and farm vegetables and grains. They rely mostly on the rain to water their plants because the closest reliable water source is two kilometers away. Her small community has saved enough money to buy a well produced by a Village Drill team. They plan on putting the well in a central location so that everyone in the village will have access to the water.

Before the well is drilled Adia has an M score of 0.53, and after her village received the well her M score raised to 0.69. When the difference is calculated, the Village Drill's PIM score is 0.16. The drill has a direct impact on her water access, while the water sub-dimension can only change the PIM score by 0.04 at most. The higher PIM score is due to the indirect impacts of the Village Drill.

While the example of a bore hole may seem to have an obvious positive impact, much is learned about indirect impacts. With easier access to clean water, she was also able to improve the family farm, which raised her income and improved her nutrition. In addition to this, she and her husband have water nearby

and can perform the farming duties with greater ease. This allows all of her children to go to school while she and her husband do the work necessary for the home and farm. These and other indirect impacts are only evident because the PIM score is multidimensional. All of the indirect impacts would not have been noticed if the engineer was only measuring how the Village Drill improved her access to clean water. The Village Drill's PIM score shows that its impact goes beyond giving people access to water.

FIGURE 1. Adia buys a bore hole from a team of drillers using the Village Drill and its impact on her is shown here.



5 Conclusion

Determining the direct and indirect impacts of engineered products on people in poverty is the purpose of the Product Impact Metric. Without measuring for potential indirect impacts, the extent of a product's influence on consumers is not entirely

captured. Even when products have different direct impacts, their PIM scores are of the same unit. Therefore, the PIM can be a means of comparing products that impact poverty. This can assist organizations seeking to generate a large social impact because they would be able to choose the products they distribute based on the product's social impact, provided by the PIM.

Also, products that have high impacts and long trial times can teach engineers more about social impact. New insight can be gained from these products such as why they might have a greater impact than others. This can be used to create better product design tools for creating products meant to alleviate underdeveloped social conditions.

The Product Impact Metric does have shortcomings. First, it is only valid with consumers who are deprived. A product that is meant to relieve deprivation, will likely not have a large impact on someone who is not deprived. If measuring from personas or people who are not deprived, a negative PIM score can result. A negative score indicates that the product has flaws or that the market chosen is not ideal.

Second, because the PIM measures impact on a personal level, measuring the PIM from more than one consumer can result in different values. Social impact is a function of the consumer's conditions and the product, so it can change from person to person. This might also be a strength because assessing the impact of the product beyond the initial purchaser can lead to additional findings. A product can have a significant impact on anyone who interacts with the product, whether they be consumers or employers.

Third, because the PIM is a universal and general metric, it might miss very specific impacts. While this is true, it is also beneficial to measure the change in each of the measurement dimensions individually to see how the product effects each dimension independently. If there is a negative impact to one or two dimensions, this can help engineers know how changes should be made. Knowing where the greatest impact is can assist engineering teams in marketing the product, making changes to the design, and creating a more positive impact. But in order to get more specific results, specific metrics must be used.

Engineers are trained to focus on the product's measurable metrics that give precise indication as to whether goals are met. Because of the nature of social and product impact, creating a tool that gives a similar indication of success has proven difficult for engineers. Engineers often do not have the education or training necessary on how to create social impacts [16]. Along with this, selecting indicators to measure social impact is not a skill most engineers have. The approach of the PIM is to stay more general and abstract so that it can be used for all types of products, without modifying the metric. While this might overlook some specific impacts, it is believed to be effective at indicating if a product has a positive or negative impact. Future work must be done to create additional, more specific metrics that can give specific impact results.

Currently, engineers are designing products destined to assist those in need in developing countries. Many of these engineers will never know the true impact their product has on a consumer. By adopting the PIM, they will know their product's impact and be able to design products that have a positive impact. In this way, we as an engineering community can better serve our consumers and can account for more of the influences of our products.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant No. CMMI-1632740. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

- [1] The World Bank, 2016. *World Development Indicators 2016*. World Bank Publications.
- [2] George, C., 2012. "Is the Community Partner Satisfied?". *Service-Learning in the Computer and Information Sciences: Practical Applications in Engineering Education*, pp. 517–530.
- [3] Pease, J. F., Dean, J. H., and Van Bossuyt, D. L., 2014. "Toward a market-based lean startup product design method for the developing world". In ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, pp. V02AT03A045—V02AT03A045.
- [4] Agyemang, M., and Johnson, N. G., 2015. "Development of Biomass Energy Technologies and Business Models for Southern Africa". In ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, pp. V02AT03A047—V02AT03A047.
- [5] Johnson, N. G., and Granato, M., 2014. "Single Cell Battery Charger for Portable Electronic Devices in Developing Countries". In ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, pp. V02AT03A048—V02AT03A048.
- [6] Santaefemia, P. S., Johnson, N. G., McComb, C., and Shimada, K., 2014. "Improving Irrigation in Remote Areas: Multi-Objective Optimization of a Treadle Pump". In ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, pp. V02AT03A049—V02AT03A049.
- [7] Becker, H. A., 2001. "Social impact assessment". *European Journal of Operational Research*, **128**(2), pp. 311–321.
- [8] Mair, J., and Noboa, E., 2006. "Social entrepreneurship: How intentions to create a social venture are formed". In *Social entrepreneurship*. Springer, pp. 121–135.
- [9] Lee, E. J., and Schwab, K. J., 2005. "Deficiencies in drinking water distribution systems in developing countries". *Journal of water and health*, **3**(2), pp. 109–127.
- [10] Bruce, N., Perez-Padilla, R., and Albalak, R., 2000. "Indoor air pollution in developing countries: a major environmental and public health challenge". *Bulletin of the World Health Organization*, **78**(9), pp. 1078–1092.
- [11] Sagar, A. D., 2005. "Alleviating energy poverty for the world's poor". *Energy Policy*, **33**(11), pp. 1367–1372.
- [12] Grantham-McGregor, S., Cheung, Y. B., Cueto, S., Glewwe, P., Richter, L., Strupp, B., Group, I. C. D. S., and Others, 2007. "Developmental potential in the first 5 years for children in developing countries". *The lancet*, **369**(9555), pp. 60–70.
- [13] UNICEF, 2015. "The State of the World's Children 2015: Reimagine the Future: Innovation for Every Child". *New York: UNICEF*, pp. 29–115.
- [14] Rogers, E. M., 2010. *Diffusion of innovations*. Simon and Schuster.
- [15] Wood, A. E., and Mattson, C. A., 2016. "Design for the Developing World: Common Pitfalls and How to Avoid Them". *Journal of Mechanical Design*, **138**(3), p. 31101.
- [16] George, C., and Shams, A., 2007. "The challenge of including customer satisfaction into the assessment criteria of overseas service-learning projects". *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, **2**(2).
- [17] Sovacool, B. K., and Dworkin, M. H., 2015. "Energy justice: Conceptual insights and practical applications". *Applied Energy*, **142**, pp. 435–444.
- [18] Bovea, M. D., and Vidal, R., 2004. "Increasing product value by integrating environmental impact, costs and customer valuation". *Resources, Conservation and Recycling*, **41**(2), pp. 133–145.
- [19] Mulugetta, Y., 2005. *Energy for rural livelihoods: a framework for sustainable decision making*. Intermediate Technology.
- [20] MacCarty, N. A., and Bryden, K. M., 2016. "An integrated systems model for energy services in rural developing communities". *Energy*, **113**, pp. 536–557.
- [21] Robinson, C., 2013. Internal Attachment Program: Monitoring and Evaluation Failure.
- [22] Programme), U. U. N. D., 2010. Human Development Report 2010.
- [23] Alkire, S., and Santos, M. E., 2010. "Acute multidimensional poverty: A new index for developing countries".

- United Nations development programme human development report office background paper(2010/11).*
- [24] Alkire, S., 2007. "The missing dimensions of poverty data: Introduction to the special issue". *Oxford development studies*, **35**(4), pp. 347–359.
 - [25] ANA LUGO, M., 2007. "Employment: A Proposal for internationally comparable indicators". *Oxford Development Studies*, **35**(4), pp. 361–378.
 - [26] Diprose, R., 2007. "Physical Safety and Security: A Proposal for Internationally Comparable Indicators of Violence I am grateful for the comments and inputs of Sabina Alkire, Proochista Ariana, Afsan Bhadelia, Alex Butchart, Anna Hiltunen, Mar{\'}a Ana Lugo, Andrew Mack, L". *Oxford Development Studies*, **35**(4), pp. 431–458.
 - [27] Ibrahim, S., and Alkire, S., 2007. "Agency and Empowerment: A Proposal for Internationally Comparable Indicators Solava Ibrahim, University of Cambridge, Cambridge, UK. Sabina Alkire, University of Oxford, Oxford, UK. We are grateful for the comments of Valery Chirkov, Ed Deci, Mridul Eapen". *Oxford development studies*, **35**(4), pp. 379–403.
 - [28] Samman, E., 2007. "Psychological and Subjective Well-being: A Proposal for Internationally Comparable Indicators Sabina Alkire, Tania Burchardt, Laura Camfield and Geeta Kingdon provided detailed comments on a draft of this article. I am also grateful for the input of Prooc". *Oxford Development Studies*, **35**(4), pp. 459–486.
 - [29] Zavaleta Reyes, D., 2007. "The Ability to go about Without Shame: A Proposal for Internationally Comparable Indicators of Shame and Humiliation I am grateful for the comments of Sabina Alkire, David Harder, Linda Hartling, Tom de Herdt, Jaqui A. Goldin and Luis Alberto Quiroga on t". *Oxford Development Studies*, **35**(4), pp. 405–430.
 - [30] WHO, 2016. Obesity and overweight: Fact sheet.
 - [31] Billig, P., Bendahmane, D., and Swindale, A., 1999. *Water and sanitation indicators measurement guide*. Food and Nutrition Technical Assistance Project, Academy for Educational Development.
 - [32] Levitt, S. D., 2004. "Understanding why crime fell in the 1990s: Four factors that explain the decline and six that do not". *The Journal of Economic Perspectives*, **18**(1), pp. 163–190.
 - [33] Edgar, J. M., McInerney, W. D., and Mele, J. A., 2013. *The Use of Locks in Physical Crime Prevention: National Crime Prevention Institute*. Elsevier.
 - [34] Welsh, B. C., and Hoshi, A., 2002. "5 Communities and crime prevention". *Evidence-based crime prevention*, **165**.
 - [35] Barslund, M., Rand, J., Tarp, F., and Chiconela, J., 2007. "Understanding victimization: the case of Mozambique". *World Development*, **35**(7), pp. 1237–1258.
 - [36] Andresen, M. A., 2011. "Estimating the probability of local crime clusters: The impact of immediate spatial neighbors". *Journal of Criminal Justice*, **39**(5), pp. 394–404.
 - [37] Khandker, S. R., Koolwal, G. B., and Samad, H. A., 2009. *Handbook on impact evaluation: quantitative methods and practices*. World Bank Publications.
 - [38] Gertler, P. J., Martinez, S., Premand, P., Rawlings, L. B., and Vermeersch, C. M. J., 2011. *Impact evaluation in practice*. World Bank Publications.
 - [39] Hanington, B., and Martin, B., 2012. *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions*. Rockport Publishers.
 - [40] Amin, M., Kuntchev, V., and Schmidt, M., 2015. "Gender inequality and growth: the case of rich vs. poor countries". *World Bank Policy Research Working Paper*(7172).
 - [41] Mattson, C. A., and Wood, A. E., 2014. "Nine principles for design for the developing world as derived from the engineering literature". *Journal of Mechanical Design*, **136**(12), p. 121403.
 - [42] Mattson, Christopher A and Wood, Amy E and Renouard, J., 2017. "Village Drill: A Case Study in Engineering for Global Development, With Five Years of Data Post Market-Introduction". *Journal of Mechanical Design*, **In Press**.