

A Method for Creating Product Social Impact Models of Engineered Products

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All products impact the lives of their users, this is called social impact. Some social impacts are commonly recognized by the engineering community, such as impacts to a user's health and safety, while other social impacts can be more difficult to recognize, such as impacts on families and gender roles. When engineers make design decisions, without considering social impacts, they can unknowingly cause negative social impacts. Even harming the user and/or society. Despite its challenges, measuring a program's or policy's social impact is a common practice in the field of social sciences. These measurements are made using social impact indicators, which are simply the things observed to verify that true progress is being made. While there are clear benefits to predicting the social impact of an engineered product, it is unclear how engineers should select indicators and build predictive social impact models that are functions of engineering parameters and decisions. This paper introduces a method for selecting social impact indicators and creating predictive social impact models that can help engineers predict and improve the social impact of their products. As a first step in the method, an engineer identifies the product's users, objectives, and requirements. Then, the social impact categories that are related to the product are determined. From each of these categories, the engineer selects several social impact indicators. Finally, models are created for each indicator to predict how a product's parameters will change these indicators. The impact categories and indicators can be translated into product requirements and performance measures that can be used in product development processes. This method is used to predict the social impact of the proposed, expanded U.S. Mexico border wall. [DOI: 10.1115/1.4044161]

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1 Introduction

As engineers, the products we design impact society. Sometimes, this impact is obvious: the design of a bridge that links two communities, the design of a medical device that extends life, or the design of sensors used in warning systems. And sometimes, the impact is not obvious: the design of entertainment systems that change family dynamics, the design of machinery that favors a male workforce, and the design of hospital ventilation that spreads infection. These are the social impacts of products, where social impact is defined as how a product affects "the day-to-day quality of life of persons" [1]. The most obvious social impacts that products have—generally health and employment—are often recognized in the engineering community. In some cases, for these obvious social impacts, engineers are able to create product requirements and performance measures that relate a product's performance to its social impact. Other social impacts, such as family and gender impacts, tend to not be considered for products as they may seem unrelated to a product's design and performance. Nevertheless, products can indeed change people's lives in more ways than are generally understood by the engineering community [2]. As a result, engineers are likely designing products without knowing the social impact of design decisions.

Social impact indicators and categories can be used to describe a product's social impact. Social impact indicators are used to know the amount of social impact a product has. Sandhu-Rojon defines indicators as "what we observe in order to verify whether—or to what extent—it is true that progress is being made" [3]. One or more social impact indicators can be chosen to partially represent

the social impacts that a product has on a person or group. Social impact indicators can be classified by their social impact category. In a collaborative work between sociologists and engineers, 11 social impact categories for products were identified by evaluating the archival literature, specifically extracting themes from papers that list social impact categories, provide case studies of products that have a social impact, and other works on the social impact of products in the field of sociology and engineering [2]. The social impact categories from this work are shown in the first column of Table 1. While it is not assumed that these are the only social impact categories that could exist, the 11 social impact categories described by Rainock et al. are used to constrain the possible social impacts of products in this paper. We recognize that these social impact categories may seem far removed from an engineer's decisions. Nevertheless, it will be demonstrated in this paper that a product's features can be connected to these social impact indicators, thus allowing the engineer to predict and improve the social impacts of the products they are designing.

Currently, there is a lack of methods that can help an engineer identify, understand, and improve a product's social impacts. A coalition of companies chose 71 social impact indicators to measure the social sustainability and impact of their products [4,5]. While the companies are able to measure some social impacts using these indicators, many of the indicators are unrealistically dependent on company policies instead of the product's design. This makes understanding and improving a product's impact more difficult. Using the approach proposed by the coalition, design decisions made by the engineer would not change many of the product's measured social impacts. Also, the coalition's method of evaluating the indicators is a ranking by self-assessment, which can bias the results. In these ways, the indicators, as identified by the coalition, are fundamentally different, which is proposed in this paper. The coalition's impact indicators are self-assessed, while the indicators in the current paper are linked with the product's performance.

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Table 1 Social impact categories and some examples of what each category includes [2]

Impact category	Example topics
Health and safety impact	Living conditions and mortality
Paid work impact	Employment rates and industrial diversification
Stratification impact	Inequality and social status
Civil rights impact	Minority and human rights
Education impact	Education and skills
Family impact	Change in family roles and structure
Gender impact	Gender roles and equality
Population change impact	Transiency of the population and age structure
Conflict and crime impact	Crime, civil, and domestic conflict
Social networks and communication impact	Personal relationships and social capital
Cultural identity/heritage impact	Values and personality traits

By linking the social impact to the product's parameters, some of the engineer's bias is removed.

In a previous work by the authors, a metric was introduced to simplify measuring the social impact of products that are designed to alleviate poverty [6]. This metric measures a product's impact in five categories (*health, education, standard of living, employment quality, security*) without attempting to measure all of the impacts that a product might have. While this simplifies the process of measuring a product's impact, some impacts identified in Table 1 are missed [2].

While the principles of social impact modeling are most often applied to assessment (defined as the evaluation of impact a posteriori), predictive models of social impact (primarily for use a priori) would be very beneficial to the engineering design community. Currently, social scientists use simple models to help predict the social impact of new programs or policies [7,8]. As engineers, we are often tasked with creating models of complex systems. In the models we create, it is common to add emphasis in areas of our expertise, at times unknowingly disregarding other aspects of the system we do not fully understand [9]. Engineers who wish to model the social impact of their products will need effective ways to identify pertinent social impact indicators that can be meaningfully linked to engineering parameters. With only a nascent understanding of social impacts, engineers can expect these models to be simple compared with more mature models typically found in engineering. However, it is expected that as the field of engineering for social impact grows, the complexity of these models will increase. Importantly, these models will allow social impacts to be scrutinized simultaneously with functional requirements during the product development process.

Within the social sciences, a typical approach to evaluating societal impact uses a method called social impact assessment. Barrow describes the typical stages of social impact analysis as (i) scoping—understanding who is impacted, (ii) formulation of alternatives—developing alternatives to the proposed program/solution, (iii) profiling—determining what/who is impacted, (iv) projection—predicting how much change will occur, (v) assessment—assessing implications of impact, (vi) evaluation—assessing the impact on all stakeholders, whether net positive or net negative impact, (vii) mitigation—improving negative impacts, (viii) monitoring—measuring actual impact, and (ix) ex-post audit—iterate on process [10,11]. It is common for social impact assessment to be applied to social programs, not engineered products. With this as context, Barrow also states that deciding what are, or will become, critical socioeconomic factors is difficult and must be undertaken by appropriately skilled social scientists [11]. If the general methods of social impact assessment is to become more useful for predicting the impact of engineered systems, it will be necessary for engineers to develop expertise in deciding what are, or will become, critical sociotechnical factors. The method in

this paper hopes to simplify the stages of profiling, projection, assessment, evaluation, mitigation, and monitoring, as introduced by Burdge in 1990 and which is still used today, so that engineers can account for and improve the social impact of their products during the design process.

Some of the details of how to assess and predict the social impact of a product can be learned from social sciences. The *Handbook on Impact Evaluation* by The World Bank details how these difficult impact studies can be done [7]. Though the handbook was created specifically for measuring the social impact of government policies, many principles of measuring and predicting social impact can be applied to products as well. The handbook describes how to use a control group, introduces a simple predictive model, and gives other important information on how to measure and predict the social impacts of programs. Wherever possible, the best practices of social science are used to inform the method presented in this paper.

The purpose of this paper is to introduce a method for creating predictive models of social impact for engineered products. In Sec. 2 of this paper, we present the method, and in Sec. 3, we use the method to predict the social impact of an expanded U.S. Mexico border wall (UMBW). The final section provides closing remarks with a description of limitations and future work.

2 Method for Modeling the Social Impact of Products

The methodology introduced in this paper is composed of four steps:

- (1) Identify a product's users, requirements, and objectives.
- (2) Determine which of the 11 social impact categories in Table 1 [2] are influenced by the product.
- (3) Select social impact indicators from data banks such as The World Bank to represent the impact categories identified in step 2.
- (4) Create predictive models of social impact by linking engineering parameters to indicators and by combining/aggregating pertinent indicators from step 3.

This four-step process fits into the product development process in traditional ways; it is used whenever models are needed, it has the potential to create low or high fidelity models, and it will produce models that need validation. Therefore, the method will likely be used iteratively to converge on trusted models of social impact. Because of the complexity of determining impact categories and indicators, this method is best completed with a multidisciplinary team, where the combined experience and knowledge of the team outweighs that of the engineer alone.

2.1 Step 1: Gather Product Development Information. As a first step, the engineer collects product and user information. Specifically, the engineer needs to identify a product's requirements, users, and objectives. This information is often used by engineers in traditional product development processes [12,13]. This information articulates why the product is useful, who uses it, and what goals the engineer has in creating it.

The information collected in this step lays the groundwork for identifying a product's social impacts. Importantly, the social impact of a product is a function of both the product and the user [6]. Therefore, if the needs of the user are not understood, then the social impact of the product cannot be predicted. This also means that products impact their users differently depending on their needs. The method introduced in this paper cannot be completed until at least a portion of the user's needs are known.

Moreover, the objective statement can contain information about the product's social impact. During the product development process, engineers often create an objective statement that guides design decisions that are made for the product. This objective often answers these questions: what is the product, what problem does it solve, and what is the target market [14]? These statements

can help understand the product's purpose, further preparing the engineer to meaningfully model a product's social impact.

An important consideration when choosing the users is to include people who might be positively and negatively impacted by the product. By doing so, the engineer can identify the negative impacts the product has and attempt to reduce them during the products development.

2.2 Step 2: Determine Social Impact Categories. Once the product development information is collected, the product impact categories are identified. The process by which impact categories and indicators are selected is shown in Fig. 1. The categories used in this paper are the 11 categories of product impact that have been identified by Rainock et al. [2]. Table 1 contains all of the impact categories as well as example topics that a product may impact in each category.

When first attempting to identify a product's social impact categories, product developers should determine which categories best match the product's development information from step 1 (Sec. 2.1). For example, the requirement "the product increases the user's income" is related to the *paid work* impact category. In addition, depending on the product, this requirement may also be related to *population change*. The product may create a new job market, providing new employment for many people and therefore increase the local population size. Additionally, user information and product objectives can point toward additional social impact categories.

In the case of users, the user's needs can change a product's social impact. An example of this is the impact of fuel-efficient biomass stoves. Often, the most substantial impact of biomass stoves in on the *health and safety* of the user because fuel-efficient biomass stoves reduce harmful indoor emissions. But, if stoves are designed for user's with additional needs, the impact of the stove can increase. For example, some fuel-efficient biomass cookstoves

are designed for displaced, refugee women [16]. These women are often victims of physical and sexual assault while they are collecting firewood. The additional need for increased security enables these stoves to also impact *gender and conflict and crime* because the user's likelihood of being assaulted decreases. Identifying the less intuitive impact categories in Table 1 can be difficult. For this reason, two additional methods of determining impact categories are introduced here.

In a study done by Ottosson et al., 150 products were assessed for their social impact, using the same impact categories as seen in Table 1 [15]. It was found that for the 150 products reviewed, some social impact categories were likely to appear together in any given design scenario. Table 2 shows the probabilities of any social impact category, given that you know at least one impact category is present. For instance, if it is known that a product impacts *health and safety*, there is a greater probability that it will also impact *paid work* (probability of 0.427) than *population change* (probability of 0.104). Table 2 should be used to explore what additional impact categories should be explored. The current paper does not establish what relationships exist between social impact categories. They are presented here to assist in determining which social impact categories may be pertinent to a design scenario.

Another method of identifying which of the 11 social impact categories are pertinent involves asking a series of questions about the product. These questions are provided in Table 3. Some of the questions in Table 3 are from a booklet that helps product designers consider social issues [17]. These questions help a design team discuss and identify which categories their product may impact and which they should include.

After completing step 2, several impact categories should have been identified. During the rest of the product development process and as more information is gained, the impact categories should be assessed for their relevancy and to ensure that the impact categories related to the product are included.

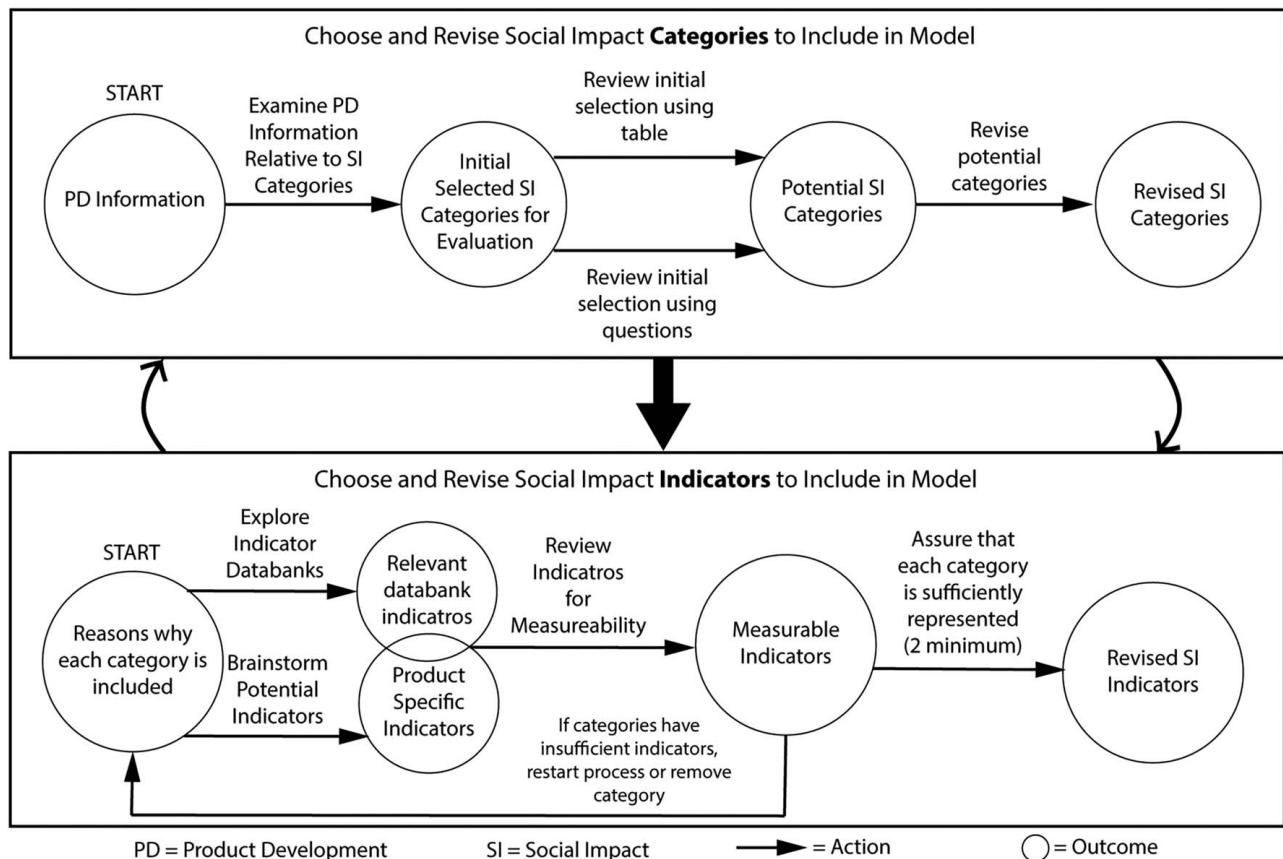


Fig. 1 Process for selecting impact categories and indicators, see Secs. 2.2 and 2.3

Table 2 Conditional probabilities for the impact categories (probability of the column category given the category in the row) [15]

	Health and safety	Paid work	Stratification	Human rights	Education	Family	Gender	Population change	Conflict and crime	Social networks and communication	Cultural identity/heritage
Health and safety	1.000	0.427	0.066	0.293	0.183	0.185	0.173	0.104	0.127	0.259	0.169
Paid work	0.867	1.000	0.076	0.340	0.211	0.292	0.214	0.170	0.154	0.471	0.278
Stratification	0.841	0.478	1.000	0.377	0.391	0.261	0.261	0.319	0.304	0.420	0.333
Human rights	0.629	0.361	0.063	1.000	0.361	0.124	0.132	0.129	0.285	0.171	0.312
Education	0.592	0.338	0.099	0.544	1.000	0.081	0.099	0.184	0.349	0.232	0.301
Family	0.911	0.709	0.101	0.285	0.123	1.000	0.201	0.184	0.117	0.436	0.223
Gender	0.869	0.528	0.102	0.307	0.153	0.205	1.000	0.102	0.074	0.301	0.205
Population change	0.829	0.667	0.198	0.477	0.450	0.297	0.162	1.000	0.414	0.315	0.414
Conflict and crime	0.560	0.335	0.105	0.585	0.475	0.105	0.065	0.230	1.000	0.175	0.320
Social networks and communication	0.870	0.782	0.111	0.267	0.240	0.298	0.202	0.134	0.134	1.000	0.271
Cultural identity/heritage	0.703	0.571	0.108	0.604	0.387	0.189	0.170	0.217	0.302	0.335	1.000

2.3 Step 3: Selecting Social Impact Indicators. Once impact categories are identified, indicators need to be chosen. Indicators are what is measured or predicted in each impact category to understand a product's social impact. Sandhu from the United Nations Development Programme stated that "the challenge in selecting indicators is to find measures that can meaningfully capture key changes, combining what is substantively relevant as a reflection of the desired result with what is practically realistic in terms of actually collecting and managing data" [3]. Indicators can come from the engineer and product development information, but more help might be needed to select the set of indicators. For this reason, some resources are given here to assist in selecting social impact indicators.

There are multiple data banks with hundreds of social impact indicators. The World Bank has compiled a databank that includes hundreds of indicators for tracking the progress of countries. Table 4 shows all of The World Bank's indicator groups, the number of indicators included in each category, and example indicators. Some of the indicator categories The World Bank uses are similar to the social impact categories used in this paper, see Table 5. Most of The World Bank's indicators, however, are measured at the national level and few products will have a measurable impact on an entire population. Nevertheless, many of the indicators can be adapted for use on smaller groups and individuals. Other sources for impact indicators are the Oxford Poverty and Human Development Initiative's working papers [18–23]. Each of these papers highlights a social issue that is under-represented in existing

data banks. The appendix of each paper includes example surveys and indicators that can be used to measure the levels of a specific social issue. Both of these resources, along with which impact category they are related to, are listed in Table 5. The resources in Table 5 are not exhaustive, similar types of indicators can be found in other resources as well. Together, The World Bank and the Oxford Poverty and Human Development Initiative's working papers include hundreds of indicators, but do not give guidance on how to select them to measure a product's social impact.

We recommend that when selecting social impact indicators, the following approach is used, see Fig. 1. First, it is important to determine the reason that each social impact category was included. The purpose of the social impact indicators is to typify the reason that each category is included. Second, brainstorm potential indicators within the product development team. This step will help capture indicators that are specific to the product. Product-specific indicators are not likely to be found in indicator data banks, such as those in Table 5. Furthermore, at this stage, it is important to not self-impose limitations on what indicators are chosen. If the team decides that the product can have a measurable effect on the value of an indicator, then it should be included. Simultaneously, the resources in Table 5 should be explored thoroughly. Using data-banks can help product developers become acquainted with the impact categories and how they are related to a product. Finally, the indicators should be evaluated. This evaluation can begin right after selecting the indicators but should also continue to

Table 3 Questions that help lead to identifying impact categories [17]

	Questions	Potential impact categories
1	Does it encourage a sense of community?	Networks, cultural identity
2	How could your design demonstrate the values of the user?	Cultural identity
3	Does it encourage participation and belonging?	Civil rights, networks, cultural identity
4	Does it improve health and well-being?	Health and safety, stratification
5	Does it encourage empowerment and promote human competence?	Stratification, education
6	Does it enrich users' lives or increase quality of life?	Health and safety, stratification
7	Does it enhance social interaction, communication, and engagement?	Civil rights, networks
8	Does it maintain local/cultural traditions?	Cultural identity
9	Does it help make money?	Paid work
10	Does it help save time?	Paid work
11	Does it enhance education?	Education
12	Does it challenge stereotypes?	Family, gender, cultural
13	Does it improve personal or communal security?	Health and safety, conflict and crime
14	Does it encourage activism?	Civil rights, education, gender
15	Does it make the community more attractive to outsiders?	Population change
16	Does it influence inequality in the community?	Stratification, civil rights
17	Does it change the user's hireability?	Paid work, education
18	Does it change the user's vulnerability?	Gender, conflict, and crime
19	Does it change the user's role in society or their family?	Civil rights, family, gender
20	Does it bring together or separate families?	Family
21	Does it encourage relocation?	Family, population change

Table 4 The World Bank's indicator groups and how many indicators are in each category (some indicators are in more than one category)

Number of indicator category	Indicators	Example indicators
Agriculture and rural development	47	Employment in agriculture
Aid effectiveness	73	Income share held by lowest 20%
Climate change	80	Nitrous oxide emissions
Economy and growth	261	Household final consumption expenditure
Education	159	Educational attainment of the population
Energy and mining	50	Access to electricity
Environment	112	Plant species threatened
External debt	229	Average interest on new debt commitments
Financial sector	85	Accounts at a financial institution
Gender	161	Children out of school (male, female)
Health	207	Prevalence of HIV
Infrastructure	51	Railway passengers
Poverty	25	GINI index, poverty gap
Private sector	173	Time required to start a business
Public sector	97	Internally displaced people
Science and technology	13	Researchers in R&D, patent applications
Social development	31	Children in employment, refugee population
Social protection and labor	151	Employment in agriculture
Trade	152	Goods or services imports and exports
Urban development	22	Mortality caused by road traffic injury

Table 5 Data banks and papers that can be used to find social impact indicators in each category

Source	Resources	Impact categories
The World Bank	Health	Health and safety
	Private sector	Paid work
	Social protection and labor	Paid work
	Poverty	Stratification
	Urban development	Stratification
	Agriculture and rural development	Stratification
	Education	Education
	Gender	Gender
OPHI working papers	Physical safety and security	Health and safety, crime and conflict
	Psychological and subjective well-being	Health and safety
	Employment	Paid work
	Agency and empowerment	Paid work, gender
	The ability to go about without shame	Stratification
	Social isolation	Civil rights, family, networks and communication

step 4 (Sec. 2.4). Measuring the indicators needs to be within the abilities of the product development team. If it is decided that measuring an indicator is outside of the product developer's ability, it should be set aside to be reevaluated at a future date.

Once the indicators have been selected, they need to be assessed by the impact category. The indicators should be assessed to assure that the categories are represented sufficiently. When necessary, impact categories can be added in this stage of the process if a selected indicator is related to a hitherto unidentified impact category.

After each impact category has sufficiently been represented by indicators, the indicators need to be evaluated on how they can be integrated into the product development process. Products are often designed to meet certain product requirements. The extent to which the product meets these requirements can be evaluated by performance measures [24]. When the method introduced in this paper is done in parallel with a product development process, indicators and impact categories can be transformed into performance measures and requirements. As the initial requirements were used to help find the impact categories, some of the impact categories and indicators may already be requirements and performance measures. As expected with any modeling approach, when more product development information is gained, social impact indicators should be improved, added, or removed.

The process of finding categories and selecting indicators should be iterative, as illustrated in Fig. 1. For example, in the first iteration

of the process shown in Fig. 1, impact categories and indicators are selected. It is possible that one or more of the indicators may also impact another, unidentified impact category. Such a category should be evaluated with another iteration of the process in Fig. 1 to hopefully identify more indicators.

2.4 Step 4: Creating Social Impact Models. Product social impact models, as discussed in this paper, are analytical equations that are used to predict the performance of a product as measured by the social impact indicators selected in Sec. 2.3.

The social impact models used for a product are unique to that product and can not be applied to other, dissimilar products. A product's social impact is a function of the product and the user, where the social impact of a product I_S is

$$I_S = f(U, P) \quad (1)$$

where f is the function that calculates a product's social impact, U is a set of user parameters, and P is a set of product parameters [6]. The social impact of a car demonstrates this relationship. A car's social impact, which includes injuries from car collisions, the ability to drive to new destinations, and improvements to the driver's employment, is dependent on the ability of the driver, the needs of the driver, as well as the size of the car, the driving range of the car, and other parameters.

The basic form of the equation that is used by social scientists to evaluate the social impact of programs using impact indicators is

$$Y = \alpha * X + T * \beta + \epsilon \quad (2)$$

where Y is the final indicator value, α is the initial indicator value, X is other relevant parameters of the individual for whom the social impact is being measured, T is a binary variable for differentiating between people or groups who are impacted by the product or not, β is the program's effect to the indicator value, and ϵ is an error term for unobserved factors that effect Y [7]. Equation (2) has been used for evaluations as well as predictions [8].

The β term can be the most difficult term in Eq. (2) to determine. The approach used in this paper is to find an existing relationship between the impact indicator and product parameter that can be measured or predicted. For example, the parameters for a model that predict how much a security system increases the protection of a household could be the brightness of external lights, the number of cameras, and other parameters.

After indicators are predicted, the impact that the product has on the indicator value can be found. One method of doing this is called difference-in-differences [7,25]. This method measures the difference between an impacted group and control group. Using this method, the impact of a product I is

$$I = Y_T - Y_C \quad (3)$$

where Y_T is the final indicator value for someone who was impacted by a product and Y_C is the final indicator value for a control someone who did not have the product. If Y from Eq. (2) is assumed to be the product's impact, then the value of the impact may be exaggerated. Often, other influences, including products and programs, are also manipulating indicator values. Using the difference-in-differences approach accounts for these other influences.

Creating accurate models requires the product developer to understand the factors that affect the indicators. In many cases, the product is not the only reason why indicators are changing. Before models are created, the user and their social environment should be understood enough to know what these factors are. Some of these factors may include government policies, development programs, family roles and dynamics, cultural practices, economic status, social class, and community behaviors. Understanding these user parameters and including them in the models will make the models more accurate.

3 Predicted Social Impact of the U.S. Mexico Border Wall

The example in this paper is a social impact prediction study for the proposed expansion of the UMBW. In this example, the method introduced in this paper is implemented to identify product development information, impact categories, indicators, integrate with the design process, create predictive models, and make predictions.

The U.S. Mexico border wall impacts the lives of Americans, Mexicans, and immigrants hoping to enter or leave the United States. Currently, the U.S. Mexico border has an intermittent wall, fencing, and vehicle barricade for 705 miles of the 1989-mile border. The current U.S. Presidential Administration has proposed building a wall along the entire border [26]. The example in this paper applied the method introduced in this paper to predict the social impact of a border wall that extends across the entire length of the U.S. Mexico border.

The UMBW is used as an example in this paper for two reasons. First, the social impacts of the UMBW are both obvious and non-trivial. While it is obvious to many that the UMBW will have a social impact, there is less consensus on if that impact is positive or negative. It is a product that has garnered the attention of Americans, Mexicans, and others around the world. Scholars have already written about the UMBWs potential to impact

immigration and the environment [27–31]. Second, the UMBW has a significant amount of historical data associated with it as over one-third of the U.S. Mexico border currently has a barrier—while at the same time, there is an active engineering design effort to further develop a border barrier (UMBW) [32]. Because of this, much data exist and many researchers from disparate disciplines have studied the border barrier, which is useful in developing impact models in this paper that can be validated to some degree.

The entire method introduced in this paper for this example took one engineer 4 days to complete. The first day was used to gather the product development information and determine the social impact categories. The second day was spent selecting social impact categories. The final two days were spent creating the initial social impact models, which were continually improved. The example was completed using only the resources detailed in Secs. 2.1–2.4. This was one of the first attempts at completing the process. Once more experience has been gained with using the method in the paper, it is expected that it will not greatly affect the length of the product development process.

3.1 Step 1: Gather Product Development Information. The authors did not complete a design process for a border wall, and so the users, objectives, and requirements for the UMBW were all identified from publications, including a solicitation for building contractors to build border wall prototypes [32], a fact sheet on the UMBW and immigration policies from the White House [33], a Customs and Border Protection Roundtable [34], and an executive order from President Trump [26]. The product development information for the UMBW is given here:

Users

- (1) Communities close to the UMBW
- (2) Illegal immigrants
- (3) Border patrol officers

Objective

- (1) Support the border patrol, decrease illegal immigration, and prevent infiltration by cartels/criminals, traffickers, smugglers, and threats to both public safety and national security.

Requirements

- (1) The wall is at least 18 ft high
- (2) The wall is difficult to climb over
- (3) The wall prevents digging 6 ft under the wall
- (4) The wall resists breaching by hand tools (such as sledgehammers, battery operated impact and cutting tools, oxy/acetylene torch, and other similar hand-held tools) for at least 30 min but ideally for over 4 h
- (5) The wall is aesthetically pleasing from the U.S. side
- (6) The wall accommodates water drainage
- (7) The wall can be built on a slope up to 45%
- (8) The wall is cost-effective to build, maintain, and repair

3.2 Step 2: Identify Impact Categories. Using the product development information, three impact categories were identified: *conflict and crime*, *population change*, and *paid work*. After identifying these categories, the questions from Table 3 were used to identify three additional categories: *health and safety*, *civil rights*, and *family*. All of the categories that are related to the UMBW and how that relationship was found can be seen in Table 6.

3.3 Step 3: Selecting Indicators. The indicators that were chosen to assess the impact of the U.S. Mexico border wall were chosen for their ability to represent each impact category and be influenced by the wall's parameters and features. The impact indicators, organized by impact categories, are as follows:

Conflict and crime:

- n_{Arr} number of arrested illegal immigrants at the border
- n_{Att} number of attacks on border patrol
- n_{Crim} number of criminals arrested who are illegal immigrants

Table 6 The social impact categories and which question or objective was used to identify it

Impact categories	Relationship to the UMBW
Health and safety impact	Question 20: Impact personal or communal security
Paid work impact	Objective: Support Border Wall Officers
Civil rights impact	Question 13: Enhance social interaction, communication, and engagement
Family impact	Question 7: Potential to separate families
Population change impact	Objective: Prevent illegal immigration
Conflict and crime impact	Objective: Prevent infiltration of criminals
p_{Border}	% of arrested illegal immigrants who come through the border
n_{Enter}	number of illegal immigrants crossing the border
Population change:	
$n_{\text{Att.}}$	number of arrested illegal immigrants at the border
Paid work:	
$n_{\text{Off.}}$	number of border patrol officers
n_{Work}	number of illegal immigrants in the U.S. workforce
c_{Border}	annual spending on protection of the U.S. Mexico border
Family:	
n_{Children}	number of children crossing the border alone, illegally
$n_{\text{Fam.}}$	number of families separated as a result of illegal immigration
Civil rights:	
n_{Court}	number of illegal immigration court cases
t_{Court}	trial time of illegal immigration court cases
Health and safety:	
$n_{\text{Att.}}$	number of attacks on border patrol
n_{Deaths}	number of deaths of illegal immigrants crossing the border

The indicators for the UMBW were selected from the resources in Table 5 as well as anticipated impacts identified by the current presidential administration [34].

3.4 Step 4: Creating Models. The social impact indicators and categories were then translated into requirements and performance measurements, shown in Table 7. Some impact indicators are included in more than one requirement. This is common, as performance measures often influence many requirements. In the same way that performance measures are used to evaluate how well a product meets the user requirements, the indicators are used to measure how well the categories are impacted. As the product development process advances to system and subsystem refinement, indicators may be used as system or subsystem requirements or performance measures.

Models were then created for each performance measure so that their performance can be predicted. In the following equations, the subscript $[]_i$ is for the current value of the indicator and the $[]_f$ subscript is for the predicted value of the indicator. In this paper, a simplified form of Eq. (2) is used to create the predictive models,

$$Y = \alpha + \beta + \epsilon \quad (4)$$

The variables T and X from Eq. (2) are not used. Instead, the β term is able to take inputs for different wall concepts, including not building the UMBW. The ϵ term from Eq. (4) is represented in the

Table 7 The requirements (in bold) and performance measures (numbered) created for the UMBW; each of the performance measures has a predictive model in Sec. 3.4

The UMBW reduces crime by reducing the:	
1.	Number of arrested illegal immigrants at the border
2.	Number of attacks on border patrol
3.	Number of criminals arrested who are illegal immigrants
4.	Percent of illegal immigrants who came through the border
5.	Number of illegal immigrants crossing the border
The UMBW improves the safety of the border patrol and immigrants by:	
1.	Number of deaths of illegal immigrants crossing the border
2.	Number of children sent across the border illegally
3.	Number of attacks on border patrol
The UMBW helps the American workforce:	
1.	Number of border patrol officers
2.	Annual spending on U.S. Mexico border
3.	Number of illegal immigrants in the U.S. workforce
The UMBW reduces illegal immigration:	
1.	Number of illegal immigrants crossing the border
2.	Percent of illegal immigrants who came through the border
3.	Number of families separated as a result of illegal immigration
The UMBW improves the civil rights of immigrants:	
1.	Number of illegal immigration court cases
2.	Trial time of illegal immigration court cases

following equations with $\delta_{[]}$. This term accounts for how much the indicator changes independent of the UMBW.

For the requirement, the UMBW reduces crime, the model for predicting the number of arrested illegal immigrants at the border $n_{f\text{Att.}}$ is

$$n_{f\text{Att.}} = n_{i\text{Att.}} + [n_{i\text{Att.}}(1 - k_{\text{Change}})(k_{\text{Cross}}k_{\text{Sec.}}k_{\text{Change}}) - n_{i\text{Att.}} * k_{\text{Change}}] + \delta_{n_{\text{Att.}}} \quad (5)$$

where k_{Change} is the rate that illegal immigrants change how they cross the U.S. Mexico border, k_{Cross} is the rate of increase in the number of illegal immigrants crossing the border, and $k_{\text{Sec.}}$ is the security factor. The number of immigrants arrested at the border is the current value plus those who do not change how they cross the border and are caught at the border minus those who change how they cross the border. While k_{Change} and k_{Cross} are values from research on illegal immigration across the U.S. Mexico border [27], $k_{\text{Sec.}}$ is a function of the UMBW's engineering parameters. The security factor $k_{\text{Sec.}}$ is

$$k_{\text{Sec.}} = 1 - \frac{t_{i\text{Through}}}{t_{f\text{Through}}} \quad (6)$$

where $t_{i\text{Through}}$ is the time for someone to get through the current border and $t_{f\text{Through}}$ is how long it takes to get through the new border wall. Because of the inconsistency of the current border wall, the value of $t_{i\text{Through}}$ changes for different sections of the border as some of it already has a fence or barrier. The value of $t_{i\text{Through}}$ used in this paper is 60 s. The security factor is a measure of how much more time it takes to cross the border with a new UMBW design relative to crossing a border with a small fence. The security factor is used to scale many of the models used in this paper. Generally stated, if the UMBW does not change the security at the U.S. Mexico border then its social impact, as measured by the indicators in this paper, is small. The model for $t_{f\text{Through}}$ is

$$t_{f\text{Through}} = \frac{E_{\text{MR}}V_{\text{M}}}{P_{\text{T}}} \quad (7)$$

where E_{MR} is the energy per unit material removal rate, V_{M} is the volume of material to remove, and P_{T} is the power of the tool. The tool used in our model is a 2-hp cordless angle grinder. This tool was chosen because the UMBW requirements stated using only hand tools.

The model for the number of attacks on border patrol officers $n_{fAtt.}$ is

$$n_{fAtt.} = n_{iAtt.} + \left[n_{iAtt.} k_{Sec.} \frac{n_{fOff.}}{n_{iOff.}} \right] \delta_{Off.} + \delta_{nOff.} \quad (8)$$

The number of attacks on border patrol officers is a function of the UMBW's security and the number of officers.

The model for the number of arrested federal criminals $n_{fCrim.}$ is

$$n_{fCrim.} = n_{iCrim.} - [n_{iCrim.} (k_{Sec.} - k_{Change.})] \delta_{Att.} + \delta_{nAtt.} \quad (9)$$

This indicator represents one of the objectives of the UMBW, as stated by the current presidential administration, reduce the number of criminals in the U.S. [26]. The predicted number of arrested federal criminals is the current value minus those who will be arrested at the border plus those who will avoid arrest by entering the country by other means.

The model for the percent of arrested illegal immigrants who come through the border $p_{fBorder}$ is

$$p_{fBorder} = p_{iBorder} - [p_{iBorder} (k_{Sec.} + k_{Change.})] + \delta_{pBorder} \quad (10)$$

The percent of illegal immigrants who come through the border is dependent on how effective the UMBW is at keeping illegal immigrants out as well as how many will change how they enter the U.S.

The model for the number of illegal immigrants entering the country through the U.S. Mexico border n_{fEnter} is

$$n_{fEnter} = n_{iEnter} + [n_{iEnter} (1 - k_{Change.} - k_{Sec.} (1 - k_{Change.}) k_{Cross.})] + \delta_{nEnter} \quad (11)$$

The predicted number of illegal immigrants entering the country is the current value minus proportion of those entering through the UMBW who will not change how they enter and still make it into the country.

The model for the number of children who are sent alone to cross the border $n_{fChildren}$ is

$$n_{fChildren} = n_{iChildren} - [n_{iChildren} k_{Cross.} k_{Sec.}] + \delta_{nChildren} \quad (12)$$

The predicted number of unattended children crossing the border is the current number minus those who will decide to not cross because of the UMBW. This performance measure came directly from the discourse that President Trump had at a Border Protection Roundtable, as it was mentioned that the UMBW could help these children who cross the border alone and sometimes die on their way [34]. Currently, UMBW does not have features or parameters that can directly change how many children are sent to cross the border, only how many make it across the border.

The model for the number of illegal immigrants who die crossing the border $n_{fDeaths}$ is

$$n_{fDeaths} = n_{iDeaths} - [n_{iDeaths} k_{Cross.} k_{Sec.}] + \delta_{nDeaths} \quad (13)$$

As less people attempt to cross the border, less people will die on the trip across the border. If a new feature is added to the UMBW that further decreases the number of deaths of illegal immigrants, such as cameras or call stations, then this model would change to reflect that. Table 8 shows the potential that adding cameras to the UMBW can have on this indicator.

The model for the performance measure, the number of families separated as a result of illegal immigration $n_{fFam.}$ is

$$n_{fFam.} = n_{iFam.} - [n_{iFam.} k_{Return.} k_{Sec.}] + \delta_{nFam.} \quad (14)$$

As less people are able to cross the border and people return to their families, less families will be separated by the border.

The model for the performance measure number of border patrol officers $n_{fOff.}$ is

$$n_{fOff.} = n_{iOff.} - [n_{iOff.} k_{Replace.} k_{Sec.}] + \delta_{nOff.} \quad (15)$$

A border wall would impact the number of border patrol officers. As the UMBW deters illegal immigrants, the need for border patrol

Table 8 Predictions for the UMBW indicators using Eqs. (4)–(17). The predicted time to break through this UMBW design is also included $t_{Through}$.

Indicator	Current value	No UMBW estimation	Predicted value with UMBW	Impact of UMBW	Impact of UMBW with cameras
$n_{Att.}$	396,579	350,430	180,974	-169,457	-169,449
$n_{Att.}$	794	744	859	115	112
$n_{Crim.}$	45,069	49,619	36,895	-12,724	-12,723
p_{Border}	37.3%	22.4%	17.8%	-4.5%	-4.5%
n_{Enter}	510,000	381,428	300,222	-81,206	-81,231
$n_{Children}$	59,692	79,464	40,224	-39,240	-39,242
n_{Deaths}	294	259	66	-193	-223
$n_{Fam.}$	150,000	168,979	161,555	-7424	-7430
$n_{Off.}$	16,605	16,183	8615	-7568	-3069
$c_{Border.}$	\$13.94 bil.	\$14.32 bil.	\$14.32 bil.	-\$1.40 mil.	\$384,817
n_{Work}	7,800,000	7,142,870	7,088,996	-53,874	-54,415
n_{Court}	295,062	361,663	362,126	464	458
t_{Court}	746	774	775	1	1
$t_{Through}$	60	N/A	492	432	432

officers will decrease. The proportion that border patrol officers are replaced by the UMBW is $k_{Replace.}$. As the UMBW's security is high, less officers should be needed. Automated security systems could further decrease the number of officers who are needed at the border, see Table 8.

The model for the performance measure, the annual spending on the U.S. Mexico border $c_{fBorder}$ is

$$c_{fBorder} = c_{iBorder} + [n_{Off.} n_{New} c_{Off.} + c_{Repair} n_{Repair}] + \delta_{cBorder} \quad (16)$$

The cost and number of wall repairs per year are directly linked to the design and material selection of the UMBW. This model does not include the initial cost of building the UMBW.

The model for the performance measure, the number of illegal immigrants in the U.S. workforce n_{fWork} is

$$n_{fWork} = \left(n_{iWork} + n_{fEnter} \frac{n_{iWork}}{n_{iPop.}} \right) [1 - (k_{Arrest.} + k_{Return.})] + \delta_{nWork} \quad (17)$$

The number of illegal workers will be affected by how many workers are entering the country and how many are either leave for their home country or arrested.

The model for the requirement number of illegal immigration court cases n_{fCourt} is

$$n_{fCourt} = n_{iCourt} + [n_{iCourt} k_{Arrest.} k_{Return.} k_{Sec.}] + \delta_{nCourt} \quad (18)$$

As the UMBW assists border patrol officers to arrest more illegal immigrants, the number of court cases will increase, but as illegal immigrants return to their families, the number of court cases decreases. The UMBW does not affect the number of arrests that occur away from the border. This is captured in $k_{Arrest.}$.

The last indicator is the trial time of illegal immigration court cases $t_{fIll. Court}$. The model for this performance measure is

$$t_{fCourt} = t_{iCourt} + [t_{iCourt} k_{Arrest.} k_{Return.} k_{Sec.}] + \delta_{tCourt} \quad (19)$$

As there is a backlog of immigration court cases, as long as more people are arrested, the trial time for court cases will continue to increase [35].

The models presented in this section represent only one of the iterations of their development. As more knowledge about the social impact of the UMBW was gained, the initial models were improved. An example of this is with the addition of two variables, the factors that accounts for the change in number of people attempting to cross the border $k_{Cross.}$ and the rate that people change their border crossing method $k_{Change.}$. These factors came from a study on how border enforcement on the U.S. Mexico

border has impacted the behavior of illegal immigrants attempting to enter the U.S. [27]. If more findings on the UMBW's social impact were to be released, these models should be updated.

3.5 An Assessment of the Validity of UMBW Predictive Models. To assess the validity of the models used in this paper, we have examined four elements of the models: the indicator-level models, the parameters used in each indicator-level model, the structure of the top-level impact models (functions of indicator-level models), and the propagation of error from unknown parameters to top-level impact models.

In Sec. 3.4, indicator-level UMBW models were developed and the logic associated with each one was presented. The logic for each model is based on how the UMBW could reasonably impact the indicators present value. For example, the predictive model for the number of illegal workers in the U.S. (Eq. (17)) is the current number of illegal workers, plus the number of incoming workers, minus those who will get arrested or leave the country, plus the expected change in the number of illegal workers without the existence of the UMBW. The logic, upon which each model is built, is based on current research on immigration trends and therefore considered by the authors to be reasonable. Nevertheless, we believe UMBW models to be akin to any engineering model in that as more information is gained, the models can be improved.

There are 44 input parameters that are used in the indicator-level models. 37 of 44 parameters come directly from databases or from the archival literature, 2 parameters are calculated, and 1 is observed data (see Table 9). Even so, each parameter is uncertain to some degree. To account for this, when the parameter value is obtained from a database or the published literature, calculated, or observed, we impose Gaussian uncertainty bound of at least a $\pm 5\%$ centered around the published value as the mean. The four parameters that are estimated have a greater uncertainty, and thus, a larger Gaussian uncertainty bound is used, $\pm 10\%$ error.

The structure of the top-level impact model is a simple aggregation of indicator-level models and is patterned after [6], which was derived from the UNs Multidimensional Poverty Index. Although there are many potential ways to model impact, we believe the approach presented in this paper is a reasonable starting point based on what is found in the literature.

The error propagated from the uncertain input parameters to the top-level impact model was handled by a monte carlo simulation with 1 million samples [36]. This simulation is valuable because it allows us to better understand the models sensitivity to uncertain parameters and to declare confidence levels for the predictions made in this paper. We use the same approach as Mattson et al. [37].

3.6 Predictions. In order to make predictions for the social impact of the UMBW, a specific design has to be selected to make specific predictions for. The design used to make predictions in this paper is one of the prototypes that were built near the San Diego border in 2018 [38]. It is composed of a concrete foundation with square steel tubes for the lower half of the wall with a top section made of concrete, see Fig. 2. The predictions that have been made for this wall design can be seen in Table 8.

One way of using the indicators presented in this paper is to aggregate them into a single value to assist in decision-making or optimization [6]. While this may not allow for a deep understanding of the product's impact, it is useful for comparing product options or different design parameters. Table 10 shows the results of an approach of aggregating the social impact indicator values for the UMBW. This approach is similar to what the UN uses in several metrics such as the Human Development Index and the Multidimensional Poverty Index [40,41]. As a first step in the approach, indicators are normalized by calculating the percent change P of each indicator. For each stakeholder group, the P values have to be interpreted to be either a positive change or negative change, by making the value either positive or negative. Then, the P values are added together into their respective impact categories C . The average value of each category $\bar{C}$ is

Table 9 Descriptions and data sources for the parameters used in Eqs. (5)–(19)

Description	Parameter	Source
Current, annual, national budget for border	c_{IBorder}	[44]
Cost of a border patrol officer	c_{Off}	[44]
Predicted cost of a typical border wall repair	c_{Repair}	[45]
Current, annual change to c_{IBorder}	$\delta c_{\text{IBorder}}$	[46,44]
Current, annual change to n_{Arr}	δn_{Arr}	[47]
Current, annual change to n_{Att}	δn_{Att}	[48]
Current, annual change to n_{Children}	$\delta n_{\text{Children}}$	[49]
Current, annual change to n_{Court}	δn_{Court}	[50]
Current, annual change to n_{Crim}	δn_{Crim}	[51]
Current, annual change to n_{Deaths}	δn_{Deaths}	[52]
Current, annual change to n_{Fam}	δn_{Fam}	[53,54]
Current, annual change to n_{Off}	δn_{Off}	[55]
Current, annual change to n_{Work}	δn_{Work}	[56]
Current, annual change to t_{Court}	δt_{Court}	[35]
Increase border arrests factor	k_{Arr}	[57]
Changing location/method of entering country factor	k_{Change}	[27]
Increased border crossing factor	k_{Cross}	[47]
Return to home country factor	k_{Return}	[58]
Length of UMBW	l_{Wall}	[26]
Current length of border barriers	l_{fWall}	[59]
Current annual border arrests	n_{iArr}	[47]
Current attacks on border officers	n_{iAtt}	[48]
Current, unaccompanied minors entering	$n_{\text{iChildren}}$	[49]
Current, annual, new immigration court cases	n_{iCourt}	[50]
Current, annual, federal criminal arrests	n_{iCrim}	[51]
Current, annual, illegal immigrant federal criminal arrests	$n_{\text{iCrim. Ill}}$	[51]
Current, annual illegal immigrant deaths while entering	n_{iDeaths}	[52]
Total illegal immigrants entering	n_{Enter}	[60]
Illegal immigrants entering through the border	$n_{\text{Enter Border}}$	[60]
Current illegal immigrant families separated	n_{iFam}	[61]
Annual new border officers	$n_{\text{New Off}}$	[55]
Current border officers	n_{iOff}	[55]
Current illegal immigrants	n_{iPop}	[56]
Current illegal workers	n_{iWork}	[56]
Percent of illegal immigrants entering across border	p_{iBorder}	[60]
Current border county crime rate	r_{iCrime}	[62]
Current time for average illegal immigration court case	t_{iCourt}	[35]
Increased security factor	k_{Sec}	Calculated
Predicted time to cross with UMBW	t_{fThrough}	Calculated
Current time to cross	t_{iThrough}	Observed from online videos
Current, annual change to n_{Enter}	δn_{Enter}	Estimated
Current, annual change to p_{Border}	δp_{Border}	Estimated
Replace border patrol officer factor	k_{Replace}	Estimated
Predicted, annual number of repairs to the UMBW	n_{Repair}	Estimated

calculated and used to calculate the total impact I_T

$$I_T = \sum_{i=1}^n \frac{\bar{C}_i}{n} \quad (20)$$

This I_T value is the average percent change to all of the impact categories. Finally, the average percent change to all of the impact categories of a control group I_C is subtracted from I_T to find the actual impact.

Deciding whether the impact of the U.S. Mexico border wall is positive or negative is not trivial. For any product, there can be positive and negative impacts for each impacted group. Table 8 shows the actual impact that is predicted for the border wall for each indicator, an increase or decrease to each indicator, but does not indicate whether these changes are good or bad. Determining if an increase or decrease is a positive or negative impact is dependent on the



Fig. 2 One of the prototypes for the UMBW, which was built in San Diego, CA [39]

stakeholder needs. For the example in this paper, three stakeholders are accounted for: border patrol, local communities, and illegal immigrants. The choice of whether an impact is positive or negative for each stakeholder should be made independently from the other stakeholders. Incidentally in this paper, border patrol and local communities share the same positivity and negativity for each indicator while the positivity/negativity of some indicator values are different for illegal immigrants. The UMBW is predicted to have a net positive impact on border patrol and local communities and a net negative impact on illegal immigrants, as shown in Table 8.

3.6.1 Specific Predictions. Table 8 shows different predictions for each indicator in different scenarios. The column labeled Current Value is the most recent available indicator value, No UMBW Estimation is a prediction of future indicators values assuming no wall is built, Predicted Value with UMBW is a prediction assuming the UMBW shown in Fig. 2 is built, Impact of UMBW is the impact of the UMBW following Eq. (3) where YT is the Predicted Value with UMBW and YC is the No UMBW Estimation, and Impact of UMBW with Cameras is the impact of the UMBW following Eq. (3) where YT is the predicted values of the UMBW with cameras (not shown in Table 8) and YC is the No UMBW Estimation.

According to the models presented in this paper, we predict that the UMBW will decrease the number of illegal immigrants who enter the country through the border on foot (Table 8, n_{Att}). At the same time, we predict that a higher percentage of illegal

immigrants will enter the U.S. through other ways such as overstaying non-immigrant visas (Table 8, p_{Border}). Already, more people enter the country illegally by overstaying visas than crossing the border on foot [42]. It is predicted that a border wall would increase the rate that illegal immigrants enter the country by other means.

Also, we predict that the border wall will have some negative impacts on border patrol officers and local communities. We predict that the number of assaults on border patrol will increase slightly (Table 8, n_{Att}) and the number of border patrol officers will decrease as the UMBW can do the work of many officers (Table 8, n_{Off}). Reducing the number of border patrol officers will also have a negative impact on border communities where border patrol officers are employed. Even so, the annual spending on the border will not change significantly (Table 8, c_{Border}). As border officers are laid-off, the costs of maintaining the UMBW will replace the cost of the laid-off officers.

It is predicted that, illegal immigrants will be negatively impacted by the UMBW. Less illegal immigrants will be able to enter the country through the border, which will make entering the country more difficult. As illegal immigrants find a new method of entering the country, we predict that more illegal immigrants will be arrested by Immigration and Customs Enforcement (ICE) officers than border patrol officers. ICE arrests often go to court, which means that the number of illegal immigration court cases will increase (Table 8, n_{Court}).

As another step in probing the validity of the models developed, a prediction of each indicator when no wall is built is also included in Table 8. This is done as a way of comparing to the current indicator trend. The results of the study show that for all but three of the indicators, the no-UMBW estimation and the UMBW prediction will both either increase or decrease the indicator value similarly. For example, the models predict that both options will decrease the number of arrests at the border (Table 8, n_{Att}) but by different amounts. Further, it is predicted that for three of the indicators, building the UMBW will have an opposite effect when compared with not building the UMBW. These three indicators are, the number of attacks on border patrol officers (n_{Att}), number of federal criminals arrested (n_{Crim}), and the number of unattended children crossing the border (n_{Children}). If the current trends for these indicators continue,

Table 10 Synthesizing the social impact data for each stakeholder group

Method	Without cameras		With cameras	
	Border patrol and communities	Illegal immigrants	Border patrol and communities	Illegal immigrants
Average	0.1549	−0.0714	0.1663	−0.0623

it is estimated that without building the UMBW, $n_{Att.}$ will decrease, $n_{Crim.}$ will increase, and $n_{Children}$ will increase. According to our predictive models, the UMBW has the potential to increase $n_{Att.}$ and decrease $n_{Crim.}$ and $n_{Children}$.

3.6.2 Synthesized Predictions. By modeling what the impacts of the UMBW are on immigrants, border patrol, and local communities, the methods by which the impact of the UMBW can be improved are found. Social impact indicators can help the engineer identify product features that could improve the impact on all identified stakeholders. For example, the indicator, deaths along the U.S. Mexico border (n_{Deaths}), negatively impacts all of the stakeholder groups identified. If a new UMBW feature could reduce n_{Deaths} then it would positively impact stakeholders. One such feature could be sensors and cameras along the UMBW where the most number of deaths occur. A system of cameras or sensors that alert border patrol agents when illegal immigrants are in dangerous areas along the border could help save lives and improve the social impact of the UMBW. It is estimated that by adding cameras to the UMBW, the impact of the UMBW on border patrol and border communities is made more positive by 0.0113, an 8.27% increase, and the impact on illegal immigrants is made more positive by 0.0091, a 6.68% increase (Table 10).

3.6.3 Sensitivity Analysis. A sensitivity analysis was conducted to determine the sensitivity the synthesized impacts have to the parameters in Eqs. (5)–(19) that were estimated ($\delta_{n_{Enter}}$, $\delta_{p_{Border}}$, $k_{Replace}$, n_{Repair}), see Table 11. It was found that when doubling the standard deviation of the parameter values, the sensitivity to these parameters is still very small. This may be due in part to how the final synthesized impacts are calculated, following Eq. (3). Potentially, the added uncertainty of these parameters may be canceled out because these parameters only appear in one equation each and are present in the impacted and control groups.

4 Concluding Remarks

Creating social impact models requires that the engineer and other members of the development team are well informed of the social factors that are affecting the indicators. Most often, the product is not the only influence that is changing indicator values. This can be seen with the U.S. Mexico Border Wall example. The indicators related to civil rights are also impacted by government policies regarding the rights of illegal immigrants. In fact, the UMBW's construction, maintenance, staffing, and completion are all impacted by government policies. This is true for many other products as well. Medical devices, automobiles, and buildings are all subject to changing government regulations that may change their social impact models.

Some of the factors that are created in the initial models will likely change as more information is gained. Many of the models for the U.S. Mexico border wall use a factor called the security factor $k_{Sec.}$. The purpose of this factor to measure how much more effective the border wall is at inhibiting people from crossing

the border. It is possible that after further testing the models, a single factor that scales many models is found to be insufficient.

Simple models, such as the models used in this paper, are likely what will be used to predict a product's social impact in the early stages of product development. Even simple social impact models can be used to improve a product's design. Using the simple models used in this paper for the U.S. Mexico border wall, it was found that by decreasing the number of deaths along the border, all stakeholders are benefited. This indicator was used to brainstorm new features that can improve the border wall's social impact. At least initially, instead of focusing on creating models that are perfectly accurate, it can be more important that they are useful [43].

Often social impact is depicted as a complex problem that cannot be constrained in a way that is usable for engineers. In this paper, it is shown that models can be created that predict the social impact of an engineered product. Because this method starts with information that the engineer already collects in the product development process, this new method of predicting and improving a product's social impact can be completed concurrently with traditional product development processes. By implementing the method introduced in this paper with an existing product development process, an engineer can have social impact indicators as performance measures alongside traditional engineering performance measures. This will enable an engineer to possibly optimize a design based on both the functional performance and its social performance.

As this paper simply introduces a method of modeling a product's social impacts, there is future work to be done. First, more complex models of product social impact could be explored. As Eq. (2) is a common method used by social sciences to predict the impact of social programs, it was used in this paper. It is possible that social impact models for products could have different forms depending on the product and impact. New visualization, data collection, and prediction techniques could allow product impact predictions to use more complex models as well. Future studies on impact modeling could be focused on how to account for multiple stakeholder types, such as humans, plant and animal life, and governments and companies, simultaneously. Such a method holds the potential to increase products sustainability. Another item of future work is how to handle multiple stakeholder groups of different sizes and to discover how the population size affects the prediction (e.g., individuals and populations.).

Nomenclature

C_{Border}	= U.S. annual federal budget for the U.S. Mexico border
$C_{Off.}$	= annual cost of a border patrol officer
C_{Repair}	= typical cost of a border wall repair
$k_{Arr.}$	= rate that illegal immigrants are arrested in the U.S.
k_{Change}	= rate illegal immigrants change the method of crossing U.S. Mexico border
k_{Cross}	= rate of increase in the number of illegal immigrants attempting to cross the U.S. Mexico border
$k_{Replace}$	= rate that border patrol officers are replaced by the border wall
k_{Return}	= rate that illegal immigrants return to their countries
$k_{Sec.}$	= security factor
l_{Wall}	= length of border wall
$n_{Arr.}$	= number of illegal immigrants arrested along the border
$n_{Att.}$	= number of attacks on border patrol
$n_{Children}$	= number of unaccompanied children that cross the border
n_{Court}	= number of illegal immigrant court cases throughout the country per year
$n_{Crim.}$	= number of federal criminals
$n_{Crim. Ill.}$	= number of federal criminals that are illegal immigrants
n_{Deaths}	= number of illegal immigrants who die attempting to cross the border
n_{Enter}	= total number of illegal immigrants who enter the country
$n_{Fam.}$	= number of illegal immigrant families separated
$n_{Off.}$	= number of border patrol officers.
$n_{Off. New}$	= number of border patrol officer new hires (annual)

Table 11 Sensitivity analysis of the parameters which are estimated, see Table 9

	UMBW no camera		UMBW with camera	
	Border patrol and communities	Illegal immigrants	Border patrol and communities	Illegal immigrants
$\delta_{n_{Enter}}$	4.44E-04	4.37E-05	-3.07E-05	5.23E-06
$\delta_{p_{Border}}$	4.19E-04	9.54E-06	2.43E-04	2.80E-04
$\delta_{n_{Fam.}}$	-4.47E-04	-1.04E-03	-1.10E-03	-1.37E-03
$k_{Replace}$	-3.84E-04	-9.72E-04	-6.80E-04	-1.25E-03
$n_{Repairs}$	2.50E-05	-5.89E-05	2.04E-05	5.23E-06

n_{Pop} = number of illegal immigrants in the U.S. population
 n_{Repair} = number of border wall repairs
 n_{Work} = number of illegal immigrant workers in the country
 p_{Border} = percentage of illegal immigrants enter the country by walking across the U.S. Mexico border instead of other entry methods (i.e., overstaying visas)
 r_{Crime} = crime rate in counties along the UMBW
 $r_{Crime III}$ = crime rate, from illegal immigrants, in counties along the UMBW
 t_{Court} = time for an illegal immigration court case from beginning to end
 E_{MR} = energy per unit volume material removal rate
 P_T = wall breaching tool horsepower
 V_M = volume of material removed to breach through the UMBW

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