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A Methodology for the Extraction of Design Principles

for Unfamiliar Markets

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

A Methodology for the Extraction of Design Principles
for Unfamiliar Markets

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Master of Science

Successful product design focuses on design principles that are relevant to a target market. Consequently, the better these principles are understood and used, the higher the likelihood that resulting products will be well-received in that market. This thesis presents a method for extracting market-specific design principles for any market. The method employs user/designer-described characteristics of products within a market to extract the design principles specific to that market. The method generalizes the product characteristics, seeks to discover design decisions that could have resulted in those characteristics, and then extracts the underlying design principles. To demonstrate the ability of the method to extract such principles, the method is applied to two disparate markets; (i) best-selling products in the US, and (ii) products created for the developing world. The two sets of resulting principles are compared and shown to be market-specific. The author conclude that the method indeed results in market-specific principles that can be used to guide design activities.

ACKNOWLEDGMENTS

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LIST OF FIGURES

C_i	Product characteristic i
G_i	General characteristic i
R_i	Root cause i
P_i	Design principle i
O_{C_i}	Number of occurrences of product characteristic i
O_{G_i}	Number of occurrences of generalized characteristic i
O_{R_i}	Number of occurrences of root cause i
O_{P_i}	Number of occurrences of design principles characteristic i
n_{pc}	Number of unique product characteristics
n_{gc}	Number of unique general characteristics
n_{rc}	Number of unique root causes
n_{dp}	Number of unique design principles
V_i	Normalized importance value of design principle i
L	Matrix of O_{C_i}s used to calculate O_G
M	Matrix of O_{G_i}s used to calculate O_R
N	Matrix of O_{R_i}s used to calculate O_P

CHAPTER 1.   INTRODUCTION

Product design teams often develop goods for familiar markets. However, these design teams may need to design for unfamiliar markets. While designers may intuit design principles for markets they are familiar with, intuition alone is not sufficient for designing for unfamiliar markets. Therefore, it would be useful for designers to have formalized methods to extract market-specific design principles from information about products within that market. This thesis presents a method for extracting market-specific design principles for any market. A useful and accessible body of information about a market is contained within user/designer descriptions of products in that target market. As such, the method presented herein employs these descriptions of products within a market to extract the design principles specific to that market. For the purpose of this thesis, a design principle is defined as a fundamental proposition used to guide the design process.

Design principles specific to a market can guide the development of products for that market [1, 2]. The better the design team understands and uses these market-specific principles, the higher the likelihood that the design efforts will result in products that are well-received in that market. In situations where these principles are not explicitly known or understood, designers will often focus on principles that they have observed in their other design experiences [3, 4]. However, when designing products for unfamiliar markets (e.g., designers from the US creating products for the developing world), the chance of creating products that are not well-received is increased. To reduce this risk, the proposed method enables designers to establish design principles for unfamiliar markets even when there is limited personal or team experience with the market.

One market with limited information and unfamiliar to most US designers is the market that exists in the developing world. The poorest people in the developing world represent a $5 trillion market [5]. Many difficulties arise when design teams attempt to develop products for the developing world due to the geographical location and cultural differences of the developing world relative to the designers [6, 7]. As such, if design principles specific to this market could

be understood without requiring designers to visit or live in the developing world, the barrier for engineers to become involved in designing products for the developing world would be decreased.

Based on this understanding, the hypothesis for this research was developed. The hypothesis states that products within a market contain information within their product characteristics that embody design principles that can be used to guide the design process. This thesis develops a method to test this hypothesis. The method begins by identifying products that are within the target market. As will be shown, characteristics of those products can then be extracted from user and designer descriptions of those products. Using the method to generalize these product-specific characteristics, design principles for the target market are then extracted from the root causes of the generalized characteristics. The resulting design principles extracted by the method can then be utilized by the designers to guide their design efforts.

The method presented in this thesis is illustrated using two case studies for disparate markets. The first case study applies the method to products in the US. This case study provides a reference to ensure the method is extracting useful design principles. The second case study applies the method to products created for and implemented in the developing world. The two sets of resulting principles are compared and shown to be market-specific in the principles themselves and in their normalized importance values. The author concludes that the method indeed results in market-specific principles that can be used to guide design activities.

CHAPTER 2.   LITERATURE REVIEW

The method developed in this thesis extracts design principles for any unknown markets to improve the design process. For this thesis, the design process is defined from Pahl et al. as a 4 stage process [8]. These stages are: (i) planning and task clarification, (ii) conceptual design, (iii) embodiment design, and (iv) detail design as shown in Figure 2.1. A major motivation for this research was design for the developing world, discussed in Section 2.1. When designing different products for the developing world, it was observed that the planning and task clarification stage was difficult to perform due to differences in market and culture of the target customer when compared to the designer. Thus, a survey of the current literature was performed to identify if this stage in the design process could be improved for the developing world.
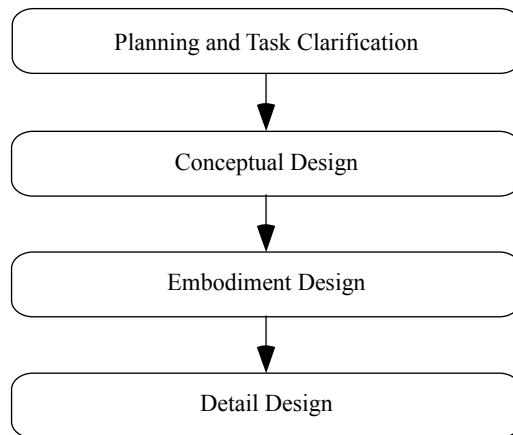
Figure 2.1: The stages of the design process.

Within the literature four main topics were researched. The first topic was design for the developing world. This helped identify problems that exist when designing for the developing world and possible areas for improvement. The next topic researched was methods for identifying customer needs. Five different methods were reviewed to help establish the current practices and

how they relate to the designing products for unfamiliar markets. Design principles was the next topic reviewed in the literature. As explained in Chapter 1, the hypothesis of the research is that products within a market contain information within their product characteristics that embody design principles that can be used to guide the design process. Researching design principles within the literature clarified the current understanding of design principles. Finally, failure modes and effects analysis (FMEA) was reviewed as the method in this thesis is loosely based on FMEA. After the reviewing these topics, opportunities for new research is discussed.

2.1 Design for the Developing World

There are approximately 1.4 billion people in the world who live on less than $1.25 a day [9]. In recent years, government and multinational agencies acting on the Millennium Development Goals have sought to improve the quality of life of this group of people [10, 11]. As a result of these efforts, many potential avenues of accomplishing this goal have been identified [12]. Two of these potential high impact avenues are through the development of products that enable the impoverished to increase their income and through the development of products that improve their quality of life [13, 14]. Two common approaches for product design in the developing world are (i) appropriate technology development and (ii) market-based development.

Appropriate technology development often focuses on time and labor saving technologies with an emphasis on community ownership [15–18]. While many solutions from appropriate technology development have fulfilled their purpose, there have been problems with lack of individual ownership, poor maintenance of the product, and lack of reliable supply chains [19].

Alternatively, a market-based approach focuses on technologies that increase an individual's income with an emphasis on individual ownership [15, 20, 21]. While market-based development has helped millions of people escape poverty [15, 22], the limited purchasing power of the target customers has restricted these benefits from expanding to those unwilling to take the financial risks required to invest in these products [5, 23, 24]. While both of these approaches have sought to guide designers creating products for the developing world, neither approach has solved the problem of designing for an unfamiliar market. As such, a method for extracting design principles for any market would be valuable.

2.2 Customer Needs

Identifying customer needs is a major step in the planning and task clarification stage of the design process. When designing for a familiar market, there are different methods that could be used to identify and interpret customer needs. These include the lead user method, empathic design, focus groups, and benchmarking products, while quality function deployment helps to rank customer needs by importance. It will be shown that while these methods are useful, most are difficult to use when designing for an unfamiliar market, such as the developing world.

2.2.1 Lead User Method

The lead user method is a useful way of gaining valuable insight into customer needs. When using the lead user method, designers rely on advanced users who have needs that are not completely satisfied by current products [25]. By not having their needs completely satisfied, the lead user has a deeper understanding of the shortcomings of current products. The designer can interview the lead users and apply their insights into new product development.

By using the lead user method, the cost and time when developing a product can be decreased [26]. Additionally, lead users may have developed their own solution to the problem [4]. These solutions from lead users can be transferred into a real marketable product [27]. It has also been shown that when the lead user method is used successfully in product development, the products will be better accepted within their market [28].

The lead user method is effective at improving both the product and the design process through the identification of customer needs. However, when designing for an unfamiliar market, it can be difficult to both identify and interview lead users. This lack of access to lead users is especially true when designing a product for the developing world where there can be distance, language, and cultural obstacles.

2.2.2 Empathic Design

With empathic design, the designer observes the customers using products in the customers own environment to identify trends [29]. By observing the product in use, the designers gain useful insights that may be difficult to identify using other design methods. These insights can help

designers be more innovative when creating products for an unfamiliar market [30]. However, empathic design is not something performed easily but requires structure and commitment to achieve the greatest results [31, 32]. While observing customers is useful, it is also beneficial when users are included in the design process [33].

When designing for an unfamiliar market, especially one that is inaccessible, it becomes cost prohibitive to perform empathic design. It is true that you can still attempt to understand how the customers use the product. However, without the customer interaction during product use empathic design loses effectiveness. Thus, empathic design is difficult to use when designing for the developing world.

2.2.3 Focus Groups

Focus groups are performed when customers are brought together into a group to identify customer needs [34]. It has been shown that focus groups are as effective at identifying customer needs as interviewing individuals [35]. Therefore, focus groups make up an important method for identifying customer needs and market research in the US. However, because of the lack of access to customers in the developing world, it can be difficult to use focus groups to identify customer needs within that market.

2.2.4 Benchmarking

With benchmarking, designers examine current products to gain insight into customer needs and product performance [4]. When using insights gained from benchmarking, there can be improved results [36]. Since designers have access to information about many of the products in the developing world, benchmarking can be performed within that market. Thus, benchmarking can be used to gain insights into the developing world where the previous methods encountered difficulty. The difference is the shift away from examining customers to examining products. As this fundamental difference allowed benchmarking to be successful in the developing world, it was decided that the method would look at characteristics of products currently within the market. This would relieve some of the difficulty of trying to utilize customers within the developing world.

2.2.5 Quality Function Deployment

Quality Function Development (QFD) has many uses within product design [37, 38]. One of those uses is helping to satisfy customer requirements [39]. Customer requirements are satisfied because QFD helps designers identify which customer needs are most heavily weighted for customer satisfaction [40]. This is done by using a house of quality [4]. Understanding which customer needs have the largest impact on customer satisfaction allows the designers to understand which customer needs are most critical in the product. Effectively using this information can result in a reduction of both cost and time during the design process [41].

Quality function deployment helps demonstrate that it is useful for designers to know which customer needs are most critical. While it is fairly straight forward to arrive at these needs in a familiar market, it can be much more difficult when designing for an unfamiliar market. This is due to the lack of customer needs information within the developing world.

2.3 Design Principles

A design principle is a fundamental proposition used to guide the design process. Therefore, if design principles could be defined for the developing world in the first stage of the design process, then it would improve the whole design process. However, design principles can be difficult to define as their definitions vary across different fields [42]. One person may define it as common elements [43], while another may define it as a strategy or recommendation for design [8]. Others have tried to develop lists of principles to guide design [44], but these are often generalized for many different areas. This confusion has prevented a standard set of design principles from being developed for product design. However, when design principles are understood and implemented, it can be useful for creating new products [45]. Thus it would be useful to have a set of design principles for product design or a way to develop design principles for each individual case.

Using this definition, the method seeks to establish a way of extracting design principles for any market, including the developing world, from characteristics of products within that market. This will allow the designers to have a set of principles for a specific market that can guide the design process to improve the product without requiring extensive interaction with customers.

Table 2.1: Comparison of FMEA and the author's method.

FMEA	Author's Method
Identify Potential Failures	Identify Generalized Characteristics
Identify Potential Causes of Failures	Identify Root Causes of Characteristics
Risk Assessment for each Cause	Compute Normalized Importance Value
Plans to Minimize Failure Risk	Extract Design Principles To Minimize Risk of Product Failure

2.4 Failure Mode and Effects Analysis

The FMEA framework is loosely related to the framework of this thesis' method (see Table 2.1). Therefore, it is useful to establish some similarities between the two methods. FMEA looks at components of the product, analyzes them for possible failures, identifies how sever those failures will be, and then minimizes the risk of the failure [8, 46]. The method developed in this thesis looks at characteristics of the product, extracts generalized characteristics, identifies root causes of the characteristics, and then extracts design principles to help improve the product. FMEA identifies components of the product while the method in the thesis identifies characteristics of the product. Each method then performs brainstorming to identify important information, FMEA for potential failures and causes of those failures and the thesis' method for root causes of the characteristics. Both methods then seek to minimize risk of product failure. Therefore, each method is a systematic approach to examining the products to reduce the risk of failure.

2.5 Opportunity for Research

The literature has shown different methods that assist designers in understanding the needs of the customers to help guide the design process. While some of these methods have been demonstrated to improve the design process, they become difficult to use when customers are not accessible. However, benchmarking has proved useful due to the focus on products instead of customers. Additionally, when an accurate set of design principles are used in product design, the product benefits. The literature has shown that it can be difficult to obtain an accurate set of design principles for product design. Therefore, there is an opportunity to create a method that establishes design

principles for unfamiliar markets. One of these unfamiliar markets is the developing world. The developing world is experiencing an increase in product design for poverty alleviation. However, it can be difficult for designers in the US to create successful products for the developing world due to their unfamiliarity with that market. A method that establishes design principles for any unfamiliar market would be useful.

CHAPTER 3.   METHOD FOR EXTRACTING DESIGN PRINCIPLES

This section presents a methodology for extracting design principles for any market by looking at product information within that market. Product information can come from lead user surveys [28], customer reviews [47], product reports, and other product research. After this information is gathered as described in Section 3.2, product characteristics are identified from the information. As the characteristics are specific to the product, the next stage of the method generalizes the characteristics. After the set of generalized characteristics has been created, root causes are then identified. Root causes are possible design decisions made during the design process that may have resulted in the generalized product characteristics. As such, there may be multiple root causes for each generalized characteristics. From the root causes, design principles are extracted. The flow of information can be seen in Figure 3.1. Figure 3.2 illustrates that the presented method incorporates five major process steps and four intermediate filtering steps. Referring to Figure 3.2, each step is now discussed.
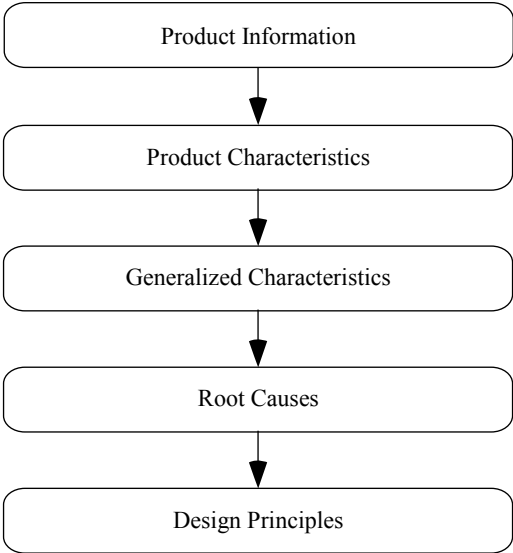
Figure 3.1: Flow chart showing the path from product information to design principles.
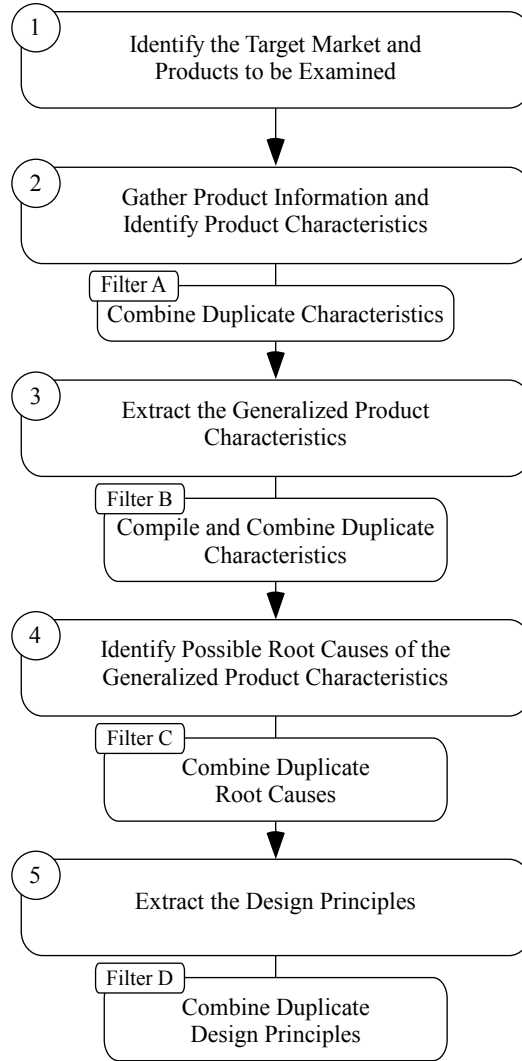
Figure 3.2: Flow chart describing the presented five-step method with filters for identifying design principles.

3.1 Step 1: Identify the Target Market and Products to be Examined

The first step of the method is to identify the target market where the new product will be distributed. After establishing the target market, existing products within this market are identified.

Increasing the number and types of products being examined will increase the understanding of the consumer behavior within the selected market. However, information from similar products to those being designed can be more useful than information from unrelated products. For example, if the product being designed is a garden tool, focus should be placed on examining

many different garden tools. However, by limiting the scope to these tools, the information gathered is specific to that market segment and does not provide a strong understanding of consumer behavior within the larger market. Similarly, expanding the scope away from garden tools can lead to unnecessary principles for designing a specific garden tool. Therefore, there is an important trade-off that must be considered between the products being examined and the market segment for the new product. When the goal of using the method is to better understand the market as a whole, a wider variety of products should be considered. Likewise, if the goal is to understand a specific market segment, then limiting the scope of products to that segment is preferred.

The author recognizes that determining the number of products and the amount of product information that should be gathered can be a difficult decision. As a guide, in the case study in Section 4.1, the author looked at an average of 175 customer reviews for 10 different products for a total of 1,764 customer reviews and from them obtained many useful design principles.

3.2   Step 2: Gather Product Information and Identify Product Characteristics

The second step of the method gathers information for the products identified in Step 1 and uses this information to identify product characteristics. For each product, information describing the product's fit, form, or function is gathered. This is accomplished through examination of the products within the market, lead user surveys, customer reviews, product reports, and other product research. In situations where insufficient information is available on the target market, information from a closely related market may be used.

The characteristics identified from the product information define the fit, form, or function of the products. To illustrate this, consider a cooking stove for use in developing countries. Potential characteristics of this product may be: *the stove does not work well with traditional wood used in cooking fires* or *the stove is inexpensive*.

During this process, identifying characteristics using information that does not define the fit, form, or function of the products may lead to unimportant or misleading principles. To avoid this, information representing user emotion, product warranties, marketing strategies, etc. should not be used in the method. For example, "I am happy with the cook stove" does not tell the designer why the customer is happy while "I am happy with the cook stove's size" tells the designer that

size is important. Step 2 is complete when all of the gathered information has been examined for characteristics.

3.2.1 Filter A: Combine Duplicate Characteristics.

At the end of Step 2, the information is filtered to combine duplicate characteristics from a single product. However, it is important to track the number of occurrences for each characteristic, or how many times a characteristic is identified within the product information. For the example of the stove from Step 1, if *the stove is inexpensive* was mentioned five times in the product information, the number of occurrences for that characteristic would be five. Tracking these occurrences will help designers understand which design principles occur more frequently in the target market. Filter A is subsequently performed separately for each product being examined.

The variables used to keep track of the number of occurrences for each product characteristic is now defined. By using the the following steps to track occurrences, the designer is able to perform other analysis on the informations, such as principle component analysis.

$$C = [C_1, C_2, ..., C_{n_{pc}}] \tag{3.1}$$

where C_i is the ith product characteristic and n_{pc} is the number of unique product characteristics. Also

$$O_C = [O_{C_1}, O_{C_2}, ..., O_{C_{n_{pc}}}] \tag{3.2}$$

where O_{C_i} is the number of times that product characteristic i occurs in the product information. So for each C_i, we have an O_{C_i} that stores the number of occurrences for product characteristic i.

For the example of the stove, *the stove is inexpensive* is mentioned five times. Therefore C_1 is *the stove is inexpensive* and O_{C_1} is 5.

3.3 Step 3: Extract the Generalized Product Characteristics

In this step of the method, the product characteristics identified in the previous step are converted into generalized product characteristics. This takes characteristics specific to the product

and makes them applicable to a wider variety of products. Returning to the example of the stove, one potential characteristic of the product was: *the stove does not work well with traditional wood used in cooking fires.* To convert this statement into a generalized product characteristic requires the words "stove" and "wood used in cooking fires" be replaced with general terms. Therefore, a suitable generalized product characteristic would be: *the product does not work well with traditional energy sources.* Without being expressed as generalized product characteristics, the design principles extracted in the final step of the method would be constrained to the individual products being reviewed. Step 3 is complete when all of the product characteristics identified in Step 2 have been stated as generalized product characteristics. Note that the number of occurrences for each generalized product characteristic is equal to the sum of occurrences for the corresponding product-specific characteristics.

3.3.1 Filter B: Compile and Combine Duplicate Characteristics.

At this point in the method, the number of occurrences for each unique generalized characteristic are combined. Although the characteristics were defined by products until this point, they are now combined since they are now generalized characteristics.

$$G = [G_1, G_2, ..., G_{n_{gc}}] \tag{3.3}$$

where G_i is the *i*th generalized characteristic and n_{gc} is the number of unique generalized characteristics. Also

$$O_G = [O_{G_1}, O_{G_2}, ..., O_{G_{n_{gc}}}] \tag{3.4}$$

where O_{G_i} is the number of occurrences of generalized characteristic *i*. To find O_{G_i}, a n_{gc} x n_{pc} matrix L is created, where

$$L_{ij} = \begin{cases} O_{C_j} & \text{if } G_i \text{ is extracted from } C_j \\ 0 & \text{else} \end{cases} \tag{3.5}$$

The rows of the matrix are then summed to compute the number of occurrences of each generalized characteristic.

$$O_{G_i} = \sum_{j=1}^{n_{pc}} L_{ij} \tag{3.6}$$

3.4 Step 4: Identify Possible Root Causes of the Generalized Product Characteristics

In this step, the underlying design decisions, or root causes, that may have resulted in the generalized product characteristics are identified. For the example of the stove, a generalized characteristic stating that *the product is inexpensive* may have root causes of *used local materials* or *avoided feature creep*. These root causes are possible decisions that could have been made by the designer. Additionally, there may be multiple root causes for each general product characteristic. By identifying multiple root causes, the resulting design principles will be more inclusive. To assist in identifying a more inclusive set of root causes in a shorter period of time, it is suggested that this step be performed by multiple people in a team setting. As a guide, case studies performed by the author found that it was difficult to identify additional root causes after 2 to 3 minutes per generalized characteristic in a team setting. Again, the number of occurrences for each unique root cause is the sum of occurrences for the corresponding generalized characteristics.

3.4.1 Filter C: Combine Duplicate Root Causes.

The number of occurrences for each unique root cause are now combined.

$$R = [R_1, R_2, ..., R_{n_{rc}}] \tag{3.7}$$

where R_i is the *i*th root cause and n_{rc} is the number of unique root causes. Also

$$O_R = [O_{R_1}, O_{R_2}, ..., O_{R_{n_{rc}}}] \tag{3.8}$$

where O_{R_i} is the number of occurrences of root cause i. To find O_{R_i}, a n_{rc} x n_{gc} matrix M is created, where

$$M_{ij} = \begin{cases} O_{G_j} & \text{if } R_i \text{ is identified from } G_j \\ 0 & \text{else} \end{cases} \tag{3.9}$$

Each O_{R_i} is now computed as

$$O_{R_i} = \sum_{j=1}^{n_{gc}} M_{ij} \tag{3.10}$$

3.5   Step 5: Extract the Design Principles

Using the filtered list of root causes from the previous step, the design principles are now extracted. As mentioned earlier, the definition of a design principle in this method is a fundamental proposition used to guide the design process. The designer extracts design principles that would lead to the root causes established in Step 4. For example, a potential principle that would result in the root cause of *used local materials* could be to *consider available materials and local supply chains*. When design principles are extracted, the number of occurrences for each principle is the sum of occurrences for the corresponding root cause.

3.5.1   Filter D: Combine Duplicate Design Principles.

The number of occurrences for each unique design principle are now combined.

$$P = [P_1, P_2, ..., P_{n_{dp}}] \tag{3.11}$$

where P_i is the ith design principle and n_{dp} is the number of unique design principles. Also

$$O_P = [O_{P_1}, O_{P_2}, ..., O_{P_{n_{dp}}}] \tag{3.12}$$

where O_{P_i} is the number of occurrences of design principle i. To find O_{P_i}, a n_{dp} x n_{rc} matrix N is created, where

$$N_{ij} = \begin{cases} O_{R_j} & \text{if } P_i \text{ is formulated from } R_j \\ 0 & \text{else} \end{cases} \tag{3.13}$$

Each O_{P_i} is now computed as

$$O_{P_i} = \sum_{j=1}^{n_{rc}} N_{ij} \tag{3.14}$$

The normalized importance value (V) is then calculated for each unique design principle extracted in Step 5 of the method. This is performed using the following equation where the occurrence value of each design principle is divided by the maximum number of occurrences.

$$V_i = \frac{O_{P_i}}{\max(O_P)} \tag{3.15}$$

The values of V are then sorted to determine which design principles occur most often. A more complete example of the math can be found in Appendix A.

When the method uses large amounts of existing information, such as customer reviews, Step 2 can be automated through data mining techniques [48, 49]. Additionally, if the method has been performed multiple times, Steps 4 and 5 can be automated using the design principles previously found from the generalized characteristics. If new generalized characteristics arise during the course of the method, then Steps 4 and 5 will need to be performed manually for those new generalized characteristics. In all cases, Steps 1 and 3 need to be performed manually, which can take a substantial amount of time.

In order to demonstrate the ability of the method presented in this section to extract design principles, two case studies are presented in the Chapter 4.

CHAPTER 4.   CASE STUDIES

4.1   Case Study: Products in the US

The purpose of this case study was to test the method presented in Chapter 3 and provide a point of reference by extracting principles for the US. Having designed products for the US, the author would be able to validate if the method extracted real and useful design principles. The case study uses product reviews of ten best-selling products in the US to identify design principles through the presented method. These products were analyzed by examining a total of 1,764 customer reviews from Amazon.com, and resulted in the identification of 19 principles for the US. Customer reviews from Amazon.com were selected due to their descriptions of products and their availability.

4.1.1   Overview

One best-selling product was selected from ten different product categories for a total of ten products. The specific product categories and selected products used in this case study are presented in Table 4.1.

For eight of the ten products, 200 customer reviews rated as most helpful by the on-line community were examined. The other two products only had 98 and 72 reviews available (Brother Professional Label Printer and Kohler Pullout Kitchen Sink Faucet respectively). The decision to read 200 reviews for each product is best understood by examining Figure 4.1. This plot shows the total number of product characteristics identified per customer review for the iTrip FM Transmitter. By examining the data presented, it was observed that after reading the first 100 customer reviews that the majority of the product characteristics were identified. Similar diminishing returns were observed in the first 5 products reviewed by the author in that only 2.3% of the characteristics were identified after the first 100 customer reviews. For this reason, it was determined that examining

Table 4.1: Products and product categories for the US case study.

Product Category	Product
Automotive	iTrip FM Transmitter
Baby	Baby Einstien Take Along Tunes
Cell Phones	5 Pack LCD Screen Protectors
Electronics	Garmin Nuvi GPS
Heath & Personal Care	EatSmart Digital Bathroom Scale
Home, Garden & Pets	Cuisinart 5-in-1 Griddler
Office Products	Brother Professional Label Printer
Sports & Outdoors	Swiss Army Champion Plus Knife
Home Improvement	Kohler Pullout Kitchen Sink Faucet
Toys & Games	Culli Sophie the Giraffe Teether

more than 200 customer reviews would not result in a sufficient increase of characteristics to justify the time required to examine each additional review.
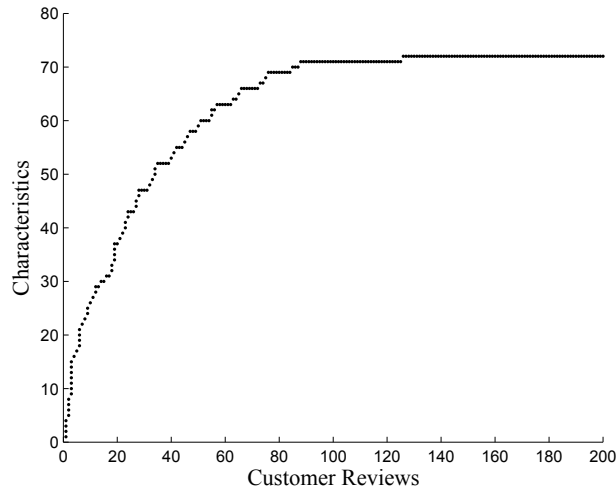

Figure 4.1: Cumulative number of characteristics identified per customer review read for the iTrip FM transmitter.

4.1.2 Design Principles for the US

Using the information gathered from customer reviews for the products presented in Table 4.1, the remaining steps of the method (Steps 3-5) were completed. The resulting principles

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Table 4.2: US case study design principles and Normalized Importance Value (V) and Common Principle # (for reference in Figure 4.3).

V	Design Principles	Common Principle #
1.00	Consider all potential uses of the product	CP_1
0.65	Consider the knowledge and skill of the end user	CP_2
0.51	Consider available technologies	CP_3
0.46	Consider manufacture and assembly of the product	CP_4
0.45	Perform failure analysis and testing throughout the design process	CP_5
0.33	Consider the product lifetime	CP_6
0.28	Consider all human interactions with the product	CP_7
0.13	Consider the maintainability and repairability of the product	CP_8
0.12	Maintain simplicity	CP_9
0.12	Design to a clearly defined product scope	CP_{10}
0.09	Consider product aesthetics	CP_{11}
0.09	Consider modularity of the product and product platform	CP_{12}
0.07	Keep clear documentation	CP_{13}
0.07	Consider all system interactions within the product	CP_{14}
0.07	Consider all system interactions outside the product	CP_{15}
0.04	Consider the culture of the target market	CP_{16}
0.03	**Perform necessary market research before and throughout the design process**	
0.02	**Adhere to safety regulations and requirements**	
0.01	**Consider the performance of competing products**	

and normalized importance values are presented in Tab. 4.2. The bolded principles in Table 4.2 are unique to the US when compared to the developing world case study.

A detailed discussion of these principles and corresponding normalized importance value is provided in Section 4.3.

4.2 Case Study: Products in the Developing World

The motivation for the presented method is to improve the design of products for those in the developing world. To that end, this section presents a case study implementing this method for the developing world. The information gathered in Step 1 of the method came from surveys

given to designers with experience designing products for the developing world, and resulted in the identification of 21 design principles.

4.2.1 Overview

Finding information for products in the developing world can be difficult. In order to obtain the needed product information, 32 surveys were completed by individuals from academia, industry, or government with experience designing products for the developing world. Criteria for identifying appropriate candidates for these surveys was participation in designing a product for the developing world that was implemented in the target market. In order to gather the necessary information, questions asked to the designers focused on the function, design, and the user's interaction with the final product. The survey questions are presented in Table 4.3.

While surveying designers is not the same as reading customer reviews, both processes were successful in identifying product characteristics. The method is performed more easily on data rich markets, such as the US. When this data is not readily available, surrogates for this information must be used. In this case study, those surrogates were the designers. It is hoped that in the future, unfamiliar markets with limited data will become more data rich and thus reduce the need for surrogates.

In order to obtain a broad view of design principles for the developing world, individuals that participated in the surveys had experience designing products for Africa, Asia, Central and South America, or the Pacific Islands. The specific products that were represented within these surveys ranged from solar-powered stoves to bio-diesel plants to housing and road development. Note that the method was developed to extract useful design principles whether considering products that were successful or unsuccessful.

4.2.2 Design Principles for the Developing World

Using the information gathered through the interviews/surveys, the remaining steps of the method (Steps 2-5) were completed. The resulting principles and normalized importance values are presented in Table 4.4. A detailed discussion of these principles and their corresponding nor-

Table 4.3: Developing world survey/interview questions.

#	Survey/Interview Question
1	Briefly describe the product/project you worked on (purpose of product/project, uses, location to be implemented, etc.)
2	Describe the positive characteristics of the implemented product (things that helped it succeed).
3	Describe the negative characteristics of the implemented product (problems that were encountered).
4	Were there any additional characteristics that dictated the success or failure of the product/project?
5	Name a few things that design engineers should know about designing for the developing world.

malized importance values is provided in Section 4.3. The bolded principles in Table 4.4 are unique to the developing world when compared to the US case study.

4.3 Comparison of Case Study Results

The case studies in Sections 4.1 and 4.2 formulated a total of 25 design principles. By examining the lists of principles presented in Tables 4.2 and 4.4, it can be seen that there are both similarities and differences between the principles extracted for each case study. Figure 4.2 illustrates this overlap between the principles for the two studies.

The principles that were extracted from the two case studies were analyzed to test if the method actually produced useful design principles. To analyze the two sets of design principles separately, each set was individually shown to designers who had not participated in the research. The designers concluded that the design principles would be useful for designing a new product. Additionally, by analyzing the list of principles for each case study against the other case study, it was discovered that there were useful differences in the sets from both unique principles in each set and the different order of common principles based on their Normalized Importance Values. Thus, it was concluded that the method produced useful design principles.

Table 4.4: Developing world case study design principles and Normalized Importance Value (V) and Common Principle # (for reference in Figure 4.3).

V	Design Principles	Common Principle #
1.00	Consider the knowledge and skill of the end user	CP_2
0.94	Consider the culture of the target market	CP_{16}
0.84	**Consider the availability and maintainability of supply chains**	
0.82	**Consider locally available materials**	
0.79	Consider available technologies	CP_3
0.73	Maintain simplicity	CP_9
0.58	**Consider the environment of the target market**	
0.52	Design to a clearly defined product scope	CP_{10}
0.39	Consider all potential uses of the product	CP_1
0.35	**Consider the purchasing power of the user**	
0.34	**Consider energy sources of the end user**	
0.27	Keep clear documentation	CP_{13}
0.24	Perform failure analysis and testing throughout the design process	CP_5
0.19	Consider the product lifetime	CP_6
0.19	Consider manufacture and assembly of the product	CP_4
0.15	**Consider the safety of the end user**	
0.15	Consider modularity of the product and product platform	CP_{12}
0.15	Consider all human interactions with the product	CP_7
0.13	Consider all system interactions within the product	CP_{14}
0.13	Consider all system interactions outside the product	CP_{15}
0.13	Consider product aesthetics	CP_{11}
0.10	Consider the maintainability and repairability of the product	CP_8

4.3.1 Similarities in the Design Principles

As is illustrated in Figure 4.2, 16 design principles for both case studies are identical. These principles represent more than 72% of the design principles for each market. Since the majority of guidelines for designing a product should be similar for most markets, this result was not surprising.

Two design principles that arose most frequently in each of the case studies are to *consider the knowledge and skill of the end user* and to *consider available technologies*. *Consider the knowledge and skill of the end user* deals directly with the customer's capability and needs. Since
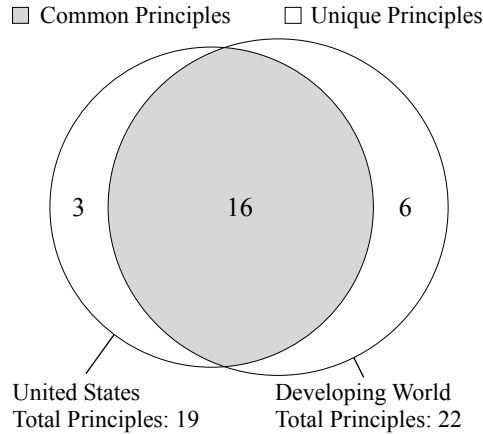
Figure 4.2: Illustration of the number of common and unique characteristics extracted per target market.

design centers around customer needs [50], it was expected that this would be mentioned many times in each case study. The other design principle, *consider available technologies*, deals with technologies that are already available in the market. This helps designers identify readily available technologies that can be utilized in the new product.

In Figure 4.2, it was shown that there was a large set of common principles. By examining Figure 4.3, it can be seen that the Normalized Importance Values of common principles vary between each case study. It was expected that the majority of common principles would fall within the shaded region of Figure 4.3. Principles within this area would have similar Normalized Importance Values between the two case studies. However, it can be seen that many of the principles fall outside of the shaded region. Additionally, with an R^2 value of 0.0598, it can be seen that the two case studies are not correlated and that it is important for the method to be performed for each market because the results are market-specific.

4.3.2   Differences in the Design Principles

Figure 4.2 illustrates that 3 design principles for the US and 6 design principles for the developing world are unique. These unique design principles provide an even deeper insight into the two target markets than the similar principles discussed in the previous section. A summary of the unique principles for each market is provided below.
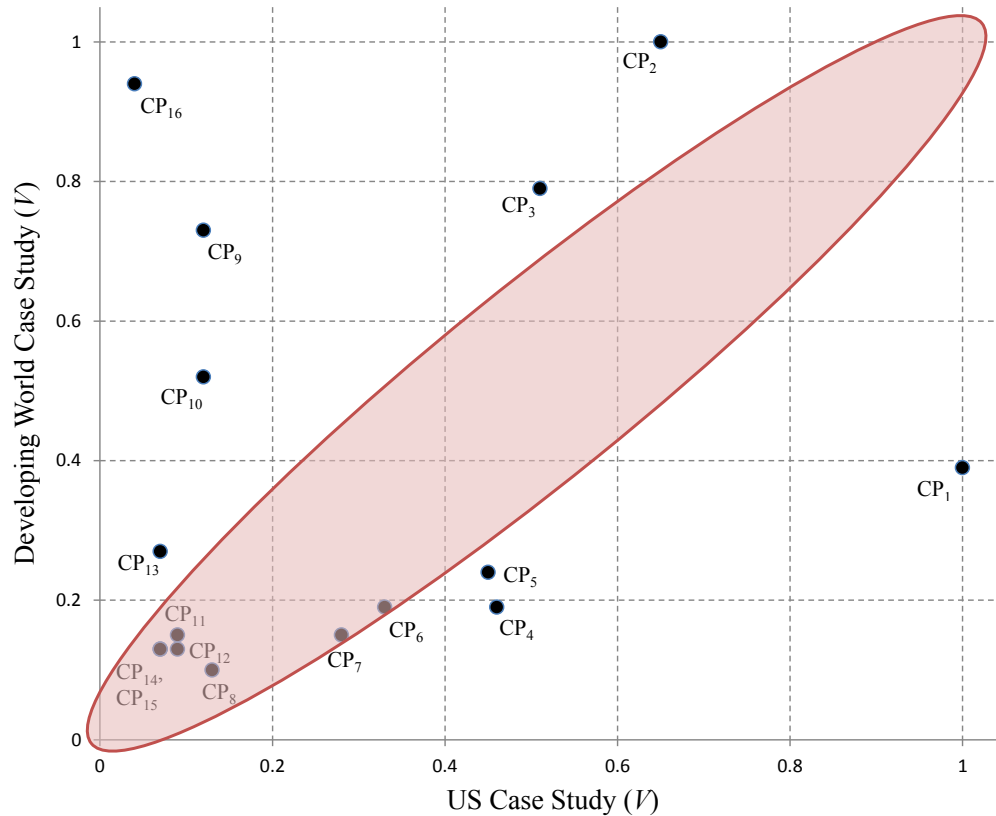
Figure 4.3: Common principles charted using Normalized Importance Values from each case study.

Unique US Principles:

- Consider the performance of competing products
- Perform necessary market research before and throughout the design process
- Adhere to safety regulations and requirements

Unique Developing World Principles:

- Consider the purchasing power of the user
- Consider the environment of the target market
- Consider consistently available energy sources of the end user

25

- Consider the availability and maintainability of supply chains

- Consider the safety of the end user

- Consider locally available materials

A close examination of these unique principles for both case studies revealed that there is a unique principle in each set dealing with safety. However, there is a distinct difference in the safety concerns addressed. For the principle from the US, the focus is that the product should *adhere to safety regulations and requirements*. While this should be followed in designing products for the developing world, often times developing areas do not have safety regulations and requirements. Therefore, the design principle from the developing world states that the designer should *consider the safety of the end user*. While both deal with safety, each principle places the responsibility of safety on a different party. For the US, it is the responsibility of agencies to ensure that products are safe and designers only need to meet the regulations and requirements. In the developing world, the responsibility lies completely with the designer. Thus, while both principles deal with safety, there are very significant differences that are important for the designer to understand.

It is important to note that all of the design principles that were different between the two studies could be applied to both markets. However, because they were not explicitly identified by experienced designers and product users in those markets, they are not considered to be the most important principles for both markets. Although the method does not guarantee to identify every possible principle, it will identify those principles that have the highest importance to a given market.

In looking at the normalized importance of each formulated principle, it is interesting to note that the unique design principles in the US case study all have the lowest importance. In contrast, three of the unique design principles in the developing world case study are within the top third of highest normalized importance values. As such, this result strengthens the assumption that these unique design principles can significantly impact the success or failure of products developed for the developing world.

CHAPTER 5.   CONCLUSION

Designing for unfamiliar markets can be difficult, especially when the market in inaccessible. While there are many methods available for identifying customer needs and improving early stage design, there is no best solution for unfamiliar markets. As such, a generic method for identifying design principles for any target market was presented, including unfamiliar markets. The method presented in Chapter 3 uses product characteristics from a selected target market to identify these principles. The product characteristics can be gathered from a variety of sources, making the method more user friendly for unfamiliar markets.

The method was implemented in two case studies of disparate markets, products in the US and products in the developing world (Sections 4.1 and 4.2, respectively). Through a comparison of the principles extracted for the two markets, it was found that 16 of the 25 total principles extracted were common to both markets. Although these similarities are interesting, the principles that were unique illustrate the major differences in what is unique to each market. Through these case studies, and the ensuing comparisons, the author concludes that the method is capable of extracting useful design principles from product characteristics for any given market and ranking the principles according to the number of times they occur. As such, the author also concludes that the extracted list of principles can be used to guide development efforts.

5.1   Limitations

There were some limitations identified in the method. One limitation deals with with the length of time it takes to perform the method. Examining all of the product information and then performing the remaining steps of the method can take an extended amount of time. While this time can be reduced by performing the method in a team environment, it is still costly.

Another limitation of the method is the influence of the designer on the method. The method is broken into steps to try and reduce the influence of the designer, but it can still impact

the resulting design principles. Step 4 in the method is especially prone to this and has the greatest vulnerability to failure of the steps in the method. When identifying root causes, it is important for the designer to identify as many root causes as possible. This will reduce the influence of the designer on the resulting principles.

Finally, the Normalized Importance Value may not be an accurate representation of importance for the principles. By adjusting the information gathered, the Normalized Importance Values will be affected. By carefully choosing the market and scope of the information, it is believed that this can be limited and that the Normalized Importance Values will give the designer important insight into the market.

5.2 Future Work

At the end of Chapter 3, it was noted that sections of the method could be automated. Initial exploration has been made into this area to determine if there is benefit to automating the method. It was determined that the right developments in automating the method could make the method a more useful tool for designers and improve the methods limitations.
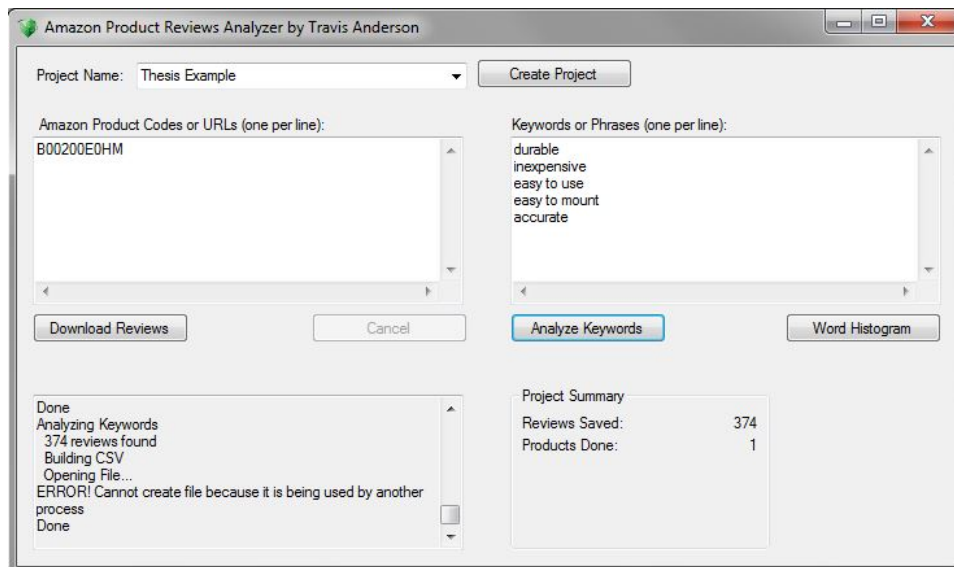
Figure 5.1: Program for scraping customer reviews.

When the method is being performed, there are various ways to collect the needed product information. One option is to use large amounts of readily available material. An example of this would be the US case study where over 1700 customer reviews were read on Amazon.com. When the designer decides to use this option, there is the possibility that the Step 2 could be automated. There are various options to data mine information, but one way that was developed in the Design Exploration Research Lab is a program that will scrape data from customer reviews on Amazon.com, see Figure 5.1. The designer enters the products they desire and then either search for keywords or have the program count the number of times each word or phrase is used in the complete set of review. This was performed on the Bushnell Red Dot Sight Riflescope shown in Figures 5.2 and 5.3. It can be seen from the figures that there is still work required from the designer to organize the data and extract useful information. Future work in this area will help establish the process of organizing the material from the program into useful information for the method.

	A	B	C	D	E	F	G	H
					fx	Product		
1	Product	DURABLE	INEXPENSIVE	EASY TO USE	EASY TO MOUNT	ACCURATE	Total Reviews	
2	B00200E0HM	5	4	4	4	20	374	

Figure 5.2: Results when performing keyword function from Figure 5.1

Step 3 is a manual step that is performed each time by the designer. It would be difficult to automate this step as it identifies generalized characteristics from product-specific characteristics. However, Steps 4 and 5 can be partially automated after the initial use of the method. Each unique generalized characteristics should always produce the same design principles. Therefore, once the method has been performed generalized characteristics and their corresponding design principles are known. Each time the designer encounters those same generalized characteristics, they will know the resulting design principles without requiring the conversion to root causes. This would reduce the amount of time required to complete the method. Additionally, the more the method is performed, the more the set of generalized characteristics with their corresponding design princi-

Figure 5.3: Results when performing word histogram function from Figure 5.1

ples will grow. This will result with larger time savings the more the method is performed. Future work in this area will compile a large resource of generalized characteristics and their corresponding design principles.

Another area of improvement is the process of tracking the occurrence values. A program has been written in Matlab to assist the designer in calculating the normalized importance values and can be seen in Appendix B. However, if a graphical user interface could be created to assist in tracking occurrences as well as calculating the normalized importance values, it would be of greater use for the average designer. Creating a program to improve the tracking of occurrence values would improve the accessibility of the method for all designers. Additionally, more analysis could be performed on the number of occurrences at each step, such as principle component analysis, to gain a better understanding of both the resulting principles and the different steps within the method.

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APPENDIX A.   EXAMPLE OF CALCULATING THE NORMALIZED IMPORTANCE VALUE

In this appendix, an example of calculating the normalized importance value is provided. This allows the reader to have a better understanding of the process to calculate the normalized importance values. Arbitrary numbers and elements have been assigned for the example.

A.1   Product Characteristics

Assume there are ten unique product characteristics.

$$C = [C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}] \tag{A.1}$$

and

$$O_C = [O_{C_1}, O_{C_2}, O_{C_3}, O_{C_4}, O_{C_5}, O_{C_6}, O_{C_7}, O_{C_8}, O_{C_9}, O_{C_{10}}] \tag{A.2}$$

Values are assigned to each O_{C_i} based on the number of times that characteristic i occurs, such that

$$O_C = [3, 5, 8, 2, 5, 9, 2, 4, 3, 12] \tag{A.3}$$

A.2   Generalized Characteristics

In Step 3 of the process, generalized characteristics are extracted from product characteristics. For the example, we have

$$C_1 \rightarrow G_1 \qquad C_6 \rightarrow G_5$$
$$C_2 \rightarrow G_2 \qquad C_7 \rightarrow G_6$$
$$C_3 \rightarrow G_3 \qquad C_8 \rightarrow G_7 \qquad\qquad \text{(A.4)}$$
$$C_4 \rightarrow G_4 \qquad C_9 \rightarrow G_2$$
$$C_5 \rightarrow G_3 \qquad C_{10} \rightarrow G_3$$

this gives us

$$G = [G_1,\ G_2,\ G_3,\ G_4,\ G_5,\ G_6,\ G_7] \qquad\qquad \text{(A.5)}$$

and

$$O_G = [O_{G_1},\ O_{G_2},\ O_{G_3},\ O_{G_4},\ O_{G_5},\ O_{G_6},\ O_{G_7}] \qquad\qquad \text{(A.6)}$$

Creating the matrix L as described in Section 3.3.1, we would have

$$
L = \begin{bmatrix}
O_{C_1} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & O_{C_2} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{C_9} & \bullet \\
\bullet & \bullet & O_{C_3} & \bullet & O_{C_5} & \bullet & \bullet & \bullet & \bullet & O_{C_{10}} \\
\bullet & \bullet & \bullet & O_{C_4} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & O_{C_6} & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{C_7} & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{C_8} & \bullet & \bullet
\end{bmatrix} \qquad \text{(A.7)}
$$

where 0 is represented by $\bullet$ for ease of visualization. Substituting values into the matrix give us

$$L = \begin{bmatrix} 3 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & 5 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 3 & \bullet \\ \bullet & \bullet & 8 & \bullet & 5 & \bullet & \bullet & \bullet & \bullet & 12 \\ \bullet & \bullet & \bullet & 2 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet & 9 & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 2 & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 4 & \bullet & \bullet \end{bmatrix} \tag{A.8}$$

remembering that

$$O_{G_i} = \sum_{j=1}^{n_{pc}} L_{ij} \tag{A.9}$$

we have

$$O_G = \left[\sum_{j=1}^{10} L_{1j}, \ \sum_{j=1}^{10} L_{2j}, \ldots, \ \sum_{j=1}^{10} L_{7j} \right] \tag{A.10}$$

Each O_{G_i} is computed as follows

$$O_{G_1} = O_{C_1} \tag{A.11}$$

$$O_{G_1} = 3 \tag{A.12}$$

$$O_{G_2} = O_{C_2} + O_{C_9} \tag{A.13}$$

$$O_{G_2} = 5 + 3 \tag{A.14}$$

$$O_{G_2} = 8 \tag{A.15}$$

$$O_{G_3} = O_{C_3} + O_{C_5} + O_{C_{10}} \tag{A.16}$$

$$O_{G_3} = 8 + 5 + 12 \tag{A.17}$$

$$O_{G_3} = 25 \tag{A.18}$$

continuing the calculations, we have

$$O_G = [3, 8, 25, 2, 9, 2, 4] \tag{A.19}$$

A.3   Root Causes

In Step 4 of the process, root causes are identified for all unique generalized characteristics. For the example we have

$$
\begin{aligned}
&G_1 \rightarrow R_1, R_2, R_3 && G_5 \rightarrow R_1, R_3, R_6, R_7, R_8 \\
&G_2 \rightarrow R_4 && G_6 \rightarrow R_4, R_8, R_9 \\
&G_3 \rightarrow R_1, R_4, R_5 && G_7 \rightarrow R_5, R_8, R_{10} \\
&G_4 \rightarrow R_3, R_6
\end{aligned}
\tag{A.20}
$$

this gives us

$$R = [R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9, R_{10}] \tag{A.21}$$

$$O_R = [O_{R_1}, O_{R_2}, O_{R_3}, O_{R_4}, O_{R_5}, O_{R_6}, O_{R_7}, O_{R_8}, O_{R_9}, O_{R_{10}}] \tag{A.22}$$

We create the matrix M as described in Section 3.4.1.

$$
M =
\begin{bmatrix}
O_{G_1} & \bullet & O_{G_3} & \bullet & O_{G_5} & \bullet & \bullet \\
O_{G_1} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
O_{G_1} & \bullet & \bullet & O_{G_4} & O_{G_5} & \bullet & \bullet \\
\bullet & O_{G_2} & O_{G_3} & \bullet & \bullet & O_{G_6} & \bullet \\
\bullet & \bullet & O_{G_3} & \bullet & \bullet & \bullet & O_{G_7} \\
\bullet & \bullet & \bullet & O_{G_4} & O_{G_5} & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & O_{G_5} & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & O_{G_5} & O_{G_6} & O_{G_7} \\
\bullet & \bullet & \bullet & \bullet & \bullet & O_{G_6} & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{G_7}
\end{bmatrix}
\tag{A.23}
$$

substituting in values into the matrix gives us

$$
M = \begin{bmatrix}
3 & \bullet & 25 & \bullet & 9 & \bullet & \bullet \\
3 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
3 & \bullet & \bullet & 2 & 9 & \bullet & \bullet \\
\bullet & 8 & 25 & \bullet & \bullet & 2 & \bullet \\
\bullet & \bullet & 25 & \bullet & \bullet & \bullet & 4 \\
\bullet & \bullet & \bullet & 2 & 9 & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & 9 & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & 9 & 2 & 4 \\
\bullet & \bullet & \bullet & \bullet & \bullet & 2 & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 4
\end{bmatrix}
\tag{A.24}
$$

remembering that

$$
O_{R_i} = \sum_{j=1}^{n_{gc}} M_{ij} \tag{A.25}
$$

give us

$$
O_R = \left[\sum_{j=1}^{7} M_{1j}, \ \sum_{j=1}^{7} M_{2j}, \ldots, \ \sum_{j=1}^{7} M_{10j} \right] \tag{A.26}
$$

Each O_{R_i} is computed as follows

$$
O_{R_1} = O_{G_1} + O_{G_3} + O_{G_5} \tag{A.27}
$$

$$
O_{R_1} = 3 + 25 + 9 \tag{A.28}
$$

$$
O_{R_1} = 37 \tag{A.29}
$$

$$
O_{R_2} = O_{G_1} \tag{A.30}
$$

$$
O_{R_2} = 3 \tag{A.31}
$$

$$O_{R_3} = O_{G_1} + O_{G_4} + O_{G_5} \tag{A.32}$$

$$O_{R_3} = 3 + 2 + 9 \tag{A.33}$$

$$O_{R_3} = 14 \tag{A.34}$$

continuing the calculations, we have

$$O_R = [37,\ 3,\ 14,\ 35,\ 29,\ 11,\ 9,\ 15,\ 2,\ 4] \tag{A.35}$$

A.4 Design Principles

In Step 5 of the process, design principles are extracted from each unique root cause. For the example we have

$$
\begin{aligned}
R_1 &\rightarrow P_1 & R_6 &\rightarrow P_6 \\
R_2 &\rightarrow P_2 & R_7 &\rightarrow P_7 \\
R_3 &\rightarrow P_3 & R_8 &\rightarrow P_5 \\
R_4 &\rightarrow P_4 & R_9 &\rightarrow P_8 \\
R_5 &\rightarrow P_5 & R_{10} &\rightarrow P_9
\end{aligned}
\tag{A.36}
$$

this give us

$$P = [P_1,\ P_2,\ P_3,\ P_4,\ P_5,\ P_6,\ P_7,\ P_8,\ P_9] \tag{A.37}$$

$$O_P = [O_{P_1},\ O_{P_2},\ O_{P_3},\ O_{P_4},\ O_{P_5},\ O_{P_6},\ O_{P_7},\ O_{P_8},\ O_{P_9}] \tag{A.38}$$

We create the matrix N as described in Section 3.5.1.

$$
N = \begin{bmatrix}
O_{R_1} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & O_{R_2} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & O_{R_3} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & O_{R_4} & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & O_{R_5} & \bullet & \bullet & O_{R_8} & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & O_{R_6} & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{R_7} & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{R_9} & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & O_{R_{10}}
\end{bmatrix} \tag{A.39}
$$

substituting in values into the matrix gives us

$$
N = \begin{bmatrix}
37 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & 3 & \bullet & \bullet & \bullet & \bullet & \bullet & & \bullet & \bullet \\
\bullet & \bullet & 14 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & 35 & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & 29 & \bullet & \bullet & 15 & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & 11 & \bullet & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 9 & \bullet & \bullet & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 2 & \bullet \\
\bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & \bullet & 4
\end{bmatrix} \tag{A.40}
$$

remembering that

$$
O_{P_i} = \sum_{j=1}^{n_{rc}} N_{ij} \tag{A.41}
$$

gives us

$$
O_P = \left[\sum_{j=1}^{10} N_{1j}, \ \sum_{j=1}^{10} N_{2j}, \ldots, \ \sum_{j=1}^{10} N_{9j} \right] \tag{A.42}
$$

Each O_{P_i} is computed as follows

$$O_{P_1} = O_{R_1} \tag{A.43}$$

$$O_{P_1} = 37 \tag{A.44}$$

$$O_{P_2} = O_{R_2} \tag{A.45}$$

$$O_{P_2} = 3 \tag{A.46}$$

$$O_{P_3} = O_{R_3} \tag{A.47}$$

$$O_{P_3} = 14 \tag{A.48}$$

so we end with

$$O_P = [37,\ 3,\ 14,\ 35,\ 44,\ 11,\ 9,\ 2,\ 4] \tag{A.49}$$

A.5   Normalized Importance Value

O_P is now used to calculate the normalized importance value of each design principle

$$V_i = \frac{O_{P_i}}{\max(O_P)} \tag{A.50}$$

where $\max(O_P)$ is O_{P_5} which equals 44. This gives us

$$V_1 = \frac{37}{44} \tag{A.51}$$

$$V_1 = 0.84 \tag{A.52}$$

$$V_2 = \frac{3}{44} \tag{A.53}$$

$$V_2 = 0.07 \tag{A.54}$$

$$V_3 = \frac{14}{44} \tag{A.55}$$

$$V_3 = 0.32 \tag{A.56}$$

so we then have

$$
\begin{aligned}
V_1 &= 0.84 \\
V_2 &= 0.07 \\
V_3 &= 0.32 \\
V_4 &= 0.80 \\
V_5 &= 1.00 \\
V_6 &= 0.25 \\
V_7 &= 0.20 \\
V_8 &= 0.05 \\
V_9 &= 0.09
\end{aligned}
\tag{A.57}
$$

Ranking the design principles by V gives us

$$
\begin{aligned}
&P_5 \\
&P_1 \\
&P_4 \\
&P_3 \\
&P_6 \\
&P_7 \\
&P_9 \\
&P_2 \\
&P_8
\end{aligned}
\tag{A.58}
$$

Thus we can see that the design principles can be ranked according to the number of times that they occur within the thesis' method.

APPENDIX B.   MATLAB CODE FOR NIV PROGRAM

This appendix provides the code for a Matlab program designed to calculate the normalized importance values. Once the designer has performed the method and has the initial occurence values for the product characterisics, they can use the program to calculate the normalized importance values.

```
% Created by Robert Campbell
% NIV calculations for principles method



clc;
clear all;



% Product Characteristics

promptp = 'How many unique product characteristics \n';
npc = input(promptp);


opc = zeros(1,npc);


for i=1:npc
        fprintf('What is the number of occurrences for product characteristic %d \n',i);
        opc(i)= input('');
end
```

% Generalized Characteristics

promptg = 'How many unique generalized characteristics \n';
ngc = input(promptg);

ogc = zeros(1,ngc);

for i=1:ngc
        fprintf('Generalized characteristic %d was extracted from how many product characteristics \n',i);
        gc(i) = input('');

        for j=1:gc(i)
                fprintf('#%d product characteristic \n',j)
                gcmatrix(i,j) = input('');

                ogc(i) = ogc(i) + opc(gcmatrix(i,j));
        end
end

% Root Causes

promptr = 'How many unique root causes \n';
nrc = input(promptr);

orc = zeros(1,nrc);

for i=1:nrc

```matlab
        fprintf('Root cause %d was identified from how many generalized characteristics \n',i);
        rc(i) = input('');


        for j=1:rc(i)
                fprintf('#%d general characteristic \n',j)
                rcmatrix(i,j) = input('');


                orc(i) = orc(i) + ogc(rcmatrix(i,j));
        end
end


% Design Principles


promptd = 'How many unique design principles \n';
ndp = input(promptd);


odp = zeros(1,ndp);
NIV = zeros(ndp,2);


for i=1:ndp
        fprintf('Design principle %d was formulated from how many root causes \n',i);
        dp(i) = input('');


        for j=1:dp(i)
                fprintf('#%d root cause \n',j)
                dpmatrix(i,j) = input('');


                odp(i) = odp(i) + orc(dpmatrix(i,j));
        end
```

```
end


% NIV

for i=1:ndp
        NIV(i,1) = i;
end

for i=1:ndp
        NIV(i,2) = odp(i) / max(odp);
end

NIV
```