DRAFT
Proceedings of DETC '04:
ASME 2004 Design Engineering Technical Conferences and
Computers and Information in Engineering Conference
September 28 to October 2, 2004, Salt Lake City, Utah

DETC04/DTM- 57498

PRODUCT USAGE CONTEXT: IMPROVING CUSTOMER NEEDS GATHERING AND DESIGN TARGET SETTING

Matthew G. Green
Dept. of Mechanical Engineering
The University of Texas at Austin
Matthew-Green@mail.utexas.edu

Palani Rajan P.K.
Applied Materials, Inc.
Austin, Texas
Palani_rajan@amat.com

Kristin L. Wood
Dept. of Mechanical Engineering
The University of Texas at Austin
wood@mail.utexas.edu

ABSTRACT

The early information-gathering stages of product design prove problematic for *frontier design environments*, or situations unfamiliar to the designer. This research provides a framework for gathering, documenting, and acting upon contextual information including the customer, market, and *product usage context*. This framework is validated through an empirical product study which shows that a chosen *functional family* of products, designed to fulfill the same primary function, exhibit significant differences in both customer needs and product requirement design targets. These differences are convincingly accounted for in terms of product usage context factors identified by the research. The functional family of "broadcast light and allow mobility" is selected, corresponding to a wide variety of candle and lantern-type products. It is shown that the products suited for long distance backpackers, for example, exhibit significantly lower volume and weight than the products intended for other usage contexts. The results presented provide a starting point to extend this research to other product domains, and support the future development of methods and tools equipping design engineers to successfully design products for frontier design environments.

Keywords: Product definition, customer needs, product usage context, empirical study.

PRODUCT DEFINITION

Multiple texts have put forward formal design methods (e.g. [1,2,3,4,5]), exhibiting some variations among definitions. For this reason, we present here our working definitions of: product definition, customer needs, and product requirements. The following two sections build on these by introducing and exploring the concept of product design context, with a focus on the context in which a product will be used.

The beginning stages of the product design process may be collectively referred to as the "front-end" of the design process [1], "understanding the problem" [2,4], or the "product definition" phase. This beginning phase is characterized by extensive information gathering, and is considered foundational to creating successful designs. This paper uses the following definition:

> *Product definition - the first phase of the design process including: background research (often including competitive benchmarking), gathering customer needs, and formulating product requirements/engineering specifications.*

Customer needs (sometimes called "customer requirements") combined with *importance ratings* show how important it is to the customer that certain expectations are satisfied. For example, the abbreviated product definition information shown in Table 1 indicates that "boil water" is a *must* (importance rating of 5) for satisfaction, whereas economical is desirable but negotiable. *Product requirements* (sometimes called "engineering specifications", "design requirements", or "functional requirements") define quantitative measures for satisfaction of each need. *Design target values* (or thresholds of satisfaction[1]) are defined in terms of metrics such as mass (kg) and cost ($). Quality Function Deployment (QFD) is a popular technique for mapping customer needs to product requirements, and specifying design targets.

[1] A *Kano diagram* represents the product requirement thresholds as the origin of the axes, the point at which degree of implementation becomes great enough to cross from negative to positive satisfaction. It also shows the effect of exceeding or undershooting the product requirement thresholds depending on whether a need is classified as basic, expected, or delighted.

Table 1: Partial Product Definition for Portable Stove.

Customer Needs	Importance[2]	Product Requirements
Boil water	5	Heat into water ≥ 1 kW
Portable	5	Total mass ≤ 20 kg Volume ≤ 5000 cm^3 Largest dimension ≤ 25 cm
Economical to buy	3	Total cost ≤ $20
. . .		

PRODUCT DESIGN CONTEXT

This research seeks to augment the product definition phase beyond current methods by accounting for the design context in which the product will be used.

> *Product design context - all environmental factors that may significantly affect the design of a product. These factors may be divided into three categories: customer context, usage context, and market context.*

The three groups of factors composing the product design context may be defined as follows: (1) *customer context factors* include consumer beliefs, values, practices, and demographics (e.g. wealth and age); (2) *market context factors*[3] include aspects of competing products; and (3) *usage context factors* cover the situation in which the product will be used such as weather and infrastructure (e.g. the state of roads, maintenance systems, central energy supply, and supply chains). Table 2 itemizes examples of product design context factors.

Table 2: Product Design Context Factors

Factors	Examples
Customer Context	• Wealth • Safety expectations • Convenience expectations
Usage Context	• Energy supply cost, availability, and characteristics. • Infrastructure (e.g. transportation) available • Harshness of environment
Market Context	• Features of available products • Performance level and quality of available products • Cost of available products

Based in part on the findings of this research, the authors believe that *product design context*, in addition to primary functional requirements, are fundamental causes which give rise to both customer needs and product requirements in the product definition phase (as illustrated in Figure 1). The term "primary functional requirements" is used here to refer to the functions a product is designed to achieve independent of the design context. For example, a radio must in some way achieve the function of receiving and playing a radio frequency, although how this is achieved may differ depending on whether the customer context factor of wealth is high or low.

[2] Scale is from 0-5 with: 5=product must satisfy the need, 3=important to satisfy the need if possible, and 0=unimportant.

[3] Customer needs capture what is required to satisfy customer expectations, which change over time with a changing market climate.

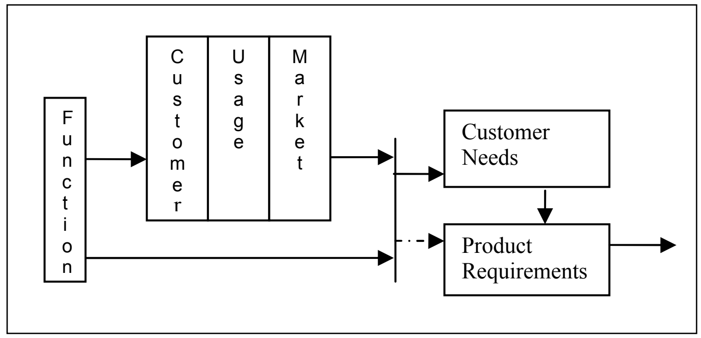

Figure 1: Model of Information Flow for Customer Needs Gathering and Product Requirements

Need for Understanding Context Factors. Engineers are often called on to design for frontier design environments (those unfamiliar to the designer). This occurs by default because engineers are a sub-set of society. Engineers design products which will be used by business people, artists, children, the uneducated, and other groups not represented among design engineers. Additionally, the importance multi-national companies place on positioning products in a global marketplace calls on engineers to design for customers in other countries and cultures. A special case of global design occurs when engineers in affluent societies create life-improving designs for use in high human-need environments, such as the Freeplay Radio initially targeted at rural African customers. (A case study of the Freeplay Radio design is included in [1]). Human interest groups estimate approximately one-third of the world's population, or over 2 billion "customers" are preoccupied with basic needs such as food and shelter, representing a significant engineering opportunity to improve the quality of life (see [6], for example).

The *product definition* step is critical for the success of any new product, and particularly problematic for frontier design environments. An opportunity exists to increase the success of products designed for these markets through formalizing methods of discovering, documenting, and addressing the product design context during the design process. This research focuses on developing an understanding of the product usage context, leaving exploration of customer context and market context for future work.

PRODUCT USAGE CONTEXT (PUC)

The product usage context (PUC) refers here to all factors relating to the situation in which a product will be used that may significantly affect its design. As shown in Table 2, PUC is one of three elements of the larger definition of product design context, which also includes customer context and market context. Examples of PUC factors include: infrastructure (such as energy supply), how the product will be used (for what application), and the conditions the product will be exposed to (such as weather). Table 3 shows examples of differences in PUC factors which result in dramatic differences in the design of the product in question.

Table 3: Examples of PUC Differences

Need (Product)	PUC #1	PUC #2	Differences
Cook food (Stove)	Wilderness	Domestic kitchen	Size constraints, Energy supply
Loosen/tighten nuts (Wrench)	Space station	Garage	Ruggedness of use, Mass constraint
Store ink writing (Paper)	Office	Clean room	Allowable particle emissions
Harvest crop (Scythe/Tractor)	Rural village	Commercial farm	Maintenance, Prevailing wages

Benefits of Understanding PUC Factors. We anticipate numerous benefits from discovering how the PUC influences the product definition phase. It is expected that an improved theoretical understanding of the fundamental contextual causes giving rise to customer needs and product requirements will improve the product definition phase, and thus the success with which products satisfy and delight customers. Specifically, this research focuses on improving the understanding of product usage context (PUC). The following three benefits are expanded in the following paragraphs:

- Improved customer needs gathering
- Improved setting of target design values
- Leveraging the known to design for the unknown – attacking frontier design problems by using correlations to generate guess values

First, an improved understanding of PUC will facilitate and organize the customer needs gathering process. This understanding will improve the quality and quantity of information gathered within limited resource constraints, and illuminate latent customer needs which might be missed otherwise. Designers can more effectively select and interview customers, and better understand and classify the information received in interviews.

Second, a PUC framework will improve the task of setting target design values by clarifying for the designer how contextual factors influence such targets. Current techniques prescribe capturing the "voice of the customer", but provide insufficient guidance on how to translate this into quantifiable numbers (QFD is a excellent technique for this conversion, however it is left to the designer to determine what the customer means by "light-weight," for example, in terms of kg). The primary technique for forming design targets is benchmarking, but this can be very difficult in frontier design situations in which comparable designs are sparse. A PUC framework and the concept of a *functional family* (a group of products which solve the same primary need) will provide the designer with tools to maximize domain cross-over of benchmarking information, intelligently selecting and adapting information from existing products which may exhibit some similarities, but do not occur in the target context.

Third, a PUC framework will equip designers to leverage the known to design for the unknown. With an improved understanding of the similarities and differences among PUC's, design problems may be attacked through the use of correlations to generate guess values for design targets. For example, a documented understanding of the weight, size, and energy constraints of backpackers gained from common camping stoves and lights may provide a solid basis for beginning the design of novel devices for this application.

RESEARCH APPROACH

The approach of this research is to conduct an empirical product study to gain insight into the fundamental causes leading to differentiation among products that solve the same primary function. The working hypothesis is:

Hypothesis: Products which solve the same primary function exhibit differences in the product definition (customer needs and product requirements) which may be explained according to differences in the intended product usage context of each product.

We have selected successful products in a mature market, and reverse engineered [7] them to re-create information which would have been part of the product definition phase for each product. We have chosen a functional family of products which solve the same primary need, in this case to "broadcast light for visibility of other objects, and allow mobility." The steps in the empirical study are as follows: selecting appropriate products, gathering customer needs through interviews and research, measuring products (quantitative benchmarking), and analyzing the data for differences indicating the effects of PUC factors.

LITERATURE REVIEW

The current texts on design methods reviewed here all address the product definition phase to a greater or lesser extent. Cagan and Vogel [1] prescribe a number of methods for understanding "the user's needs, wants, and desires" including: new product ethnography, customer scenario development, and lifestyle reference. The authors introduce SET Factors influencing the design of a product: social – culture and social interaction such as common hobbies or lifestyles; economic – the excess income people are comfortable spending; and technical – results of new discoveries. Otto and Wood [8] discuss gathering customer needs and competitive benchmarking as part of "understanding the problem". They present supporting methods such as a: product mission statement, business case analysis, customer interviews and focus groups, activity diagram of product usage throughout the lifecycle, and Quality Function Deployment (QFD). Pahl and Beitz [9] emphasize the importance of "clarifying the task" through a requirements list which itemizes demands and wishes, both qualitative and quantitative. The authors present lists of questions and suggested categories for the design engineer to reference in order to facilitate defining accurate and complete product requirements. Ullman [4] organizes his discussion of the product definition phase around the QFD framework. Major steps include: identifying customers, identifying customer requirements through surveys and focus groups, benchmarking competing products, translating qualitative customer requirements into quantitative product requirements, and setting design targets. Ullman discusses the types of customer requirements and present a checklist to reduce the problem of the design engineer overlooking important product requirements.

None of the above design methods were found to give significant attention to exploring the fundamental contextual factors leading to customer needs and product requirements, or a framework for categorizing, documenting, and correctly applying this information to a variety of design problems. The following paragraphs review research bearing significance to a discussion of product design contextual factors.

Urban and Hauser [10] provide a detailed discussion of numerous techniques for: customer measurement, perceptual mapping, and benefit segmentation. The results of these techniques facilitate identification of a product opportunity, design of a product to fill the opportunity, and product positioning (primarily through marketing and branding) to exploit the opportunity. Although contextual factors are not explicitly dealt with, the effects of context would presumably manifest as differences in customer needs and be identified as separate opportunities through benefit segmentation methods.

LaFleur [11] proposes a general framework for describing engineering design problems in terms of fundamental variables. Included in these variables are "environmental constraints" and "environmental conditions." The engineering environment is divided into four categories, including the "Application Environment (APP)" described as the "actual situation the device will encounter; real conditions and constraints, actual tasks to perform and real behavior." The Application Environment is described as a large source of public domain information, which is "fuzzy due to real complexities." Additionally, this work mentions the role of experience in the design process, noting that this experience "can be tracked and represented as information," thus making an experienced designer's knowledge accessible to others.

Crawley and Holland [12] present the "Design, Development and Marketing of Solar Lanterns" for the rural poor of African countries. They specifically address Kenya, which has a large population without hope of access to electricity in the near future; more than 90% of households use kerosene lighting, and 70% also use scarce cash supplies to buy batteries. They employed focus groups and general discussions to gather information about what customers wanted in a solar lantern. They noted the importance of: (1) picking groups not dominated by a few dominant members, (2) holding surveys during the day for travel safety of participants, and (3) focusing on individuals with incomes similar to the target customers, who often had significantly different spending patterns than wealthier individuals. In general, the authors note that for companies in developing countries, product development is expensive and high-risk and conventional research techniques for gathering customer needs are often incomplete and inaccurate in accounting for lifestyles and culture for new products being designed for use in developing countries.

A chapter on international market research [13] notes that unfamiliarity with a foreign country is a hazard faced by market researches which can cause ambiguity and false conclusions. Common blunders originate from unstated assumptions which may differ from one country and culture to another. Some kinds of market research in certain countries are not feasible. "… particularly in developing countries – it is virtually impossible to design an adequate quota sample …"due to lack of social structure definition, or lack of knowledge. Interviews do not work in some settings; for example, "Question-and-answer interaction with a strange can sometimes seem strange, even uncomfortable or threatening." Therefore there is "no substitute for close familiarity with the local culture" [italics added]. Even in some developing countries the costs of market research have risen to nearly European levels, which increases the importance of economical solutions to overcome the listed problems.

Additionally, [12] advises that when tapping global markets, multinational companies must be wary of errors on two extremes: attempting to standardize the product for significantly different markets, or excessive customization for significantly similar markets. A balance must be struck which properly accommodates real and important differences, without unnecessarily undercutting economies of scale through standardization. Examples of major differences faced when political and/or cultural boundaries are crossed include: language, ethnic, religious, social structure, tradition, literacy, income patterns, geography and climate, infrastructure, product distribution, advertising, and legal climate.

Chen et al. [14] predict that "... multicultural factors are the most difficult issues for organizations to address … [and will be a] future direction in NPD." They address the need for research in this area, commenting "… there are few successful or effective techniques available for the evaluation of multicultural factors in customer requirements." This paper proposes a system employing laddering technique and radial basis function (RBF) neural network to address the problems of multicultural barriers to customer needs gathering. A mobile phone design case study is included. The cultural factors addressed are primarily dealing with the customer context.

Some design research addresses the consideration of "culture" in the design process. Culture may be defined as the customary beliefs, values, social forms, and material traits of a group of people that are learned from preceding generations (author's adaptation from [15]). Ellsworth et al. [16] reports on the "effects of culture on refrigerator design." This paper does not define culture, but references the "needs and values" of customers which differ from place to place. The authors build a case for improved cultural understanding among design engineers, stating that products will be more successful worldwide as design engineers account for cultural needs. The authors propose the development of a Design for Culture (DfX) methodology, citing a lack of attention to the subject evidenced by a dearth of literature and suggesting that cultural considerations must include not only marketing but also design. They suggest studying the use of similar products across different cultures to begin development of such a method. Refrigerators were chosen for this study because they are in widespread use globally and the designs have stabilized with distinct differences in various countries. The paper itemizes a number of macro physical differences (such as volume, energy efficiency, and construction) in refrigerators used in the US, Europe, Japan, and Brazil, and comments on the apparent cultural reasons for these differences. The authors conclude by suggesting the following categories of cultural aspects to account for: aesthetic appeal, cultural habits (e.g. tendency to snack), traditions, available resources, physical environment.

Donaldson [17,18] proposes various items to improve product development for developing countries, and comments extensively on the particular barriers and problems associated with designing for this context. Some of Donaldson's findings may be generalized to other frontier design environments.

The research reviewed here relating to product design context is far from complete, and often emphasizes the need for greater attention to this area. No research was found that distinguishes among the effects of market, customer, and product usage context on product definition. Further, no work was found to provide a framework for formally categorizing, documenting, and correctly applying contextual information to a variety of design problems.

SELECTION OF PRODUCTS FOR EMPIRICAL STUDY (HOW, WHY, AND WHAT)

In order to illuminate the effect of PUC on products, an empirical study was designed involving the selection of a "functional family" of products hand-picked to exhibit embodiment differences for the same basic functional need. We chose the need of "broadcast light for visibility of other objects, and allow mobility." In the product domain, this need translates into a variety of lanterns; lighting products intended for signaling or self-illumination were not included. Flashlights are not included because they primarily focus light, rather than broadcast light broadly within a space. Permanently installed lighting is not included because it does not offer portability. Proper identification of a functional family is important to the effectiveness of this research, in order to avoid product differences resulting from differences in the required primary function.

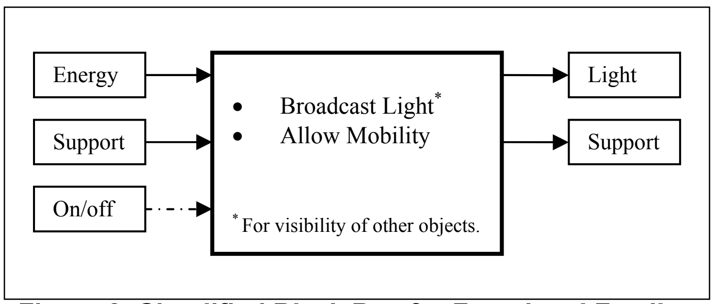

Figure 2: Simplified Black Box for Functional Family

This functional family was selected because it met the criteria of: a common need spanning multiple PUC's, a mature market, products of a reasonable size and cost for an empirical study, and consumer products dominated by energy flows.

Initially a wide range of consumer products were considered with narrowing decisions made as follows: products dominated by energy flows (as opposed to information flows and primarily static objects). Domains such as water supply, cooking, and transportation were considered. Lighting was chosen since it is a common need across many PUC's. Additionally, it represents a mature market which has had many years to stabilize, increasing the chances of finding a full suite of market-proven products relatively unaffected by transients from recent developments[4].

To discover what lighting products are available, we searched local retail outlets and internet sources: ePinions.com, amazon.com, and the Google directory. While studying the variety of lighting products, it was found that different sub-needs were being addressed under "provide light." Some of these differences were identified as follows (below). In order to compare apples to apples to begin with, it was decided to focus on lights which were designed for: portability, lighting a space, and moderate to continuous usage. The type of energy used was found to result in significant differences in product embodiment, and one or more products were chosen from each energy type sub-family.

- Energy type
- Portable vs. non-portable
- Aim-able vs. fixed
- Focused vs. light a space

From this initial survey of lighting products, the following classification was developed to organize the findings (Table 4). Products were grouped in rows according to the energy type used, and in two columns according to whether the light was broadcast or focused.

Table 4: Classification of Products "Providing Light for Visibility of Other Objects"

Energy Import	Products that Focus Light	Products that Broadcast Light
AC (or fixed DC)	Permanent fixture: wall, ceiling Floor Desk: sitting, clamp-on Task: makeup, magnifier, endoscope Transport: Automotive, marine, ~bicycle	Permanent fixture: wall, ceiling, flood Floor: torchere
Batteries (Chemical)	Flashlight: regular, spotlight, micro, flex Headlamp: waterproof, arctic	Lantern (battery) Tap light (mounted)
Fossil Fuel		Lantern (fuel) Campfire Torch Candle
Renewable	Human energy flashlight	Lantern (solar) Security (solar)
Chemical (non-battery)		Glowstick Lightning bugs Flares (for area lighting)

Products fitting into the "lantern" category above fit into the chosen functional family, all addressing the same primary need. Products were selected from this category with one or two representatives from each energy domain (shown below in Table 5). Most products chosen are from sub-families in the product market, sometimes included dozens or hundreds of similar products, such as kerosene lanterns.

[4] Products utilizing LEDs were not included due to their relatively recent market entry.

Table 5: Products selected for the empirical study.

Product	Cost	Fuel	Fuel Run Time (hr)	Fuel Cost
1) Paraffin lamp	$0	Liquid Parrafin	20+	$2
2a) Candle	$0	Wax	9	$1
2b) Candle lantern	$17	Wax	9	$1
3) Kerosene lantern	$6	Kerosene	--------	$5/gal
4) Pump-up gas	~$25	Liquid fuel ("White gas")	3	$5/gal
5) Propane lantern	$20	Bottled propane	5	$1.50/bottle
6a) Battery – krypton	$10	4 alkaline "D" cells	12	$4 for 4
6b) Battery – fluorescent	$20	6 alkaline "D" cells	14	$6 for 6
7a) Solar – low-cost	~$80	10 hours of bright sun fully charges battery	4 (fully charged)	$0
7b) Solar – camping	~$150	12 hours of bright sun fully charges battery	5 (fully charged)	$0

Figure 3: Products Selected for Empirical Study

Table 6: Description of Products Selected

Product	Description
1) Paraffin lamp	A recycled bottle with a wick through a hole in the lid. Filled with 99% pure paraffin for clean burning.
2a) Candle	A long burning, low-drip candle.
2b) Candle lantern	A spring advances the candle into a glass shielded burn chamber for better all-weather performance. The shield nestles inside the base to decrease the candle stowage volume.
3) Kerosene lantern	Hollow and lightweight, an adjustable wick draws kerosene up from the base for a controlled burn.
4) Pump-up gas	A liquid fuel poured into the base is pressurized with the built-in hand pump. The fuel vaporizes inside an ash bulb (mantle) where it burns with a bright, yellow-white flame.
5) Propane lantern	A screw-on bottle releases gas into the mantles where it burns with a bright, yellow-white flame.
6a) Battery – krypton	Rugged and almost water-proof; a krypton bulb casts a soft, pleasant glow through the frosted white cover.
6b) Battery – fluorescent	Two bright (4W) fluorescent tubes are independently controlled for two brightness settings.
7a) Solar – low-cost	Similar light to 6b, but designed as a solar re-chargeable for rural African markets.
7b) Solar – camping	Similar light to 6b, but designed as a solar re-chargeable for recreational campers.

7a - Low-cost Solar Lantern | 7b - Solar Camping Lantern

Figure 4: Products Selected for Empirical Study

GATHERING CUSTOMER NEEDS: TECHNIQUE AND RESULTS

After selecting and purchasing the products for the empirical study, the next step was to gather customer needs. Gathering and understanding customer needs for each product was achieved primarily through two means: the researchers experienced the products through setup and usage, and interviews were conducted with potential customers. In a one-on-one interview, the potential customer was asked to examine and use each product, and then comment on prompts including “What do you like? … What do you dislike? … What would you like to see improved?” Initially the interviews were encoded by hand, however this was soon replaced by voice recording which was later played back and transcribed to text. Finding interviewees who understood the various situations in which each product might be used posed a major challenge. For those products intended for extremely low-cost rural applications, finding interviewees who had experienced the products in their target PUC was nearly impossible within the time and budget limitations. We believe this situation would be similar on a larger scale for a design firm seeking to design for such a frontier design environment outside their experience range – the cost and time involved may be insurmountable. This was partially overcome by recruiting a graduate student volunteer who had spent time visiting family members in poor rural areas of his home country and therefore could comment on the usage.

The interviews were recorded in the “voice of the customer” and later translated into inferred customer needs. These were gathered and assigned weighting based on the judgment of the researchers. Weightings were assigned based on a combination of how frequently the need was articulated, how forcefully it was articulated, and the researcher’s assessment of the product and intended usage context based on the accumulated research and interviews. The chosen need grouping and assigned weightings are therefore subject to researcher bias.

Presenting the customer with multiple products seemed a very effective technique for eliciting responses, as features in one product stood out and lead to more comments on other products. Additionally, interviewees begin comparing and contrasting products. Through this process, an understanding was developed of the “functional family” of products selected for study, showing how a common need has been solved in different ways according to a sliding set of criteria (due to different usage contexts). This approach of “mapping a functional family” may hold value for preparing to position a new product design. Benchmarking is currently encouraged in reverse engineering techniques, however the formal recognition of PUC differences could allow benchmarking to be usefully extended further, to cover an entire functional family whereas it might otherwise be abridged to similar customer and PUC clusters.

As research and interviewing proceeded, it became evident that the functional family chosen addressed distinct usage contexts, relating to four PUC categories. Although these categories were not explicitly stated by many interviewees, they are largely based on a categorization of the various contexts they were collectively referring to. Most interviewee’s appeared to reference only a subset of the four identified PUCs, and in some cases it was difficult to tell which they had in mind regarding specific comments. As the research progressed, questions were added to the interview format, asking each interviewee what context they could foresee using the product in, as well as what context they viewed each product as suitable for. No further verbal cues were given for this question other than the word “context” and the implication that it might vary from one product to another. The four PUC categories determined were: (1) Backpacking, (2) Camping near a car, (3) Intermittent domestic electrical outage, and (4) Heavy domestic use (no electricity). They imply respectively: (1) an outdoor adventure in which individuals carry all personal supplies and products on their backs for several days or more, (2) an outdoor adventure involving pitching a tent within walking distance of an automobile, (3) a domestic setting with regular and reliable grid supplied electric power with occasional outages of an annoying but infrequent frequency, (4) a domestic setting with no grid electricity such as a remote cabin. Initially PUC 4 was considered to indicate a rural village situation (and the often accompanying poverty), but it was later decided that it was desirable to hold the customer factors constant in the study. Since a rural village context also implied great differences in the individual customer, PUC 4 was modified to refer to customers who were economically similar to those in the first 3 PUC’s, but who chose to live outside of the reach of established grid electricity. Table 7 shows which PUC’s each product was determined to be the most appropriate for.

Table 7: PUC's Indicated for Each Product (■ = strong, • = weak)

	Usage Context			
Product	**1**	**2**	**3**	**4**
1) Paraffin lamp			•	■
2a) Candle	•		■	
2b) Candle lantern	■			
3) Kerosene lantern			•	■
4) Pump-up gas		■	•	
5) Propane lantern		■	■	
6a) Battery – krypton		■	■	
6b) Battery – fluorescent		■	■	
7a) Solar – low-cost				■
7b) Solar – camping		■		
(1) Backpacking, (2) Camping near car, (3) Intermittent electrical outage, (4) Heavy use (no electricity)				

It is well established in the marketing literature that customers have needs which vary from one person to the next, and an accepted marketing and product development strategy is to "cluster" customers with similar needs into target groups of a size large enough to permit economy of scale and small enough to allow the product to satisfy the entire target group of customers. Perhaps this process can be used to implicitly account for difference in the context in which customers will use the product, or to use our terminology, in the intended PUC. However, in the course of our interviews we found that implicitly accounting for the PUC by clustering customers into groups was clumsy and unsatisfactory. It was clumsy, because valuable interview time was consumed during a search phase as the PUC's gradually became evident. During this time, data was collected from various interviewees without clarity as to which PUC they had in mind, leading to obscurity in results. More disconcerting was that without formal recognition of the importance, characteristics, and potential effects of PUC differences, it seems likely that some PUC's could be inadvertently (and mistakenly) combined, or missed altogether.

Further, we found that implicit accounting for PUC's by customer segmentation was unsatisfactory because it obscures the true fundamental causes which give rise to differing product definitions (sets of customer needs and product requirements), and may in fact be completely inadequate to describe such differences when identical customers are present in dissimilar PUC's. For example, if the same customer requires a lantern product for use in two distinct PUC's (e.g. "backpacking" and "car camping"), this will result in distinct product definitions which are due entirely to differences in the PUC, and not differences in the customer (the customer characteristics are identical). If different customers require different customer needs in the same PUC (for example, for a "car camping" lantern an elderly customer may require more accessible controls when compared to average customers), then this is an appropriate application of segmentation by customer.

In summary, it was found that multiple PUC's existed for the functional family under study, and the experience gained suggests it is desirable to formally account for the PUC before and during the customer need gathering process. Table 8 presents the differences found in customer needs which result from differences in the PUC (the customer context was held similar). These needs lists represent the authors' analysis based on the customer needs gathering process (research, experiencing the products, and customer interviews).

Table 8: High-level Customer Needs List for Functional Family Studied - Weights Differ Across Four PUC's

	Backpacking (on the trail)	Camping (near car)	Intermittent electrical outage	Regular domestic (no electricity)
Customer Need	**(1)**	**(2)**	**(3)**	**(4)**
Light				
Provide adequate light	5	5	5	5
Adjustable brightness	2	3	1	4
Ergonomic (no glare)	3	3	1	5
Pleasant light	1	1	1	3
Directable light	4	1	1	4
Value				
Low purchase cost	5	5	5	5
Low operating cost	5	5	5	5
Portable				
Mobile	5	5	5	5
Small	5	1	1	2
Lightweight	5	2	1	1
Hangable	3	3	1	5
Stable base	2	2	2	5
Safe				
Small chance of harm	5	5	5	5
Low O_2 consumption	4	0	5	2
Low gas emission	1	1	5	3
Low fire hazard	4	2	5	2
Low glass hazard	4	3	3	1
Operation				
Easy to use	2	4	4	2
Fast to light	2	4	4	2
Fast to setup	2	3	5	2
Durable	4	3	1	2

Product usage factors which account for differences in customer needs for this data across the four PUC's are itemized below and line itemed in Table 9.

PUC Factors Found to Affect CN's for Products Studied:

- Energy supply cost, availability, and characteristics (e.g. weight, safety, convenience of supply)
- Frequency and duration of product use
- Transportation available
- Activities (e.g. setting up a tent vs. playing cards)
- Enclosed vs. ventilated usage area
- Ruggedness of handling & conditions

Table 9: Comments on How PUC Differences Lead to Customer Need Differences

	Backpacking (on the trail)	Camping (near car)	
Customer Need	**(1)**	**(2)**	**PUC Differences (1) vs. (2)**
Light			
Provide adequate light	5	5	
Adjustable brightness	2	3	Extra functionality less expected
Ergonomic (not glaring)	3	3	
Pleasant light	1	1	
Directable light	4	1	More dependence on light for after-dark activities Often smaller light intensity, more important to focus
Value			
Low purchase cost	5	5	
Low operating cost	5	5	
Portable			
Mobile	5	5	
Small	5	1	Carrying in backpack vs. car trunk
Lightweight	5	2	Long hiking distance vs. short walk from car to campsite
Hangable	3	3	
Stable base	2	2	
Safe			
Small chance of harm	5	5	
Low O_2 consumption	4	0	More likely to be used in tent, whereas (2) primarily for outside
Low gas emission	1	1	
Low fire hazard	4	2	More likely to be used in tent, whereas (2) primarily for outside
Low glass hazard	4	3	Transported farther w/ more rugged conditions
Operation			
Easy to use	2	4	Convenience less demanded; trade-off for small & lightweight
Fast to light	2	4	Convenience less demanded; trade-off for small & lightweight
Fast to setup	2	3	Convenience less demanded; trade-off for small & lightweight
Durable	4	3	Transported farther w/ more rugged conditions

MEASURING PRODUCTS TO DETERMINE TARGET DESIGN VALUES

To understand how PUC influenced target design values required continuing the reverse engineering process by measuring metrics corresponding to product requirements. The metrics were guessed initially, and refined as customer needs gathering progressed in order to determine values for the appropriate product requirements. Table 10 shows product metrics for three major categories of customer needs: light, value, and portability. Future work includes defining and measuring metrics to quantify the remaining customer needs related to "safety" and "ease of operation."

The measurements are obtained from a combination of manufacturer data and direct measurement. Equipment cost is the retail price paid. Operating cost is determined by taking an average fuel cost (determined through searching retail and web sources) and dividing by the fuel consumption rate (determined by manufacturer specifications and experimental tests). The brightness was measured in Fc using a light meter placed one foot from the light source[5] (resulting in the indicated readings of close to "1.0 Fc" for the candles measured, consistent with the definition of the Fc unit). Each product was weighed fully fueled, using an electronic scale. Height and diameter were physically measured, twice for objects which change shape in an open and closed position. Approximate volume was calculated from the height and diameter.

Table 10: Product Measurement Data

	Equipment Cost ($)	Brightness (Fc)	Weight w/ Fuel (kg)	Operating Cost ($/hr)	Volume (mm^3)	Brightness / Op. (fc*hr/$)
1) Paraffin lamp	0	1.0	0.18	0.04	269	23.6
2a) Candle	0.80	1.1	0.05	0.09	57	12.1
2b) Candle lantern	18	0.5	0.19	0.09	216	5.5
3) Kerosene lantern	6	3.3	0.81	0.02	6923	157.4
4) Pump-up gas	25	41.0	0.90	0.10	1846	397.6
5) Propane lantern	20	43.0	1.91	0.26	5575	164.8
6a) Battery–krypton	10	3.3	0.99	0.33	1689	9.9
6b) Batt.–fluorescent	20	11.7	1.41	0.43	3313	27.4
7a) Solar – low-cost	80	~12	3.00	0.00	6011	∞
7b) Solar – camping	150	~12	0.93	0.00	4100	∞

The products vary widely in terms of the metrics chosen, indicating dramatically differing design target values during the product definition phase for each product. Figure 5 compares the weight and volume of the products, grouped according to PUC's 1-4. Note that some products appear more than once, if they are correlated with more than one PUC. The figure suggests the strict weight and volume constraints that were observed for PUC 1 – backpacking. Figure 6 shows a wide variation in the economic efficiency of each product, in terms of brightness normalized by operating cost (Fc/$/hr). The solar powered lanterns perform off-the-chart in this case, since they have no direct fuel cost. The graph shows that the pump-up gas lantern is a much better investment than the equivalent 40 candles or paraffin lamps which would be required for the same amount of brightness.

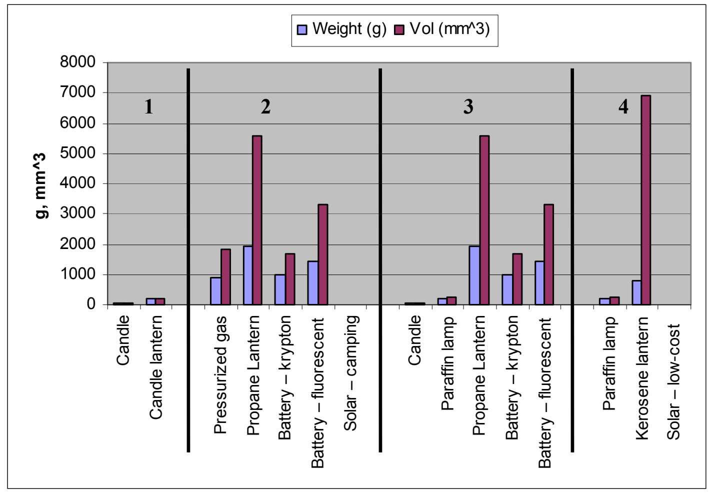

Figure 5: Product Weight, Volume Grouped by PUC

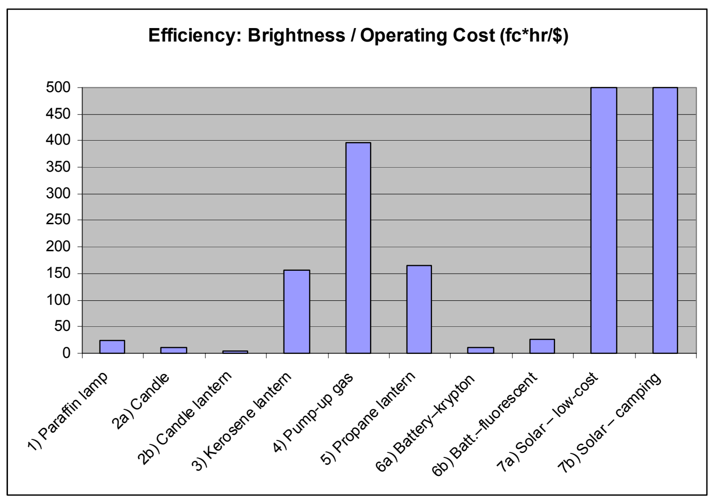

Figure 6: Product Economic Efficiency

CONCLUSIONS AND FUTURE WORK

The products studied perform the same primary function, to "broadcast light for visibility of other objects, and allow mobility." These products from the same functional family exhibit significant differences in product definition. The metrics measured show differences in product requirement design targets, and the customer needs that were gathered also show distinctions. Many of these differences have been convincingly explained according to differences in the product usage contexts, thus supporting the research hypothesis.

Future work will include extending the present study of lanterns with additional metrics to measure the remaining

[5] A 60W incandescent light bulb measures approximately 70 Fc (Foot candles) by this testing method.

customer needs, and additional lantern products to further validate the PUC differences shown here. Customer perceptions will also be measured, as a method to verify the chosen metrics are correctly correlated to the customer needs. For example, customer perceptions of product size should correlate directly to actual volume, if low volume is in fact the customer's implicit intention from a qualitative statement "it should be small."

Future work will also include generalizing this research approach to additional functional families such as: cook food, turn (plow) soil, and transport water for domestic consumption. As more PUC factors are discovered for different functional families, comparison and contrast among functional families can begin. Finally, when a general understanding of PUC is established, the research will extend into investigating the customer and market contexts.

The end goal of this work is to develop methods to facilitate accounting for product design context during the design process, thus equipping design engineers to more successfully address frontier design environments. It is hoped that one result of this work will be to increase the application of engineering design to create products for customers in high-human need environments who are traditionally less-served by technology.

ACKNOWLEDGMENTS

The work reported in this document was made possible, in part, by the National Defense Science and Engineering Graduate Fellowship program, the University of Texas at Austin College of Engineering, and the Cullen Trust Endowed Professorship in Engineering No. 1. Any opinions, findings, or recommendations are those of authors and do not necessarily reflect the views of the sponsors.

REFERENCES

[1] Cagan, J., and Vogel, C.M., 2002, *Creating Breakthrough Products: Innovation from product planning to program approval.* Prentice Hall, NJ.

[2] Otto, K., Wood, K., 2001, *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall, NJ.

[3] Pahl, G., and Beitz, W., 1996, *Engineering Design – A Systematic Approach*, Springer, New York, NY.

[4] Ullman, D., 1992, The Mechanical Design Process, McGraw-Hill, Inc., NY.

[5] Ulrich, K. and Eppinger, S., 1995, *Product Design and Development*, McGraw-Hill.

[6] "Providing Energy Needs for Two Billion People," New Release No. 97/1313S, World Bank, Accessed Mar. 2002. http://www.worldbank.org/html/extdr/extme/1313.htm

[7] Otto, K. and Wood, K., 1996, "A Reverse Engineering and Redesign Methodology for Product Evolution," *Proceedings of the 1996 ASME Design Theory and Methodology Conference*, 96-DETC/DTM-1523, Irvine, CA.

[8] Otto, K., Wood, K., 2001, *Product Design: Techniques in Reverse Engineering and New Product Development*. Prentice Hall, NJ.

[9] Pahl, G., Beitz, W., 1996, *Engineering Design – A Systematic Approach*, Springer, New York, NY.

[10] Urban, G.L., and Hauser, J.R., 1993, *Design and Marketing of New Products*, 2nd Ed. Prentice Hall, NJ.

[11] LaFleur, R. S., 1992, "Principal Engineering Design Questions", *Research in Engineering Design*, **4**, pp. 89-100.

[12] Crawley, K., Holland, R., Gitonga, S., 2001, "Design, Development, and Marketing of Solar Lanterns," *Development by Design: 1st International Conference on Open Collaborative Design of Sustainable Innovation*, Boston, MA.

[13] *Consumer Market Research Handbook*, Worcester, R., Downham, J. Eds., 1986, Chapter 23, "International Market Research"

[14] Chun-Hsien Chen Li, Pheng Khoo, Wei Yan, 2003, "Evaluation of multicultural factors from elicited customer requirements for new product development" *Research in Engineering Design*, *to appear*.

[15] Merriam-Webster, 2002, "Merriam-Webster On-Line Dictionary", http://www.m-w.com, January 29, 2002.

[16] Ellsworth, K., Magleby, S., Todd, R., 2002, "A Study of the Effects of Culture on Refrigerator Design: Towards Design for Culture," *Proceedings of the 2002 ASME Design Theory and Methodology Conference.* DETC 2002/EDC-34383.

[17] Donaldson, K., 2002, "Recommendations for Improved Development by Design," *Development by Design: 2nd International Conference on Open Collaborative Design of Sustainable Innovation*, Bangalore, India, http://www.thinkcycle.org/dyd02/

[18] Donaldson, K. and Sheppard, S., 2001, "Modification of a Methodological Design Tool for the Developing Country Scenario: A Case Study in Product Definition," in *Proceedings of ICED01 13th International Conference for Engineering Design* (Glasgow, Scotland), Professional Engineering Publishing., 505-512.

