Research in Engineering Design (2006) 16: 174–183
DOI 10.1007/s00163-006-0012-8

ORIGINAL PAPER

Krista M. Donaldson · Kosuke Ishii · Sheri D. Sheppard

Customer Value Chain Analysis

Received: 16 August 2004 / Accepted: 17 November 2005 / Published online: 23 March 2006

Abstract Customer Value Chain Analysis (CVCA) is an original methodological tool that enables design teams in the product definition phase to comprehensively identify pertinent stakeholders, their relationships with each other, and their role in the product's life cycle. By performing CVCA, design teams are better able to recognize diverse product requirements and their relative priority when undertaking Product Definition Assessment and using downstream 'Design for X' (DfX) tools. This paper discusses the evolution of the CVCA in response to the need for a DfX tool which is able to delineate customer needs early in the product development process. A step-by-step guide clarifies the implementation of CVCA with an example. Three case studies highlight the tool's broad utility and important features to support design decision making, including: (1) confirmation of the product's business model, (2) recognition of the critical stakeholders, and (3) clarification of the value proposition to be embedded in the product.

Keywords Product definition · Design support · DfX tool

1 Introduction to Customer Chain Analysis

The *Customer Chain* is a visual mapping design tool used at the start of a product development process that enables design teams to identify pertinent stakeholders and their relationships to the product or process being designed (Ishii 2001). The stakeholders, or *customers*, are all important parties who are involved with the effective delivery of the product to the end user and the support of the product throughout its life cycle (Ulrich and Eppinger 2004). For example, customers may range from the individuals who will manufacture the product to those who will handle product recycling at retirement. By understanding the key customers and their relations to each other and the product, design teams are effectively able to define the product relative to their company's market and product objectives, and flow-down customer needs (or, *VOC*: Voice of the Customer).[1]

1.1 Example of a simple Customer Chain

The best way to illustrate the Customer Chain and its utility to design teams during the product definition phase is to consider a simple example, such as the one (shown in Fig. 1). In this case, a design team has been tasked to develop a coin-operated soft drinking vending machine for a vending machine manufacturer (shown in a box in Fig. 1). The initial business model is that the vending machine will be proximate to the front entrance of a convenience store where the end user, the soft drink consumer, will be able to buy the beverages individually. A vending operator, who purchases soft drinks directly from a soft drink bottler, will restock and provide maintenance to the vending machine as required. The vending machine manufacturer, in this example, employs the design team.

Customer Chain analysis assists the vending machine design team in delineating all pertinent VOCs, not simply those of the end user, by mapping out the interactions of the customers. For example, the vending machine has additional design requirements than those

K. M. Donaldson (✉) · S. D. Sheppard
Center for Design Research, Stanford University,
Stanford, CA, USA
E-mail: kdonaldson@stanfordalumni.org
Tel.: +1-650-725-0217

K. Ishii
Manufacturing Modeling Laboratory,
Stanford University, Stanford, CA, USA

[1] Urban and Hauser (1993) characterize the *voice of the customer* as "A list of customer needs, a hierarchical structure for those needs, a set of importances to prioritize those needs, and evaluations of competitors on those needs." They add that "the voice of the customer must be heard accurately and interpreted accurately if high quality products are to be designed and marketed successfully."

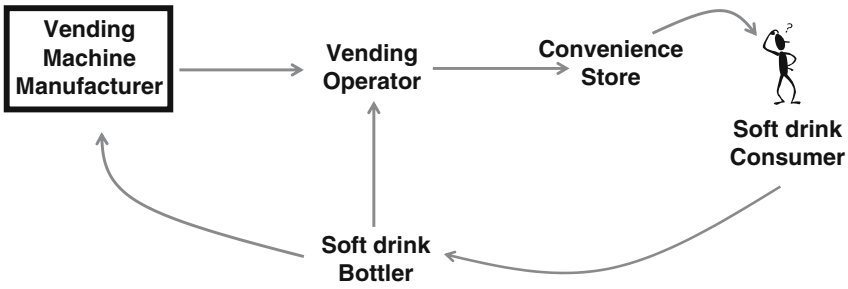

Fig. 1 Example of a Customer Chain used in the design of a coin-operated soft drink vending machine (Ishii 2001)

involved with the delivery of a consumer-selected beverage at the optimum temperature, speed and price. The vending operator may require that the vending machine be simple and quick to restock and repair. The bottler will have functional and aesthetic requirements: the machine must handle and appropriately present its product (a soft drink) because the quality of the end user's interaction with the machine affects the soft drink's name brand value. Finally, the convenience store where the vending machine is located may have specific requirements regarding space, energy consumption and noise levels.

The arrows connecting various stakeholders represent the proposed interactions in the initial business model: the vending machine manufacturer sells the vending machine to the vending operator, who places it at the convenience store; the end user purchases the soft drinks from the machine at the convenience store. By analyzing the vending machine's business model with the Customer Chain, the design team is able to comprehensively identify the important customers necessary to generate detailed VOCs.

1.2 Product definition phase

Wilson (1993) describes product definition as:

> ...the first phase of the product development cycle, (which) encompasses researching what to develop for a successful product and planning appropriate actions for the project team to develop and successfully release their products to market. This phase culminates in a business review in which the product concept, the required investment, and the projected returns are scrutinized to determine whether proceeding to the development phase is the best alternative for the organization.

Understanding customer needs and values is fundamental to the definition of a product, particularly a new product. Wilson (1990) notes that deficiencies in understanding customer needs are the most prevalent failure mode of product development. When products are poorly defined, design teams have been observed to get 'stuck' in redefinition activities, so much so that the project cannot progress to detailed design because too many issues are unresolved (Wilson 1993). It is now widely recognized that an inadequately defined product results in less revenue for the design organization because the product is late to market or the market demands have changed from projections (Patterson and Lightman 1993). While Ullman (1992) estimates that 30% of the product development costs are locked in following product definition, Barken (1995) estimates the costs can be as high as 70%.

The Customer Chain is what Herrmann et al. (2004) refer to as a *decision support tool*, which is part of the 'Design for X' (DfX) set of methodologies. Whereas the product definition phase is key to providing high value to of the customers of any new product (Ishii 2001; Wilson 1993), support tools for identifying customers and defining their needs in this phase are negligible (Herrmann et al.). In today's fast-paced world of globally distributed corporate partnerships, design teams and concurrent development of advanced technology, engineers and managers require an effective tool to capture and analyze the customer structure, the customers' relationships and each one's stake in the product (Ishii 2001).

2 Previous work

Wilson's early work (1990) on product definition highlighted the need for a methodological design tool to assist with the definition of customer needs prior to the gathering of detailed VOC information. For a design team to be able to establish how the product will be positioned and what the design project priorities are, the team must first be able to identify the customers and their associated needs. Understanding customer values requires addressing compliance issues, user needs, competitive analysis, and localization considerations (Wilson). If the design team is not clear on the strategic objectives of the product, including the target market for the product and the customer requirements, other product definition issues such as risk, availability of core competencies and needed resources cannot be addressed.

The Customer Chain was originally developed as part of Stanford University's ME 317 Design for Manufacturability (dfM) course as a means to explain the market failure of a specific product, which was traced to the design team's poor approach to customer identification (Ishii 2001). Since then, the tool has evolved with input

from researchers and design teams in industry from a visual representation relating customers, the *Customer Chain*, to an analysis process, the *Customer Value Chain Analysis (CVCA)*, where the customer structure is examined in detail and results are utilized as inputs to the Product Definition Assessment Checklist[2] (PDAC) and downstream DfX tools.

Rose and Stevels (2000) and Rose et al. (2000) applied CVCA to 'Design for Environment' to develop the Environmental Value Chain Analysis (EVCA). EVCA links businesses and end-of-life product management internal and external to a company by illustrating relationships between groups implementing environmental improvement programs. Use of the EVCA by designers was found to increase product recycling collection rates while decreasing recycling costs (Rose et al. 2000).

The Customer Chain, CVCA and the EVCA are conceptually related to Supply Chain Management, which seeks to optimize the supply and flow of products and services to customers (Rose et al. 2000). Whereas supply chain analysis normally focuses on the flow of materials, funds and related information with the goal of obtaining an optimally efficient model, CVCA and EVCA are employed in the earliest stages of the product development process to identify pertinent customers and their related VOCs based on their stake in the product.

Using graph theory to represent relationships between critical parties or techniques to identify pertinent stakeholders is not novel. However, to the authors' knowledge, the integration of a visual means to systematically and comprehensively identify customers and capture their relationships into the design process has not yet been published.

3 Extension of the Customer Chain to Customer Value Chain Analysis (CVCA)

Customer Value Chain Analysis extends the functionality and utility of the Customer Chain by requiring designers to investigate the value relationships, or *value propositions*, between the various customers and then evaluate customer needs relative to the design team's corporate strategy using Product Definition Assessment. CVCA enables the design team to better evaluate the initial business model and isolate the value propositions of individual customers for flow-down to later DfX methodological tools, such as Quality Function Deployment (QFD) and Failure Modes and Effects Analysis (FMEA).[3] By systematically carrying out CVCA, the design team ensures clarification of the value propositions to develop and better recognize the priority of the product's customer needs. Similar to the determination of the Customer Chain, CVCA should be a multi-functional team effort with the active involvement of top-level management.

3.1 Step-by-step guide to CVCA

To illustrate the steps involved with CVCA, we will return to the example of the soft drink vending machine.

3.1.1 Step 1. Define the initial business model and assumptions

For new products, it is necessary to have well-formulated knowledge of the strategic objectives of the product. It is often the case that the business models for new products are inadequately defined by the design organization, and hence are poorly understood by the design team (Wilson 1993). The design team must determine: what is the business model for this product? How will the product be profitable? By answering these and related questions, the first step of CVCA provides the necessary information to address the first item of PDAC, *strategic alignment*, where the design team must establish the strategic objectives for the design process, the boundary conditions within which the team needs to operate, and the target market for the product.

Establishing the business model for the vending machine (Fig. 2a), for example, requires answers to the questions: Who uses the vending machine? Who interacts with the vending machine? Where would the machine best be located to serve the end user? To whom would the end customer complain if there was a problem? Who provides the soft drinks? Who collects the money from the vending machine? Who services the vending machine? And so on.

We are already familiar with the vending machine's business plan to some extent from the first example in Sect. 1.1. The vending machine will be situated outside of a convenience store where it will provide beverages to the soft drink consumer. A vending operator will restock the soft drinks, collect the money (consumers' payments) and provide maintenance to the machine. The vending operator will "rent" the space for the vending machine from the convenience store. A soft drink bottler will provide the beverages to the vending operator. If the soft drink consumer has a complaint, he or she would likely go to the convenience store clerk or, in egregious cases, to the bottler.

3.1.2 Step 2. Delineate the pertinent parties involved with the product

In addition to the end user, important customers may include less obvious stakeholders such as business partners, regulatory bodies and specific departments within the design team's organization. All these stakeholders become customers in the Customer Value Chain.

[2]See http://www.me217.stanford.edu for the Product Definition Assessment Checklist

[3]For QFD references, see Hauser and Clausing (1988), and Akao (1990). For FMEA references, see Ormsby et al. (1991), McDermott et al. (1996) and Stamatis (2003).

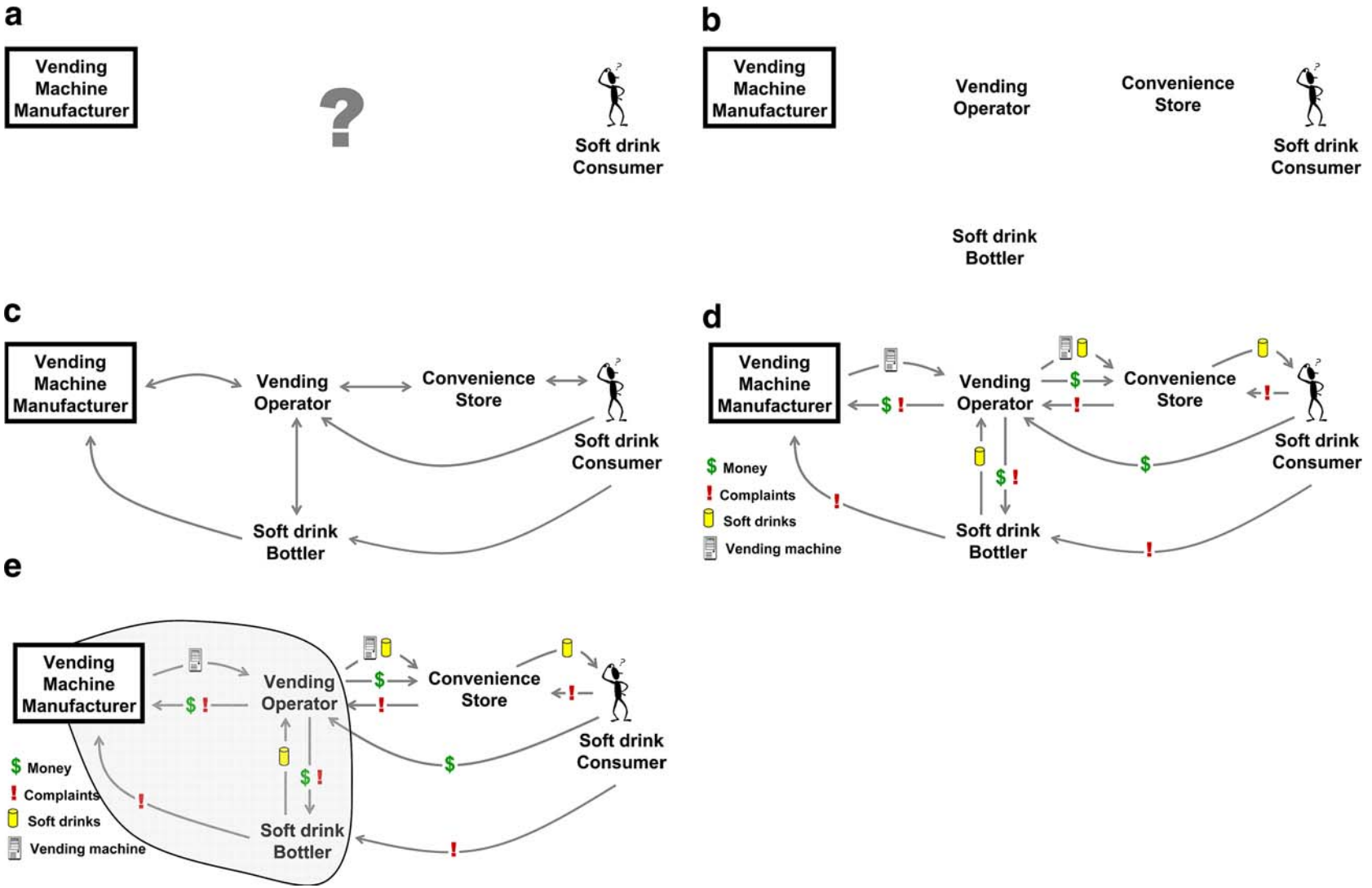

Fig. 2 **a** *CVCA Step 1*: Determine the business model for the vending machine. **b** *CVCA Step 2*: Delineate pertinent parties involved with the vending machine's life cycle. **c** *CVCA Step 3*: Determine how the vending machine's customers are related to each other. **d** *CVCA Step 4*: Identify the value propositions of the vending machine's customers and define the flows between them. **e** *CVCA Step 5*: Analyze the Customer Chain to determine the vending machine's critical customers and their value propositions. The vending operator and the soft drink bottler (*circled*) were determined to be the critical customers to the vending machine manufacturer

As shown in Fig. 2b, the main customers of the vending machine determined from the business plan are the vending operator, the convenience store, the soft drink bottler and the end user, the soft drink consumer. The design team should also consider stakeholders with important design requirements who are outside the business model; for example, approval by a federal regulatory agency may be required in the development of specific products.

3.1.3 Step 3. Determine how the parties are related to each other

Based on information from the initial business model, how are customers related to each other and the product? Use arrows to link customers. At this stage the diagram looks similar to the Customer Chain in Fig. 1 as the value propositions have not yet been added to create the Customer Value Chain. The directions of the arrows at this stage in the analysis are not as important as the lines connecting the customers.

The lines connecting the vending machine customers in Fig. 2c reflect their relationships based on the initial business model. For example, the soft drink consumer is linked to the convenience store because that is where he or she would go to purchase the soft drink from the vending machine. This arrow is shown as two-way because it is to the clerk at the convenience store that the consumer may complain about the vending machine. The consumer is connected to the vending operator because it is the operator who collects the consumer's payment directly from the vending machine. Finally, it may be recalled that the designers believed that the soft drink consumer may infrequently complain directly to the bottler.

3.1.4 Step 4. Identify the relationships among the parties by defining the flows between them

The direction of the relationship arrows now becomes important with the mapping of the value relationships or flows between the customers. The flow items represent the value propositions to each of the individual customers. To determine which types of flows are important, the design team should ask: What is each customer's main role(s) in the product life cycle? What bearing does this customer have on the success or failure of the project? By analyzing these flows the design team will be able to focus on specific consumers to delineate their needs and better recognize their relative priority.

Typical value propositions are: money or payments, complaints, regulatory influences, and tangibles such as hardware, materials, services or necessary information. The arrows show the direction of the flow accompanied by the appropriate icon or icons. For example, a dollar sign ($) may indicate money whereas an exclamation mark (!) may indicate complaints. Money and complaints often come in pairs in exchange for tangibles, but this is not always the case. Such exceptions create interesting implications to the customer structure and may signify a leak in the chain. A *leak* occurs when there is a flow into or out of a customer without a balancing flow in the opposite direction; this is a potential problem if it suggests a lack of return in investment for a member of the chain. A leak in the chain may also simply indicate to the design team that the identification of the customers and/or value propositions is not complete, and customer needs and stakeholder relationships must be more comprehensively examined.

Four value propositions are defined for the vending machine example: money, complaints, soft drinks and the vending machine (see the bottom left corner of Fig. 2d). The arrows have been redrawn from Fig. 2c to reflect the directional flow of the value propositions (see Fig. 2d). We will now walk through the construction of the completed vending machine Customer Value Chain.

First, we will determine the flow of tangibles based on the business model. The tangibles of importance to product definition are the vending machine and the soft drinks which the machine will dispense. The vending machine manufacturer sells the vending machine to the vending operator, thus we draw an arrow with the vending machine icon from the manufacturer to the operator denoting the vending machine transfer. In return, the vending operator pays the manufacturer; this transaction is represented by a return arrow with a dollar sign ($) from the vending operator to the manufacturer. Since the vending operator then places the machine at a convenience store and stocks the machine with soft drinks, there is an arrow with the vending machine and soft drink icons from the vending operator to the convenience store. Two other soft drink arrows are drawn in the Customer Value Chain to represent that the soft drinks are provided to the vending operator by the bottler and the purchase of a soft drink from the vending machine at the convenience store by the soft drink consumer.

Next, consider the flow of money starting with the end user of the vending machine, the soft drink consumer. He or she puts money in the vending machine to purchase a soft drink. This payment goes to the vending operator, who collects the money from the machine. The store benefits financially through the rent made from the vending operator who is happy to pay for the highly visible access to convenience store shoppers. The vending operator pays the bottler for the soft drinks and the vending machine manufacturer for the machine itself. While the soft drink consumer is a pertinent customer, from the perspective of the vending machine manufacturer, it is clear that the needs of the vending machine operator are vital for the success of the product.

Finally, complaints are particularly important to the design team because they indicate negative VOCs or customer dissatisfaction modes (Kmenta and Ishii 2000). What concerns each of the customers? What attributes of the vending machine would be undesirable? The end user, unaware of the arrangement between the various

stakeholders, likely complains to the convenience store clerk if, for example, his or her soft drink is warm or the vending machine malfunctions. In more serious situations, where the soft drink may be defective, the end user might complain directly to the soft drink bottler. The convenience store will report problems with the vending machine, such as it operates too loudly, to the vending operator who would pass the complaints onto the manufacturer. Complaints the store receives about the soft drink itself are relayed to the bottler through the operator. The bottler, in turn, may determine that a complaint it received, such as packaging was defective, is an issue for the manufacturer to address. (For example, the vending machine needs to deliver the soft drinks without damage to the packaging.)

Following the completion of this step the Customer Value Chain is complete. The remaining three steps involve the analysis of the chain.

3.1.5 Step 5. Analyze the resulting Customer Value Chain to determine critical customers and their value propositions

To determine who the customers critical to the success of the design project are, trace the payments ($) and complaints (!) from the design team's position in the chain. The needs of these critical customers must be included in the design team's QFD analysis. To determine the value propositions of the critical customers, look at each customer's input and output flows and consider how they will make profit and receive a return on their investments. The pertinent customers' flows can be used to generate the product's VOCs.

Based on the flows into and out of the vending machine manufacturer, the critical customers for the vending machine design team to consider are the vending machine operator and the soft drink bottler (circled in Fig. 2e). Both have significant requirements that must be addressed in the design of the vending machine. For example, the vending operator may be insistent that the vending machines be restocked and serviced quickly with minimal effort. The bottler has requirements regarding the vending machine's interface with both the soft drinks and the end consumer. The convenience store, while not critical, is certainly an important customer if one follows the trail of money. Without having done CVCA, it is unlikely that the vending machine design team would fully recognize the unique needs of this particular customer.

3.1.6 Step 6. Input the information into Product Definition Assessment

The information gained from the Customer Value Chain now facilitates the completion of PDAC, which should be used in conjunction with the Customer Value Chain. The Customer Value Chain directly addresses half of the 14 PDAC items: strategic alignment, understanding customer needs, localization issues, compliance issues, product positioning, project priorities and business model. The remaining seven items of the PDAC are easily navigated by the design team by considering the Customer Value Chain's results relative to the design team's resources and support structure within their organization. It is not unusual for a design project to be cancelled at this step if the needs of the various customers cannot be met within the defined business model.

Returning to our example, the vending machine design team has now comprehensively clarified the value propositions to be embedded in their product. They are able to refine and confirm their initial product definition and business model. At the design team's first funding review with management, the project is given a go ahead.

3.1.7 Step 7. Use the CVCA results downstream in the product design process

The CVCA process has thus far captured valuable information about the customers and their needs which can be used in downstream DfX tools. For example, these needs can be examined in greater detail and mapped using Affinity Diagrams.[4] Customer needs can be directly inputted into QFD analysis, and negative VOCs can provide input for FMEA to generate robust and error-proofed designs.

The vending machine design team now focuses on collecting detailed VOCs to better define the product and to provide as input to downstream DfX tools. Utilizing the information gained from CVCA, the vending machine design team concentrates on the needs of the vending operator, the soft drink bottler, the convenience store, and the end user.

4 Three case studies using CVCA

Three case studies from separate design processes were selected to give a broad indication of the functionality and applicability of CVCA: retrospective analysis of the market failure of an electrocardiogram machine, the reframing of design specifications for a pacemaker alert system, and the consideration of Customer Value Chain leaks and unaligned customer goals in the design of a micro-irrigation pump.

4.1 *Case study 1:* electrocardiogram (EKG) machine

A computer peripheries company had acquired a medical devices firm and, having core competencies in both domains, aimed to develop a revolutionary EKG machine. An EKG is an electrical recording of the heart's

[4] Affinity Diagrams, also called the KJ Method, are a graphical means to distinguish themes from a list of customer needs. See Jiro (1975).

behavior typically used by cardiologists to detect cardiac anomalies. The new EKG machine the design team was to develop would not only monitor a patient's heart and recognize irregularities, but it would also provide a medical assessment.

The business model for the EKG machine was that it would be sold to the doctors and hospitals where patients would come for their checkups. The design team, therefore, believed their primary customers to be the doctors with private heart clinics or in charge of cardiology units at hospitals. The product was developed, but failed to have any significant sales. Among other problems, insurance companies refused to pay for the machine's use.

The Customer Value Chain shown in Fig. 3 was used in retrospect by Wilson (unpublished data) to determine the reasons for the failure of the EKG machine project. CVCA revealed that the design team did not have a comprehensive understanding of all of the pertinent customers or their requirements and, as a result, missed critical value propositions. The design team did not account for two critical customers for the new EKG machine: the insurance company and the regulators. Insurance companies were unwilling to pay for the machine's use with patients without formal approval by federal regulators. Further, the team did not realize the lack of value proposition to the doctors. The new EKG machine was essentially performing the doctor's specialized role by providing a medical diagnosis (the negative value proposition is shown as the medical diagnosis crossed out in Fig. 3). Doctors were understandably unwilling to commit to a medical device that could not guarantee consistent accuracy and threatened to displace their profession. If the design team had performed CVCA, they would have recognized the key roles of insurance company and regulatory agencies and the lack of value proposition to the doctors.

4.2 *Case study 2:* pacemaker alert system

A large medical device company challenged their design team to develop and integrate a patient alert system into the company's implantable cardioverter defibrillators (pacemakers), which were currently on the market. A pacemaker is connected to leads positioned inside the heart or on the heart's surface. The leads deliver electrical shocks, monitor the cardiac rhythm and sometimes pace the heart as needed. According to the company's initial business plan, the new system would alert the patient when the device required service, the battery was running low, or it was about to deliver electronic shock therapy (Cobb et al. 2003).

The Customer Value Chain for the pacemaker alert system is shown in Fig. 4. The most important value propositions in this product definition, besides the hard-

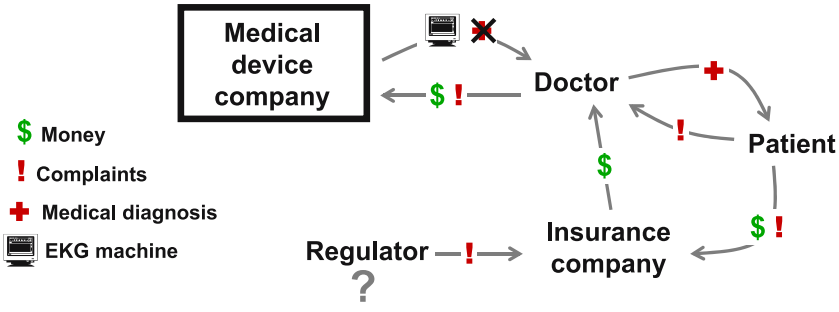

Fig. 3 Customer Value Chain for *Case study 1*, a failed EKG machine project

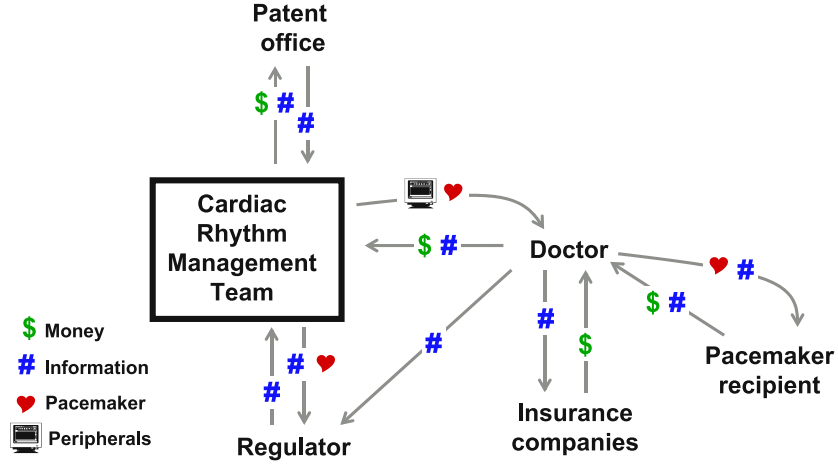

Fig. 4 Customer Value Chain for *Case study 2*, a pacemaker alert system (Cobb et al. 2003)

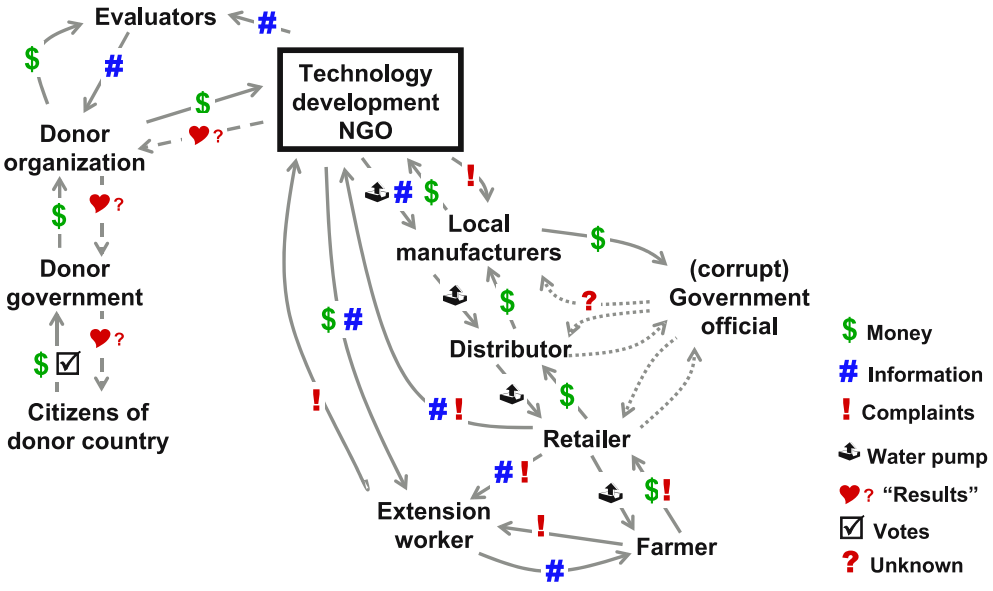

Fig. 5 Customer Value Chain for *Case study 3*, a micro-irrigation pump

ware, were the flows of money and information. As can be seen in Fig. 4, the hardware (the pacemaker and its peripherals) are sold to the doctor who provided the pacemaker to the patient. This design team, learning from the mistakes of other medical device companies, recognized several other customers involved: the insurance companies who would pay for the alert system, regulators who would approve the technology for use, and the patent office which would provide intellectual property protection in a competitive market (Cobb et al. 2003).

In performing CVCA, the design team gained several key insights. First, approval by government regulators and insurers would be crucial to the viability of the product on the market. Second, although it would be the patient who wears the pacemaker and the alert system, it is the doctor who is the key decision-maker regarding selection of a device for the patient. By focusing both on doctors and patients for VOCs, the design team discovered that both groups preferred the alert system to notify the doctor, not the patient. One doctor commented during their research: "The problem with these (alerts) is that the patient lives in fear of (hearing) it. It can cause major anxiety problems which in these patients can be extremely harmful" (Cobb et al. 2003). Recognition of this need through CVCA required the design team to appropriately adjust their business model and reframe their original design statement from alerting the patient to notifying the doctor.

4.3 *Case study 3:* donor-funded micro-irrigation pump

This case study represents a non-traditional application of CVCA to a micro-irrigation treadle pump developed by a Kenyan non-governmental organization (NGO) for small-scale farmers. The NGO is funded by a bilateral donor organization to develop technology to support micro-enterprise development and income growth in Kenya as a form of foreign aid. The Customer Value Chain shown in Fig. 5 was performed and analyzed during the later stages of the product's development to better understand customer goals to ensure appropriate priority trade-offs were made.

Since the business model in this case study has many more customers than the others reviewed so far, we will review it, the resulting Customer Value Chain, and the related analysis in some detail. The design team recognized while defining the business model that the NGO has two distinct customer sets: those related to the donor and those related to the end user. When identifying the pertinent stakeholders, the design team also realized that the two sets do not interact with each other except through the NGO. This resulted in the Customer Chain having two distinct *branches*, or chain segments with unique end customers.

In developing the Customer Value Chain, we will start with the customer set related to the end user.[5] The NGO receives money from the donor organization to research and design a product to assist small-scale farmers in Central and Western Kenya access shallow (< 6 m) groundwater. The NGO develops a foot-operated pump and the associated manufacturing system so that the pump can be made locally in Kenya's capital, Nairobi. Selected manufacturers attend a pump manufacturing training at the NGO, are given detailed engineering drawings, and are loaned manufacturing hardware in exchange for a one-time fee. Manufacturers produce the pumps, sell them to a distributor, who sells them to retailers, who in turn sell the pumps directly to farmers. The chain of money between the local manu-

[5]End users often differ from end customers; the *end user* is the target user of the designed product, whereas the *end customer* is the 'end' stakeholder of a branch. In this case study, the end user is the Kenyan farmer who uses the micro-irrigation pump. The end customers are the citizens of the donor country and the farmer.

facturer and the farmer is extremely important to the project as it demonstrates that the NGO does not need to continue its involvement once the product market matures, a feature called a *sustainable exit strategy*, upon which donor organizations look favorably. *Extension workers* are individuals paid by the NGO on a casual basis to support pump usage in the field. Farmers can request a visit from an extension worker at the retailer. The extension worker visits the farmer and gives personalized input as to effective crop irrigation using the pump and advice on its maintenance. Farmers' complaints about the product are transmitted through the extension worker or through the retailer directly to the NGO monitoring staff who periodically visit retailers to pick up the guarantee forms filled out by the farmers at the time of purchase. Any functional problems with the pump are reported to the manufacturer by the NGO so that appropriate changes can be made. The NGO will also likely have to contend with one or more corrupt government officials, a common unwelcome entity in all business transactions in most less industrialized economies, who extract payments from any or all of the businesses involved in the pump sales.

The relationships within the Customer Value Chain's other customer set, those customers related to the donor funding of the NGO, will result in a fairly *linear* branch, in that most customers are linked to only two (or less) other customers. External evaluators are hired by the donor organization to ensure that the funds given to the NGO are used appropriately. The donor organization must answer to its country's government who allocates its money to address the government's mission regarding international development. The donor government, in turn, must be able to defend its policy and expenditure of tax money to the citizens who elect its members. The citizens, donor government and the donor organization itself, in exchange for money and votes want "results", that is, these customers want to know if the donor money is being spent appropriately and that it is contributing to raising incomes in Kenya. For this branch, the citizens of the donor country are end customers. By understanding the value propositions of the donor branch of the chain, the NGO confirmed that appropriate monitoring and evaluation of the pump's impacts on Kenyan farmers was vitally needed to meet those customers' needs.

This case study is particularly informative as it highlighted two functionalities of CVCA not obvious in common use. First, the presence of the corrupt official represents a leak in the chain. Because the value added by the official is unknown—or negative—this customer is a financial drain to the pump's business model. Just how much of a drain, will need to be considered by the design team as the project may ultimately prove to not be viable. Second, the structure of this chain with its two fairly separate branches (NGO-Farmer and NGO-Citizens) is markedly different from the more interlinked structures seen with the previously discussed Customer Value Chains. From analyzing the needs of the NGO's customers, it was found that customer requirements of the two branches did not necessarily align and that a separate priority matrix should be done for each branch (as part of step 6 Product Definition Assessment). The matrices for this case study's branches showed that for the farmer, the pump cost should be constrained and the time to market accepted, whereas the donor organization was constrained by time and willing to accept pump cost. The NGO faced a quandary—if the donor was not satisfied, future funding would be lost and the project may never get off the ground, and if the farmers' priorities were not addressed, the pumps would be unaffordable and the project would be a failure. The lack of customer goal alignment was suggested by structure of the Customer Value Chain, and can be generalized to CVCA: *the more interlinked the customers are in the chain, the more likely the goals of the different customers will coincide*. (The NGO ultimately gave priority to the farmer and the product is now extremely successful in the East Africa, although the NGO continues to face funding problems.)

5 CVCA—basic rules of thumb

From the vending machine example, case studies, and other applications of CVCA, we have generated some rules of thumb to assist design teams in creating and analyzing Customer Value Chains:

- *Pick an appropriate resolution*. If we return to the vending machine example (see Fig. 2d), the vending machine manufacturer has four customers. It may be appropriate to have a higher resolution when mapping the customers—for example, include the manufacturing department and shippers of the vending machine manufacturer if the needs of both are mandated by the business plan.
- *Capturing all the customers*. The initial business model should guide the determination of pertinent customers. What is the flow of money from the design team to the end customer(s)? What are the other value propositions and how do they compare to the business model? The design team should then consider if there are additional parties, not included in the business model, which will affect the success of the product.

  Market segmentation can be represented in one large Customer Value Chain or multiple Customer Value Chains, depending on the business model. The relative weights of the market segments should be considered accordingly in downstream tools.
- *Value-in unbalanced with value-out suggests a "leak"*. A leak may indicate that not all pertinent parties have been considered—or it may demonstrate a lack of return in investment by a stakeholder. In the latter case, the design team will need to determine the impact of the negative value proposition to the business model.
- *Shape matters*. Our experience with CVCA suggests that the more interlinked the customers are in the chain, the more likely the goals of the different

customers will coincide. As was shown in Case Study 3, lack of customer goal alignment may alert the design team to competing prioritizations of design requirements.

- *Flow CVCA output into downstream DfX tools.* Knowledge gained about customers and their needs can be inputted directly into tools such as Affinity Diagrams, QFD and FMEA.

6 Conclusions and future extensions

Customer Value Chain Analysis is an original 'Design for X' methodological tool used as a first step in the product definition phase to identify pertinent customers, their relationships with each other, and their value propositions. Use of CVCA requires business and organizational models to be established early and onfidently in the design process. This ensures that knowledgeable decisions regarding product development can be consistently and systematically made based on customer needs and that weaknesses can be addressed prior to the commitment of significant project funding.

This paper presents a step-by-step guide for applying CVCA to a new product or process. Three case studies highlight the utility and value of undertaking CVCA to identify customers and their value propositions. In the first case study, the EKG machine, retrospective use of CVCA shows that the market failure of a product was due to inadequate customer identification and that key stakeholders could have been overlooked without fully considering the value propositions. In the second case study, the pacemaker alert system, the use of CVCA uncovered significant and unanticipated customer needs that resulted in the reframing of the design team's initial business model and design statement. The final case study, a micro-irrigation pump, discusses consequences and considerations when there is a leak in the Customer Value Chain. The last case study also demonstrates how the chain structure relates to customer priority alignment. Distinct branches in the Customer Value Chain require separate consideration when setting project priorities. In this case, the more interlinked the customers are in the chain, the more likely customer goals will coincide.

The CVCA methodology has grown to be one of the most significant tools used in the Stanford ME317 Design for Manufacturability course. The method has served over 100 projects at more than 12 companies spanning 3 continents, and it has consistently been voted as one of the most useful DfX tools in the last 8 years by over 1,500 students, 80% of whom are practicing engineers (Manufacturing Modeling Laboratory 2004). The authors see further development of the CVCA methodology in the following fronts:

(1) Utilization of CVCA in business model synthesis.
(2) Application of CVCA in system design including service products.
(3) Platform development for products that require diverse variety and rapid changes.
(4) Improvement of domestic and international regulatory procedures.
(5) Quantification of the customer's value propositions.

Acknowledgments The authors gratefully acknowledge Edith Wilson, the students and partner companies of the ME217/317 Design for Manufacturability (dfM) course at Stanford University and the staff of KickStart for their invaluable contributions to the development of the CVCA. This research was in part funded by the United States Department of Energy Manufacturing and Processing Fellowship.

References

Akao Y (1990) Quality function deployment: integrating customer requirements into product design. Productivity Press, Cambridge

Barkan P (1995) A road map through the ME 317 product development process. In: Ishii K (ed) ME317 dfM: product definition coursebook. Stanford Bookstore, Stanford University, pp 1.2.1–1.2.10

Cobb C, Shahani V, Stephan C et al (2003) Alert system for implantable cardioverter defibrillators (ICDs), Stanford University, Stanford, ME 317 Final Report

Hauser JR and Clausing D (1988) The house of quality. Harvard Business Rev: 63–73

Herrmann J, Cooper J, Gupta SK et al (2004) New directions in design for manufacturing, ASME DETC 9th design for manufacturing conference (DFM), Salt Lake City

Ishii K (2001) Customer value chain analysis (CVCA). In: Ishii K (ed) ME317 dfM: product definition coursebook. Stanford Bookstore, Stanford University, pp 1.3.1–1.3.8

Jiro K (1975) The KJ method—a scientific approach to problem solving. Kawakita Research Institute, Tokyo

Kmenta S, Ishii K (2000) Scenario-based FMEA: a life cycle cost perspective, In: Proceedings of the ASME DETC2000 reliability, stress analysis, and failure prevention conference, Baltimore, MD

Manufacturing Modeling Laboratory (2004) Survey of ME 317 industry sites 1996–2004. Stanford University, Stanford

McDermott RE, Mikulak RJ, Beauregard MR (1996) The basics of FMEA. Quality Resources, New York

Ormsby A, Hunt J, Lee M (1991) Towards an automated FMEA assistant. In: Adey R (ed) Applications of artificial intelligence in engineering VI. Computational Mechanics Publications, Boston, pp 739–752

Patterson ML, Lightman S (1993) Accelerating innovation: improving the process of product development. Van Nostrand Reinhold, New York

Rose CM and Stevels A (2000) Lessons learned from applying environmental value chain analysis to product take-back, In: 7th CIRP—Life cycle engineering conference, Tokyo

Rose CM, Stevels A, Ishii K (2000) Applying environmental value chain analysis. Electronics goes green, Berlin

Stamatis DH (2003) Failure mode and effect analysis: FMEA from theory to execution. ASQ Quality Press, Milwaukee

Ullman DG (1992) The mechanical design process. McGraw-Hill, New York

Ulrich KT, Eppinger SD (2004) Product design and development. McGraw-Hill/Irwin, Boston

Urban GL, Hauser JR (1993) Design and marketing of new products. Prentice-Hall, Englewood Cliffs

Wilson E (1990) Product definition factors for successful designs. Stanford University degree of engineer thesis, Stanford

Wilson E (1993) Product definition: factors for successful design. Design Manage J (Fall):62–68