Requirements Modeling For A Custom-Made Materials Handling System - A Case Of Anti-Biotic Manufacturing Plant

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Abstract: Globally, suppliers of custom-made materials handling systems (MHS) are under pressure to deliver systems that exactly meet their customer's needs. They have to elicit complete and unambiguous requirements from their customers that include stated as well as latent requirements. However, customer requirements are usually ambiguous, unstable and often have solutions embedded in it. This paper proposes a technique that can help MHS suppliers elicit all types of solution-free requirements for a custom-made MHS in order to deliver maximum value to a customer.The methodological approach in this paper employs a comprehensive review of more than twenty requirements elicitation and analysistechniques that are in use in the engineering industry. This is followed by the development of a hybrid model, one that combines KJ+ interview and Kano Analysis, which can greatly increase customer satisfaction while designing custom-made MHS. The hybrid model isapplied to a real-life case on an antibiotic tablet manufacturing MHS. The paper discusses how this hybrid modelwould be particularlyappropriate and useful in designing custom-made equipment where competitor data is unavailable

Index Terms: Requirements Elicitation, Requirements Analysis, Latent Requirements, Material Handling System (MHS), Custom-made, Kano Analysis (KA), KJ+ Interview

1. INTRODUCTION

Globalorganizations are working aggressively towards implementing lean practices(Daultani, et al., 2015). In order to reduce and eliminate wasteful movement of materials and resources, manufacturing firms are focusing on integrating material handling systems (MHS), the annual demand for which is expected to grow to USD 176.9 billion by 2020 (The Freedonia Group, 2016).Efficient MHS increases productivity, enhances quality of products and customer service, improves workplace safety, reduces inventory and delivery time, and significantly trims down overall production cost (Chakraborty & Prasad, 2016; Kulak, 2005). These are all necessary characteristics of a lean organization. MHScan be very broadly classified into two categories: 1) Standard systems, i.e., systems that are available in the catalog of a supplier. This also includes systems that require minor modifications to the standard equipment to meet customer needs, and 2) Custom built systems, i.e., systems that are to be builtto customers' needs and specifications. Most literature in domain of MHS addresses the problem of selecting standard systems (Chakraborty & Prasad, 2016; Hassan, 2010; Williams & Narayanaswamy, 1997; Sujono & Lashkari, 2007; Onut, et al., 2009) rather than designing a custom-made solution. While demand for standardMHS would continue,manufacturing firms would rely more on custom-built MHSin future to stay ahead of competition as a differentiator.Manufacturing firms will increasingly collaborate with an MHS supplier to help them design, develop and implement such custom-built systems, usually undertaken as part of a turnkey project. Value is a key concept in lean management. Womack & Jones (1996) define value asa capability provided to a customer at the right time at an appropriate price. An MHS supplierwould deliver value to their customer - the manufacturing firm - if the right systemwere delivered at the right time at the right cost. The issue is with determining the rightMHS, more so for custom-built systems. Determining the rightcustom-builtMHS requires complete elicitation and prioritization of requirements of the manufacturing firm. However, suppliers of custom-made MHS face the following challenges:

1. Customers state a solution rather than stating requirements. In other words, requirements are not solutions-free.
2. Customers make frequent changes to the design of the MHS during the execution of the project, or worse, after deployment of the system in production. This would result in low value delivered to the customer resulting in customer dissatisfaction and potential loss of future sales.
3. There is high user satisfaction when anMHSis deployed at the customer site, followed by rapid loss of value when there is a change in customer business processes since the delivered system is not flexible to adapt to the new changes.

With manufacturing firms trying to develop more agile and/or resilient supply chains (Singh, et al., 2016)to keep ahead of competition, poorly designed custom-made MHS will increase the risk of disruption and consequent business failure. A solutions-free, comprehensive, futuristic and time-bound requirements elicitationtechnique is required to ensure the manufacturing firms do not encounter any of the challenges listed above. Requirements can be broadly classified into three categories. The first category isthat ofstated requirements. These are solution-free needs statement(s) of customers that are clearly and unambiguously stated. The second categoryis the unstatedrequirements, i.e., requirements not stated by the customer, but is assumed to be part of the requirements. These are also referred to as latentrequirements. The final category of requirements is the non-functional requirements. These requirements relate to the expected performance of the system.

The purpose of this paper is as follows:

1) To review existing techniques that can help elicit all three types of requirements relevant to the domain of MHS.
2) To propose a technique or a combination of techniques that can help firms elicit all types of requirements for a custom-made MHS.

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3) To contribute to the body of knowledge, and demonstrate how an MHS supplier can deliver maximum value to a customer by eliciting all three types of requirements.

2.0 RESEARCH METHODOLOGY

This paper is written from the perspective of an MHS supplier.The methodology adopted in this research includes:

a) A comprehensive review of existing literature, including scholarly case studies, for qualitative and quantitative information on the design and development of MHS, more specifically custom-made MHS.
b) Analysis of the narrative from (a) above, followed by identification oftechniques that have been utilized along with theirindividual strengths and weaknesses
c) Developing a mechanism for decision-making for design of custom-made MHS. More specifically answering our primary research question: “which technique, or a combination of techniques, would be apt in the case of developing custom-made MHS”
d) Testing the technique, or combination of techniques, by applying it to a real-life case, followed by an in-depth discussion on results of application along with its limitations.

This paperhas been organized as follows: in the next section, we review existing literature on techniques that have been used in the past for eliciting and analyzing requirements in different domains, including mechanical and industrial engineering, medical and pharmaceutical, product and process design, and software engineering. We present the strengths and weaknesses of existing requirements engineering techniques. In section 4, we discuss techniques that are appropriate for the design and development of custom-made MHS. We discuss why a hybrid model is essential in that domain. In section 5, wepresent the application of this hybrid model to a real-life case study of requirements engineering foran anti-biotic (powder) manufacturing equipment. Section 6 includes a note on the limitation of this model along with directions for future research.

3.0 LITERATURE REVIEW

Requirements engineering process (Rzepka, 1989)may be decomposed into the following:

- Elicit: Gather requirements from various stakeholders
- Analyze: Improve understanding of requirements and ensure that all needs of stakeholders are consistent and feasible
- Validate: Check that the requirements are a true reflection of the needs of the stakeholders

Over the years, several techniques have been developed for requirements engineering, some of which are used to elicit requirements while others for requirements analysis and validation. Researchers have used different methods for studying requirements of MHS, specifically in the selection of standard equipment(Chakraborty & Prasad, 2016; Hassan, 2010; Williams & Narayanaswamy, 1997). Requirements elicitation techniques for custom-madeMHS is virtually non-existent. Researchers in other related domains, such as mechanical engineering, industrial engineering, nuclear equipment design, medical device design as well as services including disaster management, have used disparate requirement elicitation and analysis techniques. These range from simple one-on-one interviews (Mink, et al., 2015), focus groups (Bardhan & Dangi, 2016)and usability tests(Garmer, et al., 2004)to more advanced techniques such as quality function deployment (QFD) and Kano analysis (KA). Models that combine two or more methods e.g. QFD and KA etc. have also been developed. A brief discussion of these techniques is presented in this section. We restrict our discussions on elicitation techniques that have been successfully applied (in the form of case studies) and reported in literature since 1990. Analysis techniques that have been appliedto MHS design and selection since 2002 have been discussed.

3.1 Requirements Elicitation Techniques

Vieira et al. (2011) used questionnaires and surveys to collate data related to a new MHSbeing implemented in the automotive industry. The objective of their study was to understand the perception of stakeholders to the changes in MHS with respect to cost, safety, and overall user satisfaction. The authors concluded that simple methods, such as the one that was employed,are sufficient to make informed decisions. Researchers in the medical device domain have utilized requirements elicitation techniques that are user-centric. Garmer et al. (2004)deployed a combination of focus groups and usability tests to generate requirement specifications for designing a piece of new medical equipment. They argued that their approach has a positive effect on the common awareness of users’ problems amongst key project stakeholders. Martin et al. (2012) used interviews with stakeholders, including users and development team members, as well as brainstorming to elicit requirements. Data from the interviews were analyzed to identify common issues and themes. They demonstrated that this approach was not only rigorous and suitable but also met the practical constraints of small medical device manufacturers. Toola (1992) developed a methodology to elicit safety requirements in process automation. The methodology included several rounds of discussions with subject matter experts and other stakeholders, at the end of which a list of potential hazards are drawn up. It also uses the standard risk management process of identifying functional risks with their associated consequences and addressing those as part of process design. The complexity of an equipment increases while its usability decreases due to poor design. Luquetti dos Santos et al. (2011) developed a methodology that involves multi-disciplinary teams to work together in designing an equipment. This method, called participatory ergonomics, combines characteristics of joint application design, focus groups, and facilitated workshops. The method was successfully usedto design a fluoro-meter for nuclear reactor applications.Müller, Schulz and Stark (2010) presented guidelines to elicit and analyze requirements in the context of an industrial product-service system. The guidelines revolve around the idea of developing a comprehensive checklist that can be used to systematically discover requirements. Besides, the researchers also demonstrated the use of the checklist on two industrial workshops to elicit product requirements.Wang and Zeng (2009) used a generic process to elicit product requirements by asking questions based on linguistic analysis that transforms text into a graphic language, or a recursive object model (ROM). This method, which uses an iterative question-asking approach and requires strong domain expertise, was applied successfully to a mechanical engineering component design. Scenario analysis is a technique that relies on simulating different possible scenarios. This technique can be used when multiple options for MHS are readily available and can help decide the best MHS in a given situation. (Williams & Narayanaswamy, 1997; Chiocca, et al., 2013; Tsumaki & Tamai, 2006). Turner, Reeder and Ramey (2013) have also successfully used scenario analysis, personas and user stories in the development of an electronic communicable disease reporting system, a project in the information technology domain.Holder et al. (2017) used the unified modeling language (UML), which has been used successfully in the development of several software applications, to model the design of gearbox for electric multiple units of a railroad system. UML consists of two key elements – vocabulary and rules. Vocabulary is used to generate a design graphwhile rules are used to instantiate the vocabulary. Simulation models can be built and visualized when the rules are executed. Researchers argue that this method of requirements elicitation assures consistency between the requirements as well as between the product model and requirements. Other requirements elicitation techniques applied in the past range frommass interviewing (Claxton, et al., 1980), Delphi (Moskowitz, et al., 2005), and using functional prototypesand proto-trials (Jensen, et al., 2017; Yang & Epstein, 2005).

3.2 Requirements Analysis & Validation Techniques

Quality function deployment (QFD) is a philosophy thathas been used across several domains, including materials handling, mechanical and industrial component designas well as software development, to gather stated and unstated requirements of the customer. It consists of four stages, referred to as houses of quality, with the first stage used to elicit user requirements. Any familiar technique viz. interviews, surveys, questionnaires, document analysis, field data, may be used to source requirements, referred to formally as the voice of customer. The requirements are prioritized and incorporated into product specifications in the later stages of QFD. Chakraborty and Prasad (2016) used this technique to develop an expert system forthe selection of an appropriate material handling system. Their case application demonstrated the utility of this method for standard material handling equipment i.e., industrial truck. Kano Analysis (KA) has been used by researchers in the past to discover product attributes and their relation to customer satisfaction. Kano, Seraku, Takahashi and Tsuji (1984)argue that it is unproductive to focus on the improvement of all attributes of the product being designed since the effect on customer satisfaction reduces as attribute performance improves. In other words, there are asymmetric effects on customer satisfaction. Since its introduction, KA has been used extensively in the design of products (Sharif Ullah & Tamaki, 2011; Bilgili, et al., 2011; Ting & Ping, 2010)as well as services, including e-commerce (Karlsson & Le, 2017). Some researchers have developed hybrid models by combining two or more techniques, such as QFD and KA, to complement the strengths and weaknesses (Suef, et al., 2017). A survey by Ginting, Hidayati and Sirega (2018)lists several cases where the integrated model (QFD &KA) has been used successfully, i.e., tractor brake design, static bike design, design and development of pencil product and the like. KAis especially used when there are several unstated requirements.Yuan and Guan (2015) state that traditional design methods cannot satisfy the requirements of users and product structure. They demonstrated the elicitation and prioritization of requirements for a personalized wheelchair using a combination of Analytical Hierarchy Process (AHP), a technique that determinesthe importance of customer needs, and KA, which relates the users' needs to their satisfaction levels. Chan (2002)described the development of an intelligent material handling equipment selection system that had an AHP-based model to choose the most favorable material handling equipment type. He argued that the design of material handling equipment selection system could be automated by using artificial intelligence in the decision-making process.Further, Momani and Ahmed (2011) used Monte Carlo simulation to help decision-makers remove uncertainty in selection of MHS by allowing usage of different options as random variables. Other techniques that have been used by researchers include multi-criteria decision-making (MCDM) techniques such as Analytical Network Process (ANP)(Onut, et al., 2009), Integer/Goal Programming(Sujono & Lashkari, 2007), and Data Envelopment technique (Hassan, 2014)all of which have been used to make decisions (primarily selection) on MHE rather than design and prioritization of attributes.

4.0 REQUIREMENTS ENGINEERING FOR CUSTOM-BUILT MHS

As can be seen from the discussions, each technique has its own strengths and weaknesses. A technique that is appropriate in one situation may not be appropriate in another. For e.g., an interview may be a very simple method of eliciting requirements when the stakeholder group is small; however, as the size of interviewees increases, a questionnaire method becomes more appropriate and cost-effective. The choice of using a requirements elicitation technique depends on several factors, including complexity of the project, familiarity of using the elicitation technique, availability of time and information, degree of knowledge of the analyst, size and location of the stakeholder group, ability of the interviewee to describe the requirement, urgency and stakeholder communication requirements.Note that there is no single technique for the entire requirements engineering process. Analysts will have to use an appropriate technique to elicit solution-free requirements and use another to analyze and prioritize the collated requirements.

4.1 Requirements Elicitation

In this section, we discuss techniques that are appropriate for eliciting requirements for a custom-made MHS.We also describe the scenario that is apt for applying a given elicitation technique. Structured and unstructured interviews are simple and cost-effective, but may not help analysts identify solution-free requirements. Further, these interviews would need to be supplemented with prototype development to refine and confirm the stakeholder requirements. Mass interviews, brainstorming, nominal group and their variants may not lead to convergence of requirements and are therefore not suitable for a requirements elicitation for projects involving design of MHS. Document reviews can only be used when an existing MHS needs to be enhanced. Requirements analysts could use the existing documentation to study and recover the design of the MHS. While Delphi technique is good for new product design (Moskowitz, et al., 2005), this expert judgment method of eliciting requirements may be too time-consuming for a project of smaller durations. Availability of requisite skills may make Unified Modeling Language and Linguistic Analysis infeasible. On the other hand, Affinity Diagram and KJ+ interview involve all stakeholders. These techniques help in identifying not just stated but also the latent requirements. Affinity Diagrams and KJ+ Interview are, therefore, feasible techniques that may be used to prepare a list of initial requirements in the domain of custom-made MHS. Researchers at the Software Engineering Institute, Carnegie Mellon University, have used the following 4 parameters(Software Engineering Institute - Carnegie Mellon University, 2014) as part of a scoring model (on a 1-5 scale) to decide between using Affinity Diagrams and KJ+ Interview:

- Perspective: stakeholders share a common view of the problem
- Complexity: complexity of the work involved
- Urgency: Urgency of the solution to the needs
- Communication: Availability of data and ease of communication

They suggest adopting Affinity Diagrams when the score is less than six and using KJ+ interviews when the total score of these parameters exceeds 12.

TABLE 1: *COMPARISON - AFFINITY DIAGRAM AND KJ+ INTERVIEW*

Parameter	Affinity Diagram	KJ+ Interview
Perspective	1	4
Complexity	1	5
Urgency	1	4
Communication	1	4
TOTAL	4	16

As can be seen from Table 1the total assessment value for a typical custom-made MHS would be 16: stakeholders are diverse and hence have diverging opinions on requirements, the design is usually complex, and the data is not readily available for communication. KJ+ interview is, therefore,more suitable than Affinity Diagram in the requirements elicitation of custom-made MHS.A detailed description of implementing KJ+ Interview is presented in Section 4.3.

4.2 Requirements Analysis and Validation

As can be seen from the discussion in the literature review, several requirements analysis techniques have been used by practitioners in the past. The MCDM techniques and AHP, primarily decision-making techniques, have been used to select an appropriate MHS. QFD and KA, primarily analysis techniques, have been popular with respect to designing new equipment. In this section, we discuss the applicability and appropriateness of QFD and KA techniques, as applied to MHS. QFD is a great philosophy that has been used in designing new products as well as improving existing products (Chakraborty & Prasad, 2016). Analysts can use any of the elicitationtechniques such as interviews, mass interviews and questionnaires to collate the initial requirements and gradually transform those into prioritized list of requirements into design/technical specifications.While traditional QFD has been used successfully to elicit requirements, there have been studies that have reported problems as well. Firstly, QFD assumes that there is a linear relationship between product attributes and customer satisfaction, which may not be entirely correct. Secondly, in orderto be effective,QFD relies extensively on competitor product data. In the case of a custom-built MHS, the data on competitor products would not be available. Thirdly, the size of the matrix used in QFD (Kamara , et al., 1999; Ginting, et al., 2018)becomes very large, resulting in complex analysis and divergent conclusions about product attributes. Most organizations/teams, therefore, restrict themselves to the first stage of analysis, which defeats the purpose of using the very technique. Finally, another limitation of using QFD is complexity and effort required in transformation of customer requirements to technical requirements (Ginn & Zairi, 2005; Wolniak, 2018; Abu Assab, 2011).Based on the above, QFD isnot an appropriate choice for requirements elicitation and analysis in this situation.Further, in absence of comparative data, ethnography techniques, including observation and job shadowingwould also not be applicable in the given situation. KA is a technique that presumes that the relationship between requirements and customer satisfaction is non-linear, and helps classify the requirements into five different types:must-be(M), attractive(A), one-dimensional(O), in-different (I)and reverse(R). KAhas been used to design products andcanbe used for designing custom-made equipment. As part of the process, interviewees are asked two types of questions – functional and dysfunctional – for each requirement, and their response is mapped to a standard evaluation table (See Figure 2). The combination of answers to the functional and dysfunctional questions are then used to prepare a quantitative results table, whichis used to prioritize the requirements. The idea is to include all M type of requirements, maximize the O as well as Atype of requirements, and avoid I and Rtype of requirements. Satisfaction (C_s)and dis-satisfaction (C_d)indices against individual requirements may be developed using the following:

$$C_s = \frac{A+O}{(A+O+M+I)} \#(1)$$

$$C_d = \frac{O+M}{(A+O+M+I)} \#(2)$$

Unlike QFD, KA does not require any data from competing products and relies on primary information collated from stakeholders. Further, KA is much simpler to execute and less time-consuming. KAwould, therefore, be an appropriate technique in this situation. A discussion on implementing KA is presented in the next section.

4.3 Implementing KJ+ Interviews and KA

Japanese researcher Kawakita Jiro as part of an anthropological study developed the KJ+ interview technique. The primary purpose of this technique is to find hidden messages in systematic, qualitative data (Software Engineering Institute - Carnegie Mellon University, 2014). This technique has been found to be suitable when issues encountered are complex with too much qualitative data is available with the possibility of numerous interpretations. It can be used to elicit solutions-free, unstated requirements from the customers. This technique broadly consists of the following steps:

- Evaluate the stated needs of the customer. This can be done using a preliminary analysis of the statement of work / request for proposal document received from the customer.

- Design the interview script. The script is expected to contain open-ended, probing questions. Key stakeholders must participate in the interview process to ensure completeness of requirements gathering.
- Four types of questions may be included(Creveling, et al., 2008):
  - ➢ What: What problems have you encountered in the past with the current equipment while loading the raw material(s) in the hopper?
  - ➢ How: How would you load raw material(s) in the hopper?
  - ➢ Why: Why does the hopper and conveyor make more noise than expected?
  - ➢ Could: Could you please give me an example of …?

Conduct the KJ interview session. The idea is to capture the need along with the context. The objective would be to collate factual data. At no time should solutions be discussed. Emotional and superficial data is removed and only the needs data along with context is retained. Focus of the KJ+ interview is to collate the needs and contextual data, using personas (i.e., a specific user operating the system)

- Review results and prepare KJ Reports Statement. The KJ+ interview output is a KJ+ reports statement, which is a context-rich, solution-free, list of customer needs.
- Identify Themes: Repeatedly review the KJ+ reports statement and identify themes of experience(Software Engineering Institute - Carnegie Mellon University, 2014)
- Identify Unstated Needs: Hypothesize unstated needs from the discovered themes.

There are subtle differences between a traditional interview and the KJ+ interview technique for eliciting requirements. Some of these differences are listed in Table 2.

TABLE 1: *DIFFERENCES BETWEEN KJ+ INTERVIEW AND TRADITIONAL INTERVIEWS*

Traditional Interviews	KJ+ interview
Interview questions focus initially on areas of dissatisfaction	Interview questions focus on two extremes – "what makes them very happy" and "what makes them very dis-satisfied"
Discussions focus shifts to possible, acceptable solutions	No discussions related to solutions ever
All participants – interviewer and interviewees – participate in solution building. Data collated is on generic user. Not much importance is given to personas and roles.	As much focus on "needs data" and "contextual data" on positives and negatives are collated during interviews. This means data related to personas (who would work on the equipment) as well as their role and what is important to them is to be collated.
Discussions then shift to design and implementation issues. Interviewees are highly satisfied that their voice has been heard, and they will soon get their solution	Data is then abstracted under themes, using which solutions-free requirements are constructed. Stated and unstated requirements can be isolated and documented.

At the end of thisprocess, a list of stated and unstated requirements is produced which forms the basis for developing one or more detailed customer requirements. Once an initial list of requirements, including stated and unstated requirements, is available, KA can be used to identify those that are a necessity and those that are not. The KA model is schematically shown in Figure 1

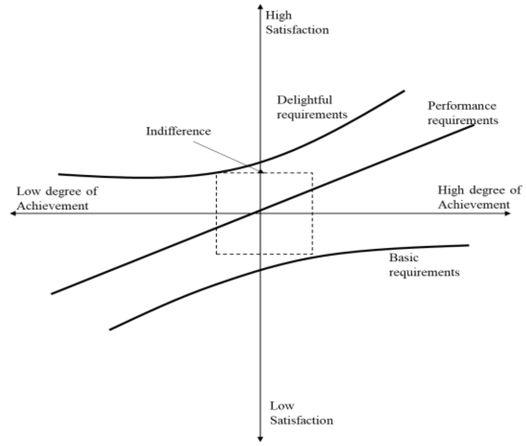

Figure 1: *Concept of Kano Analysis (KA) technique (See Kano, et al., 1984)*

TABLE 3: *KANO ANALYSIS - DESCRIPTION OF ATTRIBUTE TYPES*

Attribute	Meaning
Must-be (M)	Absence of this attribute produces dis-satisfaction; presence does not increase satisfaction
Attractive (A)	Presence of this attribute produces greater satisfaction but is not expected by users in the product
One-dimensional (O)	Presence of this attribute increases satisfaction when fulfilled and dissatisfaction when not present.
Indifferent (I)	Presence or absence of this attribute does not increase or decrease satisfaction
Reverse (R)	Presence causes dis-satisfaction, and absence causes satisfaction

In order to improve satisfaction of the users, the following actions must be taken:

a. Ensure all must-be requirements are implemented in the MHS
b. Maximize the one-dimensional and attractive requirements
c. Avoid indifferent and reverse requirements

Kano model prescribes a standard questionnaire that needs to be administered to stakeholders. Interviewees are asked two types of questions – functional and dysfunctional – for each requirement, and their response is mapped to a standard evaluation table (See Figure 2). The combination of answers to the functional and dysfunctional questions are then used to prepare a quantitative results table, which can be used to prioritize the requirements. Satisfaction (C_s)and dis-satisfaction (C_d)indices may be developed using equations (1) and (2).

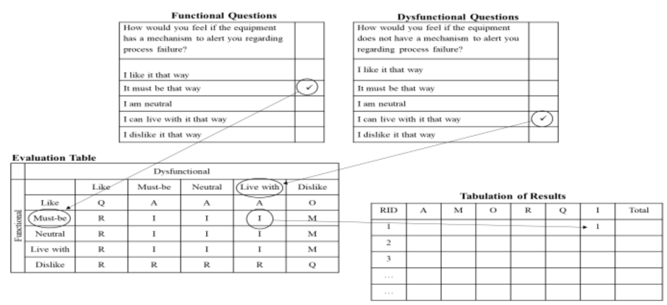

Figure 2: *Kano analysis - process of tabulating results*

In summary, the following combination of techniques would be apt in the case of developing custom-made MHS:

- KJ+ Interview, to help identify stated and latent requirements, which can then be elaborated and specified. The requirements thus collated would be free from solutions, which is an expectation of a requirements elicitation technique.
- KA, to prioritize the MHS requirements that would delight the stakeholders. KAcan be used to classify collated requirements into must-be, attractive, one-dimensional, indifferent and reverse. The designer can then take actions to include all must-be requirements, maximize the one-dimensional as well as attractive requirements, and avoid those classified as indifferent and reverse requirements.

By combining the KJ+ interview with Kano analysis, we get a hybrid model, whichcan be used to gather requirements that can deliver maximum value to the customer. In the next section, we discuss the application of this hybrid model to a real-life case of eliciting requirements for MHS, and prioritizing those.

5.0 CASE STUDY - ANTIBIOTIC TABLET MANUFACTURING

CT (Name of the company has been camouflaged) is amedium-sized firm in India that is engaged in manufacturing custom built MHS for their customers. They design, build and install turnkey MHS for their customers around the world. With a workforce of 85 experienced engineers and more than 100 other skilled technicians, CT has expertise in designing solutions to a wide range of industries, including chemicals, pharmaceutical and food processing. They manage each customer initiative as a project. Some of their customers include large pharmaceutical manufacturers and food processors. In the past, business analysts and engineers at CT have usedmultiple requirements elicitation techniques, including interviews and lead user analysis, to gather requirements. One of the key concerns for CT is that customers, as part of requirements engineering process, give them solutions rather than needs, which on several occasions has resulted in requirements instability during implementation of the project, or in rapid loss of value of systems after delivery of the project.In order to eliminate this risk, engineers at CThave been researching requirements elicitation and analysis techniques that can help them identify prioritized, solution-free needs of the customer and design and deliver the MHS that meets those needs. A large globalpharmaceuticalfirm, which has several offices around the world,had requested CT to supply a custom-made MHS for packaging medical anti-biotic tablets (powder handling system). The project had an initial scope that included an operator manually charging (bulk-loading) the raw material (i.e., anti-biotic powder) to the system, which then passes through several stages of chemical processing till it is eventually packaged into tablets in the required size, shape and form. While the procedure of handling medical-grade powder is very standard and used by many firms, the pharmaceutical firm wanted to make the process lean, i.e., maximize productivity using minimal resources, while keeping the safety of the operators in mindDesign and development of any pharmaceutical packaging equipment, as in this case study, places stringent demand on purity of the powder as it moves from one stage of processing to another. At the same time, the operator loading the raw material must be protected from inhaling the dust and hazardous vapors arising from the powder handling process. CTengineers visited the project site to learn about the requirements, observe the current process in place and take measurements of the area over which the new equipment has to be installed.26 stakeholders – from CT as well as the pharmaceutical firm - were part of the project. It included end-users, line supervisors, quality control staff, maintenance staff, managers and product owners from the pharmaceutical firm, and engineers, designers and a project manager from CT. Past experience and results of using traditional techniques such as interviews and lead user analysis have been far from satisfactory, and usually had some solutions built-in. In the current case, engineers fromCT used a combination of KJ+ interview and KA for requirements engineering. The KJ+ interview technique was used to elicit the stated, unstated and performance requirements while KA was used to analyze, classify and prioritize those. The process followed to elicit preliminary list of requirements was recovered from the request for proposal (RFP) document received from the customer.The KJ+ interview script contained open-ended, probing questions. All stakeholders participated in the interview process. Questions included what, how, why and could (Creveling, et al., 2008) types.The needs of the stakeholders were captured along with the context, with factual data associated with personas. At no time were solutions discussed. Using the KJ+ interview technique, a list of solutions-free requirements for the proposedMHSwas developed. Table 4lists these requirements.

TABLE 4: *REQUIREMENTS FROM STAKEHOLDERS OF THE POWDER HANDLING SYSTEM*

Req. ID	Requirements statement
1	The equipment must fit nicely in the available space.
2	The equipment must be safe for operators from dust and vapors
3	Loading of raw material in the system must be simple/easy
4	Cleaning of equipment must be easy
5	Less or no noise during operation
6	Quick service on partial or complete outage
7	Reliable equipment and sub-components, i.e., Low failure rate
8	Output of the process must be as per standard (or better in terms of shape, size and color)
9	Valves / Ports must be easily accessible and smooth to operate
10	Easy to monitor extraction process with required controls
11	Online monitoring of process – alerts sent to at least 5 mobile numbers as text messages (Quality of output, no output)
12	Online monitoring of system and sub-systems – alerts sent to at least 5 mobile numbers as text messages indicating abnormality (vibrations, temperature, leakage)
13	Low power consumption
14	Reliable and well calibrated instrumentation
15	The equipment must look good when completely installed
16	The equipment must have smooth edges
17	Code of Federal Regulations (CFR) compliant
18	Follows Food and Drug Administrator (FDA) guidelines on good manufacturing practices
19	Works first time after installation – no trial and error

Engineers from CT next used the KA technique to classify and prioritize the requirements. 19 requirements identified using KJ+ interviews were converted to 19 pairs of functional and dysfunctional questions. Table 5shows the list of functional (prefixed with F) and dysfunctional questions (prefixed with D) that were administered on 26 stakeholders. Table 8 presents the results of KA.

TABLE 5: *FUNCTIONAL AND DYSFUNCTIONAL QUESTIONS*

F1	How would you feel if the equipment fits nicely in the available space?
D1	How would you feel if the equipment does NOT fit nicely in the available space?
F2	How would you feel if the equipment is safe for operators from dust and vapors?
D2	How would you feel if the equipment is NOT safe for operators from dust and vapors?
F3	How would you feel if the loading of raw material in the system is simple/easy?
D3	How would you feel if the loading of raw material in the system is NOT simple/easy?
F4	How would you feel if cleaning of equipment is easy?
D4	How would you feel if cleaning of equipment is NOT easy?
F5	How would you feel if the equipment operates noiselessly, or less than 70db?
D5	How would you feel if does NOT operate noiselessly (or more than 70db)?
F6	How would you feel if the service provided by the equipment manufacturer is quick on partial or complete outage?
D6	How would you feel if the service provided by the equipment manufacturer is NOT quick on partial or complete outage?
F7	How would you feel if equipment and sub-components is reliable (low failure rate)?
D7	How would you feel if equipment and sub-components is NOT reliable (high failure rate)?
F8	How would you feel if the output of the process is as per standard (or better, in terms of shape, size, quantity and color)?
D8	How would you feel if the output of the process is below standard (or lower, in terms of shape, size, quantity and color)?
F9	How would you feel if the valves and/or ports of the equipment are easily accessible to operate?
D9	How would you feel if the valves and/or ports of the equipment are NOT easily accessible to operate?
F10	How would you feel if monitoring of extraction process is easy?
D10	How would you feel if monitoring of extraction process is NOT easy?
F11	How would you feel if online monitoring of output of the process (i.e., product) is made available?
D11	How would you feel if online monitoring of output of the process (i.e., product) is NOT made available?
F12	How would you feel if online monitoring of system and sub-systems, indicating abnormality (vibrations, temperature, leakage etc.), is made available?
F13	How would you feel if the equipment consumes low power?
D13	How would you feel if the equipment consumes high power?
F14	How would you feel if the electronic instrumentation of the equipment is reliable and well calibrated?
D14	How would you feel if the electronic instrumentation of the equipment is NOT reliable and well calibrated?
F15	How would you feel if the equipment looks good?
D15	How would you feel if the equipment does NOT look good?
F16	How would you feel if the equipment has smooth edges?
D16	How would you feel if the equipment does NOT have smooth edges?
F17	How would you feel if the equipment complies with Code of Federal Regulations (CFR)?
D17	How would you feel if the equipment does NOT comply with Code of Federal Regulations (CFR)?
F18	How would you feel if equipment follows the Food and Drug Administrator (FDA) guidelines on good manufacturing practices?
D18	How would you feel if equipment does NOT follow the Food and Drug Administrator (FDA) guidelines on good manufacturing practices?
F19	How would you feel if the equipment works first time as required after installation (i.e., no trial and error changes to equipment settings)?
D19	How would you feel if the equipment requires lot of trial and error changes in setting during and after installation?

TABLE 8: *SUMMARY OF RESULTS*

Question No.	A	I	M	O	Q	R	Grand Total	Satisfaction Index	Dissatisfaction Index
1	3.85%	7.69%	69.23%	19.23%	0.00%	0.00%	100.00%	75.00%	88.5%
2	7.69%	3.85%	76.92%	11.54%	0.00%	0.00%	100.00%	83.33%	88.5%
3	61.54%	15.38%	7.69%	15.38%	0.00%	0.00%	100.00%	83.33%	23.1%
4	57.69%	19.23%	7.69%	15.38%	0.00%	0.00%	100.00%	4.76%	23.1%
5	11.54%	65.38%	15.38%	3.85%	3.85%	3.85%	100.00%	19.05%	20.0%
6	15.38%	15.38%	38.46%	30.77%	0.00%	0.00%	100.00%	75.00%	69.2%
7	0.00%	15.38%	73.08%	11.54%	0.00%	0.00%	100.00%	42.86%	84.6%
8	3.85%	3.85%	42.31%	50.00%	0.00%	0.00%	100.00%	93.33%	92.3%
9	65.38%	11.54%	11.54%	11.54%	0.00%	0.00%	100.00%	86.96%	23.1%
10	65.38%	7.69%	7.69%	19.23%	0.00%	0.00%	100.00%	91.67%	26.9%
11	73.08%	19.23%	0.00%	7.69%	0.00%	0.00%	100.00%	80.77%	7.7%
12	69.23%	11.54%	11.54%	7.69%	0.00%	0.00%	100.00%	86.96%	19.2%
13	73.08%	7.69%	7.69%	11.54%	0.00%	0.00%	100.00%	91.67%	19.2%
14	7.69%	11.54%	65.38%	15.38%	0.00%	0.00%	100.00%	66.67%	80.8%
15	11.54%	84.62%	3.85%	0.00%	0.00%	0.00%	100.00%	12.00%	3.8%
16	15.38%	69.23%	15.38%	0.00%	0.00%	0.00%	100.00%	18.18%	15.4%
17	0.00%	23.08%	69.23%	7.69%	0.00%	0.00%	100.00%	25.00%	76.9%
18	7.69%	3.85%	65.38%	23.08%	0.00%	0.00%	100.00%	88.89%	88.5%
19	61.54%	3.85%	19.23%	15.38%	0.00%	0.00%	100.00%	95.24%	34.6%

5.1 Results and Discussion - Uncovering latent requirements

The KJ+ interviews were very useful in recovering complete, solution-free requirements, including latent requirements. During the interview, stakeholders were asked questions related to their experience. The questions focused on positive and negative experiences. This deliberately shifts the discussions from opinion to facts and from solutions to problems. For example, the operators were asked about the ease of loading antibiotic powder manually into the system. The theme, however, revealed that the operators and their supervisors were more concerned about health issues (i.e., inhaling the dust and vapors) rather than the effort of loading. This resulted in two requirements: one stated (Req ID 3) and one unstated (Req ID 2). Another key unstated requirement (Req ID 19) was that the equipment must work first time after installation without any trial and error. While this is an expectation of key stakeholders, this is never stated in their requirements.

5.2 Results and Discussion – Classification of Requirements

Table 8shows the summary of the responses obtained against the 38 functional and dysfunctional questions: 42.1% (8 out of 19) requirements were from the attractive (A) category. These requirements increase customer satisfaction. These include requirement IDs 3, 4, 9, 10, 11, 12 13 and 19. A review would indicate that these requirements are more functional in nature, impacting the users/operators of these equipment. 36.8% (7 out of 19) requirements belong to the must-be (M)category. These include requirement IDs 1, 2, 6, 7, 14, 17 and 18. These requirements relate to regular maintenance of equipment and to some extent to the regulatory guidelines. 15.8% (3 out of 19) requirements were marked indifferent(I). These include requirement IDs 5, 15 and 16. These requirements are more non-functional, and relate to aesthetics and ergonomics. 5.2% (1 out of 19) requirements (requirement ID 8) were marked one-dimensional(O) None of the requirements was marked reverse (R)or questionable (Q)– indicating the absence of requirements that will increase dissatisfaction. Finally, we computed the satisfaction and dis-satisfaction indices using Equations (1) and (2). Req ID 19 (Work first time after installation), which was marked attractive,had the maximum satisfaction index (95%) while Req ID 9 (Ability to clean valves and ports) had maximum dis-satisfaction index (92.3%). Using this information, the engineers would be able to design an equipment that would maximize customer satisfaction.

6.0 CONCLUSION

Manufacturing firms are demanding custom-made MHS to stay ahead of their competitors and make their processes lean. Suppliers of custom-madeMHS are under pressure to deliver systems that delight their customers. In order to achieve this objective, a supplier must be able to elicit complete set of solution-free customer requirements and prioritize those. Techniques such as QFD have been popular and been used in the past to meet the design challenges posed by manufacturing firms. However, researchers have exposed several limitations of this technique. In this paper, we have reviewed more than 20requirements elicitation and analysis techniques, along with their advantages and shortcomings. In addition, we have also discussed the scenario(s) under which each of these techniques may be used. We have presented a hybrid model that combines KJ+ interview and KA techniques. KJ+ interview can be used to elicit functional, non-functional and latent customer requirements. Because of the philosophy involved, this technique helps discover solution-free requirements. KJ+ interview technique is appropriate especially when stakeholders have divergent views of the product to be designed, the work involved is complex and data for communication is insufficient. KA is requirements analysis technique that is based on the philosophy that product attributes and customer satisfaction have a non-linear relationship. Designers would be able to design better products if they have a better understanding of this relationship. With the help of a real-life case study– designing of an antibiotic tablet manufacturing equipment - we have shown how a combination of KJ+ interview and Kano analysis was used effectively to identify key and latent requirements as well asclassify those into categories that can delight the users. Like any other practical research, our work also has its own limitations. The work presented in this paper uses a combination of techniques – KJ+ and KA. Both these techniques require skilled facilitators. In addition, being a survey-based method, KA will require a lot of attention while designing the survey instrument and interpreting the results correctly. The hybrid model presented in this paper has been validatedempiricallyon a single case study. While the paper will be of interest to designers of custom-made MHS, the results of applying this hybrid model would need to be validated further in other domains.

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