Product Configuration via Negotiation for Mass Customization: An Interactive Goal Programming Approach

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Abstract - **In the context of product customization, customers and manufacturers are often unable to accurately articulate need and solution information. This paper takes product configuration as a process of collaborative design and introduces negotiation as a new method to support interactive decision making. A general framework for negotiation-based configuration is developed based on negotiation analysis and the domain concept of axiomatic design. Product configuration is formulated as two interdependent goal programming problems between customers and manufacturers. An interactive problem solving procedure is also developed to implement the proposed methodology.**

Keywords - **Customization, Configuration, Negotiation, Goal Programming**

I. INTRODUCTION

Product configurators have been recognized as a critical enabler in mass customization [1]. A main challenge in product customization is elicitation of customer need information [2]. Customers are generally unable to accurately articulate needs in terms of concrete and precise requirements, and manufacturers have difficulty to effectively convey their customization capabilities. The problem is succinctly summarized as "*information asymmetry and stickiness*" by von Hippel [3]. Product configurators mitigate this challenge by facilitating information exchange and matching customers' need information with manufacturers' solution information. With product configurators, the task of design in customization can be simplified to a series of selections of predefined attribute options [4].

The range of application of product configurators is expanding from consumer products like personal computers and watches to capital goods like machine tools, network servers, and cement plants, etc [5]. One particular area of application of configurators is to assist sales personnel in making quotations in response to customers' request for quotes (RFQs). However, our project experience in a number of industries reveals a dilemma. The configurators that many companies have adopted are best in breed and maintained up to date, but they are underutilized while "special teams" of experienced engineers are frequently called in for RFQ processing. The reason, as it turns out, is not simply a technical issue due to customers' lack of domain knowledge but has strategic reasons behind. Customers usually approach several competing manufacturers when procuring a customized product. Different manufacturers, however, usually have distinct capabilities. In order to promote competition among manufacturers, customers tend not to specify RFQs in favor of any particular manufacturer. Not surprisingly, the resulted customer requests rarely fit readily into the solution space of a manufacturer's configurator.

The actual configuration process often involves back and forth iterations between customers and manufacturers, in which configurators are often used as a supporting tool. In a large-scale empirical study on the implementation of product configurators, Salvador and Forza show that sales personnel generally feel lack of support and tend to stick to some "favorite solutions" in configuration, thus failing to tap into the variety of choices offered in the system [6]. In general, there is a need to develop configurators that can effectively handle ambiguities in customer requirements and assist decision making in resolving discrepancies between customers' requests and manufacturers' solutions. Towards this aim, this research introduces negotiation as a new methodology for collaborative configuration.

II. LITERATURE REVIEW

Negotiation is widely practiced as a means of joint decision making in situations that are characterized by ill defined problem structure, asymmetric information, and conflicting preferences. It has been studied extensively in various disciplines that include social science, economics, computer science etc. In economics literature, negotiation is interchangeably used with bargaining, which is usually modeled as a bi-lateral zero-sum game. Myerson and Satterthwaite have proved *"...the general impossibility of ex post efficiency of bargaining without outside subsidies"* [7]. In other words, bargaining is inherently inefficient because of lack of incentives for truth telling. Although the result corroborates the public perception of negotiation, it is derived based on the assumption that there is a single dimension in negotiation and negotiators are economically rational.

In reality, however, there are usually multiple issues at stake and negotiators have only bounded rationality [8]. Raiffa et al. define negotiation as "*a process of joint decision making, which entails joint consequences, or payoffs, for each individual*". By integrating decision science and game theory, they develop negotiation analysis as a systematic methodology for collaborative decision making [9]. They further differentiate *integrative negotiation* from *distributive negotiation*, arguing that different parties usually have different preferences over different issues in negotiation. Through a take-and-give process, negotiators could both gain by sharing (partial) information and move the joint solution towards an efficient frontier.

Negotiation theory, negotiation analysis in particular, has been recently applied in collaborative design, which is becoming increasingly multidisciplinary and cross functional. Traditional design methodologies seek to dismiss the necessity for negotiation through aggregation of individual preferences into a group preference by means of assigning weights to different design objectives. Arrow's impossibility theorem (AIT) [10], however, rules out the possibility of defining a utility function that can consistently represent the preference of a group. Hazelrigg interprets the implication of AIT in engineering design and cautions against design optimization towards aggregated customer preferences, which could result in "irrational" designs [11]. Franssen and Bucciarelli [12] extend the game-theoretic model of collaborative design to allow bargaining and demonstrate that "rational" designs can be obtained in a group setting with diverse preferences. Configuration can be taken as a process of collaborative design between customers and manufacturers, who have asymmetric information and conflicting preferences. Thus, there is a theoretical foundation to apply negotiation theory in engineering design in general and product configuration in particular. In an earlier paper, Chen and Tseng [13] proposed a multi-attribute negotiation approach to defining the specifications of custom products.

A critical challenge in negotiation is how to effectively navigate through an often ill-defined problem structure with partial information. With bounded rationality and preferential conflicts, negotiators often take a "tug of war" stance on each issue at stake and end up with inefficient solutions while "*leaving money on the table*" [14]. The advent of information technology provides new venues as well as new means to conduct negotiations. There has been growing research interest in computer science, artificial intelligence in particular, on electronic negotiations [15]. Among various approaches that have been proposed, negotiation support systems (NSSs) can effectively assist negotiators in processing information, making decisions, and searching for efficient agreement. The general motivation of this research is to incorporate the functionality of an NSS into a product configurator so as to facilitate collaborative decision making in the configuration process.

III. A NEGOTIATION FRAMEWORK FOR CONFIGURATION

This research models product configuration as a special form of design and introduces the domain concept from axiomatic design theory to represent customers' and manufacturers' decisions. Design in general can be viewed as a series of what-to-how mappings from customer needs {CN} to functional requirements{FR}, to design parameters{DP}, and finally to process variables {PV} [16]. {CN} represents a customer's real, but often hidden, needs; {FR} is the articulated customer needs in terms of desired product functionality or features; {DP} represents a technical solution; and {PV} describes how the designed product can be produced. Collectively, {FR,DP,PV} represents a complete set of product specification. The mappings between {FR},{DP}, and {PV} are characterized by design matrix [A] and [B], respectively.

$$\{FR\} = [A]\{DP\} \tag{1}$$
$$\{DP\} = [B]\{PV\} \tag{2}$$

It is worth noting that design matrix may or may not be in numeric form but generally indicate the inter-relationships between different design domains. In the context of product configuration, design matrix can be interpreted as codified design knowledge and assumed as given in the configuration process. {PV} and [B] are functionally equivalent to {DP} and [A], respectively, and henceforth dropped from discussion in the rest of the paper without loss of generality.

Customers' and manufacturers' objectives in design can be assumed as to maximize value (v) and minimize cost (c), respectively. The value and cost of a configured solution depend on what the customer receives in terms of functionality and what the manufacturer needs to deliver in terms of the technical solution. Hence, v and c can be modeled as functions of {FR} and {DP}, respectively.

$$v = V(\{FR\}) \tag{3}$$
$$c = C(\{DP\}) \tag{4}$$

Value function and cost function are private information to customers and manufacturers, respectively. The objectives to maximize v and minimize c are often in conflict given the coupling between {FR} and {DP}. As commonly observed in industry, customers often start an RFQ process by asking for high quality, high performance, but low price. On the other hand, manufacturers often respond with quotes that have proven configurations and low cost. Discrepancies often emerge between request and quote, and the process becomes iterative with customers and manufacturers alternately making compromises on functionalities and cost, respectively, i.e. a negotiation process.

Figure 1 illustrates a general framework for collaborative configuration via negotiation. The vertical lines represent the decision variables in configuration. Arrows represent directions of preference. For simplicity reasons, vectors {FR}and {DP} are represented on a single dimension and the scale is normalized to be within [0, 1] for all variables. A horizontal line represents a configuration {FR,DP} with corresponding v and c. The customer has a reserve value and an aspired value for v, which represent thresholds beyond which solutions are not acceptable and readily acceptable, respectively. The problem structure is mirrored with manufacturer in terms of c and {DP}. Solutions that are superior to both customers' and manufacturers' reserve values form a so-called zone of possible agreement (ZOPA) [9], which corresponds to the feasible solution space in configuration. The task of configuration is then to search for a mutually acceptable solution (or an agreement) in ZOPA, as represented by the dotted line. The extra values of the joint solution over reserve values of v and c are defined as surpluses for the customer and manufacturer, respectively. The objectives to maximize v and minimize c are equivalent to maximize customer surplus and manufacturer surplus, respectively.

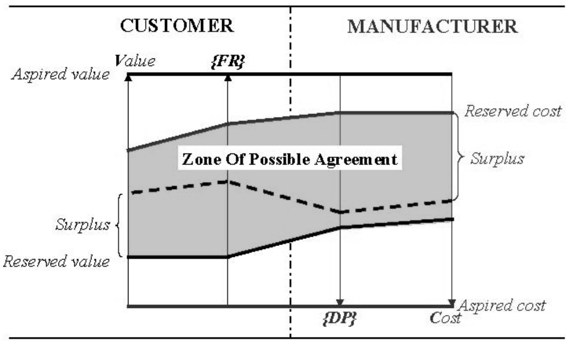

Fig.1.A negotiation framework for configuration

IV. PROBLEM FORMULATION

For a given set of customer requirements ({FR}), configuration can be generally formulated as a constraint satisfaction problem (CSP) to search for a solution ({DP}) that satisfies constraints imposed by {FR} and other constraints ($f_m(DP) \leq 0$) with minimum cost (c), as depicted in Figure 2. The sign '$\succ$' indicates preferential superiority. When {FR} is inaccurate, solving CSP will yield suboptimal solutions or no solutions if is over specified, which is commonly observed in RFQ practice.

CSP:
Given: $\{FR\}$, $[A]$
Find: $\{DP\}$
Satisfy: $[A]\{DP\} \succ \{FR\}$,
$f_m(DP) \leq 0$.
Minimize: $c = C\left(\{DP\}\right)$

Fig.2.Constraint-based configuration

This research assumes {FR} as negotiable and develops algorithms based on goal programming to provide negotiation support during the configuration process. The specific issue that this research aims to address is how to make offers (or counter offers) based on partial information revealed so as to effectively explore the solution space and locate efficient configurations. An empirical rule in negotiation is to seek agreements with minimum concessions [14]. In the context of configuration, this research interprets this empirical rule as: with a fixed amount of concession to make, negotiation should be directed towards minimizing outstanding difference between contending solutions.

Figure 3 and 4 illustrate the decision formulation for the manufacturer and customer in the negotiation-based configuration, respectively. In each round of negotiation, the manufacturer's decision is modeled as a goal programming problem (GP-M) to find a solution () within cost concession (Δc) that minimizes the aggregated distance to the customer's current requirements ($\{FR_c^g\}$), which are taken as goals instead of constraints. The distance is measured by deviation variables (d_i) on each dimension of the vector of requirements {FR}.

GP-M:
Given: $\{FR_c^g\}$, $\{DP_m^g\}$, Δc, $[A]$
Find: $\{DP\}$
Satisfy:
$[A]\{DP\} = \{FR\}$;
$FR_i + d_i^- - d_i^+ = FR_{ci}^g$;
$d_i^- * d_i^+ = 0, d_i^- \geq 0, d_i^+ \geq 0$;
$i = 1, 2, \ldots, M$;
$f_m(DP) \leq 0$;
$C\left(\{DP\}\right) - C\left(\{DP_m^g\}\right) \leq \Delta c$
Minimize:
$$Z_m = \sum_{i=1}^{M} (d_i^+ + d_i^-)$$

Fig.3.The manufacturer's decision

GP-C:
Given: $\{FR_c^g\}$, Δv, $\{DP_m^g\}$, $[A]$
Find: $\{FR\}$
Satisfy:
$\{FR_m^g\} = [A]\{DP_m^g\}$
$FR_i + d_j^- - d_j^+ = FR_{mj}^g$;
$d_j^- * d_j^+ = 0, d_j^- \geq 0, d_j^+ \geq 0$;
$j = 1, 2, \ldots, N$;
$f_c(FR) \leq 0$;
$V\left(\{FR_c^g\}\right) - V\left(\{FR\}\right) \leq \Delta v$.
Minimize:
$$Z_c = \sum_{j=1}^{N} (d_j^+ + d_j^-)$$

Fig.4.The customer's decision

The customer's decision is similarly formulated as a goal programming problem (GP-C), in which a limit on value concession (Δv) is assumed and the decision is to specify a set of requirements ({FR}) that are closest to the manufacturer's current offer ($\{FR_m^g\}$). Similar to $f_m(DP) \leq 0$, $f_c(FR) \leq 0$ represents the additional constraints on {FR} in the customer domain. Thus, both manufacturers and customers have partial information concerning product configuration and they need to collaborate in decision making to explore for a mutually acceptable solution.

V. AN INTERACTIVE PROBLEM SOLVING PROCEDURE

This research develops an interactive problem solving procedure to implement configuration via negotiation. The process starts with the customer initializing request ($\{FR_c^g\} = \{FR\}$). The manufacturer responds by taking as an input and solving CSP. If no feasible solution, the manufacturer quotes his aspired solution ($\{FR_m^g, DP_m^g\}$); if there is a feasible solution that costs less than $\{DP_m^g\}$, the manufacturer will accept $\{FR_c^g\}$ and the negotiation concludes with an agreement ($\{FR^*, DP^*\}$); otherwise, the manufacturer specifies an amount of cost concession (Δc) and solves GP-M for a counteroffer ($\{DP\}$), which also updates his aspired solution ($\{FR_m^g, DP_m^g\}$). The customer accepts the manufacturer's offer if it gives higher value than FR_c^g and the process ends with an agreement; otherwise, the customer specifies an amount of value concession (Δv) and solves GP-C for a counteroffer ($\{FR\}$), which updates her aspired solution ($\{FR_c^g\}$). The process iterates and terminates either with an agreement or non-agreement when it reaches the limits K_c or K_m, which represent the maximum effort that the customer and manufacturer are willing to invest, respectively.

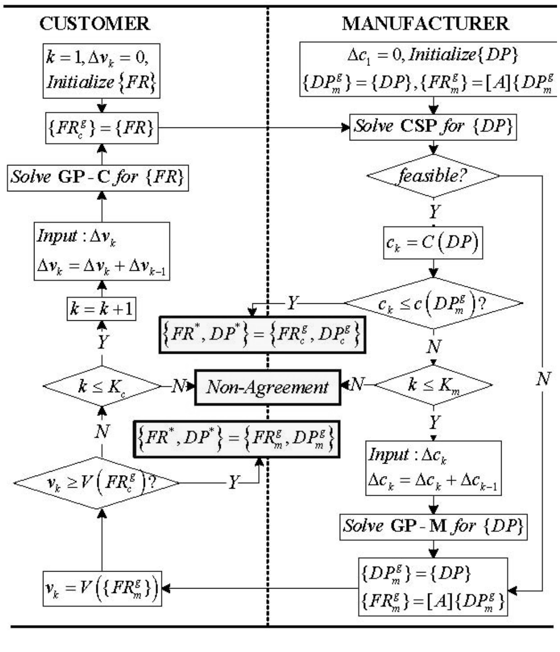

Fig.5.An interactive problem solving procedure

It is worth noting that concessions on and are assumed as exogenously determined for each side. In other words, the algorithms developed are not to automate the negotiation process but rather to provide assistance in decision making. Human decision makers need to evaluate the dynamic situation in the negotiation process and decide whether to make concession or not as well as how much to concede. The algorithms then propose the best offers/counteroffers to move negotiation process forward. The procedure can be assumed as being carried out between a customer's procurement system and a manufacturer's configuration system.

VI. SUMMARY

Application of configurators for making quotations of customized products requires the configurators to be able to handle inaccuracy in customer requirements. This paper introduces negotiation as a new methodology to support interactive decision making in product configuration. By synthesizing research on negotiation analysis, engineering design, and electronic negotiation, this research models configuration as a collaborative design problem and incorporates functionalities of a negotiation support system into configurator design. A negotiation framework for configuration is constructed based on the domain concept of axiomatic design. Algorithms based on goal programming are developed to assist making offers/counteroffers in the negotiation process. An interactive problem solving procedure is developed accordingly to implement the proposed methodology.

The focus of the current research is on laying a theoretical foundation for applying negotiation theory in configuration problem solving. Discussion in this paper is mostly on the conceptual level assuming continuous variables. Future research is needed to consider discrete solution space in configuration problem formulation and problem solving. Metrics for evaluating negotiation results need to be developed, and the algorithms and problem solving procedures developed in this research need to be tested with industrial examples.

VII. ACKNOWLEDGEMENT

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