DESIGN AUTOMATION FOR THE COMPONENT PARTS INDUSTRY

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Abstract

Design automation in the component parts industry from purchase inquiry to finished product delivery is described. The computerized process simulates human decision makers, eliminates bottlenecks, and frees human decision makers from doing routine work.

Fuzzy set analysis appears to be a natural method to be used in the early stages of a design process. Its language describes well the imprecise or blurred specifications at the initial phase of an engineering design (Ref. (1), (3), (4), (5)). The mathematics of fuzzy-set analysis leads naturally to a process which can be identified with heuristic selection (Ref. (2)). They are alternative means for realizing the product selection and design specification program (PSDS) in the computerized process.

Introduction

The component parts industry is an important element in manufacturing. Very frequently some components in a manufactured product are purchased from different companies, e.g. the electrical motor in a typewriter, washing machine, or machine tool, switches, filters, and IC's in electronic circuits, and etc. The manufacturer usually has more than one source of supply to insure the component's quality, price, and punctuality in delivery. The selling and purchasing processes of these components are an active and integral part of manufacturing.

The design automation process to be described applies to a generic class of the component parts industry in which the components to be supplied are not shelf items but engineered specifically for the application. Electrical motors and filters are well known examples. The appliance manufacturers are generally not satisfied by the characteristics and external dimensions of a standard motor. Motor manufacturers (the component suppliers) are willing to design specific motors for such applications because of the large production volume involved.

A generic property then is the necessity of going through engineering during the bidding and sales phase. Since there are a large number of sales offices distributed throughout the world and far fewer engineering offices, the above mentioned need represents both a drain on the engineering manpower and a substantial delay in responding to an inquiry. Vertically integrated design automation (VIDA), eliminates these problems in addition to doing what it normally does: facilitating the design and manufacturing processes.

A Comparison of Two Systems

The flow of information in an unautomated sales to engineering to production cycle is as follows: Responding to a customer's inquiry, a sales representative obtains the pertinent specifications and relays the information to engineering, which makes a preliminary design of the product, has it costed and tentatively scheduled. An unscaled drawing of the product, sometimes with calculated performance curves, price, and estimated delivery date are then sent back to the customer through sales. If a purchase order follows, engineering makes the final design and production scheduling. Since one engineering office serves many widely distributed sales offices, it becomes a bottleneck in the sales phase.

There are three essential disadvantages:

1. Since most purchase inquiries do not result in a purchase order, much of the engineering work in the preliminary design phase is wasted.
2. There is substantial delay in the preliminary design phase. The purchase specifications usually go to a chief engineer or another experienced engineer, who, based on his broad experience makes a number of preliminary choices, so that a less experienced engineer can follow through with detailed design work. Usually each engineer has a number of jobs lined up, and the job has to wait in its queue.
3. The tentative production schedule is very uncertain when there is a large number of jobs in the purchase inquiry and response phase. One has to be conservative in estimating a delivery date.

Figure 1 shows a vertically integrated design automation system (VIDA), from sales to production. After obtaining specifics in a customer's inquiry, the sales representative inputs such information into a VIDA terminal interactively. The VIDA program asks clarification

This work was supported by the National Science Foundation under Grant DMC - 8702465.

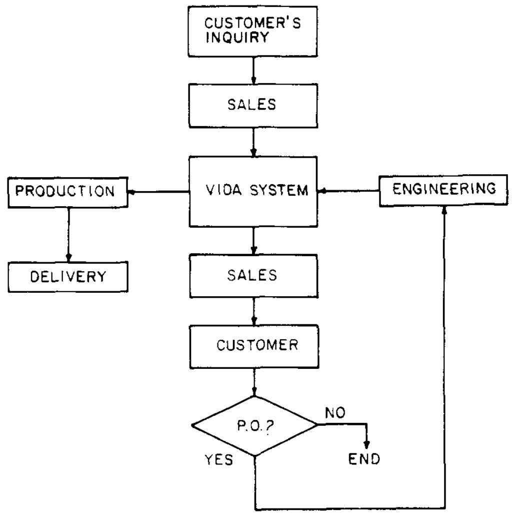

Fig. 1 Sales to Production with VIDA

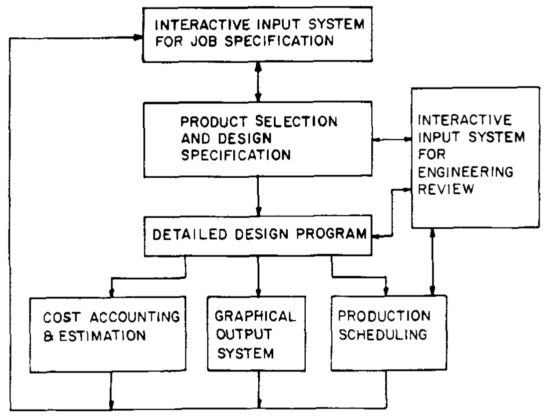

Fig. 2 Software Components in VIDA

if the specifications are incomplete. With a complete set of specifications, the product selection and design specification (PSDS) program makes the preliminary choices and passes this information to the Detailed Design Program (DDP) which makes the detailed design to meet the specifications. The completed design is then entered into a cost analysis and scheduling program which yields price and delivery information. Only successful bids are reviewed by engineering and modified interactively.

The VIDA system eliminates unnecessary use of engineering manpower, and speeds up the sales and bidding operations. Preliminary design by a computerized VIDA can be made within minutes.

Another distinct advantage of VIDA is that its preliminary design results can be conveyed directly to a graphical output program (GOP). Professional grade drawings of the component, and characteristic curves representing its performance are then obtained at very little cost. They give a favorable impression in the bidding process.

Knowledge Based VIDA System

Figure 2 illustrates the major software components in a VIDA system. It is organized as a parallel to human operations. A detailed description of the major software components is given below:

a. Interactive Input System (IIS)

Customer's job specifications can be entered in two different ways:

(i) An input routine is provided by the IIS, and a salesperson may type in the job specifications accordingly.

(ii) The IIS prompts the salesperson with a set of nested questions. A salesperson may select either method (i) or (ii) as listed above. IIS acknowledges when the input data is sufficient for the PSDS to proceed. If the salesperson selects (i) but his input data is insufficient, the IIS automatically goes into (ii).

b. Product Selection and Design Specification System (PSDS) (Chief Engineer, experts)

The PSDS is a knowledge-based system and is a most important part of the VIDA. It will be discussed in some detail. The PS DS can be implemented in two ways:

(i) Heuristic Selection

The heuristic selection algorithm for realizing PSDS is illustrated in Fig. 3A. Customer's specifications are used to generate a set of qualitative or binary features through a process of abstraction. A product class is then selected by heuristically matching the qualitative features to the product classes. Knowledge based rules or decision trees are used in the matching process. Since a substantial amount of information in the customer's specifications is not used in feature abstraction, the unused information is then used for refinement of the selection process: from product class to product type, with design specifications further defining the product.

(ii) Fuzzy Set Representation

Customer's specifications and expert's experience are often expressed in imprecise terms. One possible formulation in terms of fuzzy mathematics is as follows: Let D_i

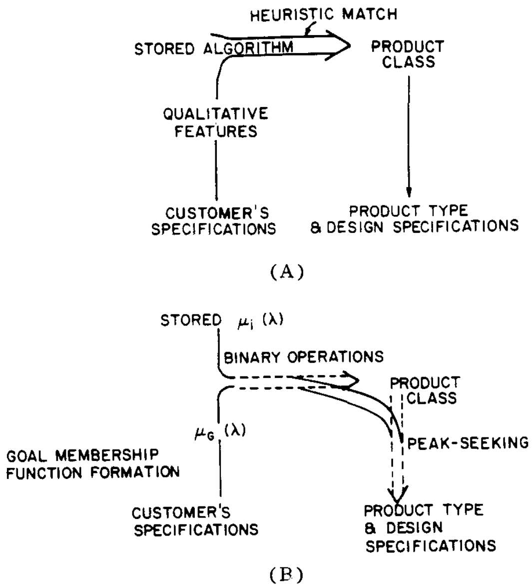

Fig. 3 Two ways of realizing PSDS

, i=1, 2, ...n be the product types or design alternatives, and λ_j , j=1, 2,...k be the performance features. Let $\lambda = \left\{\lambda_j\right\}$. Each design alternative D_i has a membership function $\mu_1(\lambda)$ on the feature space. The customer's specifications or the design goal can be expressed as a fuzzy set $\mu_G(\lambda)$ on the feature space. Then, using Zadeh's intersection rule [Zadeh, 1965], μ_{iG} expresses the suitability of design alternative D_i for the specified design goal:

$$\mu_{iG} = \max_{\lambda} \mu_i(\lambda)\Lambda\mu_G(\lambda) \quad (1)$$

The design alternative D_a with highest μ_{aG} is then selected.

There is a certain parallelism between heuristic classification (HC) and fuzzy set analysis (FSA) as illustrated in Fig. 3B. Abstraction of qualitative features in HC is similar to formulation of the goal membership function $\mu_G(\lambda)$ from customer's job specifications in FSA. Matching the qualitative features with similar features in the solution space is parallel to the maximizing operation of equation (1). The membership functions of certain groups of features λ are binary or almost binary in nature. Using these features first, a product class is selected. The final maximizing operation is performed over the selected product class to arrive at the product type and design specifications. The last operation in FSA is parallel to the refinement process in HC. The use of FSA will be detailed in a subsequent section.

c. Detailed Design Program (Design Engineer)

The detailed design programs are easiest to computerize. Most engineering offices have clearly written design procedures for their products, including all pertinent equations, constants, and curves. Once the product type and design specifications are made available, detailed design is a matter of routine.

d. Cost Analysis (Cost-accounting)

Cost analysis of the detailed product includes (i) labor, (ii) materials, (iii) production tooling, and (iv) overhead. Equations with cost factors which may vary from time to time constitute this program. Quite often, a few alternatives, representing production tools with different degrees of automation are available. The costs for all alternatives are computed, and the lowest is selected.

e. Production Scheduling and Estimation of Delivery Date (production)

The methods used for estimation of a delivery date may have varying degrees of sophistication:

(i) Estimated waiting time plus production time

(ii) Estimation of Delivery Date from Scheduled Production Routing

In general, method (i) is used in the bidding - sales cycle. Once a sale is confirmed, its production is then worked in with all other scheduled work already in the production line. An accurate estimate of the delivery date using (ii) then can be made.

f. Graphical Output Program (GOP) (draftsman)

An important component in the GOP is a Parts Library. Most sales drawings can be done by calling items in the Parts Library with appropriate transformations.

g. Interactive Input System for Engineering Review (IISER)

The IISER allows an engineer to override computer decisions where alternatives are allowed, or to enter certain design constants where "default values" (nominal values) are normally used. The effects of such alterations, in the form of DDP computed results, will be fedback to the engineer.

Fuzzy Set Analysis in PSDS

Membership Function

Two types of membership functions are found to be useful:

1. A binary function B(λ) is defined as follows:

$$B(\lambda) = \begin{cases} 1 & \text{if } \lambda \in A \\ 0 & \text{if } \lambda \notin A \end{cases} \qquad (2)$$

where A is the "acceptable" class.

2. A merit function M(x) is defined as

$$M(x) = \begin{cases} 0 & \text{if } x \le L \\ (x - L)/(U - L) & \text{if } L < x < U \\ 1 & \text{if } x \ge U \end{cases} \qquad (3)$$

where x is a function of λ . The merit function approaches the binary function if L → U, and $x(\lambda) \ge U$ defines the acceptable class A.

The meanings of B(λ) and M(x) are obvious when they are used as the goal membership function. When M(x) is used as a product membership function, the variable x represents demerit or negative merit. Equation (3) means that all product can do better than x = U, but none can do better than x = L.

The following design problem will illustrate the use of FSA for PSDS:

Problem: Design an electric motor for the garage door opener.

Design Goals

(a) Power: 120 volts, 60 hertz, 20 amperes, single phase, (b) Horsepower: approximately 1/2 H.P., preferrably more, (c) Running current: approximately 7 amperes, preferrably less, (d) Starting current: approximately 15 amperes, preferrably less, (e) Starting torque: 100% of full-load torque or more, (f) Efficiency: The higher the better, no less than 50%, (g) Cost: Lowest possible, (h) Life expectancy: Longest possible, (i) Radio noise: None.

The motor manufacturer produces the following types of fractional horsepower motors: 1) hysteresis motors, 2) reluctance motors, 3) stepping motors, 4) permanent capacitor motors, 5) capacitor start motors, 6) capacitor start, capacitor run motors, 7) resistive split phase motors, 8) shaded pole motors, 9) d.c. motors, 10) universal motors.

Design goals (a), (d), (e), (f), (g), (h), and (i) eliminate all motor types except (4), (5), and (7). The goal membership function for the feature group λ_b = horsepower, and λ_c = running current can be expressed as

$$\mu_G(\lambda) = \min[\mu_{Gb}(\lambda_b) \ , \ \mu_{Gc}(\lambda_c)] \qquad (4)$$

All five membership functions μ_{Gb}, μ_{Gc}, μ_4, μ_5, and μ_7 are of the form M(x) in (3). The variable x for product membership functions are given in (5);

$$x = C_1 \log \lambda_b + C_2 - \frac{746\,\lambda_b}{120\,\lambda_c} \qquad (5)$$

Table 1 gives the parameter values of the five membership functions:

Table 1

Membership Function	Variable x	L	U	C_1	C_2
μ_{Gb}	λ_b	.25	.75	---	---
μ_{Gc}	$-\lambda_c$	-9.00	-5.00	---	---
μ_4	Eq.(5)	-.05	.05	0.20	0.72
μ_5	Eq.(5)	-.05	.05	0.32	0.68
μ_7	Eq.(5)	-.05	.05	0.32	0.67

The highest grade of membership is μ_{4G} , μ_{4G} = 0.75 at the parameter values λ_b = 0.625 H.P. and λ_c = 6 amperes.

Conclusion

Vertically integrated design automation (VIDA) enables a component parts manufacturer to respond quickly to purchase inquiries, to improve its chance of a successful bidding, and to save engineering manpower for research and development. Its engineering expertise is documented and accumulated automatically.

A knowledge based system is used in a crucial link in VIDA. Either the heuristic selection method, or fuzzy set analysis can be used for its algorithm. The two methods are shown to be similar, but not completely equivalent.

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