LEAD USER INNOVATION: CONCEPT ANALYSIS AND MANAGEMENT IMPLICATIONS

by
Anton P. Teodorescu

Submitted to the
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in Partial Fulfillment of the Requirements
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ABSTRACT

This Thesis presents the preliminary results of the research project conducted in support of the "Lead User" innovation methodology developed by professors Glen Urban and Eric von Hippel at M.I.T.

The goal of the project was to develop a radically innovative product concept for a Printed Circuit Board CAD system, by involving the leading users of the industry directly into the design process, and then test the concept with a large crossection of industry users to determine the industry's perception of its value and potential success as a future product.

One hundred and seventy eight users of PCB CAD systems in a variety of industrial settings were interviewed and screened to determine the primary issues in future PCB design, and select the leading users in the industry. Six of the leading users were invited to a creative session at MIT together with the CAD vendor. They generated a product concept that in their view addresses the most critical needs for future PCB Design. That concept was in turn sent back to all 178 companies to evaluate against two other advanced system concepts currently available, as well as the system they currently use.

In addition to showing the "Lead" system more capable than all others, the research also yielded significant insights into the perceptual dimensions of PCB CAD systems, satisfaction with current technology,as well as implications for further developing the methodology.

Thesis Supervisor: Dr. Glen L. Urban

Title: Professor of Management Science

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Sloan School of Management

Eric von Hippel
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Computervision

Owen Knox
Computervision

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

This research project was undertaken in support of the "Lead User Innovation" methodology developed at MIT by Professors Eric von Hippel and Glen Urban. It represents the first full scale attempt to apply the methodology in a real corporate setting. This thesis presents the preliminary results of the project, since the timing and quantity of the data did not allow a full scale statistical analysis to be performed as part of a single thesis.

The research was sponsored by one of the leading vendors of CAD/CAM/CAE equipment, and focussed on Printed Circuit Board Design applications. There were two underlying goals to the project: From an academic viewpoint, to test and refine the hypothesis that "lead users" generate the most advanced innovations in a technology, and from a managerial perspective, to learn about the corporate issues involved in implementing the methodology. For a more in deapth overview of the methodology and management implementation issues, see David Israel-Rosen, 1985, Users' Innovations as a Source for New Products, S.M. Thesis.

1.2 Objective - Revolutionary Innovation

For most companies today, and for those in the high technology field in particular, the innovation process is taking on a position of higher and higher strategic importance. As the high technology field becomes more and more market driven, the competitive edge will increasingly belong to the companies that can introduce today the product with the capability and functionality needed tomorrow. In an age when some product life cycles can be measured in months and most are steadily dropping, it is becoming increasingly important to anticipate the market's needs one or two generations down the line, in order to focus the development process, set up the manufacturing facilities, and have the product ready in the distribution channels at the time the market is ready to accept it.

For companies that do not have the benefit of an in-house genius' intuition or even a crystal ball, a more pedestrain but deterministic innovation process is needed to maximize the likelihood of generating a product that is truly advanced, and radically different from current technology, rather than a simple extension of it.

1.3 Problem - Evolutionary Innovation

The main problem can be traced back to the evolution and structure of the High Technology Industry. The typical "high-tech" company was started by an entrepreneur with technical expertise, either to produce a product that was a radical innovation, such as Instant Photography for Polaroid, or fault-tolerant computing for Tandem Computer, or to provide a specialized service for an initial client whose needs were different enough from the market at large to provide a niche for the startup. Such examples could be seen in Data General's entry into the computer industry with a machine geared towards the scientific applications market, and Computervision's initial relationship with Sperry Gyroscope, that eventually lead to its presence in the Process Automation field.

As companies grow and industries mature, the tendency is to get more and more involved around the initial product, comitting increasing resources to the support of the existing customer base. Few companies understand the need and organize to design and deliver follow up products of a similar innovative level as the first one. Examples are numerous from the difficulties experienced by some of the early computer manufacturers when their original product lines became obsolete, to the fate of Osborne Computer, and the current problems of some companies in the personal computer software industry.

The founder's allegiance to his initial innovation often becomes a stumbling block in the path of more radical innovations, which is one reason why many entrepreneurs give way to professional management after the initial growth period of the company. Similarly, the commitment to the installed customer base, as well as the evolutionary nature of human creative processes usually channel the innovation process within a company towards improvements of and extensions to the current product line.

The traditional approach to marketing and innovation is, at best, to channel sales force feedback about problems and needs of the current customer base to the Product Management and possibly the Research and Development teams. This is at best an idealized picture however, since the industry is replete with cases and anecdotes of companies, even some of the more established ones, to whom the customer is nothing but a necessary nuisance to pay the bills. In many technology founded companies, R & D and Marketing have yet to find a way to talk to each other, let alone feed back information and collaborate in the innovation process. The increasing pressures of the market place, however, are rapidly forcing awareness of this problem, and a need for solving it.

1.4 Solution - Lead User Innovation Methodology

Much of the research performed within the last ten years, and in particular some of the work carried out at MIT, have concluded that the community of users within a particular industry can be an extremely rich source of innovative ideas. Works such as G.L. Urban and J.R. Hauser, Design and Marketing of New Products, 1980, and Eric von Hippel, Novel Product Concepts from Lead Users: Segmenting Users by Experience, 1983, have set the groundwork for developing a proactive methodology to incorporate user creativity into the corporate innovation process. In this paper we will be more concerned with the issues involved in the first attempt to apply the methodology, rather than a detailed discussion and justification of the theory. For a more elaborate examination of the underlying theory, see Israel-Rosen, op. cit., 1985, or some of the literature mentioned in the Reference section.

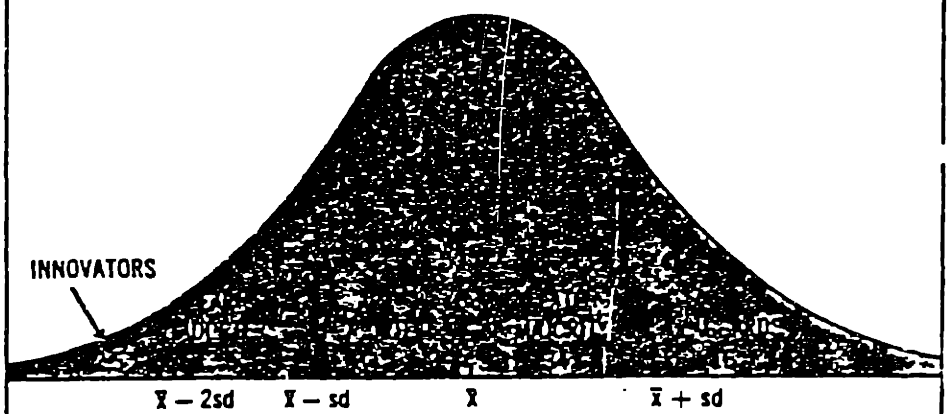
The phenomenon of user innovation differs in various industry sectors, depending largely on the ratio of expected cost/benefit for the particular industry. The user of an automobile, for instance, is much less likely to produce a significant innovation, since the machining and tooling required would raise the cost beyond any possible expected benefit, than a user of software or scientific instrumentation, which would require much more modest outlays, and could yield significant benefits. Significant user innovations have been traced in industries as diverse as processed food, the idea of motocross bikes for children, and the computer industry. In industries with high incidence of user innovation, the companies that will be able to link up with users as part of their innovation process will hold a distinct advantage in the future. It is to this end that some computer companies are now actively promoting user groups

One of the more revolutionary ideas germane to high technology innovation was developed by Eric von Hippel in Novel Product Concepts from Lead Users: Segmenting Users by Experience. It is the distinction between Routine, Lead and Innovating users. The paper proposes that the different kinds of users will provide insights into different aspects of an industry. The Routine users are preoccupied with today's average needs for their industry, and thus their study could yield information mainly on the current state and needs of the industry. Innovating users typically have high need-related problem solving capabilities, and could generate novel product concepts related to high need dimensions, but are not necessarily indicative of the general market needs in the future. Lead users on the other hand, are the ones working in the most advanced stages of the industry, and are usually indicative of future general trends. Figure 1 shows where the innovators are positioned with respect to the general product life cycle, and the innovation diffusion process.

It follows that by somehow working together with the Lead and Innovating users of an industry, the potential for developing radically innovative products, attuned to the future needs of the market, is maximized. What is needed, and this is what the methodological development work is focussed on, is a generic methodology, that could be applied across industries, to determine who the Leaders and Innovators of an industry are, and how to initiate a collaborative process between them and the manufacturer. By presenting the steps and issues involved in the first industrial application, we hope to further understand the theoretical foundations, as well as strengthen the framework for practical implementation of the methodology.

Figure 1

Figure 1
Adopter categorization
on the basis of innovativeness.



The innovativeness dimension, as measured by the time at which an individual adopts an innovation or innovations, is continuous. However, this variable may be partitioned into five adopter categories by laying off standard deviations from the average time of adoption.

SOURCE: EVERT M. ROGERS WITH FLOYD SHOEMAKER, COMMUNICATION OF INNOVATIONS
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CHAPTER TWO
CONCEPT DEVELOPMENT

2.1 Lead User Screening

The foremost questions that need to be addressed before starting a project of this nature are :

1) How is the Industry to be Segmented?

2) Which Segment(s) of the Industry should be examined?

3) How are Lead Users to be distinguished from Routine ones?

Each answer by its very nature has to be somewhat judgemental, because it depends on the particular industry, expertise of the marketing staff, as well as the resources available for undertaking the project. Typically the project would be targeted towards the segment of application for the particular product, but a thorough project would also investigate the potential in related industries. The automobile industry for instance, benefited a great deal when some of the adhesive technology from aeronautical companies was found applicable to autos and transferred across. Similarly, computer science was greatly advanced when some of the work performed by linguists was used to enhance Natural Language Processing.

Once the desired segments have been targeted, there are so far three possible ways of determining who the lead users of the industry are:

1) **Expert knowledge** - Either a member of staff, or the project team who is familiar enough with the industry to know the needs and innovating capabilities of the lead users. Most often this kind of knowledge is either unavailable, or, when present, the potential bias makes a certain amount of cross-verification desirable anyhow.

2) **Interviews** - Interviewing a large cross-section of the industry would perhaps be the ideal solution, since personal open answers yield more information than questionnaires, however, depending on the size of the industry and the available resources,this may not always prove practical.

3) **Screening Questionnaires** - While this method does not provide as much information as interviews would, it can be the most practical solution to covering a respectable size sample. One important issue that needs to be resolved before designing a questionnaire is to determine the important trends in the industry, and express them in some quantifiable form, that can later on be tabulated and analyzed.

Our research project focussed on the Printed Circuit Board Design sector of the Electronic Industry. The primary factor in determining segmentation and size of the sample was the trade-off between the benefits yielded by each method, versus the marginal increase of validity yielded by additional sample size, versus the human and material resources available for the project. For a broader discussion of the user segmentation, identification of trends, and questionnaire design process, see Nell, Lead Users: Screening and Testing of Lead User Generated Product Concepts, S.M. Thesis 1985.

For this project it was decided to sample a large crossection of the PCB industry (approximately 200 firms) in general. Companies were sampled from the membership list of the Institute of Printed Circuits (IPC), near Chicago. For such a large and geographically dispersed sample, questionnaires seemed to be the only practical solution, but a few companies were interviewed in the pre test phase to determine the important trends in the PCB Design industry. **Figures 2, 3 and 4** show graphically some of the most important findings.

Figure 2

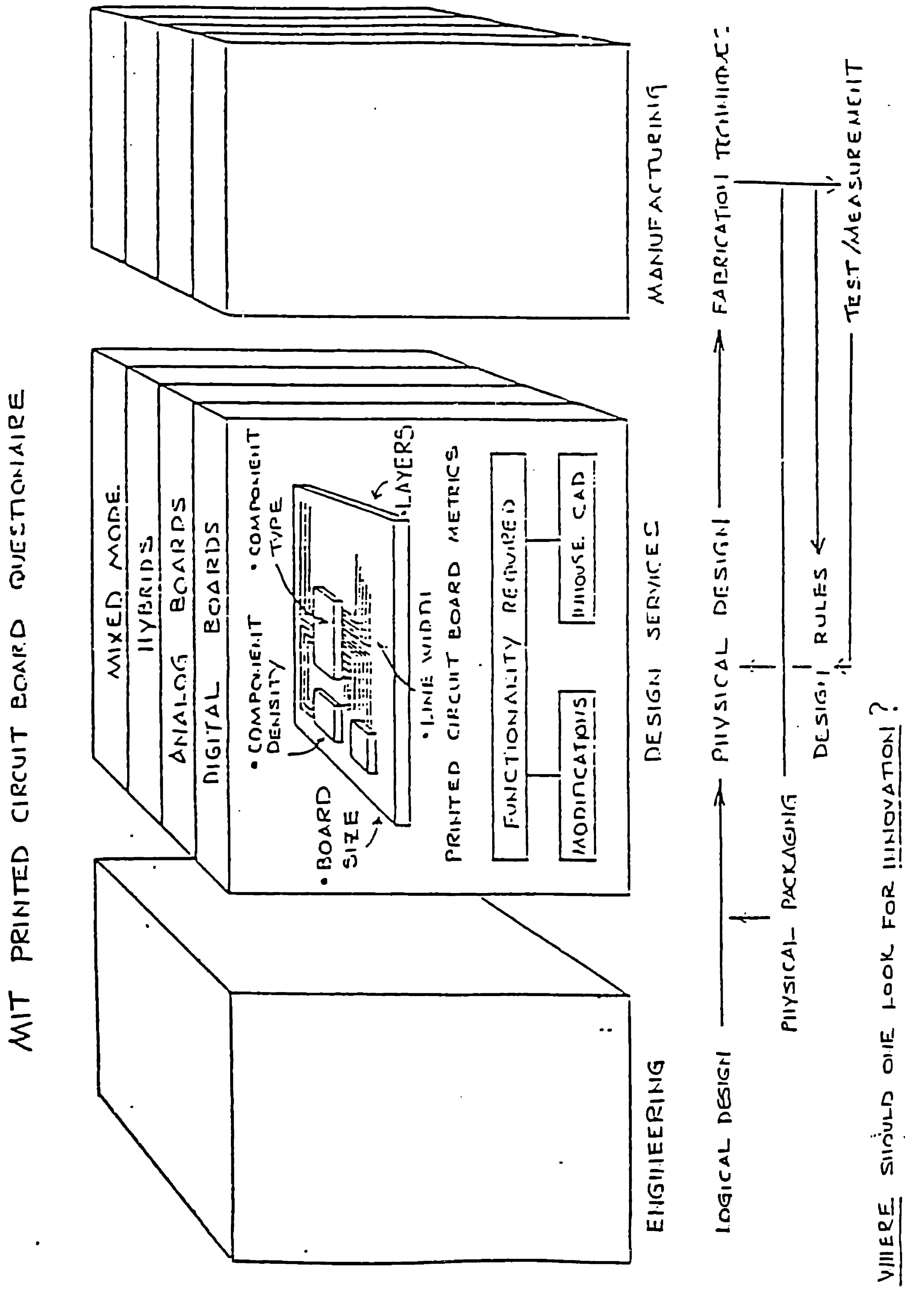

MIT PRINTED CIRCUIT BOARD QUESTIONAIRE
ENGINEERING
DESIGN SERVICES
MANUFACTURING
MIXED MODE
HYBRIDS
ANALOG BOARDS
DIGITAL BOARDS
• COMPONENT DENSITY
• COMPONENT TYPE
LAYERS
• BOARD SIZE
• LINE WIDTH
PRINTED CIRCUIT BOARD METRICS
FUNCTIONALITY REQUIRED
MODIFICATIONS
INHOUSE CAD
LOGICAL DESIGN
PHYSICAL DESIGN
FABRICATION TECHNIQUE?
PHYSICAL PACKAGING
DESIGN RULES
TEST/MEASUREMENT
WHERE SHOULD ONE LOOK FOR INNOVATION?

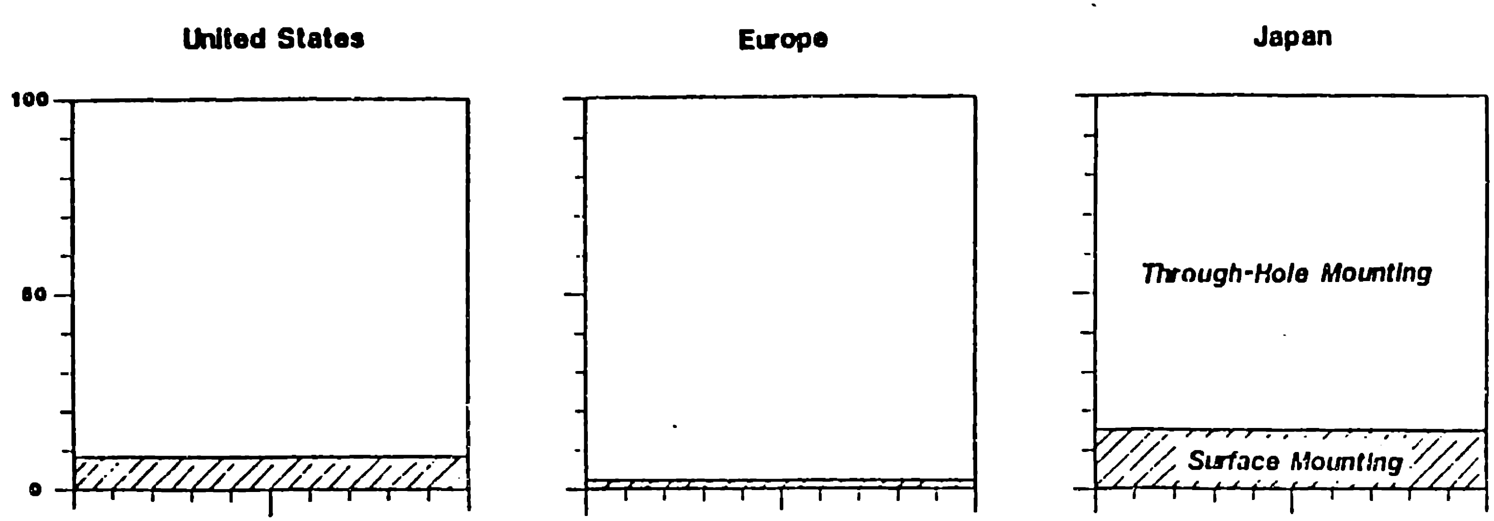
Figure 3

PCB Technology

		COMPONENTS	BOARD		
Packaging	TRENDS	• HIGHER IC POWER DISSIPATION • HIGHER IC PIN OUT DENSITY • SHORTER PACKAGE LEADS • SIMPLIFIED PACKAGE ASSEMBLY • NEW PACKAGE MATERIALS	SUBSTRATES FOR SURFACE MOUNTED COMPONENTS: • KEVLAR (ARAMID FIBER) • KEVLAR/EPOXY • POLYMIDE/QUARTZ • QUARTZ FIBER	SINGLE-LAYER	Materials
	TYPES	• DUAL IN-LINE PACKAGES • LEADLESS CERAMIC CHIP CARR. • LEADED CHIP CARRIER • PLASTIC LEADED CHIP CARR. • PIN GRID ARRAYS • PAD ARRAY CARRIERS • PAD GRID ARRAYS	• CERAMIC SUBJECT TO EXPANSION PLACING STRESS ON SOLDER JOINTS DURING THERMAL OR POWER CYCLING. • METAL CORE BOARDS USED AS BASE FOR BONDING OR INTERNAL GROUND OR POWER PLANES.	MULTI-LAYER	
Interconnections	PROBLEMS	FUTURE REQUIREMENTS FOR 25MIL CENTERS WITH ULTRA FINE LINES AND SPACES DIFFICULT BECAUSE: • UNDERCUTTING OCCURS IN ETCH • UNAVAILABLE IMAGING/DEV.EQP • EXPENSIVE AUTOM. INSPECTION • HIGH SCRAP RATES (40%)	• THE INSERTION OF COMPONENT LEAD THROUGH A HOLE AND SOLDERED TO ELECTRICAL CONTACT. • THIS IS THE MOST COMMON METHOD OF MOUNTING TODAY.	THROUGH-HOLE	Mounting
	SOLUTIONS	• MICROTHIN COPPER ELIMINATES UNDERCUTTING DURING ETCHING • MULTILAYER (20) BOARDS HAVE HI-RELIABILITY/LO-SCRAP RATES VS. FINE-LINE BOARDS • BURIED VIAS USING LASER DRILLING REDUCE BOARD AREA W/ 5MIL HOLES ON 10MIL PADS	• COMPONENT IS ATTACHED TO ONLY ONE SIDE OF BOARD. • ALTERNATIVE METHOD IS SOLDER PADS PLATED UNDERSIDE COMPONENT SOLDERED DIRECTLY TO TRACE PADS ON SUBSTRATE OR BOARD.	SURFACE-MOUNT	

Figure 4

Trends in Mounting Techniques



PCB CAD/CAM MUST SUPPORT TREND TOWARD INCREASING USE OF <u>SURFACE-MOUNTED COMPONENTS</u>:

- SMALLER PARTS (60%)
- REDUCED COMPLEXITY
- INCREASED RELIABILITY
- FEWER LAYERS (50%)
- LOWER COST PER BOARD (DESIGN & MFG) (¼ COST)
- INCREASING AVAILABILITY (10,000 PARTS, 25 MFRS)

By interviewing staff both within the company, as well as within the user community, we identified the following trends as having a major influence on the future of PCB Design:

1) **Density** - The trend, common for most of the high technology sector, is to increase the physical number of components, and the functionality of components on each board. This manifests itself and can be measured as:
   a) Increased Number of Components per Board
   b) Increasing Number of Layers
   c) Narrowing Line Widths
   d) Faster Clock Speed

2) **Packaging** - Related to the increasing density and functionality, IC manufacturers are placing more and more functionality at the chip level, which leads to designing new packaging methods to adapt to the need for board surface and connection capability. Surface Mounted Devices are already used widely in Japan, and are becoming more and more popular in the U. S.

3) **Physical Board Design** - With the downscaling and packaging advances for Integrated Circuits, boards are rapidly reaching extremes of size and shape. Extremely large boards, as well as boards smaller than 1 sq. inch are becoming common place. Curved and oddly shaped boards are rapidly evolving as electronics take over more areas of the auto industry, home appliances, and smaller aeronautics. Three Dimensional systems are evolving to allow non- planar board design.

4) **Integration of Design and Manufacturing** - A trend that is much harder to quantify, but one of the most important, shows an increased emphasis on systems that can communicate to the manufacturing facilitites in order to automate and shorten the entire product design cycle.

One other aspect that became evident during the questionnaire design period is equally important in determining lead users, but also rather difficult to quantify. It is the fact that some users, who could not find suitable solutions to their needs commercially, have developed **In House** systems. Almost by definition this qualifies them as lead users, if one carefully distinguishes the ones who have developed and use them because of lacking current technology, from those who developed them because of lacking commercial technology 15 years ago, and currently use them out of inertia ! Also, some of those users are vendors in the same industry, and as such would not willingly discuss technical issues that could jeopardize their competitive position.

The questionnaire was finally designed to incorporate as many issues as could be safely and briefly quantified, while keeping its length below the threshold of discouragement. It was administered over the telephone to 178 company representatives across the country, either PCB CAD managers or designers. **Appendix A** presents a copy of the Screening Questionnaire.

2.2 Creative Group Session

After administering the screening questionnaire and compiling the results, the Lead User group was selected based on the following criteria:

1) In House System Developed
2) Ability and Need to process Surface Mounted Devices
3) Number of Layers allowed in their designs
4) Board Size and Density

The numbers do not necessarily indicate a priority, but all these factors were taken into account to form a judgemental decision.

The original list of respondents was initially narrowed to about fifteen companies considered as "Lead Users". After considering geographical and budgetary restraints, six leading companies, primarily from the New England area were invited to MIT together with representatives of the vendor to take part in a creative group session. All companies were aware of the sponsoring company and the presence of its representatives, which is one indicator of the perceived value of the process, and the willingness of lead users to collaborate.

The session was designed to have minimal impact on the participants' work schedules. It lasted from 3:00PM until about 6:00PM, so that most people could attend by simply taking the afternoon off, and still have enough time for a constructive meeting. Professor von Hippel moderated the discussion, with the explicit goal of developing a next generation product concept. The main topics covered followed the following structure:

1) Each participant took about 10 minutes to present the main features of their In House system, and the rationale behind developing it.
2) In a brief free-form discussion, current problems and perceived trends in the industry were brought up and debated.
3) The last part of the meeting centered around the ultimate goal of the session, developing a system concept that would address the main issues of concern to the group, as well as their perceived future needs of the PCB Design industry. **Concept K**, on the following page represents the description of the system concept developed by the group.

Overall, there was a remarkable degree of cooperation and good will, which in retrospect actually has a rational explanation, and provides an important insight into the interests and motivations of technological user communities.

CONCEPT K

This system allows the user, in a user friendly environment, to place components on the printed circuit board, route interconnections between components and produces all of the necessary outputs for manufacturing and assembling the completed design. It also performs board analysis, and the software design is modular to allow easy replacement of functional modules with updated or third party modules. The software can be customized to run on different hardware configurations.

DATA ENTRY: Designs can be entered into the system using any of three available modes: 1) Block diagrams expressed in a high level language, 2) Boolean logic description, and 3) Schematic diagrams. The system uses an Icon driven interactive menu (similar to the Apple Macintosh) to shorten the designer's learning curve. Data is stored in a central database that can be accessed and modified by all functional modules of the system.

ANALYSIS: Using data stored in its library, the system can perform full functional simulation of all circuit components, including complex components such as microprocessors. It can also perform thermal analysis, electrical interaction and signal timing analysis on the design.

PLACEMENT/ROUTING: Placement and routing of components can be either manual or fully automatic on boards up to 20 layers, with up to 3 lines between pads. Surface Mounted Devices can be mounted on boards up to 20"x20". Changes to the design are automatically checked for consistency. Automatic routing is optimized according to specified design rules. The vias do not need to be widened at the hole and pad locations. A post-processing step can spread the vias to allow for bending of the component leads.
Engineering design changes can be entered easily without requiring reprocessing of the entire board. Since the system is driven off a central database, the schematic is automatically updated.

OTHER FEATURES: The system is available integrally from a single vendor. However, the design is highly modular, with standard interfaces between the modules. This allows functional modules from different vendors to be added to fit the individual needs of various design groups, or to accommodate changes in technology.

OUTPUT: The output of the system includes all traditional manufacturing information including photo etching artwork, soldering mask artwork, interfaces to photoplotters, drill and automatic insertion machines, automatic testers, etc.

COST: In this configuration, the system costs $150,000 and can support up to four users. Additional users can be accomodated at comparable costs per user.

Most participants indicated that, although they were in related businesses, computer manufacturers among others, they were not commercially involed in the design and manufacture of CAD/CAM systems, and had been forced to develop their own systems because they were unable to purchase commercial systems that could provide the needed capabilities. All would have preferred to have the technology available on the market, saving their companies significant development and capital resources,as well as the lead time required to implement the systems.

The outcome of the meeting also demonstrated the potential value of this process to all parties involved. All participants found the meeting to be a valuable learning experience, for having the chance to be exposed to as well as discuss the problems and development process of the other companies. Mutual interests were discovered, and the potential for future cooperation became apparent to everyone involved. For a technology vendor, the future potential to tap into such a rich source of experience and cooperation can prove invaluable.

CHAPTER THREE
CONCEPT TESTING

3.1 - Concept Generation

Once the "Lead User" system concept has been generated, the next major step involves testing that concept against the market place, to determine how it is perceived by the potential users. The important issues to be addressed in the concept test are:

1) Is the system actually perceived as superior to currently available or planned technology?
2) Do the capabilities of the system address the needs of the entire market segment, or does it just happen to represent the idiosyncrasies of the particular group?
3) What are the economic tradeoffs of the group? What price would the system have to be developed at to make it attractive?

For this particular project, we decided that the best way to address those issues would be by comparing the system against two other described systems, as well as against an evoked set. By describing one currently available commercial system, one other advanced "In House" system, and allowing users to compare them against their current CAD system, we could normalize any discrepancies in the descriptions, as well as developing a set of attributes that all systems could be rated on, providing data for determinig the important factors perceived in the PCB CAD system market. The actual descriptions of the two other system concepts compared in this questionnaire appear in **Appendix B** as Concept J and Concept L.

1) **The Evoked Set** was determined to be the **current system** used by the respondents for PCB Design. Ideally a well known industry standard would have been better suited to provide a uniform base for comparison, but currently there is no such standard in the PCB CAD industry, and the only systems most respondents could be assumed to be familiar with was their own.

2) **A Routine System** was deemed necesary to be included in the test in order to provide a term for comparison with current technology. In this case one of the leading commercial system was selected, to provide a comparison with the current state of the art. The system was stripped of its commercial identity, and described strictly in terms of its functionality. It does not provide any outstanding functions compared to the others, but it represents the currently available state of the art. It appears as **Concept J** in Appendix B.

3) **An In House System** was included to provide a non-commercial state of the art alternative to the others. The system was inspected on site at one of the leading companies and the system description was designed to emphasize the system's unique features, its primary reasons for existence. The main functionality provided by the system is the ability to automate designs in three dimensions. It supports a three dimensional database, and placements can be defined in x, y and z coordinates, which allows the design of curved PC boards, such as might fit in automobile dashboards, missiles, and other awkward packaging. In the questionnaire (Appendix B) it is described as **Concept L**.

Concept K, again, is the description of the "Lead" system.

3.2 - Survey

The questionnaire was mailed to all 178 initial respondents, together with a cover letter and a prepaid return addressed envelope. During the first interview all respondents had been told over the phone that a follow up questionnaire would be sent to them at a later date, and they agreed to return it. In the letter they were asked to return it within approximately one week. Allowing for geographical distribution, we allowed about two weeks before estimating the response rate.

The **Response Rate** after more than two weeks was not very encouraging. We had received only about 35 questionnaires, with a few more that were to trickle in over the next few days. Although a 22-23% response rate on a mailed non trivial questionnaire is not really dismal, we decided to try and boost the response rate by changing the technique. Although the additional data would not arrive in time to be analyzed and included in this thesis, it will provide a rich source of data to be analyzed in the future.

The **Second Phase** of the mailing began the moment we realized that hopes for additional data were getting too slim to even try calling respondents and asking them to return the initial questionnaire. We decided to quickly send out another mailing to all people who had failed to return the questionnaire. Two days after mailing, we called all approximately 130 respondents to announce its arrival, and ask them once again to return it. The timing of the calls was designed to be within a day of the questionnaire's arrival, to make sure that it was still fresh in the respondents' mind. Some had already received it. One of the most valuable insights of the project was yielded by the respondents' reactions on that day. With very few exceptions, people were extremely helpful and apologetic about not returning the first ones. Most promised to return it as soon as it arrived. At this time it is still too early to estimate the success of the second strategy, but we are very optimistic.

3.3 - Demographic Characteristics

All the analysis up to this point is based upon the 38 valid questionnaires received from the first mailing. One questionnaire had to be discarded because the respondents were not actual users of PCB CAD equipment. This implies a certain caveat about the ultimate validity and accuracy of the results. The final analysis will be performed in much more deapth after all other questionnaires will be received, perhaps as the subject of another thesis, but for now we are working under the assumption that the basic results yielded eventually will not be very different in substance from the ones generated by the initial sample. For more detailed reference about the actual questions during the analysis, please refer to the questionnaire in **Appendix B**.

The **Demographic Information** collected in the first part of the concept test was designed to address the following issues:

1) **Roles** of the respondents within the PCB CAD group.

The actual Breakdown of respondents' roles,after converting all "Other" responses to one of the first three, is:

	Designers	Managers	Support Spec
Responses	5	26	7

2) **Sizes** of the design groups surveyed.

The response options were coded 1-5 respectively for groups smaller than 5, 6-10, 11-20, 21-30, and greater than 31.

The Breakdown of responses for different size groups is:

<10	6-10	11-20	21-30	30+
7	13	10	3	5

3) **Number of Designs** generated by the groups.

Again, the response options were coded 1-5 for <10, 11-20, 21-30, 31-40, and groups generating more than 40 designs per year.

The Breakdown of respondents by Number of Designs per Year is:

<10	11-20	21-30	31-40	40+
3	5	8	1	21

4) **Purchasing Power** of the respondents.

The respondents were asked to allocate 100 points between the principal decision makers in the purchasing decision.

On Average, the respondents allocated 28 points to themselves, more than any other group. Engineering Managers and CAD Managers followed with 23 and 20 points respectively. The respondents actually had more purchasing power than the scores would indicate, since some of the questionnaires were answered by technical staff who checked both the Designer and a Manager field, indicating that they serve both functions.

Following is the actual Breakdown of the average point allocations:

Self	Eng. Mgr	CAD Mgr	Designer	Top Mgmt
28.6	23.3	20.0	9.0	19.1

Tabulating by self-described title, we get a much higher purchasing power:

Title	Designer	Manager	System Support
Respondents	2	22	6
Avg. Points	10	37.3	8.3

Figures 6 and 7 show some of the most important demographic statistics displayed displayed graphically.

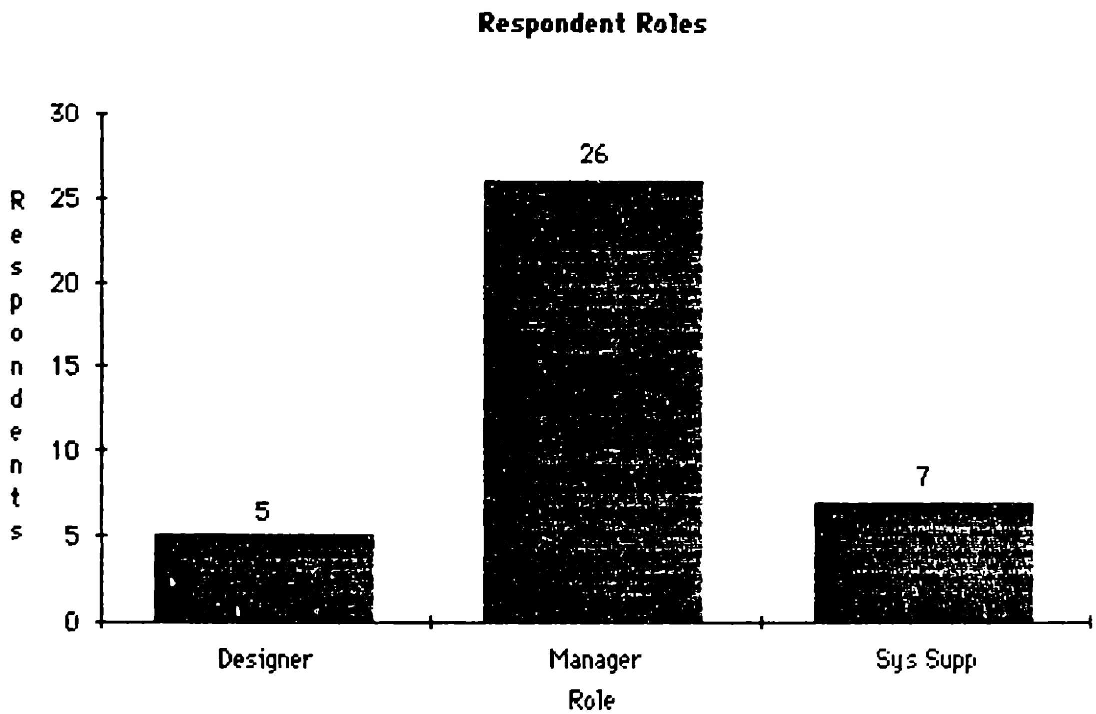
3.4 - Attribute Ratings

Respondents were asked to rate all the system concepts on a similar set of 17 attributes, in order to provide a more detailed insight into the perceptual aspects of the PCB CAD system performance evaluation. The attribute questions were selected after discussing with experts the practical issues apparent in the daily operations and design functions of a PCB CAD system.

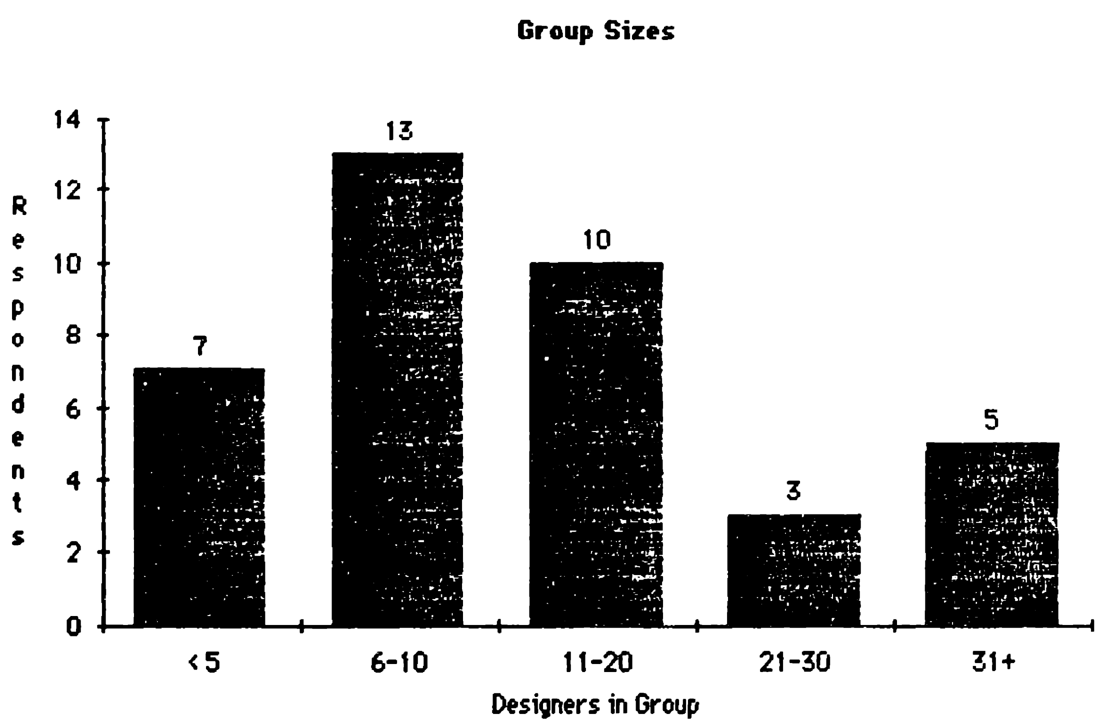
With the help of the attribute ratings, we are hoping to determine:

1) What differences do users currently perceive among the systems?
2) How many Factors are needed to describe the PCB CAD system market?
3) What are those Factors?
4) Where do users currently position the tested system concepts on those dimensions?
5) Are there any other areas of significant opportunity?

Figure 6



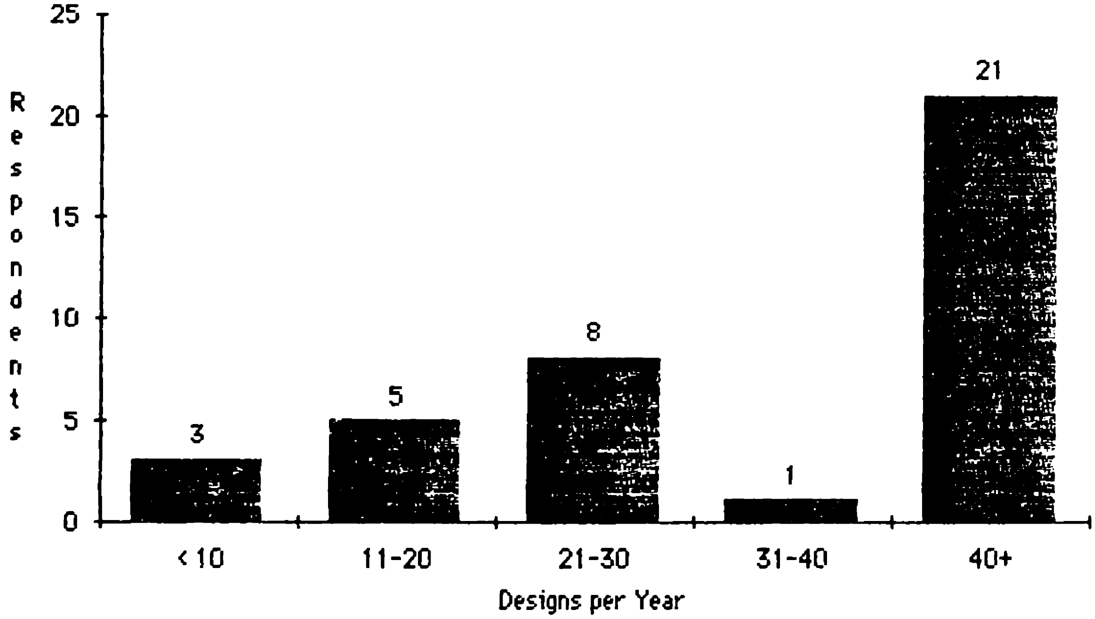
Respondent Roles
30
25
20
15
10
5
0
Respondents
26
5
7
Designer
Manager
Sys Supp
Role



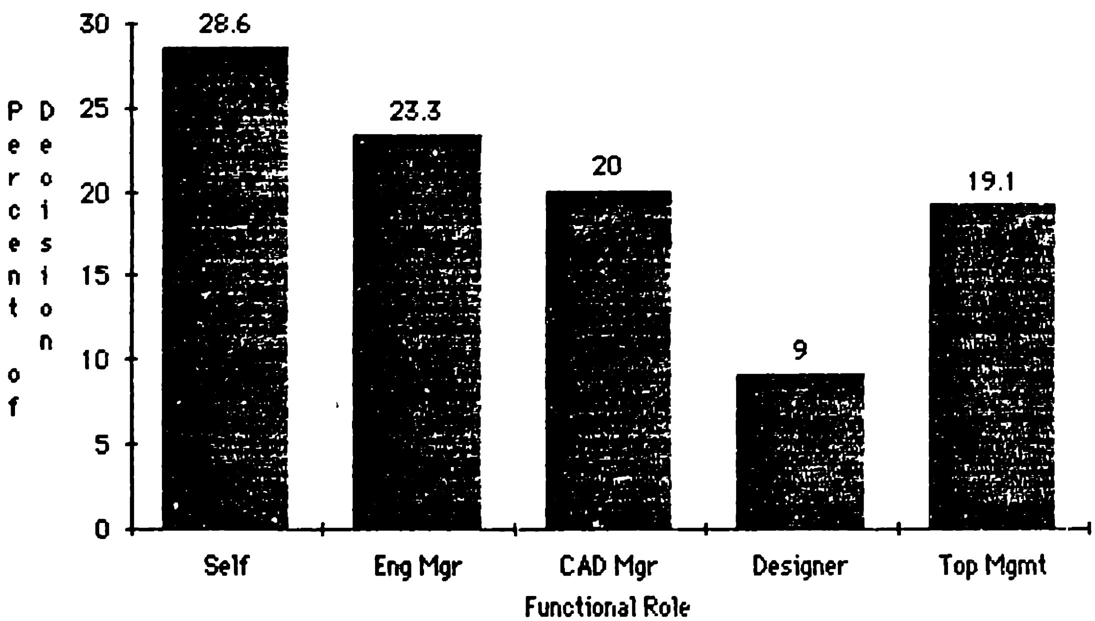
Group Sizes
14
12
10
8
6
4
2
0
Respondents
13
7
10
3
5
<5
6-10
11-20
21-30
31+
Designers in Group

Figure 7

Designs Produced



Purchasing Power of Respondents



Figures 8 and 9 show the average attribute ratings as a **Snake Plot**. In the normalized plot, attribute questions # 5, 6, 10, 11 and 14, which were phrased negatively in the questionnaires, were recoded positively in order to provide a uniform visual effect of the positive versus negative perceptions across all systems and all questions. Thus, as a general rule of thumb, a higher rating of a system concept implies a more positive perception on that attribute.

From a simple visual examination of the snake plots, a few possible issues already become apparent:

1) Concept K (Lead) dominates questions 1, 2, 3, 4, 6, 9, 15, 16, 17, most of them related to issues of functional capability and ease of use.
2) The Current System ranks highest in layer capability, manufacturable designs and reliability, suggesting perhaps that the current layer capacity is suitable for the industry, and that people are satisfied with the basic designs and reliability of current technology. On the other hand, it ranks lowest on questions 15 and 16, on perceptions of placing /routing capabilities, and general value for the money.
3) Concept L (In House) ranks visibly lower on a number of different attributes, suggesting that its functionality is either too esoteric, or untimely, or perhaps simply that it was not understood by respondents.

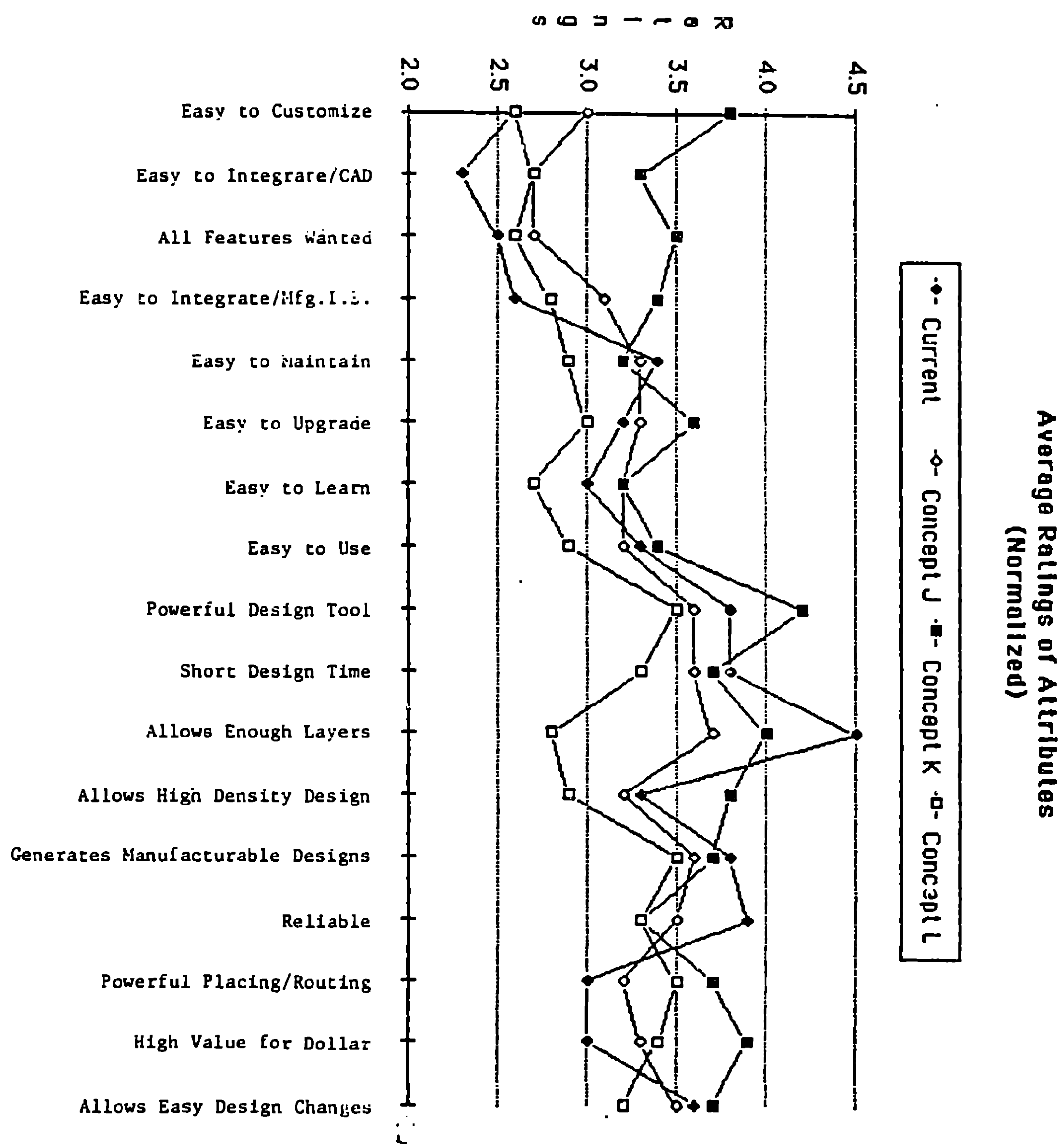
With only 38 responses it is still too early to draw any conclusions, but it is important to keep in mind the possibility that the questionnaire may not have offered enough information to allow respondents to make a meaningful comparison. Some of these issues will be addressed again after the additional understanding provided by Factor Analysis.

Figure 8

RATING OF CONCEPT

	STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
1. This system would be easy to customize	( )	( )	( )	( )	( )
2. This system would be easy to integrate with our existing CAD system(s)	( )	( )	( )	( )	( )
3. This system has all of the features I want in a PCB CAD system	( )	( )	( )	( )	( )
4. This system would be easy to integrate with our existing manufacturing information system	( )	( )	( )	( )	( )
5. This system would be difficult to maintain	( )	( )	( )	( )	( )
6. This system would be difficult to upgrade	( )	( )	( )	( )	( )
7. This system would be easy to learn	( )	( )	( )	( )	( )
8. This system would be easy to use	( )	( )	( )	( )	( )
9. This system would be a powerful design tool	( )	( )	( )	( )	( )
10. This system would cause long design times	( )	( )	( )	( )	( )
11. This system would not allow enough layers for all my applications	( )	( )	( )	( )	( )
12. This system would serve my needs for high density board design	( )	( )	( )	( )	( )
13. This system would generate designs that are manufacturable	( )	( )	( )	( )	( )
14. This system would be unreliable	( )	( )	( )	( )	( )
15. This system has powerful placing/routing capabilities	( )	( )	( )	( )	( )
16. This system offers high value for the dollar	( )	( )	( )	( )	( )
17. This system would allow me to easily change my PCB designs and update my database/design libraries	( )	( )	( )	( )	( )

Figure 9


Average Ratings of Attributes
(Normalized)
Current
Concept J
Concept K
Concept L
Ratings
2.0
2.5
3.0
3.5
4.0
4.5
Easy to Customize
Easy to Integrare/CAD
All Features Wanted
Easy to Integrate/Mfg.I.E.
Easy to Maintain
Easy to Upgrade
Easy to Learn
Easy to Use
Powerful Design Tool
Short Design Time
Allows Enough Layers
Allows High Density Design
Generates Manufacturable Designs
Reliable
Powerful Placing/Routing
High Value for Dollar
Allows Easy Design Changes

3.5 - Factor Analysis

The analytical tool that can help us shed more light on the meaning of the attribute ratings, as well as the relevant dimensions of the PCB CAD market as a whole is Factor Analysis. By analyzing the correlations between the ratings of various attributes, we can distill the few factors that are really important in defining the market.

An analysis of the attribute data contained in the 38 questionnaires received so far, leads to a judgemental decision between 3 or 5 dimensions that would be most important in defining the market. We will examine all five in this paper, since additional later on data may add weight to one of the factors, shifting the ultimate balance.

Figures 10 and 11 show the Eigenvalues of the different factors, plotted in the Scree Test, as well as the Percent of Variance explained by each factor. We can easily distinguish the first three factors as being significant:

1) Their Eigenvalues are much higher than the typical value of 1 required by the rule of thumb.
2) Each individual factor explains over 10% of the Variance.
3) Cumulatively the three factors explain 46.2% of the Variance.

The more delicate question is whether to include factors # 4 and 5. Their Eigenvalues are marginally close to 1 (1.09 and .97 respectively), and together they explain 14% of the variance, so the decision rests on their logical interpretation from the correlated attributes.

Figure 10

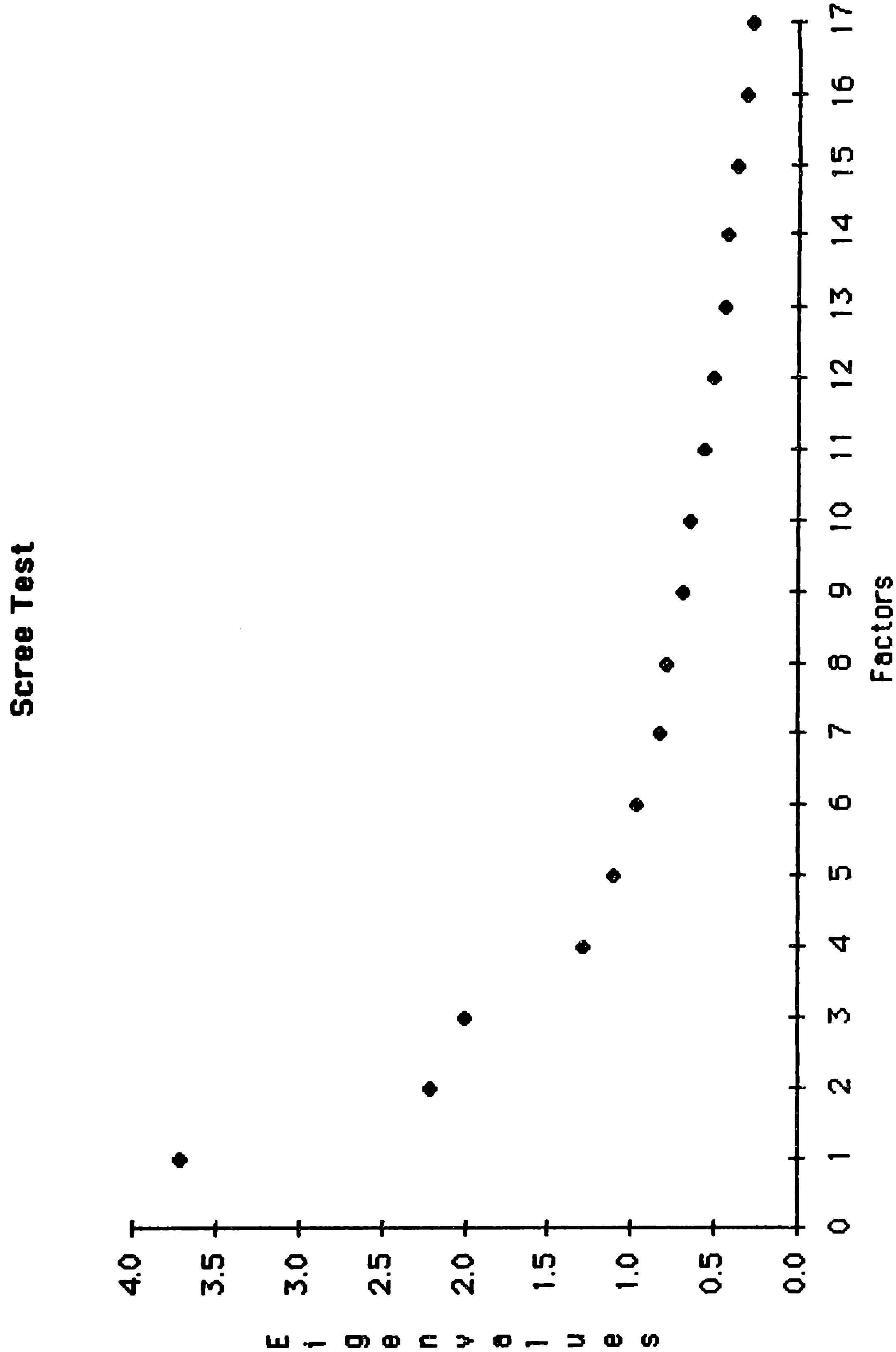
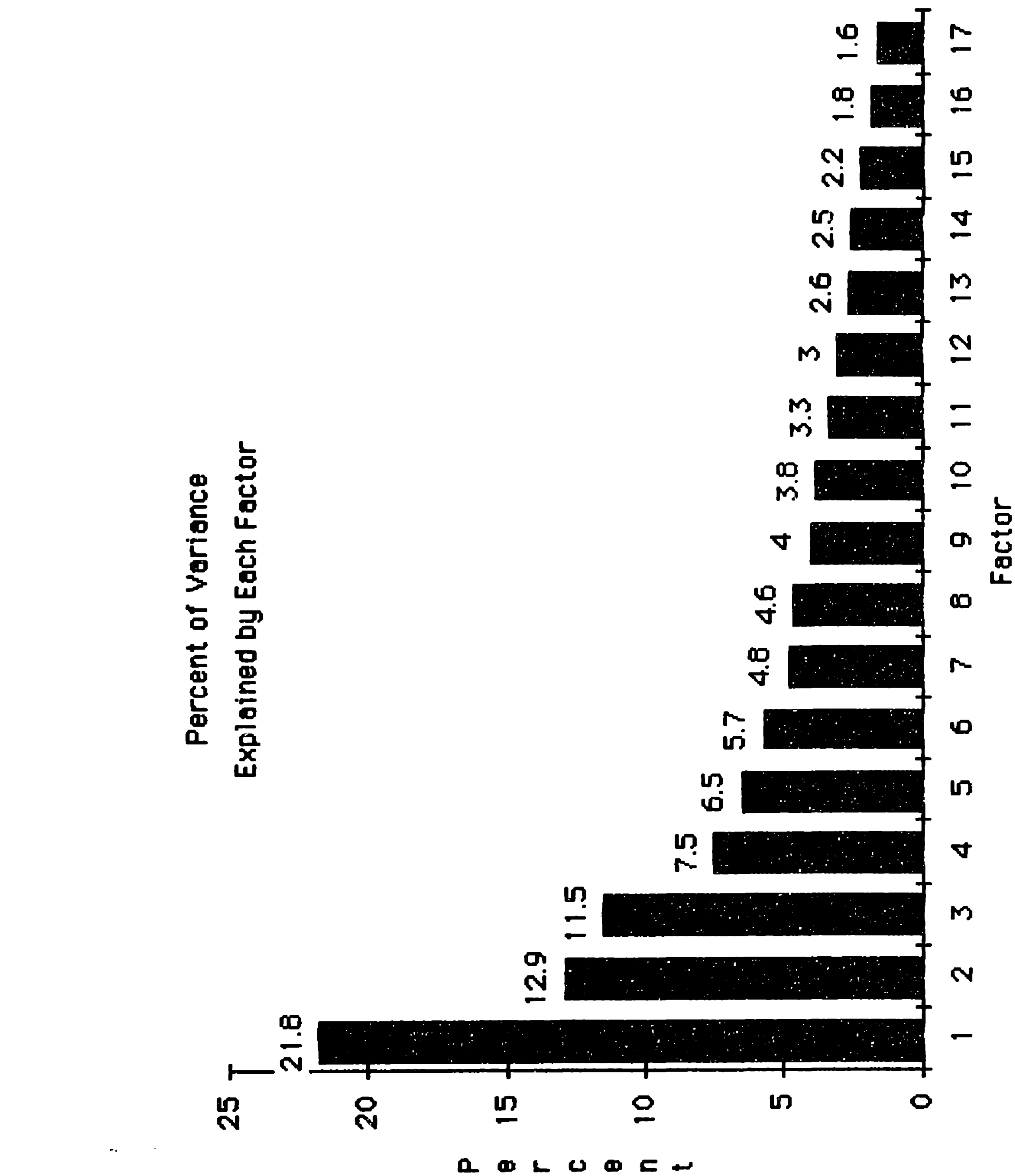

Scree Test
Eigenvalues
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Factors

Figure 11



Percent of Variance
Explained by Each Factor
Percent
25
20
15
10
5
0
21.8
12.9
11.5
7.5
6.5
5.7
4.8
4.6
4
3.8
3.3
3
2.6
2.5
2.2
1.8
1.6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Factor

Rotated Factor Matrix

(Cut Off Point at .40)

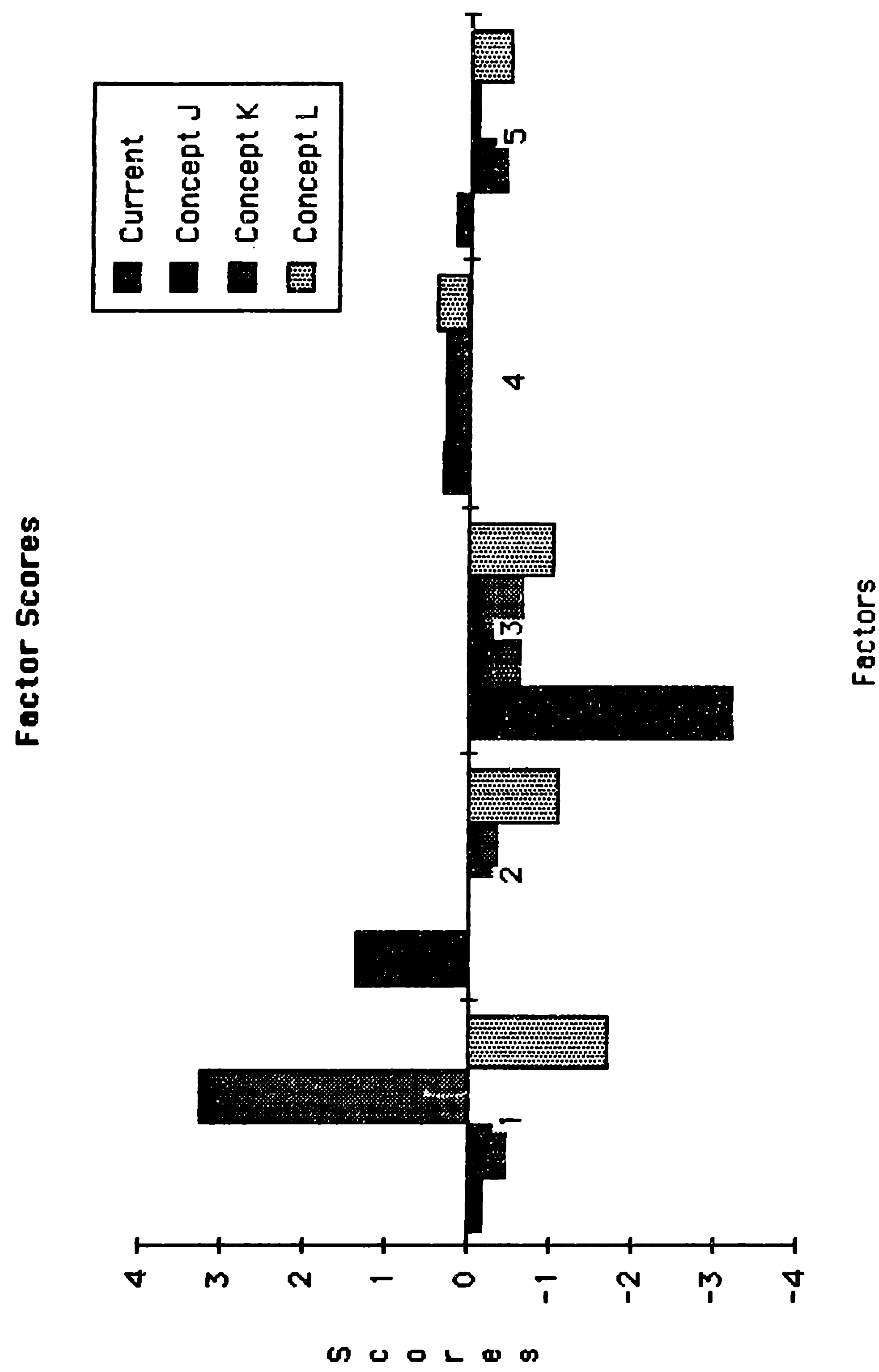
Question	Power Factor 1	Ease of Integration Factor 2	Design Efficacy Factor 3	Ease of Use Factor 4	Maintain-ability Factor 5
Q15	.85 (Powerful Placing/Routing)				
Q16	.66 (High Value for $)				
Q 9	.61 (Powerful Design Tool)				
Q17	.51 (Easy Changes)				
Q12	.47 (High Density)		.44		
Q 4		.82 (Easy to Intgrt w Mfg)			
Q 2		.67 (Easy to Intgrt w CAD)			
Q 1		.60 (Easy to Customize)			.43
Q 3	.41	.54 (All Needed Features)			
Q11			.71 (Enough Layers)		
Q14			.65 (Reliable)		
Q10			.56 (Short Design Time)		
Q13			.54 (Mfgable Designs)		
Q 7				.90 (Easy to Learn)	
Q 8				.86 (Easy to Use)	
Q 5					.80 (Maintain)
Q 6					.64 (Upgrade)

Figure 12

Attribute #	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
15	.85128	-.07101	-.11179	-.05658	.03853
16	.65694	.32423	-.03751	.07629	.00612
9	.61463	.17577	.33878	.11302	-.01574
17	.50777	-.07751	.33861	-.03525	.23722
12	.46773	.35469	.44463	-.16084	-.10193
4	-.01385	.82417	.05025	.02361	-.02762
2	.08266	.67340	-.14606	.17982	.21414
1	.16790	.60447	-.04339	.06338	.43441
3	.40772	.53986	.20482	-.08556	-.38646
11	.01431	-.10761	.70825	.05737	.01318
14	-.25741	-.08979	.65301	.10685	.23917
10	.31297	.02271	.55838	.20011	.11145
13	.27794	.16883	.54543	-.15970	.04928
7	.00669	.13252	-.00668	.90361	.06496
8	.01307	.02926	.12311	.86821	.09448
5	-.11144	-.01319	.27712	.13200	.80323
6	.24409	.28574	.06912	.03900	.63676

Figure 13

Figure 14


Factor Scores
Current
Concept J
Concept K
Concept L
1
2
3
4
5
4
3
2
1
0
-1
-2
-3
-4
Scores
Factors

The most effective way to determine how may factors to select and what to name them, is with the help of the **Rotated Factor Matrix** shown in **Figure 12**. This matrix displays the attribute questions that were most closely correlated in order to define each factor. A cutoff point of .40 was used in displaying the correlation coefficients, to simplify the reading. In parentheses we have typed each attribute question's key words, to facilitate synthesis of the factor. The factor names have been given tentatively, since they are not as clear cut as a single word would suggest, but some succint name is needed to identify each dimension. **Figure 13** shows the entire Rotated Factor Matrix, without cutoff.

Looking at the Factor Matrix it becomes very clear that factors *4 and 5 should be included in the analysis as well,since they are both highly correlated, and can easily be translated into dimensions meaningful to the industry. We will discuss all of them at this time, hoping that further data will expand their meaning, as well as further defining the first three.Another useful map to refer to as we discuss the factors is the **Factor Scores** map shown in **Figure 14**.

Factor 1 (Power) clearly appears as the dominant dimension of the market:

- By itself it explains 21.9% of the Variance
- The questions defining it are highly correlated
- It can be easily understood within the industry context.

Actually a more accurate definition would be along the lines of Power / Capability / Value, but Power seemed the most encompassing term. It is also the one dimension that the "Lead" system concept clearly dominated. One very surprising result was the weak performance of the Three Dimensional system concept on this factor. The result could be anticipated from the snake plots, since the Concept L line generally trails below the others, but it still came as a surprise given our expectations about the industry.

Comparing the snake plot with the Rotated Factor Matrix in more detail, we can see that, on the Power dimension, Concept L scores lowest on attributes number 9(Powerful Design Tool),12 (High Density) and 17 (Easy Changes). Since those also happen to be the attributes that the Lead system scored highest on, this seems to imply that those attributes are the most important ones of the dimension. A more accurate judgement will be supported by regressing the factor scores to determine the importance of the individual attributes. This, unfortunately, cannot be done in time to include in this thesis.

Factor 2 (Ease of Integration) also appears clearly defined and understood.

- It explains 12.9% of the Variance
- The most highly correlated attributes are easily understood

The factor defines what most people in the high technology field would call "Compatibility", or "Ease of Integration and Modification". In this factor we can clearly see the trend toward integration of the design and manufacturing systems, from the correlations and identities of the most significant attributes 4 (Easy to Integrate w Mfg), and 2 (Easy to Integrate with CAD). The Current Systems tended to score very well on this dimension, while the 3D system was perceived as very weak. This is an even more disconcerting puzzle, since a closer examination of the snake plot and factor matrix reveals the fact that the Current Systems on average scored equal to, or below Concept L on all the attributes defining this particular dimension (Questions 1, 2, 3, 4). One possible explanation is that question 12 (High Density Designs), which is also correlated with the Power Factor,is very important(consistent with hypothesis in Factor 1), and is also where Concept L scored lowest. We can only hope that regression of the attributes will confirm this.

Factor 3 (Design Efficacy) appears as a more diffuse dimension.

- The factor explains 11.5% of the Variance
- 5 attributes with a fairly high correlation define it

The factor is clearly significant, but it is not very easy to define. It seems to be more of a hybrid between Reliability, Capability (Allows enough layers, and high density), and Design Quality (Short design times, manufacturable designs). "Design Efficacy" seems to be the most encompassing term. Interestingly enough, the Current Systems scored by far the weakest on this dimension. This again points to a potentially serious discrepancy between the attribute ratings and the factor analysis. On the snake plots, the current systems on average scored higher than the others on the questions defining this factor, so the expectation would be to see them score much better than they did. Again, questions 12(High Density), together with 9(Powerful Design Tool), and 17(Easy Changes), seem to come to our rescue with an explanation, since they are also highly correlated on this factor.

One other potential explanation for this is the high variance of current system ratings, since people are rating a large number of different systems, and some were very dissatisfied with the current performance. Also, users may be all too aware of the current system's shortcomings, and could easily perceive a future concept as more reliable. When combined with the effect of added capabilities, this could translate into lower scores for the current one. The issue remains open, however, until a truly convincing explanation is found.

Factor 4 (Ease of Use) in this context clearly becomes necessary.

- The variance explained is 7.5%, less than the others, but still high.
- The Attributes are very highly correlated (>.86).
- Its meaning is clearly emerging as important within the industry.

Only two attributes define this dimension, but they are highly correlated, and the dimension was actually expected to emerge even before the analysis. Ease of Use is steadily gaining in importance as the industry becomes more and more sophisticated. The idea emerged in the lead user meeting as well, with complaints that engineering training time is one of the heaviest investments in acquiring a PCB CAD system. No system concept appeared significantly differentiated on this dimension, even though one of the features of Concept K mentioned specifically was its icon driven interface and ease of use. Perhaps the scant data did not allow enough differentiation, or the descriptions were not clear enough to indicate the differences clearly.

Factor 5 (Maintainability) also seems a useful definition given this matrix.

- It explains 6.5% of the Variance.
- The attributes are highly correlated, and also have practical meaning.

This would normally be the most questionnable factor, since it has no clear strength, and somewhat resembles the Flexibility factor, but the issues of Maintenance and Upgrade potential are important enough to be considered in a single factor. Current Systems showed only a slight lead, with no clear differentiation among the others.

3.6 - Perceptual Mapping

Perceptual Maps allow us to make pairwise comparisons between the important dimensions of the market. The perceptual maps for all five factors are displayed in **Appendix C** because of their number (10). The results are not dramatically different from what we have seen already, but they do allow us to create a visual perception of the relative positions between concepts on individual dimensions. The overall results can be seen much more synthetically on the Factor Scores map (Figure 14), but the perceptual maps present a more detailed view.

The highest differentiation is perceived on the Power/Ease of Integration and Power/Design Efficacy maps, which confirms the earlier conclusion that Power, Ease of Integration, and Design Efficacy are the most clearly defined dimensions. Again, drawing conclusions from such limited data is dangerous, but if we assume the tested systems to be representative of the market, there is very little capability in the Ease of Use and Maintainability areas, and there is clearly a gap to be filled by systems that can perform well on those dimensions.

Concept K appears clearly differentiated and leading the Power factor. It showed no significant differences on the other dimensions.

Current Systems scored high on Ease of Integration and very poorly on Design Efficacy. The reasons are still to be determined.

Concept J (Routine System) appeared generally neutral and uninspired. It scored lower than normal on Power and Maintenance (probably meaning Upgrade)

Concept L (3D In House System) scored surprisingly low on all factors except Ease of Use. Hopefully additional data will improve our understanding of the reasons.

3.7 - Concept Rankings

The Overall System Evaluation section of the questionnaire had two ranking questions designed to complement each other. The first was a straight ranking of all concepts by preference with no attempt at quantification. The second question was a constant sum pairwise comparison between all system concepts allocating 100 points within each pair. Since the computing capability to perform a Torgenson least squares regression on the constant sum comparison data is not available at this time, we have limited ourselves to crosstabulating the straight preference data, displayed below. There are only 27 responses included in this tabulation, because the others were either incomplete, or not answered at all.

<u>Concept Rankings</u>

(Scoring Weight in Parentheses)

	First(1)	Second(2)	Third(3)	Fourth(4)	Avg. Score
Current	2	14	3	8	2.63
Concept J	1	3	13	10	3.19
Concept K	22	3	1	1	1.30
Concept L	2	7	10	8	2.89

Clearly, Concept K is the overall winner. Taking into account all factors in a straight comparison, there is an overwhelming preference for the Lead User generated concept, with the current systems ranking surprisingly high in second place. However,before drawing any final conclusions, we have to include the price factor in the decision making process as well.

3.8 - Price Sensitivity Analysis

The basic system concept descriptions were all priced at $150K, in order not to detract attention from the functional characteristics of the systems. The price level seems to be comparable to the better commercial systems available now, so it was deemed reasonable as a base comparison price. Also, it seemed to provide the best pricing alternatives that would not touch the psychological barriers of below $100K and $300K.

After all other questions and rankings had been answered, respondents were asked to indicate the probability of purchasing the systems at three different price levels ($100K, $150K and $200K), on a 0 to 10 scale. The results of the questions,plotting average scores, are shown in **Figures 15 and 16**. Even though the probabilities of purchase at the base price of $150K are not very high, what is remarkable is the consistency of the results across price levels, and also with the rest of the questionnaire results.

The Lead User system (Concept K) is almost twice as likely to be purchased than both the others at any price level. Furthermore, even at a price of $20 it still is more likely to be purchased than any of the other two at $100K. Concept L (3D In House system) seems to come back into favor at the actual purchase decision. Although the preference level is not necessarily significant, it does show a slightly higher purchase probability than the Routine System (Concept J).

Figure 15

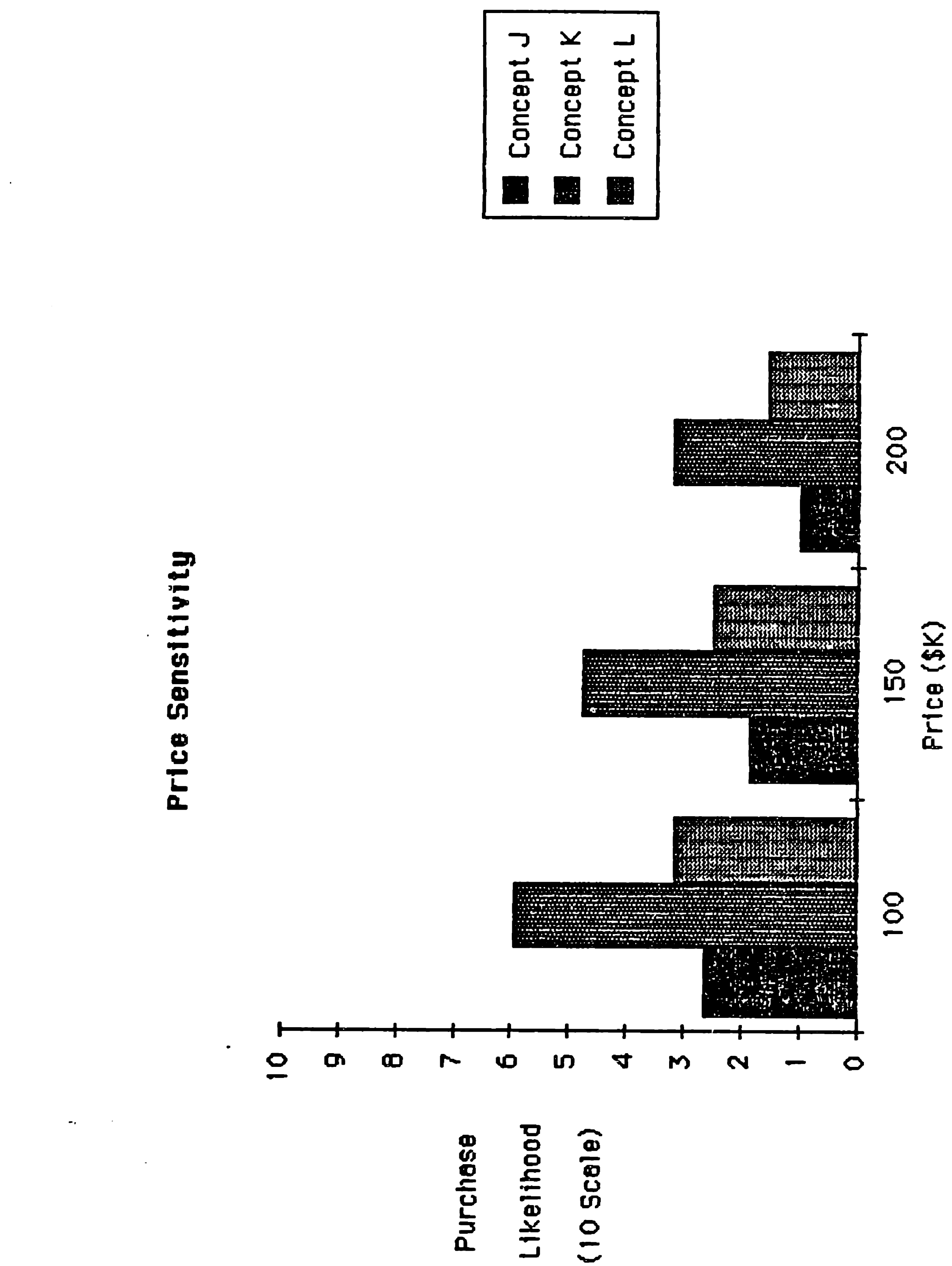
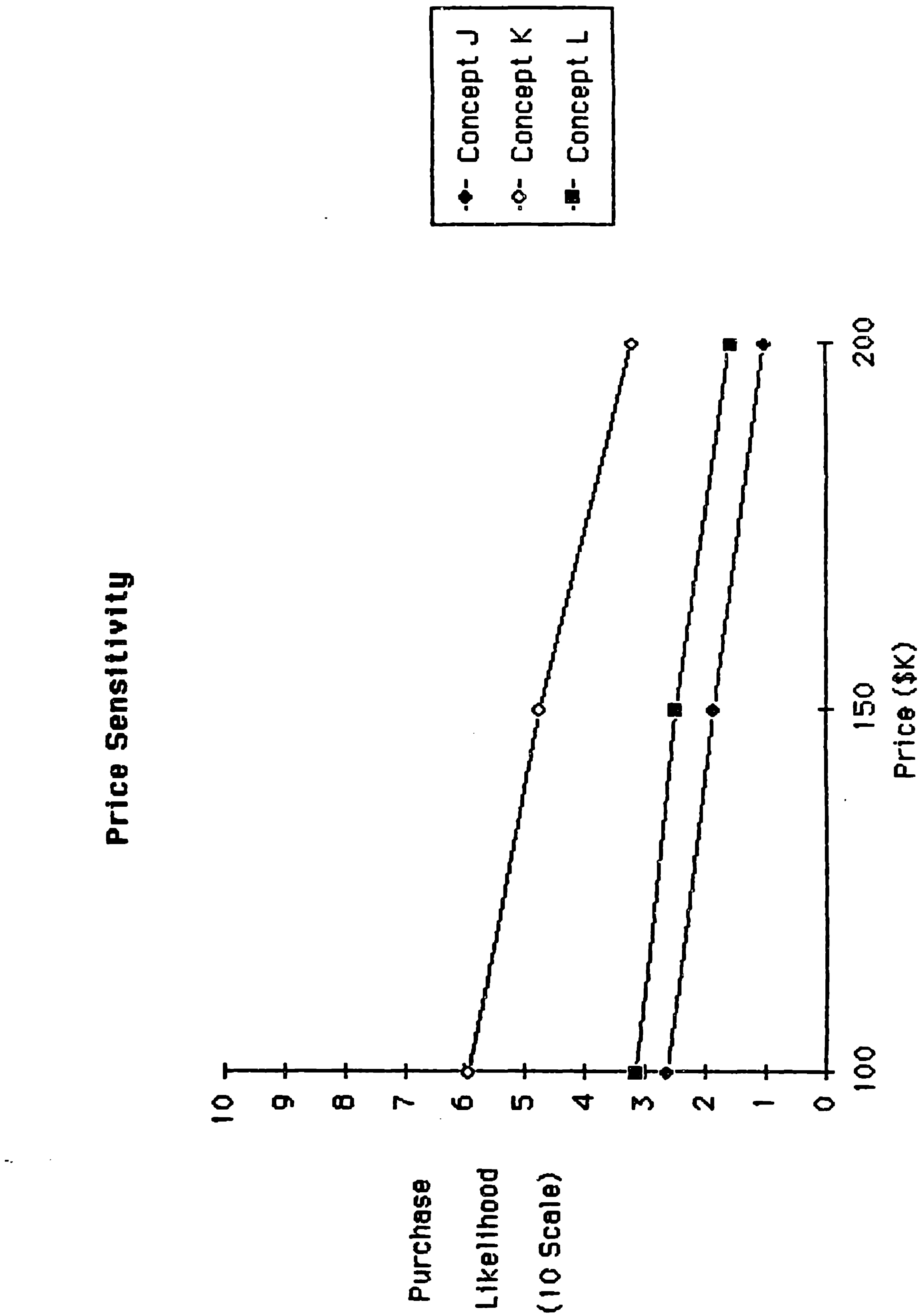

Price Sensitivity
Concept J
Concept K
Concept L
Purchase
Likelihood
(10 Scale)
0
1
2
3
4
5
6
7
8
9
10
100
150
200
Price ($K)

Figure 16



Price Sensitivity
Concept J
Concept K
Concept L
Purchase Likelihood (10 Scale)
0
1
2
3
4
5
6
7
8
9
10
100
150
200
Price ($K)

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

4.1 - Conclusions

The survey has clearly shown the Lead User system (Concept K) to be the most desirable system. However, given the initial quality of the data, further thought and analysis is needed before reaching a final and fully accurate decision. Hopefully, the additional data coming in will provide more substantive support to our analysis. Neverthless, the process has been very worthwhile, and is leaving a number of lessons that could be very useful in the future.

Time constraints have been the most significant roadblocks for the project. Between the class and thesis deadlines over the semester, time pressure has forced many compromise decisions to be made. It seems that a project of this nature would have to be done either over a full academic year if done by students, or ideally done separately without arbitrary deadlines imposed by the academic schoolyear.

Survey techniques have definitely shown their differences during this project. The difference in response between the first and second mailing with a phone follow up was very sizeable. As of this time, we have already received another 35 responses, doubling our initial rate, with more expected.

Questionnaire Design was one of the areas most affected by time pressure. More time could have definitely been spent designing both the screening and the concept test questionnaires. This would have improved significantly the internal consistencies, such as having identical title designations between the Role and Purchase Power questions on the Concept Test, to allow better cross tabulation. Although not clear yet, perhaps better system descriptions could have been generated through a more careful layout and more pretesting.

4.2 - Management Implications

Once the Lead User Concept has been shown to be superior, the next logical question is what should the management of a company do with this result? Should the manufacturer rush and build the product at all, and if so, How? The questions that still need to be answered at this stage are very fundamental:

1) Is the product feasible at all with current technology?
2) Is the product compatible with the company's areas of engineering and production expertise?
3) Is the product compatible with the company's area of marketing and distribution expertise?
4) Does the product represent an extension of the company's current busines or will it imply a major strategic shift?
5) How will the product be perceived and associated with the company?
6) Is the cost of production (and, implicitly, sale) acceptable?
7) Which segment of the market should the product be targeted to initially?

While a complete answer to these questions could be the subject of a whole new thesis, the most important conclusion to be drawn from the project, and one that has been proven much more convincingly than the viability of ConceptK is the value of the process itself. It seems very clear that once the process is refined and continued over a longer period of time with more feedback, the potential for both innovation and collaboration is tremendous.

APPENDIX A

Screen Questionnaire

1. Do you use, supervise, or provide technical support for a DIGITAL Printed Circuit Board CAD system?

Yes__________________ If yes, please proceed to the next page.

No__________________

2. Please indicate the name of the person within your firm whom you believe to be the most knowledgable about the use of CAD systems for printed circuit board design?

Name________________________ Title________________________

Company____

Address____

City________________________ State__________ ZIP________

Phone Number ( )____
area code

3. Do you use Surface Mounted Devices (SMD) in your printed circuit boards?

Yes________________ No________________

4A. What is the narrowest line width used in your PCB designs?

________________Mil.

B. What is the widest line width used in your PCB designs?

________________Mil.

C. What is the most frequent line width used in your PCB designs?

________________Mil.

5A. What is the largest PCB designed by your group?

length____________inches width____________inches

B. What is the smallest PCB designed by your group?

length____________inches width____________inches

C. What is the most frequent size PCB designed by your group?

length____________inches width____________inches

6A. What is the greatest number (total = signal + non-signal layers) of layers used in your PCB designs?______________________

B. What is the most frequent number of layers used in your PCB designs?

____

7A. What is the highest density achieved in your PCB designs? Circle the closest one. (Density defined as $\frac{\text{14 Pin IC equivalent}}{\text{square inch}}$ e.g., if you place a 42 pin ic on a square inch your density will be $\frac{42}{14}=3$)

1 2 3 4 5 6 7 8 9 10 other________

B. What is the most frequent density achieved in your PCB designs? Circle one.

1 2 3 4 5 6 7 8 9 10 other________

8. Which of the following commercially available digital PCB CAD system(s) do you use? Check each system used, specify model if known, and rate your satisfaction with its technical properties. Circle 7 if you are completely satisfied and 1 if completely dissatisfied.

Vendor	Model	Dissatisfied						Satisfied
Optima	________	1	2	3	4	5	6	7
Sci Cards	________	1	2	3	4	5	6	7
Computervision	________	1	2	3	4	5	6	7
Calma	________	1	2	3	4	5	6	7
Calay	________	1	2	3	4	5	6	7
Applicon	________	1	2	3	4	5	6	7
Omnicad	________	1	2	3	4	5	6	7
Telesis	________	1	2	3	4	5	6	7
EAS	________	1	2	3	4	5	6	7
Cadnetix	________	1	2	3	4	5	6	7
Zukin	________	1	2	3	4	5	6	7
Prince (ASI)	________	1	2	3	4	5	6	7
IBM	________	1	2	3	4	5	6	7
Intergraph	________	1	2	3	4	5	6	7
Redac	________	1	2	3	4	5	6	7
Other	________	1	2	3	4	5	6	7
	________	1	2	3	4	5	6	7

9. Has your firm ever modified the software or hardware of a commercial PCB CAD system?

Yes__________________ No__________________

10. Has your firm ever developed an in-house/proprietary digital PCB CAD system?

Yes__________________ No__________________ If no, please skip to question #12.

11. If yes to question No. 10, Who in your company was responsible for the in-house system development?

Name______________________________

Telephone Number (   ) ______________

12. Please describe the main functionality (ies) you tried to achieve by developing an in-house PCB CAD system?

Functionality	Why Needed
1.________________	______________________________
2.________________	______________________________
3.________________	______________________________

13. How satisfied are you with the technical functionality of your in-house system? Circle one

Dissatisfied 1 2 3 4 5 6 7 Satisfied

14. In what year did your company begin using a CAD system for DIGITAL PCB design? ____________

15. Check the statement which best characterizes your company's efforts in PCB design.

____ A. Always at the leading edge of technology in our industry.

____ B. Up to date with new technology, but not necessarily first to adopt it.

____ C. In the mainstream of technology within our industry.

____ D. Adopt new technology only after well established and standardized.

16. Please tell us about yourself:

Name____

Title____

Company____

Address____

City____________________ State__________ ZIP__________

Phone Number ( ) ________________________________
area code

17. Finally, can you tell us who you contact when you need assistance in solving technical problems concerning your PCB CAD system

Name____________________ Telephone____________________

Thank you for your assistance.

APPENDIX B

Concept Test Questionnaire

Massachusetts Institute of Technology
Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

PRINTED CIRCUIT BOARD DESIGN QUESTIONNAIRE

About two weeks ago we sent you a questionnaire asking for your opinion about three different potential PCB CAD systems. Unfortunately, it seems to have been misplaced and it never reached us. Since our thesis deadline is approaching rapidly, we are enclosing another copy just in case the old one is beyond resurrection. Please take a few minutes right now to complete it and return it in the enclosed envelope. The questionnaires are numbered for our records only, but the identities of individual respondents are kept strictly confidential.

We hope that it is not too much of an inconvenience, and we are very grateful for your time. Thank you very much.

Sincerely,

David Israel-Rosen

David Israel-Rosen
Project Coordinator

1. What is your role within the PCB CAD Group

_____ Designer
_____ Manager
_____ System Support Specialist
_____ Other__________________

2. How many technical people work in your design group?

_____ 5 or less
_____ 6 - 10
_____ 11 - 20
_____ 21 - 30
_____ 31 or more

3. How many new designs per-year does your group design?

_____ 10 or less
_____ 11 - 20
_____ 21 - 30
_____ 31 - 40
_____ 40 +

4. Please allocate 100 points among the following who influence(d) the PCB CAD system purchasing decision:

_____ Yourself
_____ Engineering Manager
_____ CAD Manager
_____ Designer
_____ Top Management (VP & up)
_____ Other

5. What is the primary product that your digital PCBs are used in?

____

YOUR CURRENT PC CAD SYSTEM

Please read the following statements regarding your current printed circuit board CAD system. For each statement, check the appropriate column indicating your level of agreement or disagreement. If you have more than one system, please rate the system which you feel best suits your needs.

After rating your current system, please rate the subsequent system concepts in a similar manner.

RATING OF CURRENT SYSTEM

		STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONG AGREE
1.	My system is easy to customize	( )	( )	( )	( )	( )
2.	My system is easy to integrate with our other existing CAD systems	( )	( )	( )	( )	( )
3.	My system has all of the features I want in a PCB CAD system	( )	( )	( )	( )	( )
4.	My system is easy to integrate with our existing manufacturing information system	( )	( )	( )	( )	( )
5.	My system is difficult to maintain	( )	( )	( )	( )	( )
6.	My system is difficult to upgrade	( )	( )	( )	( )	( )
7.	My system is easy to learn	( )	( )	( )	( )	( )
8.	My system is easy to use	( )	( )	( )	( )	( )
9.	My system is a powerful design tool	( )	( )	( )	( )	( )
10.	My system causes long design times	( )	( )	( )	( )	( )
11.	My system has does not allow enough layers for all my applications	( )	( )	( )	( )	( )
12.	My system serves my needs for high density board design	( )	( )	( )	( )	( )
13.	My system generates designs that are manufacturable	( )	( )	( )	( )	( )
14.	My system is unreliable	( )	( )	( )	( )	( )
15.	My system has powerful placing/routing capabilities	( )	( )	( )	( )	( )
16.	My system offers high value for the dollar	( )	( )	( )	( )	( )
17.	My system allows me to easily change my PCB designs and update my database/design libraries	( )	( )	( )	( )	( )

CONCEPT J

This system enables the user to place components on the printed circuit board, route interconnections between components and produces all of the necessary outputs for manufacturing and assembling the completed design. The system includes a user defined component library to simplify data entry. The system is very flexible and easily allows the user to make changes in the printed circuit board design without requiring its complete reprocessing.

DATA ENTRY: Designs can be input into the system interactively, via menu driven commands displayed on the terminal. Schematic capture is possible when interfaced to CAE workstations.

PLACEMENT/ROUTING: Placement and routing of components is either manual or fully automatic, with a maximum of 8 layers plus power and ground, and up to 3 lines between pads. The system can incorporate Surface Mounted Devices. Changes to the design are automatically checked for consistency. Automatic routing is optimized according to specified design rules.

OUTPUT: The output of the system includes all traditional manufacturing information including photo etching artwork, soldering mask artwork, interfaces to photoplotters, drill and automatic insertion machines, automatic testers, etc.

COST: In this configuration, the system costs $150,000 and can support up to four users. Additional users can be accomodated at comparable costs per user.

RATING OF CONCEPT

		STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGL AGREE
1.	This system would be easy to customize	( )	( )	( )	( )	( )
2.	This system would be easy to integrate with our existing CAD system(s)	( )	( )	( )	( )	( )
3.	This system has all of the features I want in a PCB CAD system	( )	( )	( )	( )	( )
4.	This system would be easy to integrate with our existing manufacturing information system	( )	( )	( )	( )	( )
5.	This system would be difficult to maintain	( )	( )	( )	( )	( )
6.	This system would be difficult to upgrade	( )	( )	( )	( )	( )
7.	This system would be easy to learn	( )	( )	( )	( )	( )
8.	This system would be easy to use	( )	( )	( )	( )	( )
9.	This system would be a powerful design tool	( )	( )	( )	( )	( )
10.	This system would cause long design times	( )	( )	( )	( )	( )
11.	This system would not allow enough layers for all my applications	( )	( )	( )	( )	( )
12.	This system would serve my needs for high density board design	( )	( )	( )	( )	( )
13.	This system would generate designs that are manufacturable	( )	( )	( )	( )	( )
14.	This system would be unreliable	( )	( )	( )	( )	( )
15.	This system has powerful placing/routing capabilities	( )	( )	( )	( )	( )
16.	This system offers high value for the dollar	( )	( )	( )	( )	( )
17.	This system would allow me to easily change my PCB designs and update my database/design libraries	( )	( )	( )	( )	( )

CONCEPT K

This system allows the user, in a user friendly environment, to place components on the printed circuit board, route interconnections between components and produces all of the necessary outputs for manufacturing and assembling the completed design. It also performs board analysis, and the software design is modular to allow easy replacement of functional modules with updated or third party modules. The software can be customized to run on different hardware configurations.

DATA ENTRY: Designs can be entered into the system using any of three available modes: 1) Block diagrams expressed in a high level language, 2) Boolean logic description, and 3) Schematic diagrams. The system uses an Icon driven interactive menu (similar to the Apple Macintosh) to shorten the designer's learning curve. Data is stored in a central database that can be accessed and modified by all functional modules of the system.

ANALYSIS: Using data stored in its library, the system can perform full functional simulation of all circuit components, including complex components such as microprocessors. It can also perform thermal analysis, electrical interaction and signal timing analysis on the design.

PLACEMENT/ROUTING: Placement and routing of components can be either manual or fully automatic on boards up to 20 layers, with up to 3 lines between pads. Surface Mounted Devices can be mounted on boards up to 20"x20". Changes to the design are automatically checked for consistency. Automatic routing is optimized according to specified design rules. The vias do not need to be widened at the hole and pad locations. A post-processing step can spread the vias to allow for bending of the component leads.
Engineering design changes can be entered easily without requiring reprocessing of the entire board. Since the system is driven off a central database, the schematic is automatically updated.

OTHER FEATURES: The system is available integrally from a single vendor. However, the design is highly modular, with standard interfaces between the modules. This allows functional modules from different vendors to be added to fit the individual needs of various design groups, or to accommodate changes in technology.

OUTPUT: The output of the system includes all traditional manufacturing information including photo etching artwork, soldering mask artwork, interfaces to photoplotters, drill and automatic insertion machines, automatic testers, etc.

COST: In this configuration, the system costs $150,000 and can support up to four users. Additional users can be accomodated at comparable costs per user.

RATING OF CONCEPT

		STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
1.	This system would be easy to customize	( )	( )	( )	( )	( )
2.	This system would be easy to integrate with our existing CAD system(s)	( )	( )	( )	( )	( )
3.	This system has all of the features I want in a PCB CAD system	( )	( )	( )	( )	( )
4.	This system would be easy to integrate with our existing manufacturing information system	( )	( )	( )	( )	( )
5.	This system would be difficult to maintain	( )	( )	( )	( )	( )
6.	This system would be difficult to upgrade	( )	( )	( )	( )	( )
7.	This system would be easy to learn	( )	( )	( )	( )	( )
8.	This system would be easy to use	( )	( )	( )	( )	( )
9.	This system would be a powerful design tool	( )	( )	( )	( )	( )
10.	This system would cause long design times	( )	( )	( )	( )	( )
11.	This system would not allow enough layers for all my applications	( )	( )	( )	( )	( )
12.	This system would serve my needs for high density board design	( )	( )	( )	( )	( )
13.	This system would generate designs that are manufacturable	( )	( )	( )	( )	( )
14.	This system would be unreliable	( )	( )	( )	( )	( )
15.	This system has powerful placing/routing capabilities	( )	( )	( )	( )	( )
16.	This system offers high value for the dollar	( )	( )	( )	( )	( )
17.	This system would allow me to easily change my PCB designs and update my database/design libraries	( )	( )	( )	( )	( )

CONCEPT L

This system enables the user to design, test and manufacture formable and flexible printed circuit boards as well as conventional, rigid PCBs. Formable and flexible printed circuit boards can be shaped into any desired configuration in two or more planes, eliminating the need for multiple rigid printed circuit boards and interconnecting hardware. This allows a more efficient use of the design volume, as well as configuring boards into awkward spaces. Both the database and component library are 3 dimensional and the system performs extensive board analysis functions.

DATA ENTRY: Designs can be input into the system interactively, via menu driven commands displayed on the terminal. The graphics terminal can generate and display 3 dimensional graphics including both normal view and hidden line representations. Schematic capture is possible when interfaced to CAE workstations.

ANALYSIS: Structural and load analysis of the design is performed to ensure design integrity. Components are prevented from being placed in curvature or bends in the PCB by system design rules.

PLACEMENT/ROUTING: Placement and routing of components is in 3 dimensions, either manual or fully automatic, with a maximum of 8 layers plus power and ground, and up to 3 lines between pads. The system can incorporate Surface Mounted Devices. Changes to the design are automatically checked for consistency. Automatic routing is optimized according to specified design rules. Strict design rules ensure that signal lines are perpendicular to the radius of curvature of bends.

OUTPUT: The output of the system includes all traditional manufacturing information including photo etching artwork, soldering mask artwork, interfaces to photoplotters, drill and automatic insertion machines, automatic testers, etc.

COST: In this configuration, the system costs $150,000 and can support up to four users. Additional users can be accomodated at comparable costs per user.

RATING OF CONCEPT

		STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
1.	This system would be easy to customize	( )	( )	( )	( )	( )
2.	This system would be easy to integrate with our existing CAD system(s)	( )	( )	( )	( )	( )
3.	This system has all of the features I want in a PCB CAD system	( )	( )	( )	( )	( )
4.	This system would be easy to integrate with our existing manufacturing information system	( )	( )	( )	( )	( )
5.	This system would be difficult to maintain	( )	( )	( )	( )	( )
6.	This system would be difficult to upgrade	( )	( )	( )	( )	( )
7.	This system would be easy to learn	( )	( )	( )	( )	( )
8.	This system would be easy to use	( )	( )	( )	( )	( )
9.	This system would be a powerful design tool	( )	( )	( )	( )	( )
10.	This system would cause long design times	( )	( )	( )	( )	( )
11.	This system would not allow enough layers for all my applications	( )	( )	( )	( )	( )
12.	This system would serve my needs for high density board design	( )	( )	( )	( )	( )
13.	This system would generate designs that are manufacturable	( )	( )	( )	( )	( )
14.	This system would be unreliable	( )	( )	( )	( )	( )
15.	This system has powerful placing/routing capabilities	( )	( )	( )	( )	( )
16.	This system offers high value for the dollar	( )	( )	( )	( )	( )
17.	This system would allow me to easily change my PCB designs and update my database/design libraries	( )	( )	( )	( )	( )

OVERALL SYSTEM EVALUATION

1. Please rank the concepts by preference, recalling that all systems are priced at $150,000.
(You may want to quickly review the systems before proceeding.)

BEST ________

SECOND ________

THIRD ________

FOURTH ________

2. From each of the following pairs of concepts, including your current system, please allocate 100 points between each concept in the pair, depending upon your degree of preference.

EXAMPLE:

Concept A 80 Concept B 20

I prefer concept A to concept B in roughly the 80 to 20 proportion.

1. Concept L ____ Concept J ____

2. Concept L ____ Concept K ____

3. Concept L ____ Current System ____

4. Concept J ____ Concept K ____

5. Concept J ____ Current System ____

6. Concept K ____ Current System ____

For each of the following questions, please use the provided scale and tell us how likely it is that you would buy that particular system to replace your current one. Assume it is the only alternative to your system, and indicate the likelihood at each of the three price levels. At first, please indicate the likelihood at the initial price of $150K, then consider the same product at $100K and $200K.

Concept J	$150K	$100K	$200K
CERTAIN, PRACTICALLY CERTAIN (99 in 100)..	10	10	10
ALMOST SURE (9 in 10)......................	9	9	9
VERY PROBABLE (8 in 10)....................	8	8	8
PROBABLE (7 IN 10).........................	7	7	7
GOOD POSSIBILITY (6 in 10).................	6	6	6
FAIRLY GOOD POSSIBILITY (5 in 10).........	5	5	5
FAIR POSSIBILITY (4 in 10)................	4	4	4
SOME POSSIBILITY (3 in 10)................	3	3	3
SLIGHT POSSIBILITY (2 in 10)..............	2	2	2
VERY SLIGHT POSSIBILITY (1 in 10).........	1	1	1
NO CHANCE, ALMOST NO CHANCE (1 in 100)....	0	0	0

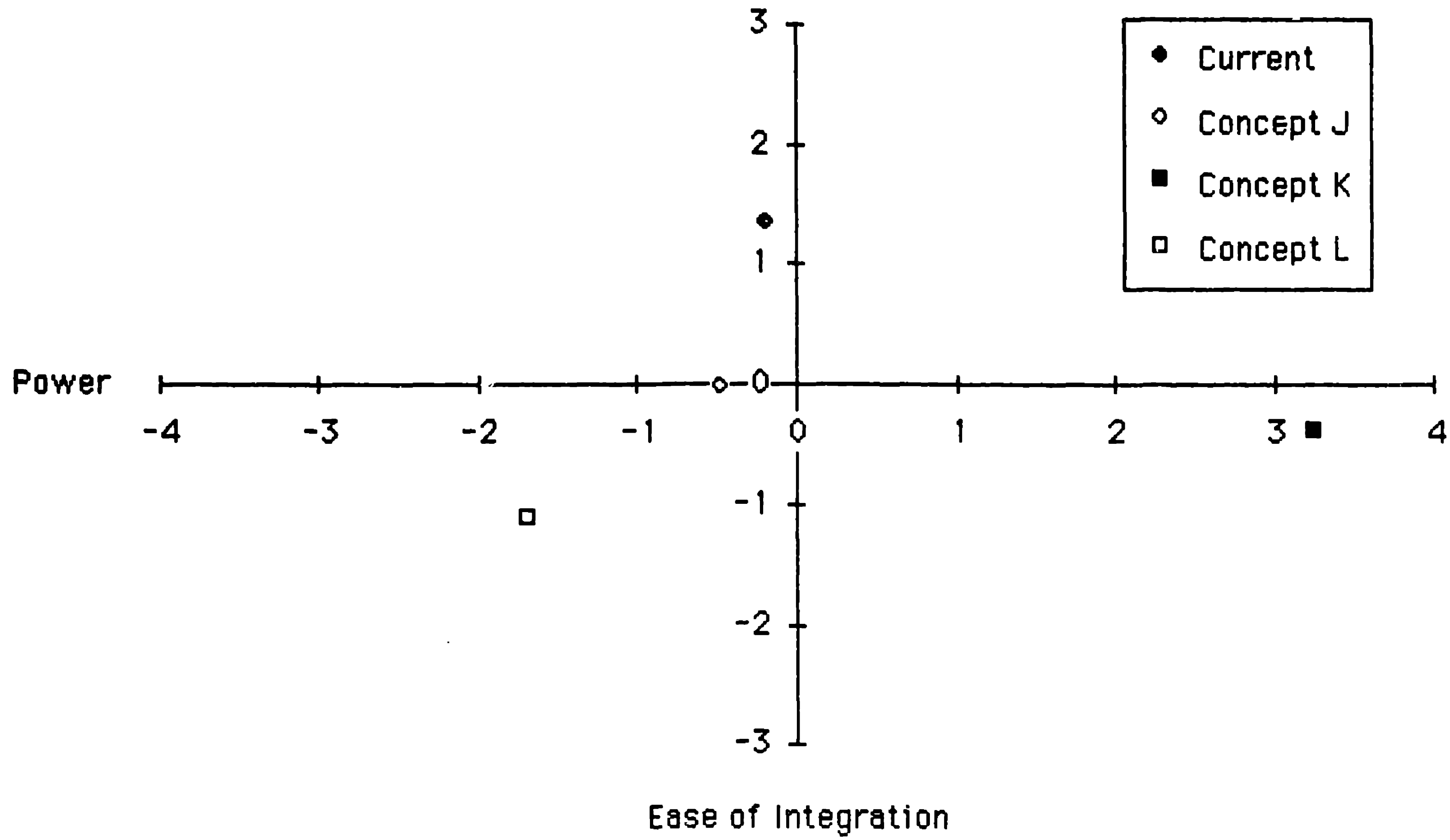
Concept K	$150K	$100K	$200K
CERTAIN, PRACTICALLY CERTAIN (99 in 100)..	10	10	10
ALMOST SURE (9 in 10)......................	9	9	9
VERY PROBABLE (8 in 10)....................	8	8	8
PROBABLE (7 IN 10).........................	7	7	7
GOOD POSSIBILITY (6 in 10).................	6	6	6
FAIRLY GOOD POSSIBILITY (5 in 10)..........	5	5	5
FAIR POSSIBILITY (4 in 10).................	4	4	4
SOME POSSIBILITY (3 in 10).................	3	3	3
SLIGHT POSSIBILITY (2 in 10)...............	2	2	2
VERY SLIGHT POSSIBILITY (1 in 10)..........	1	1	1
NO CHANCE, ALMOST NO CHANCE (1 in 100)....	0	0	0

Concept L	$150K	$100K	$200K
CERTAIN, PRACTICALLY CERTAIN (99 in 100)..	10	10	10
ALMOST SURE (9 in 10)......................	9	9	9
VERY PROBABLE (8 in 10)....................	8	8	8
PROBABLE (7 IN 10).........................	7	7	7
GOOD POSSIBILITY (6 in 10).................	6	6	6
FAIRLY GOOD POSSIBILITY (5 in 10)..........	5	5	5
FAIR POSSIBILITY (4 in 10).................	4	4	4
SOME POSSIBILITY (3 in 10).................	3	3	3
SLIGHT POSSIBILITY (2 in 10)...............	2	2	2
VERY SLIGHT POSSIBILITY (1 in 10)..........	1	1	1
NO CHANCE, ALMOST NO CHANCE (1 in 100)....	0	0	0

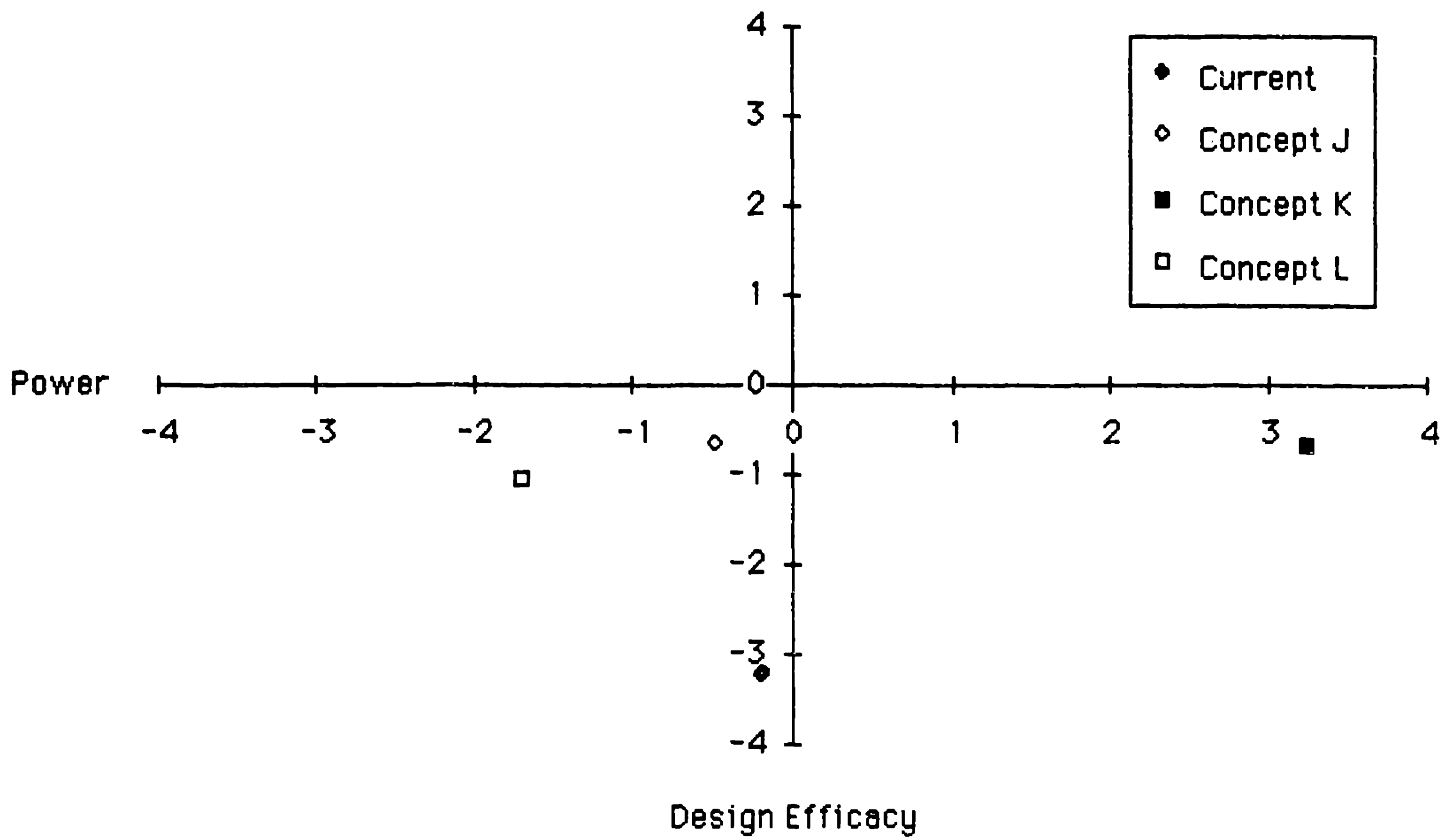
APPENDIX C

Perceptual Maps

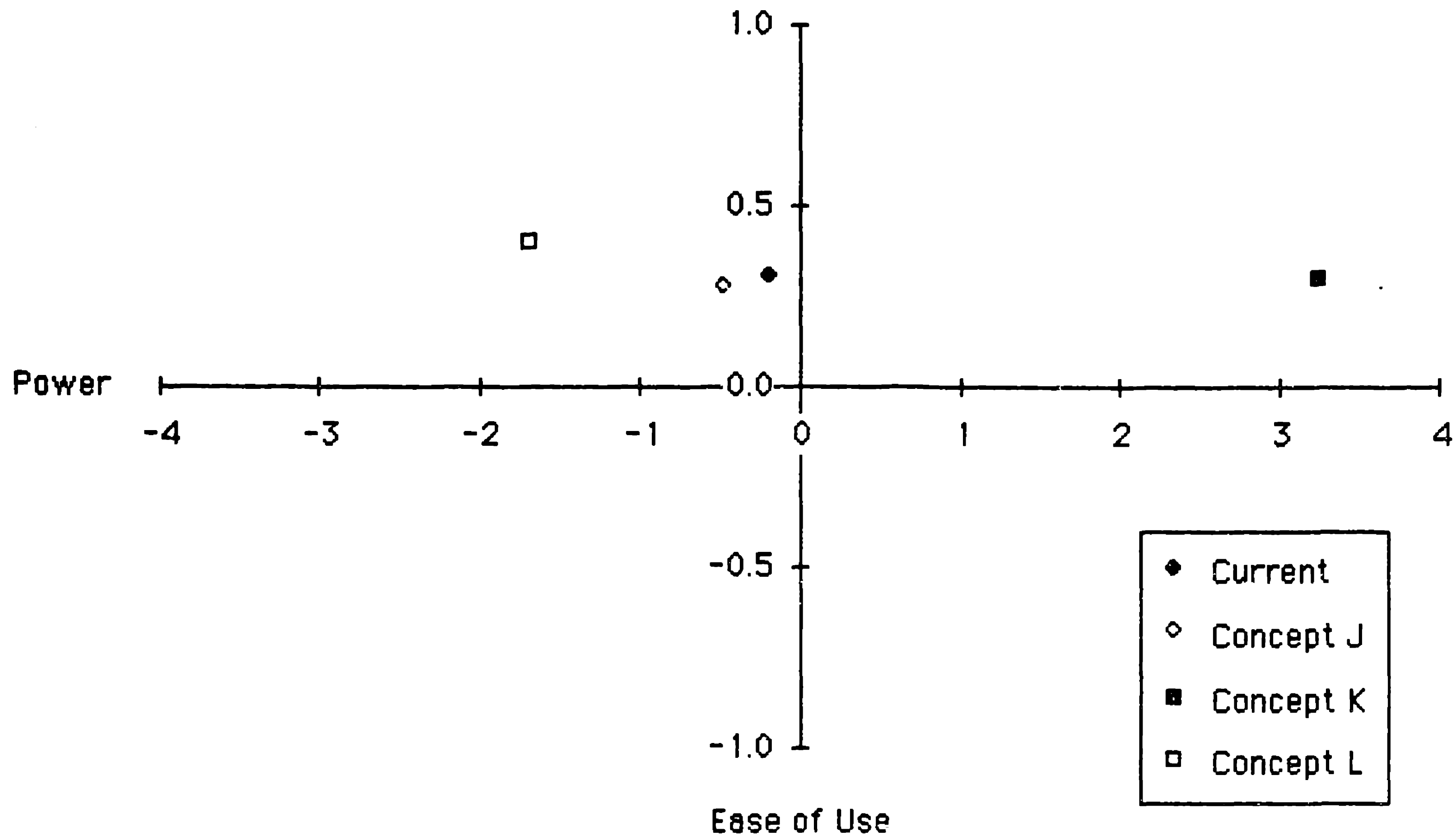
Power/Ease of Integration



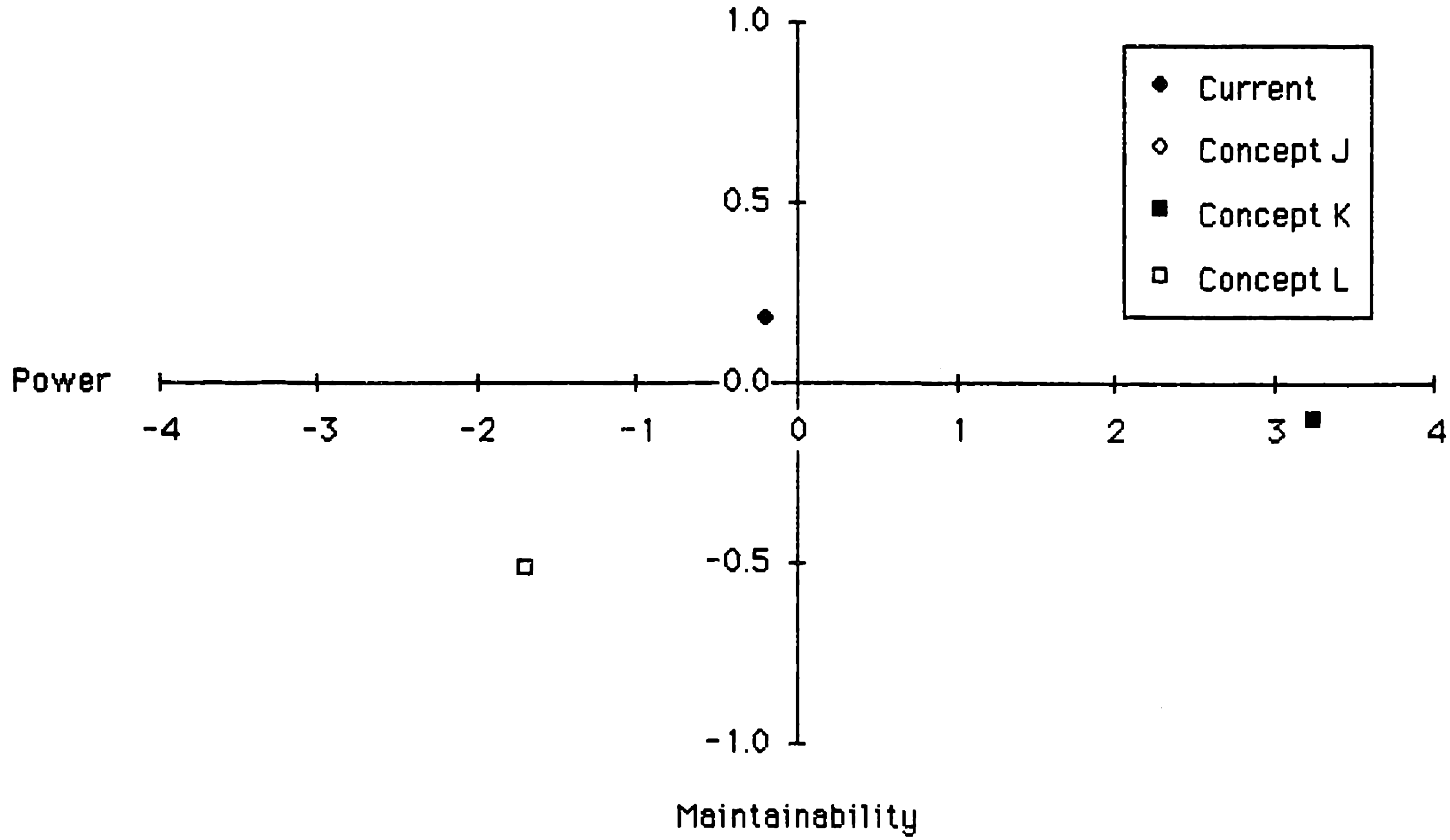
Power/Design Efficecy



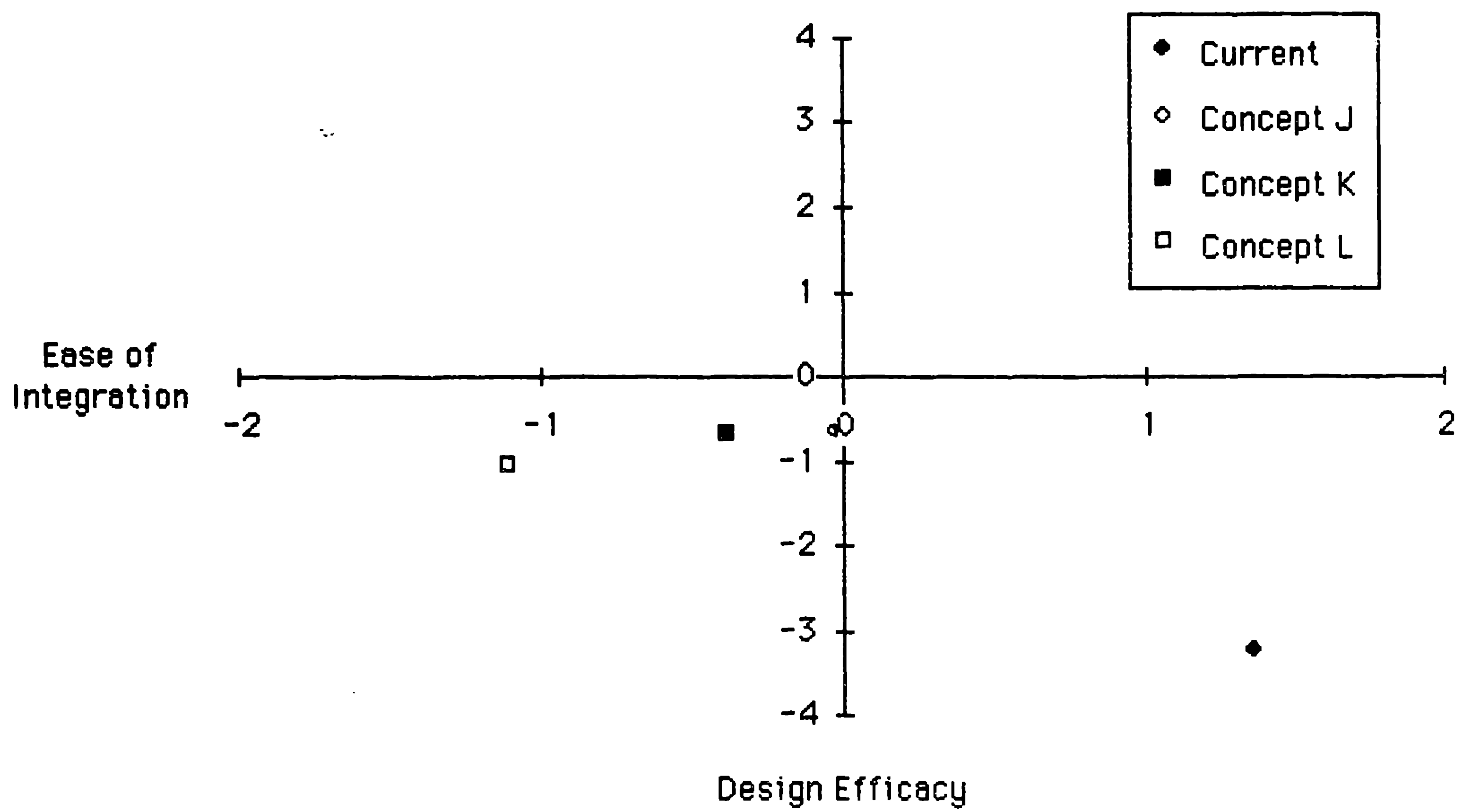
Power/Ease of Use



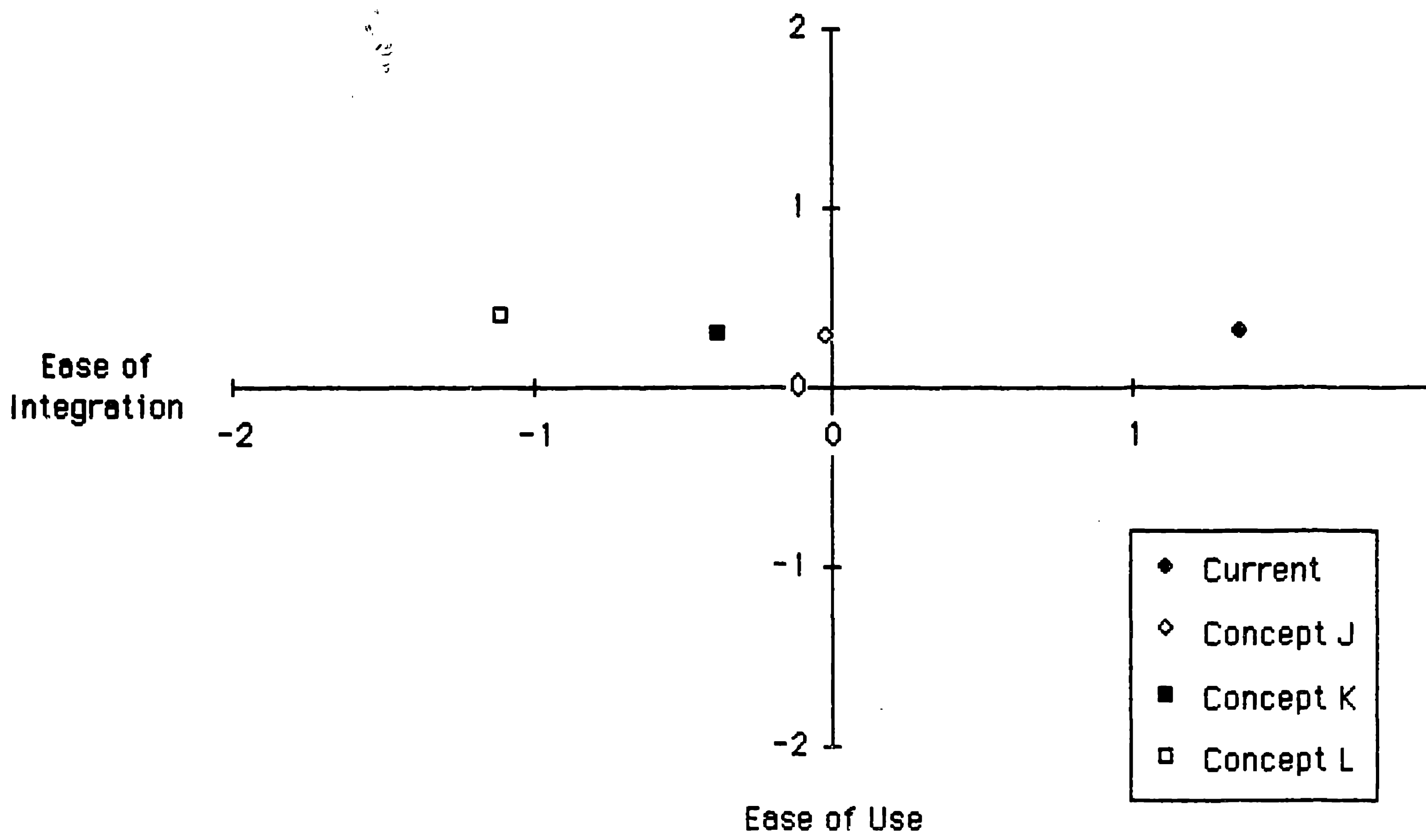
Power/Maintainability

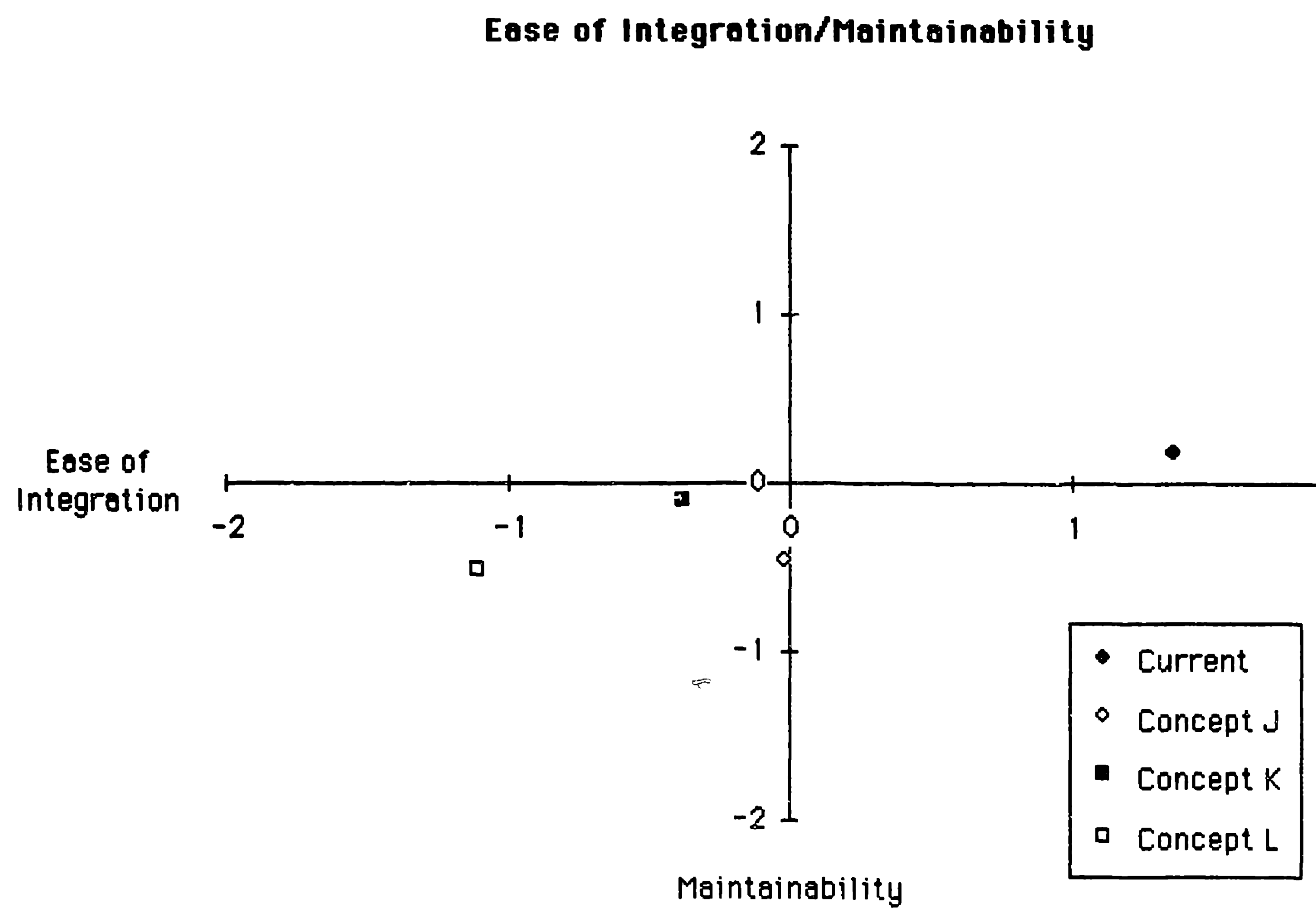


Ease of Integration/Design Efficacy

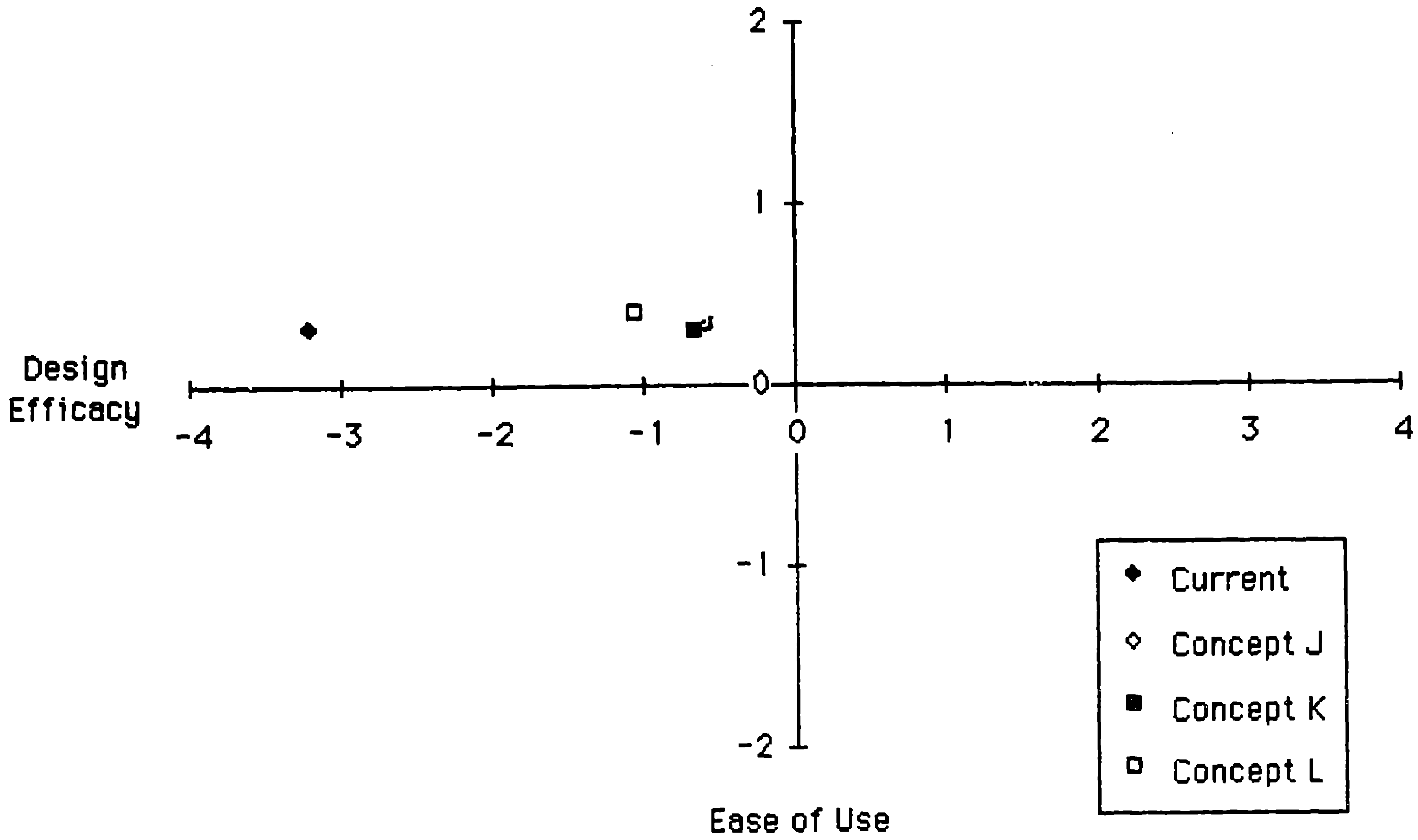


Ease of Integration/Ease of Use

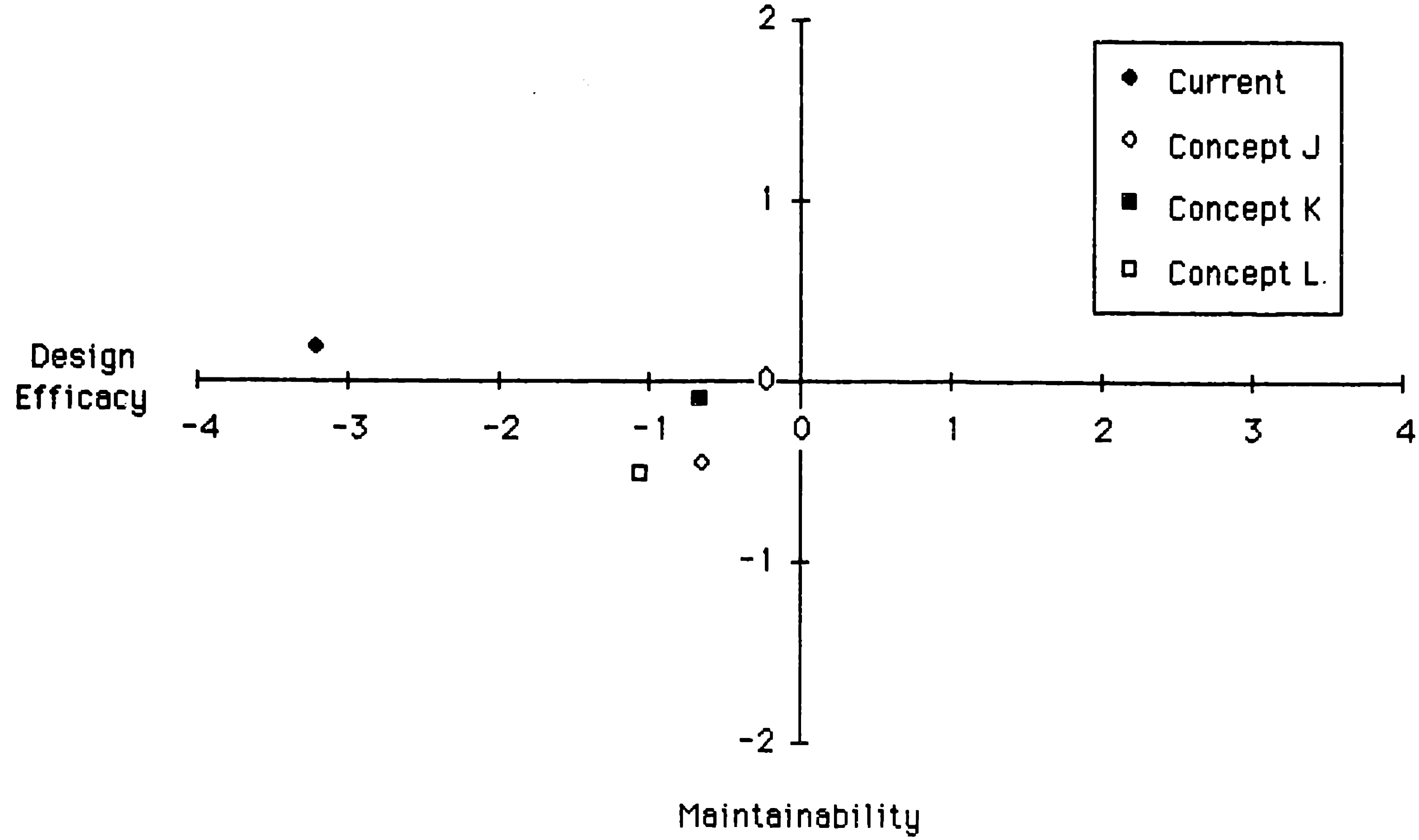



Ease of Integration/Maintainability
Ease of Integration
Maintainability
2
1
0
-1
-2
-2
-1
0
1
2
Current
Concept J
Concept K
Concept L

Design Efficacy/Ease of Use



Design Efficacy/Maintainability



Ease of Use/Maintainability