10:41:41 OCA PAD INITIATION - PROJECT HEADER INFORMATION 07/19/94

Active

Project #: E-24-X55 Cost share #: Rev #: 0
Center # : 10/24-6-R8197-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: DMI-9412694 Mod #: Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 47.041
Main project #: PE #: N/A

Project unit: ISYE Unit code: 02.010.124
Project director(s):
MCGINNIS L F ISYE (404)894-2363

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 940701 to 950630 (performance) 950930 (reports)

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Contract value	24,986.00	24,986.00
Funded	24,986.00	24,986.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: RESEARCH & TECHNOLOGY DEPLOYMENT IN ELECTRONICS ASSEMBLY

PROJECT ADMINISTRATION DATA

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Security class (U,C,S,TS) : U
Defense priority rating : N/A
Equipment title vests with: Sponsor GIT X

ONR resident rep. is ACO (Y/N): N
NSF supplemental sheet

Administrative comments -
INITIATION OF PROJECT. EXPENDITURES FROM FUNDS MADE AVAILABLE BY THIS GRANT WILL BE MATCHED BY THE GIT FROM NON-FEDERAL SOURCES.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

U

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 02/09/96

Project No. E-24-X55 Center No. 10/24-6-R8197-0A0

Project Director MCGINNIS L F School/Lab ISYE

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Contract/Grant No. DMI-9412694 Contract Entity GTRC

Prime Contract No.

Title RESEARCH & TECHNOLOGY DEPLOYMENT IN ELECTRONICS ASSEMBLY

Effective Completion Date 950630 (Performance) 950930 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments
LETTER OF CREDIT APPLIES. 98A SATISFIES PATENT REQUIREMENT.

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

E-24-X55 #1

OMB Number 345-0058

NATIONAL SCIENCE FOUNDATION
1800 G STREET, NW
WASHINGTON, DC 20550

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National Science Foundation
Permit No. G-69

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NATIONAL SCIENCE FOUNDATION FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION		
1. Program Official/Org.		
2. Program Name		
3. Award Dates (MM/YY)	From: July, 1994	To: June, 1995
4. Institution and Address Georgia Tech Research Corporation Georgia Institute of Technology North Avenue Atlanta, Georgia 30332		
5. Award Number DMI-9412694		
6. Project Title Research and Technology Deployment in Electronics Assembly		

This Packet Contains
NSF Form 98A
And 1 Return Envelope

PART IV – FINAL PROJECT REPORT – SUMMARY DATA ON PROJECT PERSONNEL

(To be submitted to cognizant Program Officer upon completion of project)

The data requested below are important for the development of a statistical profile on the personnel supported by Federal grants. The information on this part is solicited in resonse to Public Law 99-383 and 42 USC 1885C. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. You should submit a single copy of this part with each final project report. However, submission of the requested information is not mandatory and is not a precondition of future award(s). Check the "Decline to Provide Information" box below if you do not wish to provide the nformation.

Please enter the numbers of individuals supported under this grant.
Do not enter information for individuals working less than 40 hours in any calendar year.

	Senior Staff		Post-Doctorals		Graduate Students		Under-Graduates		Other Participants[1]	
	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.
A. Total, U.S. Citizens	1				1					
B. Total, Permanent Residents										
U.S. Citizens or Permanent Residents[2]:										
American Indian or Alaskan Native										
Asian.										
Black, Not of Hispanic Origin.					1					
Hispanic										
Pacific Islander										
White, Not of Hispanic Origin										
C. Total, Other Non-U.S. Citizens										
Specify Country 1.										
2.										
3.										
D. Total, All participants (A + B + C)	1				1					
Disabled[3]										

☐ Decline to Provide Information: Check box if you do not wish to provide this information (you are still required to return this page along with Parts I-III).

[1] Category includes, for example, college and precollege teachers, conference and workshop participants.

[2] Use the category that best describes the ethnic/racial status fo all U.S. Citizens and Non-citizens with Permanent Residency. *(If more than one category applies, use the one category that most closely reflects the person's recognition in the community.)*

[3] A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment. *(Disabled individuals also should be counted under the appropriate ethnic/racial group unless they are classified as "Other Non-U.S. Citizens.")*

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the orignal peoples of Hawaii; the U.S. Pacific territories of Guam, American Samoa, and the Northern Marinas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.

Research and Technology Deployment in Electronics Assembly
DMI 9412694
Part II: Summary of completed project

The project reported here represents a collaboration between Ford Motor Company and Georgia Tech, with support from the National Science Foundation. The objective of the project was to design and execute a printed circuit card assembly benchmarking study for two purposes: (1) developing a method to identify best performance among a set of plants, and to identify best practices that could be transferred; and (2) to identify opportunities for manufacturing research to support printed circuit card assembly.

Through an extended brainstorming process, a very detailed survey instrument was developed for the collection of quantitative information from a manufacturing site. The survey instrument was used in a sample of five plants, and was augmented by site visits to four of the plants, where qualitative observations were recorded. Data collected was analyzed, and conclusions drawn relative to best performance and best practice. In addition, research opportunities were identified.

The project successfully identified measurable quantitative attributes that can be compared across sites for the purpose of assessing potential opportunities for improvement. What remains to be determined, possibly from a larger benchmarking database, is whether or not all exogenous factors can be normalized in a statistical model built upon the database. Second, it appears that the most effective approach, at this time, to assessing best practices is case studies, with quantitative benchmark data to support them

Additional manufacturing research opportunities were identified: (1) better process optimization tools, addressing both specific machines and assembly lines; (2) quantitative diagnostic tools, that would allow plant personnel to identify opportunities for significant improvements in performance; and (3) a generic implementation platform for process engineering tools, similar to the platform that CAD systems provide for design engineering tools.

Part III Technical Information

McGinnis, Leon F., Cranmer, Laura, and Bill Colwell, "Benchmarking in Printed Circuit Card Assembly," Georgia Tech working paper, 45 pp, January 15, 1996.

BENCHMARKING PRINTED CIRCUIT CARD ASSEMBLY

Leon F. McGinnis
Georgia Institute of Technology

Laura Cranmer
Bill Colwell
Ford Motor Company

January 15, 1996

The work reported here was supported by the National Science Foundation (grant DMI 9412694), Ford Motor Company, and the Georgia Tech Manufacturing Research Center.

1. Executive Summary

The manufacture of printed circuit card assemblies is an essential element in the production of a large fraction of modern consumer and industrial products. Both the products and the manufacturing processes used to produce them are highly technical systems. Units of a given product, or printed circuit card assembly, from a given factory will, unless defective, give identical performance results, However, no two printed circuit card assembly plants are identical, nor do they perform identically. At the present time, there is no generally accepted technical method for assessing printed circuit card assembly plants to evaluate their manufacturing performance in either relative or absolute terms.

The project reported here represents a collaboration between Ford Motor Company and Georgia Tech, with support from the National Science Foundation. The objective of the project was to design and execute a printed circuit card assembly benchmarking study for the purpose of developing a method to identify best performance among a set of plants, and to identify best practices that could be transferred.

Through an extended brainstorming process, a very detailed survey instrument was developed for the collection of quantitative information from a manufacturing site. The survey instrument was used in a sample of five plants, and was augmented by site visits to four of the plants, where qualitative observations were recorded. Data collected was analyzed, and conclusions drawn relative to best performance and best practice. In addition, research opportunities were identified.

There were several general conclusions from the project. First, it is possible to identify measurable quantitative attributes that can be compared across sites for the purpose of identifying best performance, or potential opportunities for improvement. What remains to be determined, possibly from a larger benchmarking database, is whether or not all exogenous factors can be normalized in a statistical model built upon the database. Second, it appears that the most effective approach, at this time, to assessing best practices is case studies, with quantitative benchmark data to support them. Broad spectrum quantitative data gathering to assess best practices does not seem practical.

The project also identified potential opportunities for additional manufacturing research to improve printed circuit card assembly. First, there is a need for better process optimization tools, addressing both specific machines and assembly lines. Second, there is a need for quantitative diagnostic tools, that would allow plant personnel to identify opportunities for significant improvements in performance. Finally, there is a need for a generic implementation platform for process engineering tools, similar to the platform that CAD systems provide for design engineering tools.

1. Table of contents

Benchmarking Printed Circuit Card Assembly

1. Abstract

This report presents the results of an NSF-sponsored GOALI project, involving Georgia Tech and the Automotive Components Division (previously, the Electronics Division) of Ford Motor Company. Built upon a collaboration of several years, the GOALI project was an attempt to employ benchmarking methods to develop a deeper understanding of the opportunities for process improvement and the needs for additional research in printed circuit card assembly. The report provides some background for the project, describes the process followed by the project team, summarizes the results of the benchmarking effort, and offers some general observations and conclusions regarding printed circuit card assembly and benchmarking.

2. Introduction

Electronics assembly is a key component of almost every high-tech consumer and industrial product today. Electronics technology allows manufacturers to improve functionality and performance, and represents a continuously growing fraction of the cost of many products. Printed circuit card assembly is the "upstream" process of electronics assembly, i.e., it is the first process in the stream of manufacturing activities. Requirements for flexibility and agility "downstream" (i.e., final product assembly) place stringent performance requirements on printed circuit card assembly. The predominant technology in printed circuit cards today is surface mount technology, or SMT.

SMT allows the high speed placement of large numbers of very small components onto printed circuit cards (PCC) to create printed circuit card assemblies (PCCA). SMT assembly employs specialized, expensive, numerically controlled assembly equipment, and requires the management of hundreds, perhaps even thousands of component types. SMT assembly operations may be organized as a classical assembly line or flow line, with continuous handling of PCCA between operations using a conveyor. Alternatively, the operations may be organized as a job shop, with batches of PCCA moved between operations. Regardless of the organization, however, workload planning and operational efficiency are key factors contributing to manufacturing cost.

Process planning for printed circuit card assembly involves allocating the workload for each product among the available assembly processes, and for each process, developing complex pick-and-place programs for numerically controlled machines. The workload allocation problem can be difficult to optimize if assembly processes are shared between products. Furthermore, there are so many degrees of freedom in the arrangement of feeders and sequencing of placements that it is often difficult to determine a "best" program for a specific assembly operation. Thus, process planning for PCCA is technically challenging. See [17] for a more complete discussion of PCCA process planning.

Starting around 1983, a number of companies recognized the opportunity to improve printed circuit card assembly operations through better process planning. In some cases, this took the form of developing optimization models for the setup or placement sequencing on a single placement machine (see, e.g., the pioneering work at IBM by Ahmadi, Grotzinger, and Johnson [1], or Ball and Magazine [11]). In other cases, the goal was to achieve better workload balance across machines in a cell, or to minimize the handling of product between machines (see, e.g., [2], work that was done collaboratively with Data General).

By and large, the R&D work that has been done with regard to printed circuit card assembly process planning has focused on specific problems or situations. Our experience has been that, while such R&D is valuable, it has yet to make the major impact one might have expected. The reasons for this are complex, but key among them is the lack of a common frame of reference, common terminology, and common metrics within industry. Thus, it is often difficult to directly transfer results from one R&D project to a similar situation in a different company or different operating unit within the same company.

The work reported here was motivated by twin concerns. First, we wanted to be able to identify "best practices" in PCC assembly. In order to do this, we felt it would be necessary to be able to identify "best performance" within a sample of PCCA operations. Second, we wanted to identify the significant issues within process planning for PCCA that represented opportunities for further research and development to make major contributions to productivity. The approach we have taken is to conduct detailed benchmarking of existing PCC assembly operations.

3. Background

This work is the result of a collaboration between Ford Motor Company and Georgia Tech. Ford and Georgia Tech have significant experience in the printed circuit card assembly arena, through both independent and joint activities. This section provides a brief description of our prior experience.

3.1 Ford Electronics

One of the authors (Colwell) heads Manufacturing Process Design (MPD), a staff function within the Automotive Components Division (formerly the Electronics Division) of Ford Motor Company that is charged with developing manufacturing processes. In particular, this group has responsibility for recommending strategy and developing process designs and process management tools for printed circuit card assembly operations in the Ford Automotive Components Division, world-wide. Among the issues being addressed within this group are: how to select appropriate assembly technology; how to configure assembly resources to maximize effectiveness; how to load work onto lines and/or machines; how to schedule/sequence production; and how to optimize the operations of each machine. The goal is to develop specific solutions and to deploy those solutions throughout the Ford Automotive Components Division.

MPD has been quite successful in developing computational tools for analyzing PCCA issues. For example, a large spreadsheet model has been developed to bring together information about assembly machine capacity, production requirements, and product design, in order to analyze alternative line configurations for capacity feasibility. In another project, a large optimization model was developed to analyze strategies for allocating product volumes among available product sources.

The MPD staff have deep understanding of the manufacturing requirements of the Ford Automotive Components Division, as well as the technologies associated with printed circuit card assembly. The staff of MPD work continuously with the operating units.

3.2 Georgia Tech

One of the authors (McGinnis) has been leading printed circuit card assembly research at Georgia Tech since 1983. That research effort has addressed almost every aspect of the PCCA process planning problem, resulting in a number of publications (see citations [2]-[10], and [12]-[17]), and a sustained stream of industry support for the research, through the Material Handling Research Center and the Manufacturing Research Center. The goal has been to develop generic methods that are useful in solving process planning problems in practice.

The Georgia Tech research team has developed both a framework for organizing PCCA process planning decisions (see, e.g., [17]), and a variety of optimization models to support decision making. Optimization models have been developed for cycle time optimization of specific machines, e.g., the Panasonic MVII, and for line balancing in a variety of scenarios (see, e.g., [9]). The team has worked closely with industry, has been involved in several implementation projects, and has an ongoing relationship with a third party provider of process planning software.

3.3 Joint Work

Over the past several years, Georgia Tech and Ford have collaborated on several research efforts. Together, we have developed process planning tools for specific placement machines, in some cases requiring detailed study of the machine operations to obtain timing data. We also have collaborated on the development of optimization models for line balancing.

Through this prior collaboration, we have recognized a shared need for a better understanding of the PCCA process. We have recognized that, while we can develop tools for analyzing specific situations, or optimizing specific decisions, we have no global framework for best practices or best performance. Thus, we cannot determine if a significant improvement opportunity exists, prior to conducting a project. Likewise, there is little corporate leverage for best practices between sister plants within the Automotive Components Division.

The recognition of this shared need is the motivation for the benchmarking study presented in this report.

4. Goals

Five primary goals were identified for this study:

1. Develop a method for assessing best performance, normalizing for differences in products, equipment portfolios, scale of production, and location. Ford has a number of electronics plants, and they differ with regard to these factors. Furthermore, the intention was to benchmark other firms, so it is essential that the raw data be normalized in some fashion.

2. Develop a benchmark database, so that individual manufacturing sites can determine how they compare on key performance indicators. The intent was that the benchmark data be used to help plants identify their potential opportunities for improvement.

3. Identify those "best practices" which lead to best performance. Assuming that the benchmarking activity is successful in assessing performance, the intent was to use the benchmarking data to identify best practices, which may be different for different scenarios.

4. Initiate benchmarking collaborations that can continue beyond the initial study. The intent was that this benchmarking activity continue, allowing longitudinal analysis of specific plants.

5. Develop guidelines for future Georgia Tech and National Science Foundation research planning. The study was intended to provide insight into the significant issues relevant for academic research.

5. Method

The GOALI grant was awarded in the Spring of 1994, and work officially began on the project on June 15. The bulk of the work was performed during the summer of 1994, although some data collection and analysis continued during the academic year 1994-95. The project was conducted in four phases:

1. Planning. A considerable amount of the effort involved in the project was focused in planning. In particular, it was difficult to identify specific measurable attributes that would be benchmarked. This phase involved both the research team and individuals from plant locations.

2. Data collection. The data collection phase involved sending survey instruments to the benchmark sites, completion of the surveys by plant personnel, and the review and editing of the surveys by the research team. In addition, site visits were conducted, to better understand the quantitative data, and to make qualitative observations.

3. Data analysis. The original intent was to create a large benchmark database and to use Data Envelope Analysis (DEA). However, because the GOALI project focused on Ford plants, the initial database was too small to support DEA. Instead, simple linear ratios were computed for the relevant quantitative data, tabulated, and compared. In addition, a summary of qualitative data was prepared for each site visited.

4. Reporting. Each benchmark site was visited to report the findings of the benchmark study, and to discuss the conclusions reached by the project team.

Each of the phases is discussed in greater detail below.

5.1 Planning

The planning phase addressed two basic issues:

1. What will be measured as part of the benchmarking study? and
2. What sites would be involved in the benchmarking study?

The second question was answered easily, as three major printed circuit card assembly operations within the Ford Motor Company agreed to participate, and another later joined the project. A second company provided one additional site, for a total of five sites. From the beginning, it was hoped that a successful completion of the GOALI project would lead to a larger benchmarking study, involving many more sites.

The question of what to measure proved to be much more difficult to resolve. Benchmarking has been one of the "hot" topics of the nineties, and much has been written about benchmarking. Despite the attention given to benchmarking as a business practice, however, the project team found little published work to guide the design of this particular benchmarking study.

The approach taken was to use an extended brainstorming process, which initially involved the core research team, but eventually engaged other experts from various Ford Motor Company sites. The brainstorming activities revolved around four key questions:

1. What are appropriated performance measures, leading to the identification of "best performance"?
2. What are the measurable attributes that indicate best practice, and how are they related to performance measures?
3. What are the exogenous factors that differ from site to site, and need to be captured to support "normalization" of results?
4. How should the data collection effort be organized, to insure that the needed data is captured, but that the expense and effort required are not excessive?

The brainstorming process took place over an extended time period, and the answers to the four questions evolved during that period. The following briefly describes, not the entire process, but what finally emerged.

A fundamental issue was the definition of the study scope. After considerable debate, it was decided to focus on printed circuit card assembly and the support for assembly, and to leave out testing and rework operations.

Six general performance indicators were identified as important. Three were considered key indicators for current financial performance:

1. cost
2. quality
3. responsiveness

Three more were considered key indicators of future financial performance:

4. rate of improvement
5. adaptability
6. innovation

The next step was to determine, for each of the six generic indicators, specific measurable attributes related either to performance or practices. Again, the team found some difficulty in identifying an appropriate set of measurable attributes. Further brainstorming, using "fishbone" diagrams, resulted in a lengthy list of attributes, which were roughly grouped into nine categories: equipment, facility, product, people, practices, overhead, material, customer, and manufacturing cycle time. An example of the fishbone diagrams is included as appendix 10.1.

As might be expected, a large number of contributing factors appeared in more than one fishbone diagram. In an effort to better understand the complex relationships, and to reduce the set of attributes to measure, the information from the fishbone diagrams was reduced to a large table, with columns corresponding to the six key indicators, and rows corresponding to measurable (or potentially measurable) attributes. The project team then looked at the attributes to consider how many indicators each affected, and whether the attribute was controllable at the plant level. At this point, many of the attributes were simply identified, rather than precisely defined. For example, "maintenance" was identified as an important attribute to be measured with regard to "equipment", but the precise measure to be used was not defined. This table was the basis for detailed discussions, leading to the attributes to be measured, and the specific metrics to be used.

The brainstorming, utilizing both the fishbone diagrams and their tabulation, lead to several key decisions. First, it was concluded that we simply did not have enough knowledge to identify reliable, measurable attributes that would allow us to draw conclusions regarding the indicators of future financial performance. Therefore, the study was limited to the first three indicators, addressing only current financial performance. Second, after much debate, we agreed that asking for detailed, specific financial information would jeopardize the participation of many companies. Therefore, the measurable attributes would not include detailed cost or revenue data. Third, we felt that it would be important to measure not only the average values of important attributes, but also to capture information about variability of certain attributes, since variability often seems to be a key element in performance.

The final result from the extended brainstorming was a draft of a survey instrument that could be used at each site to capture information for the study. After testing the instrument at the first site, it was revised slightly for use at the remaining sites. The complete instrument is included in Appendix 10.2. What is immediately apparent is that the survey instrument captures a very significant amount of information about the site, addressing both performance and practices.

It is especially relevant to note that the survey instrument includes a glossary of terms. We found that, even within a single corporation, the terminology employed in discussing printed circuit card assembly was not the same at every site. Even within the project team, we often used the same word to mean different things, or described the same process or part using different terms. A glossary became essential.

Before leaving the discussion of the planning phase, a final comment is in order. We cannot overemphasize the difficulty of defining the metrics to be used in the benchmarking study. This was somewhat surprising, considering that the core project team represented well in excess of twenty-five person-years of experience in PCCA, and had access to plant personnel representing several times that much experience. Moreover, the study was being designed largely (though not completely) from the perspective of a single corporation.

5.2 Data Collection

Data collection for the first three Ford sites, and the other company site involved three phases:

1. the survey instrument was mailed to the plant, and completed by plant personnel
2. the completed survey was returned to the project team, examined for completeness and accuracy, and any obvious anomalies were resolved in discussions with the plant personnel
3. the project team visited the site, walked through the PCCA area, and interviewed plant personnel to resolve any remaining quantitative data questions, and to develop qualitative survey data.

The human resources required in data collection were substantial. The average estimate of the time required by plant personnel to complete the written survey was one to two person-weeks. The time required to evaluate the completed survey instrument and enter the data into a spreadsheet was approximately another person-week. The site visits generally involved three or four people from the project team, as well as a number of people from the site, over a two day period.

For the fourth Ford site, data collection was as for the first three with one major exception. Since the site was not in North America, it was considered infeasible for the project team to visit the site. Instead, the "site visit" was conducted by teleconferencing. This option was judged by the project team to be acceptable for most purposes of the benchmarking study. The only limitation is in the assessment of some of the qualitative aspects of performance and practices.

For each site in the benchmarking study, a spreadsheet was created to support numerical analysis of the quantitative data. In addition, a paper file was created, containing the completed survey instrument, and any supporting documents provided, such as floor plans, product descriptions, process time data, etc. Security of the data was a key concern, and the survey participants were assured that specific data would be treated as proprietary and confidential.

5.3 Data Analysis

The first step in data analysis, for each site, was to examine the returned survey instrument for completeness and consistency, and "reasonableness" of the responses. Often, this step involved communications with the plant to clarify or confirm responses. Next, a number of aggregate measures were computed from the detailed data contained in the survey instrument. For example, the extensive tables describing the equipment portfolio were used to compute two measures of placement capacity: total number of feeder slots available, and total placement rate capacity. Clearly, these two measures represent an ideal limit, which is never approached in practice. In order to compute the placement rate capacity, it was necessary to assign to each type of placement machine, a "rated" placement capacity, rather than using estimates generated by the plants themselves.

In the process of data analysis for the first three sites in the survey, it became clear that there was a potential problem. The sites differed significantly in the amount of through hole production, relative to surface mount production. We also found it difficult to "normalize" the data across the two technologies. For that reason, and considering that the trend is away from through-hole technology, we decided to limit the scope of the benchmarking analysis to the SMD portion of PCCA.

It was clear from the beginning of the project that the sample of Ford plants would be too small to support a DEA analysis, and that more traditional measures of performance would be used. After collecting data from the first three sites, the team assembled again to discuss what metrics could be computed that would serve the goals of the project, namely, to identify best performance, in terms relevant for competitive success. Once again, the team encountered some difficulty in identifying a reasonably small set of performance indices that seemed to capture the essence of "best performance" and could reasonably be compared across multiple sites.

Because a large amount of quantitative data had been collected, there were a large number of alternative indices that could be computed. The team discussed a number of utilization and productivity ratios, as well as direct measures, such as days of inventory. The result was a set of indices corresponding to the groups of questions in the survey instrument:

1. output statistics
2. facility data
3. equipment data
4. workforce analysis
5. time analysis
6. quality analysis
7. product characterization
8. process analysis

These indices could be tabulated for ease of comparison across plant sites.

In addition, for each site, a summary of the qualitative observations was prepared. In particular, the team attempted to identify, for each site, the areas of special competence, and the areas of potential improvement, relative to the other sites.

5.4 Reporting

After the first three sites had been surveyed, and their data analyzed, a presentation was prepared to summarize the findings of the survey. The first three sites were visited again, and the formal presentation made. At each site, there was a frank discussion of the results of the survey, and how the results could or should be interpreted. The presentation to the fourth Ford site was conducted by teleconference. The other company site was not visited for a followup presentation.

6. Benchmarking Results

Table 6.1 presents a sample of the quantitative benchmark results. In the table, some entries have been normalized, i.e., all site values have been divided by the largest site value, in order to avoid revealing proprietary data. Some entries are given in absolute terms, since they represent ratios or percentages. Normalization is indicated by an N in the second column of the table, absolute values by an A. A complete tabulation of results computed from the survey instrument is included as appendix 10.3

Table 6.1 Sample Quantitative Benchmark Results

Survey Topic		Plant #1	Plant #2	Plant #3	Plant #4	Plant #5
Total panels (X1000)	N	100.00%	35.57%	70.68%	39.58%	12.98%
Placements (X10E6)	N	100.00%	56.51%	47.23%	33.96%	4.46%
Space/Equipment	A	373	248	375	357	1356
Placements/sq.ft. (x1000)	A	54	40	33	41	1.43
Rate capacity utilization	A	43.55%	32.45%	22.42%	25.32%	7.36%
Staging capacity utilization	A	29.29%	22.57%	9.83%	21.84%	520.36%
(Failure DT)/(Total Maint DT)	A	49%	9%	79%	23%	35%
Reported % Brkdwn Maint.	A	13%	10%	20%	35%	75.00%
Hourly HC	N	67.01%	58.76%	20.79%	19.93%	100.00%
Plcmnts per HC (x10E6)	A	6.02	3.88	9.17	11.05	0.25
Panels per HC (x1000)	A	18.14	7.36	41.32	24.18	1.58
Salaried HC	N	33.90%	42.37%	38.98%	8.47%	100.00%
Plcemnts per HC (x10E6)	A	58.73	26.54	24.13	128	1.23
Panels per HC (x1000)	A	176.85	50.32	108.7	280	7.78
Hourly HC/Salaried HC	A	9.75	6.84	2.63	11.58	4.93
PPM (typical panel)	A	500	70	98	50	
First pass yields (typ panel)	A	90%	99.50%	100%	99.70%	NR
% Rework	A	1.00%	1.25%	0.00%	0.50%	15.00%
# panel types	N	15.23%	21.83%	13.71%	10.15%	100.00%
# product types	N	15.02%	29.11%	31.92%	10.33%	100.00%
# component part numbers	N	10.80%	10.25%	3.42%	6.15%	100.00%
(total plcmnts)/(total panels)	A	222	528	222	285	114
unique comp per panel	A	60	18	92	105	39
component density	A	0.37	0.52	1.21	1.74	0.23
Product churn	A	22%	24%	19%	22.73%	39.91%
% products in family setups	A	47%	75%	86%	100%	0
Largest family (% of prod)	A	9%	13%	68%	13.64%	24.41%
% plcmnt mach static setup	A	65%	100%	20%	NR	NR
Average process utilization	A	0%	75%	73%	90%	75%
Average lot size (panels)	A	1400	200	800	800	24

The only obvious conclusion that one might draw from Table 6.1 is that the five sites are quite different from one another. For each attribute in the table, one site is "best", considering only that single attribute. It is not so clear, however, if that represents best performance. For example, the site with the lowest staging capacity utilization also has the highest panels per headcount. What the table does bring into sharp focus is simply that there are very large differences in specific performance measures. These large differences may or may not represent opportunities for improvement, but they do provide a starting point for the improvement process.

From the quantitative data, as represented by Table 6.1, and from qualitative, subjective evaluations, some additional conclusions may be drawn. First, despite the provision of a glossary, and extensive conversations between the project team and site personnel, it appears that there are substantive differences in interpretation of certain terms. For example, the results for mean cycle time and average hours of work-in-process appear inconsistent for some sites, indicating confusion regarding the definition of one or both terms. Generally speaking, the benchmark data can be viewed as varying in reliability, with reliability decreasing in the following order: productivity (most reliable), utilization, quality, maintenance, time (least reliable).

A number of purely qualitative conclusions were reached by the project team, based on the combination of site visits and survey results. Table 6.2 lists some of these conclusions, independent of the associated site, to illustrate the nature of these conclusions. From a scientific point of view, these observations may not be very important, but from a pragmatic point of view, they may be critical in the continuing process of further benchmarking or process improvement.

Table 6.2 Sample Qualitative Results

Overhead cost conscious
    delayed equipment upgrades
    lean engineering staff

Disruption conscious
    stable sequence/schedule
    minimized feeder changes

Response time conscious   every line runs every product, no changeovers

Error conscious
    visual setup cues
    on-line repair in through hole
    manual inspection in SMD

Ownership conscious
    white board data displays
    very low turnover

Open, energetic, eager to improve
Self-assured, cooperative
Harried, annoyed, eager to get back to work

Based on the quantitative and qualitative results, each site was given a list of its potential best practices, and also its potential opportunities for improvement. It was emphasized to the sites that these conclusions were tentative, at best, and should be taken as starting points for further investigation.

7. Lessons Learned

There were a number of valuable "lessons learned" through this project. With regard to Ford Motor Company, it became quite clear that each of the PCCA operations was unique, had a distinctive "personality", and had its own special expertise or competencies. While it was not possible to make a definitive statement regarding "best performance", it was possible to identify potential opportunities for improvement. As a result, a division-level activity was initiated to promote the sharing of "best practices" between the sites. Such an activity had not existing prior to the benchmarking study, and represents a significant benefit for Ford Motor Company.

The project team also learned some important lessons about benchmarking. Perhaps the most important lesson learned has to do with the definition of goals for benchmarking. In this project, the original goals were broad in scope, and addressed both performance and practices. Performance was broadly defined, rather than being narrowly or specifically defined. Because we had no preconceived notions regarding practices, we attempted to capture all the information we could think of that might lead us from performance to practice. In retrospect, this is not a good strategy for a benchmarking study. It leads to a study that is too broad in scope, too diffused in its data requirements. Moreover, the conclusions we reached regarding best practices tended to come from our qualitative observations, perhaps in conjunction with performance data.

The implicit assumption that we could capture enough quantitative data to lead us to best practices was not a good assumption. In retrospect, a better strategy would have been to pursue the issue of best performance, without confounding it with the issue of best practice. Once a sufficiently large database was developed, and DEA could be employed, the best performers could be identified. At that point, intensive case studies of the best performers, to develop hypotheses regarding best practices, probably would be a more successful strategy.

Because the survey asks for so much information, it has been difficult to gain acceptance by a broad spectrum of PCCA manufacturers. Limiting the initial study to performance benchmarking probably would have resulted in a much simpler survey, and a greater participation by other companies. Because the study was not successful in attracting a large sample of participating companies/sites, not enough data points are available to support a DEA analysis. Again, it may be possible that reducing the scope of the survey to best performance may result in wider acceptance.

The project also offers some lessons when viewed from the research perspective. A fundamental problem in PCCA (and perhaps in manufacturing in general) is to determine whether or not a complex process is performing well. Thus, there is a need in practice for robust diagnostic tools. Benchmarking attempts to diagnose opportunities for improvement by making comparisons within a specific sample of operations. A true diagnostic tool would be based on a more fundamental or generic model, or generic norms, much as a physician uses in diagnosing a patient's condition. Extensive benchmarking is likely a prerequisite for developing such diagnostic tools, but is not likely to be the complete solution.

It is quite clear, both from the benchmarking project and from our other experiences, that process planning for PCCA is done in a very *ad hoc* manner in practice. There are few specific process planning tools that are in common use, and those few are quite limited in capability. There is a proliferation of notebooks, *ad hoc* spreadsheet tools, intuition, and trial and error. In short, given the complexity of the problem, it appears that there is significant opportunity for more powerful process optimization tools to have a significant impact in practice.

As an illustration of the state of process planning, consider question 22 from the "operations:" section of the survey instrument. The question, in essence, asks if there is any tracking of the actual placement machine cycle time relative to an ideal placement machine cycle time, considering the number of placements to be made. Uniformly, the response was "no". Not only are the process planning tools *ad hoc*, there is no consistent attempt to understand the maximum opportunity for improvement.

Finally, while we were convinced that there is an opportunity for significantly improving process planning, we also recognized a major inhibitor to improvement. For better planning algorithms to find widespread use, there must be some implementation platform; otherwise process planners are simply faced with an even larger array of seemingly *ad hoc* tools. Thus, a second fundamental research opportunity is to develop a sufficiently robust model of the process planning problem that can be used to design a generic computing platform for process planning tools.

8. Summary

8.1 Goals Achieved

The project began with some ambitious goals. It is relevant to ask how well the goals were met.

1. Develop a method for assessing best performance, normalizing for differences in products, equipment portfolios, scale of production, and location. This goal was partially achieved. A set of measures was identified, a survey instrument was developed, tested, and implemented, and an small database was created. What was not completed was the implementation of a data envelope analysis to achieve the multidimensional normalization.

2. Develop a benchmark database, so that individual manufacturing sites can determine how they compare on key performance indicators. The database developed during the project did highlight potential opportunities for improvement. It remains to be seen if the database can be augmented by other sites, and will prove generally useful. This goal was partially achieved.

3. Identify those "best practices" which lead to best performance. Through the qualitative benchmarking, or "case study" approach, some potentially best practices were identified, within the relatively small sample of sites surveyed. This goal was partially achieved.

4. Initiate benchmarking collaborations that can continue beyond the initial study. During the course of the project, several other companies were approached, with mixed results. While some agreed to participate, the initial study results lead the team to conclude that further work on the survey instrument and process would be needed before extending the study to other sites. Since discussions are continuing with some of the other companies, this goal was partially achieved.

5. Develop guidelines for future Georgia Tech and National Science Foundation research planning. As indicated in section 7, there were some valuable lessons learned through this project, regarding the needs for and opportunities for future research. Those conclusions are summarized below.

8.2 Future Research

There is no question that many opportunities remain for university-based research to have a significant impact on the practice of printed circuit card assembly. Some of those opportunities, identified through this project, include:

1. Process optimization tools for specific machines, that take into consideration typical practices, such as dedicating feeder slots, or bulk exchange of feeders.

2. Process optimization tools that deal with families of cards, or with complete assembly lines.

3. Diagnostic tools, that consider the basic descriptive parameters, such as type of placement machines, family of products being produced, lot sizes, etc., and provide an indication of the level of performance relative to best possible performance.

4. Implementation platforms for engineering tools to improve card assembly operations; such platforms should integrate diagnostic tools, process optimization tools, and tools for identifying specific operational opportunities for improvement.

8.3 Conclusion

Benchmarking performance in printed circuit card assembly is both technically feasible, and worth doing. Benchmarking best practices appears to be a less technical, more intuitive undertaking, which will be most successful if based on a solid base of performance benchmarking results.

There are a host of opportunities for technical improvements in printed circuit card assembly. The greatest challenge for researchers is to discover those opportunities for which improvements can have a widespread impact. The difficulty of this challenge should not be underestimated. Each printed circuit card assembly site is unique--creating technical tools that accommodate a wide range of operating conditions, yet provide useful specific results requires a robust implementation platform, which does not exist today.

The linking of industry and academic researchers through the GOALI project has been successful. Not only have some of the goals of the project been met, providing benefits to the members of the project team, but the team members have come to view printed circuit card assembly in a different light. While this change of perspective may be hard to capture in scientific terms, it is the essence of engineering research on difficult system-based problems.

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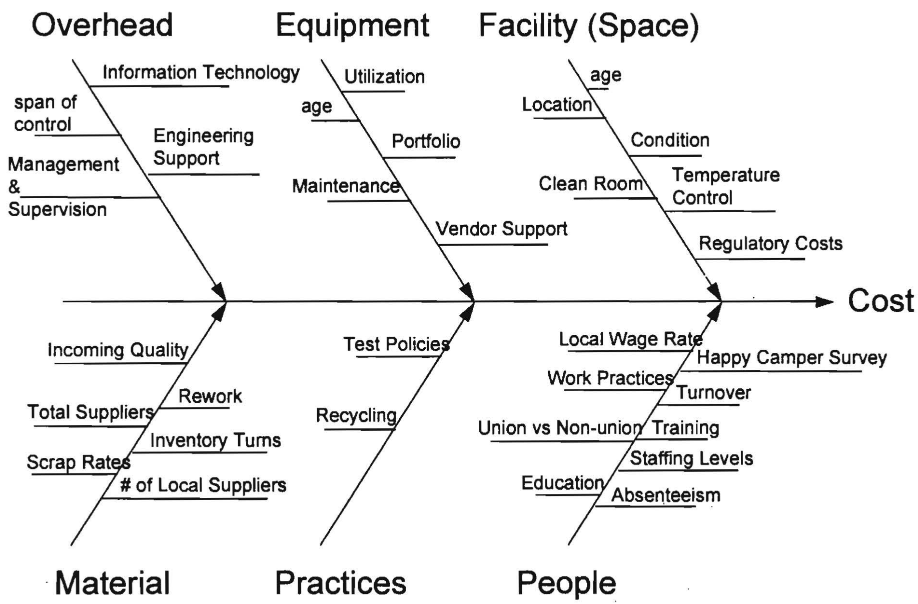
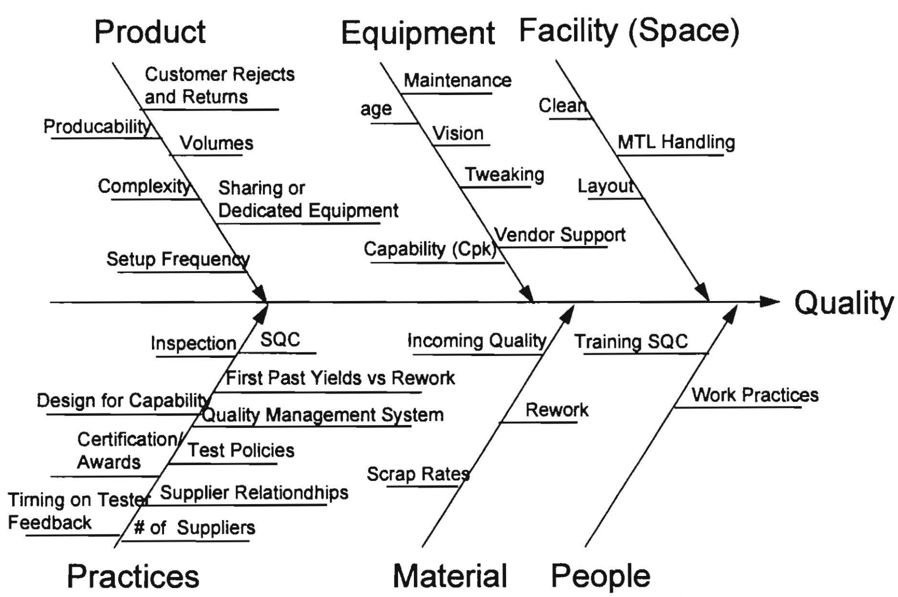
10. Appendices

10.1 Fishbone Diagrams

These are examples of two fishbone diagrams. Similar diagrams were developed for the other key attributes.





10.2 Survey Instrument

This appendix contains the complete survey instrument as it was used for the final data collection activities.

ABOUT THIS SURVEY

This survey is one part of a large scale benchmarking of printed circuit card assembly. The goals of this benchmarking study are to study a broad spectrum of printed circuit card assembly operations and:

1. to develop a method for assessing best performance, normalizing for differences in products, equipment, scale, and location;
2. to develop a benchmark database, so that individual manufacturing sites can determine how they compare on key performance indicators; and
3. to identify those "best practices" which lead to best performance.

Questions in the survey focus on several areas:

- facilities (e.g., space, equipment portfolio, organization, and layout)
- products (e.g., mix, technologies, and lot sizes)
- people (e.g., staffing levels, education, and training)
- performance (e.g., volumes, quality, efficiency, and cost)
- practices

The survey also asks for suggestions for improving the survey, and for issues that you believe are important, but not adequately addressed.

BENEFITS OF PARTICIPATION

Participating sites will learn how they compare to the benchmark set as a whole, and in particular, their opportunities for improvement. The benchmark data will be aggregated and analyzed, and a summary project report issued. This report will present our findings with regard to best performance and best practice. In the project-level report, confidentiality of data sources will be preserved. Each participant in the benchmarking study will receive a specific analysis showing how they compare to the benchmark set as a whole.

HOW YOU CAN PARTICIPATE

You can participate by completing the survey and then hosting a follow-up site visit by the benchmarking team. The survey is detailed, but should not involve more than a couple of person-days of effort. The quality of the benchmark results, and the benefit you gain, depends upon answering all the questions. However, if there are some questions that you cannot answer, or choose not to answer, the survey still will be of benefit.

PLEDGE OF CONFIDENTIALITY

The information you provide in this survey will be treated as confidential and proprietary. You will have an opportunity to correct any errors or misunderstandings before your data is analyzed. No publication or presentation will in any way identify you. All published or pr esented results will be based on aggregated data.

Card Assembly Benchmarking Survey

GENERAL INSTRUCTIONS

Because the goal of this benchmarking study is to identify best practices, it is essential to collect information that represents the entire assembly and test process, from bare board to tested circuit card assembly. For example, if you do topside surface mount, followed by through-hole, and then bottomside surface mount, we want to collect data on all three, plus the material handling operations that link them, in order to benchmark manufacturing cycle times and work-in-process inventories. The survey asks for information about the products being assembled. It is essential that the product set and the process set correspond, that is, there are no unreported products assembled on the processes included in the survey, and the products included in the survey do not have unreported assembly operations. We will consistently use the abbreviation PCCA for *printed circuit card assembly.*

At several points in the survey, you are asked to **attach** an explanation, a chart, a sample report, etc. Whenever you **attach** a response, be sure to indicate on the attachment the question and page number in the questionaire for which the attachment is provided.

If there are unreported products being processed by the operations included in the survey, **attach** an explanation. We will need to agree on a method for factoring the unreported products into the process performance analysis.

If there are unreported processes for the products included in the survey, **attach** an explanation. These may or may not require us to adjust cycle time and WIP performance measures.

Insofar as possible, please provide actual rather than estimated information. You will be asked to indicate the reporting period.

Our basic assumption is that card assembly and test are part of a single production organization. In some situations, this may not be the case, and testing may not occur until after additional mechanical or other assembly operations. If this is your situation, do not include test in the survey data, but include an explanation in your response to the FACILITY portion of the survey.

If at any time, you find that you are having difficulty understanding the intent of a survey question, or difficulty deciding how to shape your response, do not hesitate to call Leon McGinnis at 404-894-5562 (or email to leon.mcginnis@isye.gatech.edu) for assistance.

Card Assembly Benchmarking Survey

BASIC INFORMATION

1. Company name: ______________________

   Company location (city, state): ______________________

2. Survey coordinator's name: ______________________

3. Coordinator's phone number: ______________________

4. Coordinator's mailing address: ______________________

   ____

5. Coordinator's title: ______________________

   (Please **attach** business cards for the coordinator and the key people who provided data for the survey.)

6. Date survey completed: ______________________

7. **Attach** a description of the organization of the printed circuit card assembly operation. For example, are top side and bottom side managed separately? Are through hole and surface mount managed separately? What support services are provided by external organizational units? Is maintenance internal to printed circuit card assembly, or is it provided by another organization? If possible, **attach** an organization chart showing functions.

8. In the table below, provide a summary description of the product(s) included in the survey. We are not asking for a detailed listing of all your products. Instead, we want to know the general categories of products. For example, if they are grouped in families, indicate the common name you use for the families. For each family, provide a brief description of the type of product, such as computer motherboard, engine control module, cellular telephone transceiver, digital switch, etc. At several points in the survey, you will be asked to provide a product (or product family) identifier, so that we may organize the data appropriately. Use the identifiers from this table. (Copy the table and repeat if necessary.)

Product Family Identifier	Brief Description

9. **Attach** a description of the operations included in the survey, along with a layout of the area(s) occupied by the operations. Briefly describe how this set of operations was selected.

10. You will be asked to provide historical data for one year, and predictions for one year. We would like to have the most current information possible, i.e., covering the twelve months just ended when you complete the survey. However, you may provide data for the most recently completed fiscal year, if necessary. Please specify the period for the "past year" (e.g., September 1, 1993 to August 31, 1994). ______________________

Card Assembly Benchmarking Survey

FACILITY

1. Year building was constructed:______ Date of last major building renovation: _________

2. What percent of components and materials (by value) are shipped from a location within a four hour drive of your plant? ___________%

3. What percent of your product (by units shipped) is made to order? ___________%
   What percent of your product (by units shipped) is made to stock? ___________%
   How frequently is product shipped from this plant (shipments per week)? ___________

4. Quality certifications or awards the plant has received in the last 5 years: (ISO9000, Malcolm Baldrige, internal awards, etc.)____
   ____

5. Total floor space allocated to card assembly and test? ________ (ft^2)

6. What distance does a panel travel from the point at which it is delivered into the PCCA area until it leaves the PCCA area as a completed (and tested) assembly?
   Minimum case:______ft, Median case: ______ft, and Maximum case:______ft.

7. What is the original investment value of the equipment used for PCCA (round to ten thousands)?
   Through hole equipment (including wave solder) $________
   Surface mount equipment (including screen print, glue, cure and reflow ovens) $________
   Test equipment $________

9. Within the PCCA area, are there groups of machines that are dedicated to particular products or product families? If so, please **attach** a layout drawing, identify these machine groups on the layout, and briefly describe the products assigned to each machine group. NOTE: the identifiers that you use for these machine groups will be used again in the survey; please use the product family identifiers from question 9, page 3. If necessary, use additional copies of this page.

Machine Group ID	
Key machines in group	
Product families	

Machine Group ID	
Key machines in group	
Product families	

Machine Group ID	
Key machines in group	
Product families	

Machine Group ID	
Key machines in group	
Product families	

PEOPLE

These questions address the people working in the PCCA area. If you have only total site data for some questions, please indicate by checking the column labeled "Site". The headcount distribution is particularly important for the benchmarking study. Note: if people perform multiple functions, then estimate the **equivalent full time headcount** for each function (you may have fractional headcount for some functions). Even though material handling and maintenance may be performed by other organizations, estimate the equivalent full time headcount for these functions in the PCCA area. **Important note:** the data is total for all shifts, not just one shift.

	Question	**Site**	**Operator**	**Technician**	**Engineer**	**Others**
1	Turnover (annual %)					
2	Absenteeism (annual %)					
3	Headcount allocated by function					
	-screenprint					
	-glue application					
	-surface mount placement					
	- reflow or glue cure					
	-through-hole placement					
	-wave solder					
	-inspection (other than electrical testing)					
	-testing in PCCA area					
	-rework in PCCA area					
	-material handling in PCCA area					
	-maintenance in PCCA area					
	-programming PCCA equipment					
	-product engineering					
	-process engineering					
	-other function (describe)					
	Total equivalent full time headcount					

	Question	Site	Operator	Technician	Engineer	Others
4	Overtime per person (weekly avg.)					
5	Average education level (# years)					
6	Average years with company					
7	Average years in PCCA area					
8	Average hours of initial training					
9	Average hours ongoing training per year					
10	Primary topics for training					
			1	1	1	1
			2	2	2	2
			3	3	3	3
11	Percent trained in statistical methods		%	%	%	%
12	Indicate if hourly or salaried					
13	Indicate if members of a union (Y,N)					

14. The following questions are about your Suggestion Program (if you have one):

a. How many suggestions per month are submitted on the average? ________

b. What percent of suggestions come from:
operators? ________%
technicians?________%
engineers?________%
others?__________%

c. What percentage of the suggestions submitted each year are implemented? _______%

d. What is the average savings per implemented suggestion realized? $________

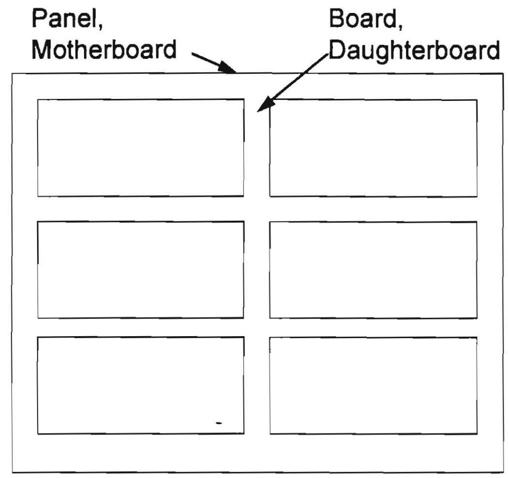
e. Of the implemented suggestions, what percent are:
manufacturing process related? _________%
product related? _________%
people related? _________%
Total 100%

f. Is this site data, or PCCA only? _________

PRODUCT

The following questions are about the set of printed circuit card assemblies produced in the PCCA area.

There is not a consistent terminology for describing printed circuit card assemblies. We will use the term *panel* to refer to the "bare board" which constitutes the unit which is handled through production. A panel may contain only a single *board*, or it may contain multiple images of a board, or in some cases, it may contain multiple images of different boards (e.g., a panel which contains the boards for several related modules in, say, a stereo receiver). A panel will have a product code or stock keeping unit (SKU) code. Generally, the completed PCCA, i.e., the boards, will have different product or SKU codes.



1. What is the total number of raw panel *types* (bare boards, copper patterns, etc) consumed in the PCCA area? (Each one would have a unique raw material part number) ________

2. What is the total number of populated panel *types* produced in the PCCA area (a given raw panel may be populated in several different ways; each would be a different populated panel)? ________

3. What is the total number of board assembly *types* produced in the PCCA area (i.e., the number of different board product codes or SKUs)? ________

4. What is the number of boards per panel?
   - largest ________
   - typical ________
   - smallest ________

5. What is the total number of panels produced in the past year? (last 12 months) ________
   Expected to be produced in the next year? ________
   What percent of total production is the single largest volume panel? ________%
   In a pareto analysis, how many panel types constitute 80% of the panel volume? ________

6. What is the total number of boards produced in the past year? (last 12 months) ________
   Expected to be produced in the next year? ________
   What percent of total production is the largest volume board? ________%
   In a pareto analysis, how many board types constitute 80% of the board volume? ________

7. List the panel dimensions (width and length) for the
   - largest panel ________ x ________
   - typical panel ________ x ________
   - smallest panel ________ x ________

8. Do you change panel width on any of the PCCA equipment?(Y/N) ________
   (If "yes", then please **attach** a list showing the number of panel widths for each machine group identified in the FACILITIES section, question 9.)

9. What is the total number of components placed in the past year? (last 12 months) ________
   Forecasted for placement in the next year? ________

10. What is the largest package size placed? ________
    What is the largest pin count placed? ________
    What is the finest pitch placed? ________
    Check all that are used for fine pitch placement:
    - molded carrier ring _____
    - ball grid array _____
    - bumpered QFP _____
    - ceramic QFP _____
    - TAB _____
    - tube _____
    - tray _____
    - tape and reel _____
    - other ___________ _____

11. List the types of board materials and thicknesses used (e.g., ceramic, FR4, polyimide, etc)

12. Product breakdown:

	On panel part num basis:	On panel volume basis:
panels with only SMD	___% *SMD* only	___% *SMD* only
panels with both SMD & through hole	___% Mixed technology	___% Mixed technology
panels with through hole only	___% Through hole only	___% Through hole only
	100% TOTAL	100% TOTAL

13. In the following table, describe the distribution of components placed in the past year.

Component type	Total # of unique part numbers	Estimated percent of total placements
Through-hole ICs		%
Through-hole axial		%
Through-hole radial		%
Through-hole connectors		%
SMD fine pitch ICs		%
SOICs		%
Discrete SMDs		%
1210 or larger		%
0805 up to 1210		%
0603		%
0402 and smaller		%
SMD connectors		%
Other SMD		%
		%
		%
Total		100%

14. For each of the questions in the following table, please determine minimum, median, and maximum data within your product mix. Note: the rows are independent. That is, the same *panel* will not necessarily be in the same slot for each question and each question may be answered considering different *panels*.

Question	Minimum	Median	Maximum
Total # unique component types (i.e., component part numbers) per *panel*			
Total # components to be placed on *panel* (component placement count)			
Annual 1994 volume requirements (*panels*)			
Volume fluctuation: (percent difference between monthly or biweekly forecast and actual requirements); *please **attach** sample report*			
Product life: (length of time product has been in production)			
# design changes/year			
What % of design changes affect BOM or board layout?			

15. How many products currently in production will no longer be produced after the 1994 calendar year? _______
What would be a typical number to be dropped? _______
How many new products will be introduced during the 1994 calendar year? _______
What would be a typical number of product introductions? _______

16. Check all the following which you produce:
_____single sided: reflow (SMD only)
_____single sided: wave solder (Through hole only)
_____dual sided: glue cure, wave solder (through hole and bottom side SMD)
_____dual sided: glue cure, screen print, reflow, wave solder (all SMD or mixed SMD and through hole)
_____dual sided: screen print, reflow, screen print, reflow (SMD only)
_____dual sided: screen print, screen print, reflow (SMD only, reflow two sides simultaneously)

17. Indicate the distribution of the per unit selling price, transfer price, or estimated value of the printed circuit card assemblies produced in this facility (percent of volume in each range):
_____% < $20 per unit
_____% $20 - 50
_____% $50 - 200
_____% $200 - 500
_____% $500- 1000
_____% $1000-5000
_____% >$5,000
100% TOTAL

18. Do you transport panels within the PCCA area in magazines? (Y/N) _________
Are panels held on traveling fixture through placement equipment? (some, none, or all) _________

19. What percentage of your products are multi-layer boards? ________%

20. What is the total number of suppliers of raw panels, components, solder, flux, cleaner, etc? ________

21. a. In terms of planned operating time (hours or shifts), how much raw material is kept on hand? ________
    b. In terms of planned operating time, what is the target for on hand raw material ? ________
    c. Briefly explain the strategy is used to set the target for on hand raw material?

22. Do you run prototypes or service requirements in the PCCA area? (Y/N) ________
    Do you handle rework/repair in the PCCA area? (Y/N) ________

23. Do you have a program for supplier qualification/validation? (Y/N) ________
    Is it statistically based? (Y/N) ________

24. Breakdown of incoming material inspection process:
    _____% directly to production floor - no inspection
    _____% directly to stock with no inspection or minor paperwork inspection only.
    _____% tested in inspection using skip lot or other sampling techniques
    _____% 100% inspection performed
    100% TOTAL

25. Do suppliers monitor their performance in your assembly shop via a computer connection (i.e. modem, email, internet, etc.) (Y/N): ________
    If so, how often is the data updated? ________

26. Are your suppliers proactive in identifying quality issues? (Y/N) ________
    If yes, what percent of the time do they contact you before you realize there is an issue? ________%

27. What is the typical supplier's response time to notify after identifying a quality concern? ________
    What is the typical supplier's response time to resolve the identified quality concern? ________
    (please specify time units: e.g. minutes, hours, days, etc.)

28. When a new product is introduced, how much time is required? Consider the interval from the initial product design release to the first production run. Please specify calendar days:
    Best case: __________, Typical Case: __________, Worst Case:__________

EQUIPMENT

1. In the following tables, please provide an inventory of the key equipment in the PCCA area. For “type of vision”, the categories are: N=none; F=fiducial; C=centering/orientation; O=other. For “routine maintenance”, please list the amount of time and frequency, e.g., 2 hours per day, 4 hours per week, etc. Under program generation, please indicate the software used by program name (e.g., Panatools), with additional options being: Self=your own software; and none=no software. In rating the vendor support: E=excellent; G=good; F=fair; P=poor. Simply indicate “yes” or “no” for long term maintenance contract.

SMD Placement Equipment

Vendor, Model #	**# units**	**Type of vision** N, F, C, O	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

Solder Dispense

Vendor, Model #	**# units**	**Type of vision** N, F, C, O	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

Glue Dispense

Vendor, Model #	**# units**	**Type of vision** N, F, C, O	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

Ovens, Wave Solder, and Cleaning

Vendor, Model #	**# units**	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

Stand Alone Vision Inspection

Vendor, Model #	**# units**	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

Through Hole Placement Equipment

Vendor, Model #	**# units**	**Type of vision** N, F, C, O	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

In-circuit/Function/other Test

Vendor, Model #	**# units**	**Routine Maintenance** hours per day or per week	**Program Generation Software**	**Vendor Support Rating** E,G,F,P	**Long Term Maintenance Contract** Y, N

2. Material Section:
   a. Type(s) of adhesive used: ______________________________
   b. Type(s) of solder used: ______________________________
   c. Type(s) of flux used: ______________________________

4. How much of the *SMD* equipment is used or refurbished? __________%

5. How much of the *SMD* equipment is leased? _______%

6. Do you use *reel verification systems*? (Y/N) ______ If so:
   a. What % of machines have *reel verification systems* installed? ___________%
   b. List type(s) of reel verification:____
   c. Choose all that apply:
      Are they internally designed? ___
      Purchased from a 3rd party? ___
      Purchased from vendor? ___
      Are they lockout? ___
      info-only? ___
      manual? ___

7. a. Do you have variable width conveyors? (Y/N) ____
      Do you change the width of your conveyors? (Y/N) ____
      If so, is the change automated or manual? _________
   b. Do you use dual track panel conveyors? (Y/N) ____
   c. On any process equipment other than wave solder, reflow, or glue cure, do you process more than one panel at a time? (Y/N) ____

8. a. Do you use bar code download changeover? (Y/N) ____
      If so, does it happen (check one) in front of each machine _____
      or at the beginning of the line? _____
   b. Please check all that apply for feeder types used:
      Tape and Reel ____
      Tube ____
      Tray ____
      Bulk ____
      Other___________ ____
   c. Other features/options installed on placement equipment?_______________________________

9. What inspection technologies do you use (e.g. electrical verification, manual (visual)), and at what point in the assembly process? (Enter "none" if no routine inspection is performed.)

Location	**Technology**
after screen print or glue dispense	____________
Component inspection in placement machine	____________
after placement	____________
after reflow or glue cure	____________
after wave solder	____________
other____________	____________

10. What were your annual spare parts costs for placement equipment in the past year: $ _________
    Forecasted for the next year $_________

11. What is your average total cost (fixed and variable cost) per placement for the past year:
    $_______/placement.
    Forecasted for the next year:
    $_______/placement.
    Is this information formally tracked?_____

12. What is the distribution of your production costs for the past year?

Material cost	_________%
Labor cost	_________%
Overhead cost	_________%
Total	100%

OPERATIONS

1. What percent of maintenance work (by cost) is performed by:

equipment vendor	________%
other outside service provider	________%
dedicated maintenance staff	________%
PCCA operators or technicians	________%
other (describe)	________%
Total	100%

2. What percent of maintenance downtime for PCCA equipment is:

breakdown	________%
preventive	________%
predictive	________%
Total	100%

Is this information formally tracked? (Y,N) ________

If so, please identify the system or report, and ***attach** an example.*

3. The following table takes a product oriented view of operations. Each row of the table asks a question about the maximum, minimum, and median (or typical) panel in your production mix. The rows are independent, so a different panel could correspond to the answers in different rows. Report past year's data, unless you clearly note otherwise.

Question	Minimum	Median	Maximum
Lot size (in panels; average for the year)			
# process machines visited			
# inter-process moves OTHER than by conveyor (i.e. by hand, in a tote, magazines, cart, etc.)			
# major setups per week (involve hardware changes)			
# setups per week that involve software download only			
Changeover time (when changing to this panel)			
Manufacturing cycle time for a lot (from bare *board* through finished card assembly). Please specify time units (hours, minutes etc.)			
% panels requiring repair or rework	%	%	%
Manually placed components (as % of total placements)	%	%	%
Scrap rate as % of total panels	%	%	%

4. How many different (unique) panel types are in process in the PCCA area at any one time?
   Minimum Case _______, Median Case:_______, Maximum Case________
   On the average, how much work-in-process is in the PCCA area (hours of production)? ____________hrs

5. a. In a *family setup* any panel from a family of panels can be produced with only software download, or perhaps the swapping of a small number of feeders. Do you use family setups?(Y/N) _____
   b. If so, what percentage of panels are produced using a family setup? ____%
   c. What is the largest number of unique panels in a single family setup? _____
   d. What is the smallest number of unique panels in a single family setup? _____

6. a. Are operators cross-trained?(Y/N) _______
   b. If yes, is operator's compensation increased when they are cross-trained? (Y/N) _______

7. a. Are you using work teams?(Y/N) _______
   b. If yes, what percentage of hourly workers are participating in a formal team? _____%
   what is the typical size of the work teams? _______
   c. Briefly describe the responsibilities of the work team.

8. Recycling:
   a. $ savings (previous year)________ next year forecast:_________
   b. Operating wastes recycled _______%

10. Annual Premium freight as % of total shipping budget? ____________________%

11. What was the total number of Engineering Changes in the past year? __________
    Distribution of engineering changes by purpose:
    _____% reduce mfg cost
    _____% improve design
    _____% other
    100% TOTAL
    What is the *typical* number of engineering changes per year in the PCCA area? _________

12. ESD Policies: Are the following required for the production floor? (Y/N)
    Smocks ______
    Anti-static shoes ______
    wrist straps ______
    anti-static floor/mats: ______
    safety glasses ______
    other? ____

13. For each machine group identified in the FACILITIES section, question 9, please complete the following table (please copy this table as many times as necessary). Note: these are total hours for the past year.

Machine group ID						
First shift regular time hours						
First shift overtime hours						
Second shift regular time hours						
Second shift overtime hours						
Third shift regular time hours						
Third shift overtime hours						
Fourth shift regular time hours						
Fourth shift overtime hours.						
Total annual operating hours						

Machine group ID						
First shift regular time hours						
First shift overtime hours						
Second shift regular time hours						
Second shift overtime hours						
Third shift regular time hours						
Third shift overtime hours						
Fourth shift regular time hours						
Fourth shift overtime hours.						
Total annual operating hours						

Machine group ID						
First shift regular time hours						
First shift overtime hours						
Second shift regular time hours						
Second shift overtime hours						
Third shift regular time hours						
Third shift overtime hours						
Fourth shift regular time hours						
Fourth shift overtime hours.						
Total annual operating hours						

14. The following questions address PPM defects as determined at incircuit test (or your equivalent). The table asks for results for the best, typical, and worst panel. The data will be most useful if it is an annual average, rather than the results from a single production run.
    a. Do you track first pass yields by panel type? (Y,N) _____
    b. What is the distribution of defects, in percentage terms:

Distribution of defects	Best panel	Typical panel	Worst panel
missing component	%	%	%
defective component	%	%	%
misaligned component	%	%	%
defective panel	%	%	%
screen print defect	%	%	%
solder wave defect	%	%	%
other solder defect	%	%	%
glue defect	%	%	%
other defect	%	%	%
Total defects	100%	100%	100%

c. Do you assign defects found at incircuit test to specific operations, machines, or machine groups? (Y/N) _____

d. For the critical operations, machines, or machine groups (in terms of product PPM), do you routinely track contribution to PPM? (Y/N) _______

e. For these critical operations, machines, or groups, do you have process attribute data? (Y/N) _______
process variables data? (Y/N) _______

If so, please **attach** an *example report.*

f. Is an inspection performed at the critical machine(s), or machine group(s)? _____
If so, is a PPM tracked at that machine? _____
If so, is the machine PPM formally correlated to the incircuit test PPM? _____
If it is, please **attach** a sample report.

15. The following questions address operating performance of a machine group. The table asks for the "best," "typical," and "worst" performance, which could be three different machine groups, or the same machine group in three different reporting periods. For the data to be useful, it should cover a reporting period of at least a week. For this question, "utilization" is defined as "earned hours" divided by "scheduled hours", where "earned hours" is based on the planned cycle time per unit multiplied by the number of good units produced. If your definition of utilization is different, please **attach** a brief explanation.

Question	Best	Typical	Worst
Machine group utilization (i.e. the constraint utilization for the machine group)			
Ratio of setup time to earned hours (average week)			

16. The following questions address setup time for SMD equipment, particularly in integrated lines. Two issues are of concern: 1) how much (clock) time is involved in setup/changeover for *SMD* equipment, and 2) the "opportunity cost" of setups in terms of lost production time. The amount of time a line or machine group is down for setup would be the opportunity cost.

Question	Best	Typical	Worst
SMD equipment setup time			
Equipment type (e.g. MVII)			
What is the machine group associated with this setup time? (use the machine group ID from question 9 in the FACILITIES section)			
Is this equipment the throughput bottleneck within the *operating set* or line? (Y/N)			
If no, what is the bottleneck?			
Does this setup involve changing over feeders? (Y/N)			
How often is this set up done? (Specify time period)			
Please indicate with a "C" if you flush out the line for changeovers or cycle the line out, an "F" if this is done on the fly, without flushing the line.			
What is the opportunity cost of setup for this machine group (Opportunity cost is the amount of production time lost from a line or operating set when changing from one product or family to another product or family.)			

17. Does the bottleneck process for a machine group change, depending upon the product being run?(Y/N) ______
If so, what processes are most often the bottleneck? ______________________________
____

Questions 18 and 19 address planned and unplanned production interruptions for the best, typical and worst case lines or machine groups, considering total scheduled production hours (regular plus overtime).

18. Unplanned Production Interruptions:

Question	Best	Typical	Worst
Number of production interruptions/week (total # of interruptions in typical week)			
Average duration of production interruption (hrs)			
Percentage of scheduled time due to:			
Incorrect forecast/schedule change	%	%	%
Materials shortage	%	%	%
Expedite for late or special orders	%	%	%
Labor shortage	%	%	%
Balance production line	%	%	%
Equipment failure	%	%	%
Other (list)	%	%	%
	%	%	%
TOTAL	100%	100%	100%

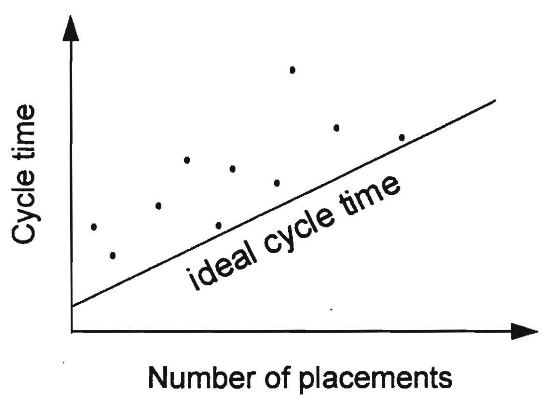
19. Planned Production Interruptions:

Question	Best	Typical	Worst
# production interruptions/week (total # of interruptions)/(total hours worked)			
average duration of production interruption (hrs)			
Percentage of line lost time due to:			
Prototype build	%	%	%
Training	%	%	%
Team meetings	%	%	%
Maintenance	%	%	%
Other (list)	%	%	%
	%	%	%
TOTAL	100%	100%	100%

20. Describe the process for generating placement machine programs (who does it, what software tools are used, how cycle times are estimated).

21. Are placement machine cycle times monitored routinely? __________
    If "yes", describe the process and **attach** a sample report.

22. In the graph shown to the right, each data point corresponds to the average cycle time for a particular panel type, and the graph corresponds to a particular placement machine, e.g., a Panasonic MVII. The "ideal cycle time" is the panel shuttle time (into and out of the machine), plus time to read fiducials, plus the placement time at the machine's rated placement speed. The actual cycle time reflects inability to achieve the rated speed, due to component size, number of feeders used, panel layout, or other reasons.



Could you construct such a graph for your placement equipment, based on actual cycle times? (Y/N) _____
If "yes", attach samples of the data sources you would use.

23. Describe the process for computing "earned hours" in the PCCA area.

24. How frequently do component "misloads" occur (an incorrect component type is loaded in a feeder, and the error is detected in a downstream inspection) per week? ________
per component load? ________

USER REACTION

1. What (if any) parts of the survey were especially burdensome or difficult for you to complete?

2. What (if any) issues were not addressed in the survey that you would like to see comparative data for?

3. What total person-hours did you spend in completing the survey? ________________

4. What suggestions can you make for improving the survey instrument, either in content or format?

Glossary of Terms

Card Assembly: includes assembly, test, and rework processes, but no stockroom activities or finished goods storage.

Average allowed lead time: the average based on number of orders, amount of time between the date an order is released to production, and the committed ship date on the order. May be negative.

Board: (image) a panel may consist of one or more boards; following assembly, the panel will be separated into the individual boards.

Changeover time: for a machine-the clock time from the beginning to change setup for a different product until the machine is ready for production; for an operating set-the effective production time lost in changing from one product to another

Customer order lead time: quoted lead time to a customer from order acceptance to product delivery

]Fine pitch: less than 20 mils spacing on leads

First pass yields: percent of assemblies that pass product test on the first trial without rework or repair

Line: a set of assembly processes that are coupled, either physically or logically, so that all processes in the set produce the same product at the same time

Line setup time: how much potential production time is lost due to line changeover; result of both equipment setup time and strategy for coordinating equipment setup with product change

Line utilization: governed by the utilization of the bottleneck process in the line

Maintenance: three types

breakdown: repairs conducted after machine fails

preventive: repairs performed on a planned schedule

predictive: repair is performed based on monitored machine condition

New product introduction time: how much lead time is required to plan and execute a new product introduction, including deciding where to produce it, generating machine programs and producing the first lot

Operational group: a major area within the assembly shop that represents a distinct set of products or processes and has a corresponding management structure. A shop probably has at most two or three operating groups

Operating set: a set of assembly processes that are closely related by operation; they may or may not be directly coupled by conveyor, and may be capable of producing more than one product at a time

Panel: the basic unit of placement assembly process; panels are moved between assembly processes, either on conveyor, or in magazines, totes, carts, etc.

Process line: set of machines linked by conveyor; panels are not routinely handled manually within a process line

Process machine: individual piece of equipment, e.g., a screen print, glue, placement, etc.

Published manufacturing lead time: the typical standard lead time quoted to the internal sales organization by the production organization

Reel verification system: how you verify that the proper reel of components is mounted in the proper feeder at the proper slot

SMD: surface mount device

1.1 Quantitative Benchmark Results

Survey Topic		Plant #1	Plant #2	Plant #3	Plant #4	Plant #5
OUTPUT ANALYSIS						
Total panels (X1000)	N	100.00%	35.57%	70.68%	39.58%	12.98%
Total boards (X1000)	N	100.00%	71.72%	26.43%	16.92%	5.11%
Placements (X10E6)	N	100.00%	56.51%	47.23%	33.96%	4.46%
Boards per panel	A	2.67	5.39	1	1.14	1.05
Placements per panel	A	222	528	222	285	114
Placements per board	A	83	98	222	250	109
FACILITY ANALYSIS						
Space allocated (sq.ft)	N	59.15%	44.81%	46.05%	26.37%	100.00%
Equipment count	N	87.88%	100.00%	68.18%	40.91%	40.91%
Space/Equipment	A	373	248	375	357	1356
Placements/sq.ft. (x1000)	A	54	40	33	41	1.43
Scheduled hours	N	95.65%	81.84%	75.52%	80.55%	100.00%
OT hours/HC	A	2.27	8	15	0.9	4.88
EQUIPMENT ANALYSIS						
Placement rate capacity	N	100.00%	59.19%	77.64%	46.39%	16.88%
Rate capacity utilization	A	43.55%	32.45%	22.42%	25.32%	7.36%
Staging capacity (# slot)	N	81.19%	100.00%	76.52%	62.00%	42.33%
Staging capacity utilization	A	29.29%	22.57%	9.83%	21.84%	520.36%
Downtime						
Planned	A	6%	5%	7%	4.17%	8.00%
- prototype build	A	0.83%	0.00%	1.85%	0.00%	3.20%
- team meetings	A	0.83%	2.50%	0.21%	0.00%	0.00%
- maintenance	A	4.17%	2.50%	3.70%	4.17%	2.40%
- other	A	0.00%	0.00%	1.12%	0.00%	2.40%
Unplanned	A	13%	5%	27%	1.39%	2.75%
- incorr forecast/sched change	A	2.67%	0.25%	0.00%	0.07%	0.00%
- materials shortage	A	4.67%	4.00%	6.01%	0.03%	0.63%
- expedite late or special orders	A	0.13%	0.00%	0.00%	0.00%	0.00%
- labor shortage	A	0.00%	0.00%	0.23%	0.00%	0.85%
- balance production line	A	1.33%	0.50%	0.00%	0.00%	0.00%
- equipment failure	A	4.00%	0.25%	14.22%	1.25%	1.27%
- other	A	0.53%	0.00%	6.53%	0.04%	0.00%
(Failure DT)/(Tot Maint DT)	A	49%	9%	79%	23%	35%
Reported % Brkdown Maint.	A	13%	10%	20%	35%	75.00%

Survey Topic		Plant #1	Plant #2	Plant #3	Plant #4	Plant #5
WORKFORCE ANALYSIS						
Hourly HC	N	67.01%	58.76%	20.79%	19.93%	100.00%
Tenure (yrs) (group)	A	2	3	4	3	21
Turnover (site)	A	27%	1%	3%	2%	<5%
Absenteeism	A	6%	5%	5%	2%	NR
Education	A	9	11	12	11	13
Initial training	A	120	40	110	300	21
Ongoing training	A	32	40	40	48	15
Placements per HC (x10E6)	A	6.02	3.88	9.17	11.05	0.25
Panels per HC (x1000)	A	18.14	7.36	41.32	24.18	1.58
Boards per HC (X1000)	A	48.51	39.67	41.32	27.63	1.66
Salaried HC	N	33.90%	42.37%	38.98%	8.47%	100.00%
Tenure (yrs) (group)	A	2	3	4	3	15
Turnover (site)	A	19%	1%	20%	2%	<5%
Absenteeism	A	0%	2%	2%	2%	NR
Education	A	16	16	16	16	17
Initial training (hrs)	A	10	40	140	0	100
Ongoing training (hrs)	A	15	32	40	45	40
Placements per HC (x10E6)	A	58.73	26.54	24.13	128	1.23
Panels per HC (x1000)	A	176.85	50.32	108.7	280	7.78
Boards per HC (X1000)	A	472.93	271.36	108.7	320	8.19
Hourly HC/Salaried HC	A	9.75	6.84	2.63	11.58	4.93
Suggestions						
Rate (monthly)	A	188	157	75	30	410
Rate per hourly HC	A	0.57	0.92	1.24	0.52	1.41
People	A	1%	0%	10%	10%	5%
Process	A	70%	0%	80%	80%	40%
Product	A	29%	0%	10%	10%	55%
Acceptance rate	A	25%	70%	50%	99%	30%
# Accepted per month	A	47	109.9	37.5	29.7	123
Impact (per accept sugtn)	A	$12,300	$941	$800	NR	$4,400
Time Analysis						
Mfg Cycle Time (hours)	A	3	20.4	12	17.95	60
WIP (hours)	A	7.54	NR	2	5	55
Customer Lead Time	A	1week	NR	2 days	NR	NR
% Premium Freight	A	1.07%	NR	40%	8%	15%
Lot size	A	1400	200	800	800	24
Setup Time (minutes)	A	25	10	20	20	10
New Prod Intro Time (days)	A	547.5	14	90	500	8

Survey Topic		**Plant #1**	**Plant #2**	**Plant #3**	**Plant #4**	**Plant #5**
Quality Analysis						
PPM (typical panel)	A	500	70	98	50	
- placement	A	85%	100%	100%	54.00%	41.80%
- screen	A	5%	0%	0%	0.00%	18.70%
- glue	A	5%	0%	1%	0.05%	0.00%
- material	A	0%	0%	0%	2.20%	3.20%
- other	A	5%	0%	0%	43.75%	0.00%
First pass yields (typ panel)	A	90%	99.50%	100%	99.70%	NR
% Rework	A	1.00%	1.25%	0.00%	0.50%	15.00%
Scrap rates	A	0.056%	0.00%	0.20%	0.02%	0.50%
Product Analysis						
# panel types	N	15.23%	21.83%	13.71%	10.15%	100.00%
# product types	N	15.02%	29.11%	31.92%	10.33%	100.00%
# component part numbers	N	10.80%	10.25%	3.42%	6.15%	100.00%
boards per panel	A	2.67	5.39	1	1.14	1.05
Median plcmnts per panel	A	179	292	280	400	149
(total plcmnts)/(total panels)	A	222	528	222	285	114
unique comp per panel	A	60	18	92	105	39
avg panel size (sq cm)	A	485	562.6	231	229.95	638.71
component density	A	0.37	0.52	1.21	1.74	0.23
Product churn	A	22%	24%	19%	22.73%	39.91%
Process Analysis	A					
MCT (hours)	A	3	20.4	12	17.95	60
Average WIP (hours)	A	7.54	NR	2	5	55
% products in family setups	A	47%	75%	86%	100%	0
Largest family (% products)	A	9%	13%	68%	13.64%	24.41%
% plcmnt mach static setups	A	65%	100%	20%	NR	NR
Average setup/runtime ratio	A	0%	3%	5%	2%	NR
Average process utilization	A	0%	75%	73%	90%	75%
Annual % premium freight	A	1.07%	NR	40%	8%	15%
Average lot size (panels)	A	1400	200	800	800	24

NR: not requested or not reported
A: absolute value
R: relative value