INTERN EXPERIENCE AT
INTERNATIONAL BUSINESS MACHINES CORPORATION
STD/AUSTIN

AN INTERNSHIP REPORT
by
EMILE J. TAYAR

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INTERNATIONAL BUSINESS MACHINES CORPORATION

An Internship Report

By

Emile Joseph Tayar

Approved as to style and content by:

Don E. Bray
Chairman, Advisory Committee

for William D. Turner
Head, Mechanical Engineering

Sherif T. Noah
Member

Ramon E. Goforth
Member

Don E. Dameron
Internship Supervisor

Victor L. Willson
Member

Joseph W. Foster
College of Engineering
Representative

May 1986

ABSTRACT

This report highlights the author's major activities and accomplishments during his 15 months internship at the International Business Machines (IBM) Corporation in Austin, Texas. The internship objectives were set so as to provide him with an experience commensurate with the requirements of the Doctor of Engineering Program at Texas A&M University.

During his internship, the author was involved with a variety of technical and non-technical projects. His assignments included:

1) The design of an automation strategy for one manufacturing center.
2) The overall supervision and coordination of a major automation project.
3) The development of a project scheduling/tracking system.
4) Co-authoring an "Equipment Specifications Guidelines" form.
5) Other assignments as needed.

The nature and scope of the above assignments provided the author with a broadly based experience in the Manufacturing Engineering field. Additionally, the leadership role he played in some of the assignments afforded him with first hand exposure to many aspects of management and leadership skills.

All in all, the author believes that this internship proved to be an enriching experience and a valuable addition to his overall education.

ACKNOWLEDGEMENTS

It gives me a great deal of pleasure and satisfaction to arrive at this point in my academic and professional education. This would not have been possible without the encouragement and support given by many special people.

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Finally, my heartfelt thanks and gratitude goes to my wife, Adrianne, for her patience, support, and typing of this report.

TO

MY DEAREST PARENTS, WIFE AND CHILDREN

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CHAPTER I

INTRODUCTION

The Doctor of Engineering Program at Texas A&M University emphasizes actual engineering practice in an environment of potential leadership. The internship period provides the engineer with the opportunity to apply theory to practice and to make decisions on technical and non-technical matters affecting many facets of an organization. The objectives set forth by the College of Engineering are:

a) To enable the student to demonstrate an ability to apply knowledge and technical training in an area of practical concern to the organization or industry in which the internship is served, and

b) To enable the student to function in a non-academic environment in a position where he or she will become aware of the organizational approach to problems.

In partial fulfillment of the Doctor of Engineering degree requirements, the author spent a 15 month internship at the International Business Machines Corporation in Austin, Texas. During this time, the intern was given every opportunity to learn as much as possible about the manufactured product, the manufacturing process, as well as the organizational composition and procedures of the company. This was accomplished by personal efforts as well as by attending orientation programs and seminars designed specifically for new employees. In addition to being an objective by itself, orientation and familiarity with the overall organization proved to be essential in achieving the other goals of the internship; namely, development and contribution. Development of interpersonal, technical, and managerial skills was an ongoing effort throughout the internship period. Moreover, the leadership activities assigned were the catalyst that enhanced the development process. Contribution, on the other hand, was accomplished through the various projects and tasks assigned to the author throughout the internship period.

This report is intended to establish that the objectives of the internship have been met through a description of the author's activities during the period June 1984-August 1985 with the IBM Corporation. The following Chapter briefly describes the firm. Then, the report gives some insight on the author's internship position and scope. Chapter IV elaborates on each of the author's assignments and related technical and administrative activities. Chapter V summarizes the report and concludes with a discussion of the overall internship accomplishments in relation to the objectives.

CHAPTER II

THE FIRM

A) OVERVIEW

The International Business Machines (IBM) Corporation was founded in 1911 by Thomas J. Watson, Sr. IBM today is a multi-billion dollar corporation and is an acknowledged leader in the business of information technology. The company employs over 364,000 people worldwide, with a large percentage of that population working at 21 plants in the U.S., 23 plants in foreign countries and 25 laboratories worldwide. IBM's main R&D and manufacturing facilities in the United States and abroad are shown in figures 1 & 2, respectively.

Since 1911 IBM has been a pioneer in the development of data processing products and a leader in an industry making a far reaching impact on our lives and work. IBM's operations are primarily in the field of information handling systems, equipment and services to solve the increasingly complex problems of business, government, science, space exploration, defense, education, medicine, and many other areas of human activity. IBM's products include information processing systems, program products, telecommunication systems, office systems, typewriters, copiers, educational and testing materials, and related supplies and services. Most products are both leased and sold through IBM's worldwide marketing organizations. Selected products are marketed and distributed through authorized dealers and remarketeers.

B) THE INTERNSHIP SITE

The author completed his internship at the Systems Technology Division (STD) in Austin, Texas. A brief description of the site, its organization, and mission is in order.

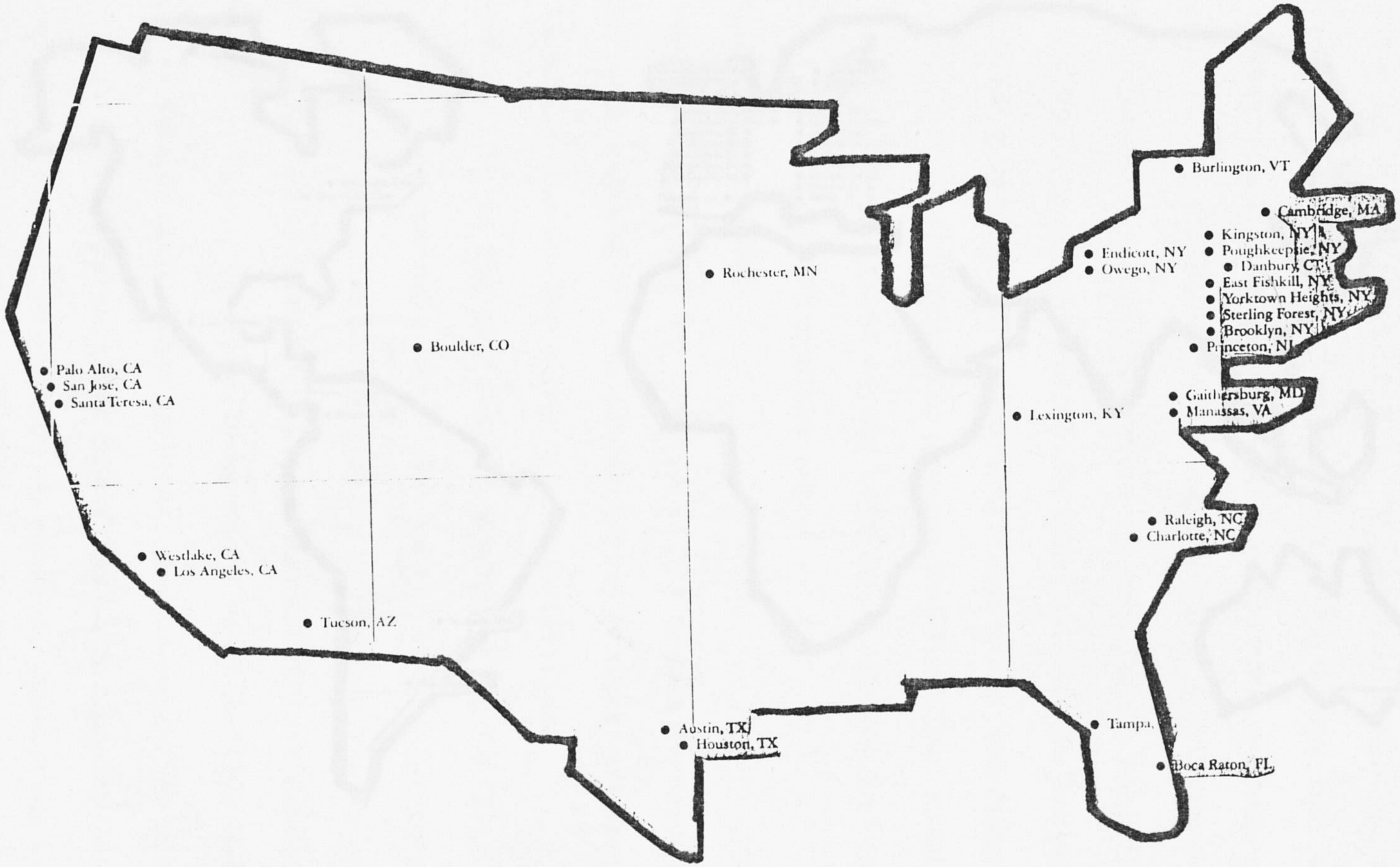


Figure 1: Main R&D and Manufacturing Sites in the U.S.A

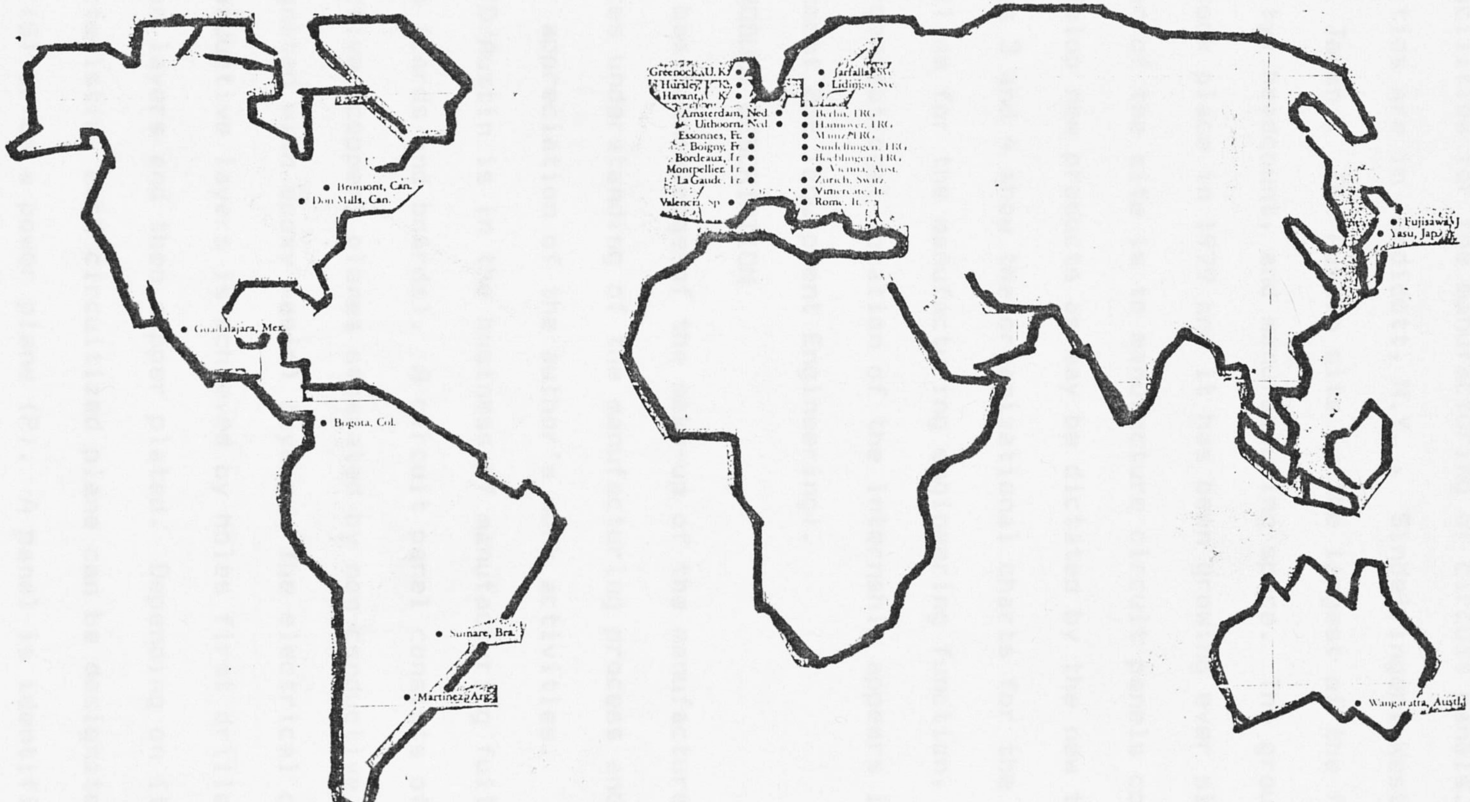


Figure 2: Main R&D and Manufacturing Sites Worldwide.

STD is one of many IBM divisions, and STD in Austin is one of four IBM facilities for the manufacturing of circuit panels. The other three facilities are in Endicott, N.Y. , Sindelfingen, West Germany , and Yasu, Japan . The Austin site is the largest of the four in terms of capacity, headcount, and manufacturing space. The groundbreaking of the site took place in 1979 and it has been growing ever since. The primary mission of the site is to manufacture circuit panels competitively and to develop new products as may be dictated by the new technologies. Figures 3 and 4 show the organizational charts for the overall facility as well as for the manufacturing engineering function, respectively. The organizational location of the internship appears in Figure 4 under Department 23E (Equipment Engineering).

C) PRODUCT DESCRIPTION

A basic knowledge of the make-up of the manufactured product enhances understanding of the manufacturing process and leads to a better appreciation of the author's work activities.

STD/Austin is in the business of manufacturing fully circuitized panels (cards and boards). A circuit panel consists of circuitized conductive (copper) planes separated by non-conductive (glass cloth impregnated with epoxy resin) layers. The electrical continuity between the conductive layers is achieved by holes first drilled through the various layers and then copper plated. Depending on its electrical characteristic, each circuitized plane can be designated as a signal plane (S) or as a power plane (P). A panel is identified by the number of Signal and Power planes it contains. Therefore, 4S2P panels contain 4 signal and 2 power planes. Similarly, 2S2P panels contain 2 signal and 2 power planes - see Figure 5.

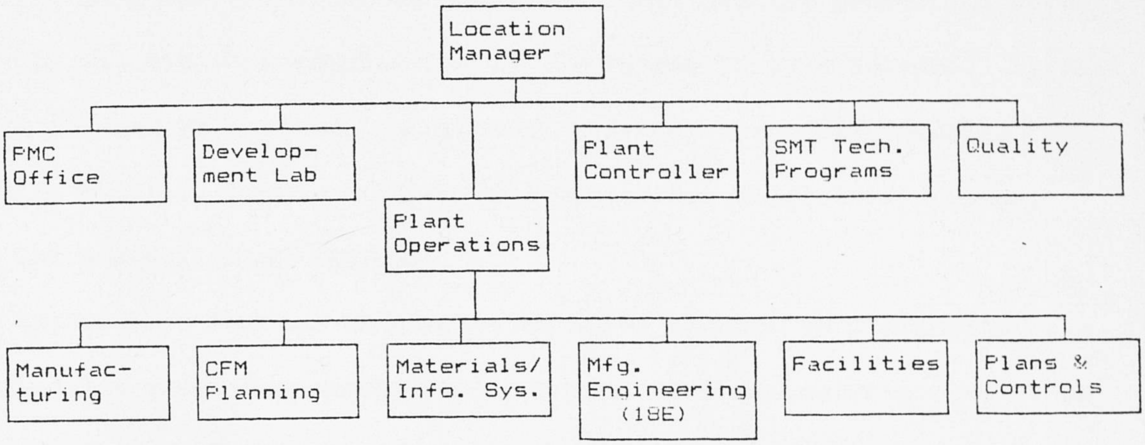


Figure 3: Organizational Chart -- STD/Austin plant

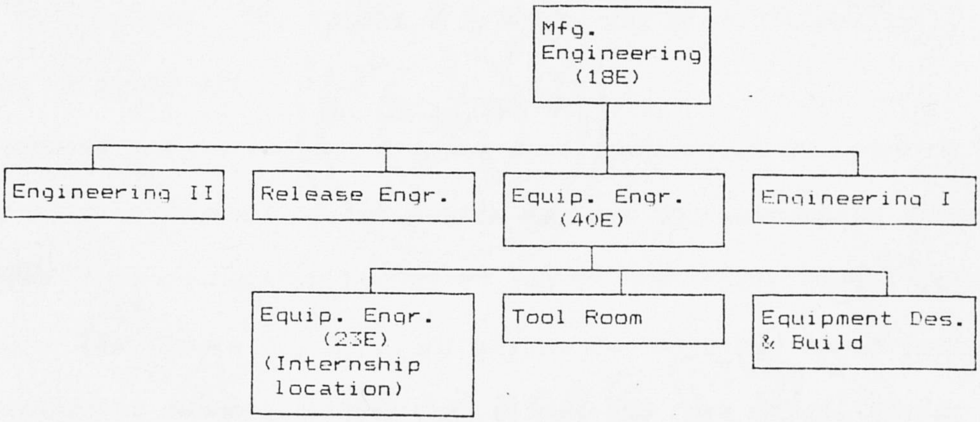


Figure 4: Organizational Chart -- Manufacturing Engineering (Organizational location of internship position)

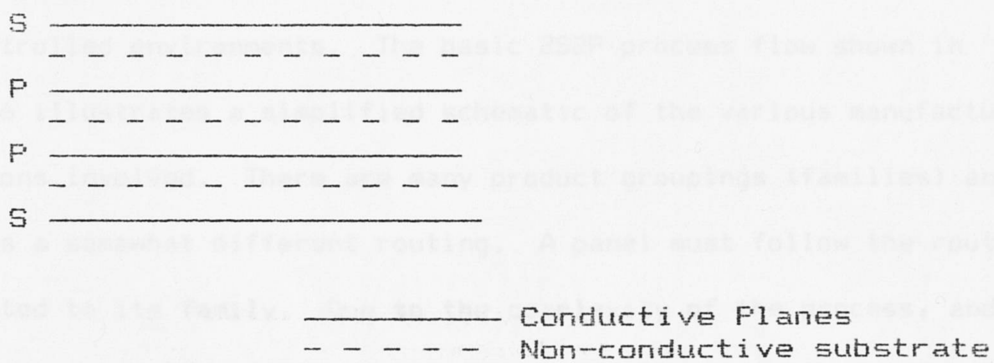


Figure 5: 2S2P Panel Configuration

The more the number of circuitized planes and the denser the circuit pattern is, the more complex the manufacturing process becomes. Circuit cards and boards are used in computer systems, keyboards, modems, banking systems, laser printers, and many other electronic devices.

D) THE MANUFACTURING PROCESS

The Circuit Package Manufacturing (CPM) process in STD/Austin is a complex and complete process that converts such raw materials as glass cloth, varnish mix, and copper foil into fully circuitized cards and boards. The process requires sophisticated equipment, delicate handling and controlled environments. The basic 2S2P process flow shown in Figure 6 illustrates a simplified schematic of the various manufacturing operations involved. There are many product groupings (families) and each has a somewhat different routing. A panel must follow the routing designated to its family. Due to the complexity of the process, and for sake of brevity and clarity, only major product groupings and significant value-add manufacturing operations will be included in this process description. The status of a panel may be sufficiently described in terms of:

1) The type of the lamination process used (sequential vs. pin lamination). Sequential lamination employs the successive lamination of additional conductive planes on top of previously circuitized planes - see Figure 7. Pin lamination, on the other hand, employs the method of merging previously circuitized core panels (refer to Glossary for the meaning of "core panels") and then laminating them together using registration pins and plates, Figure 8.
2) The degree of completion as measured by the number of lamination passes. Depending on the value of the number of actual lamination

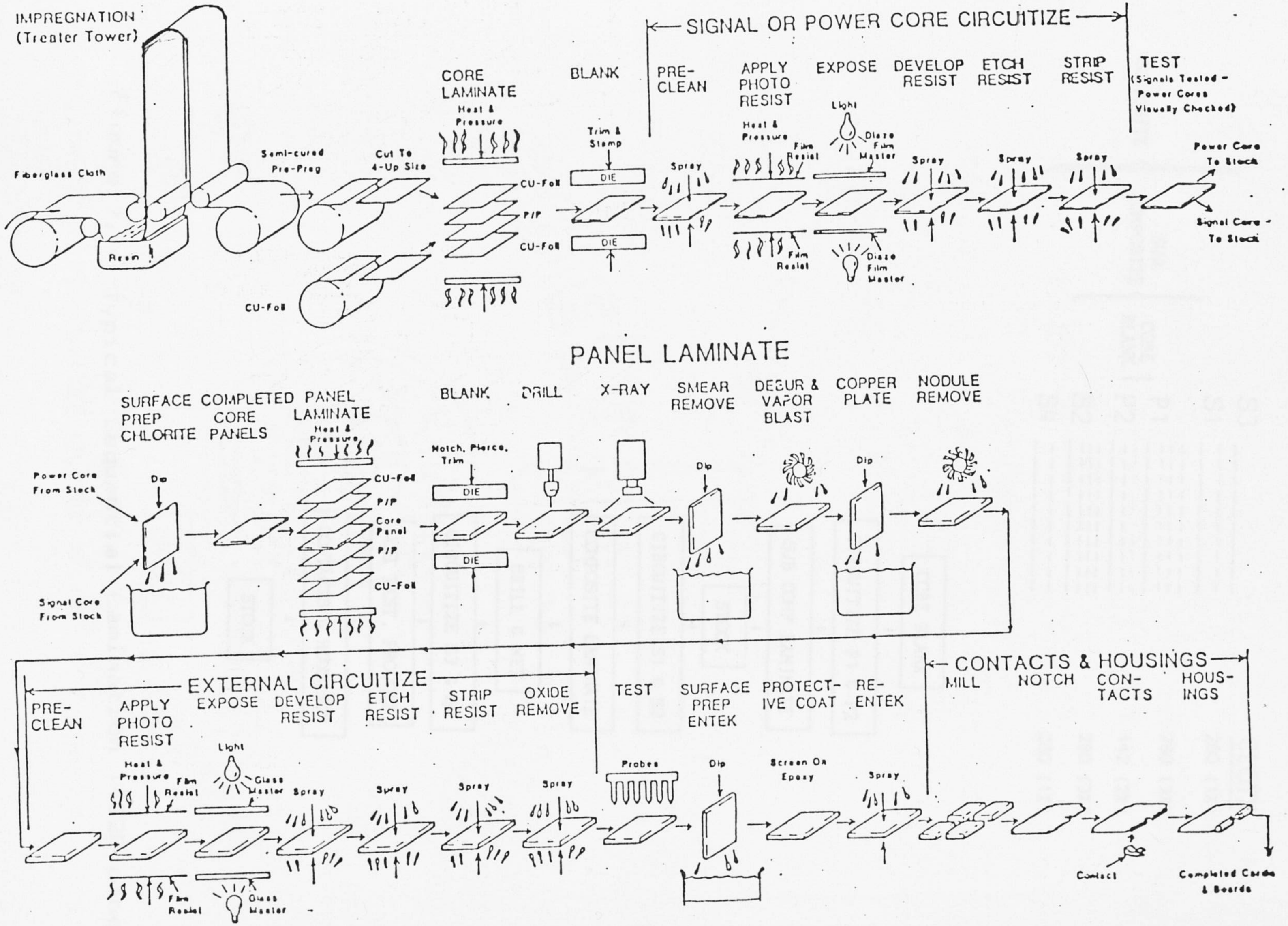


Figure 6: Basic 2S2P Process Flow

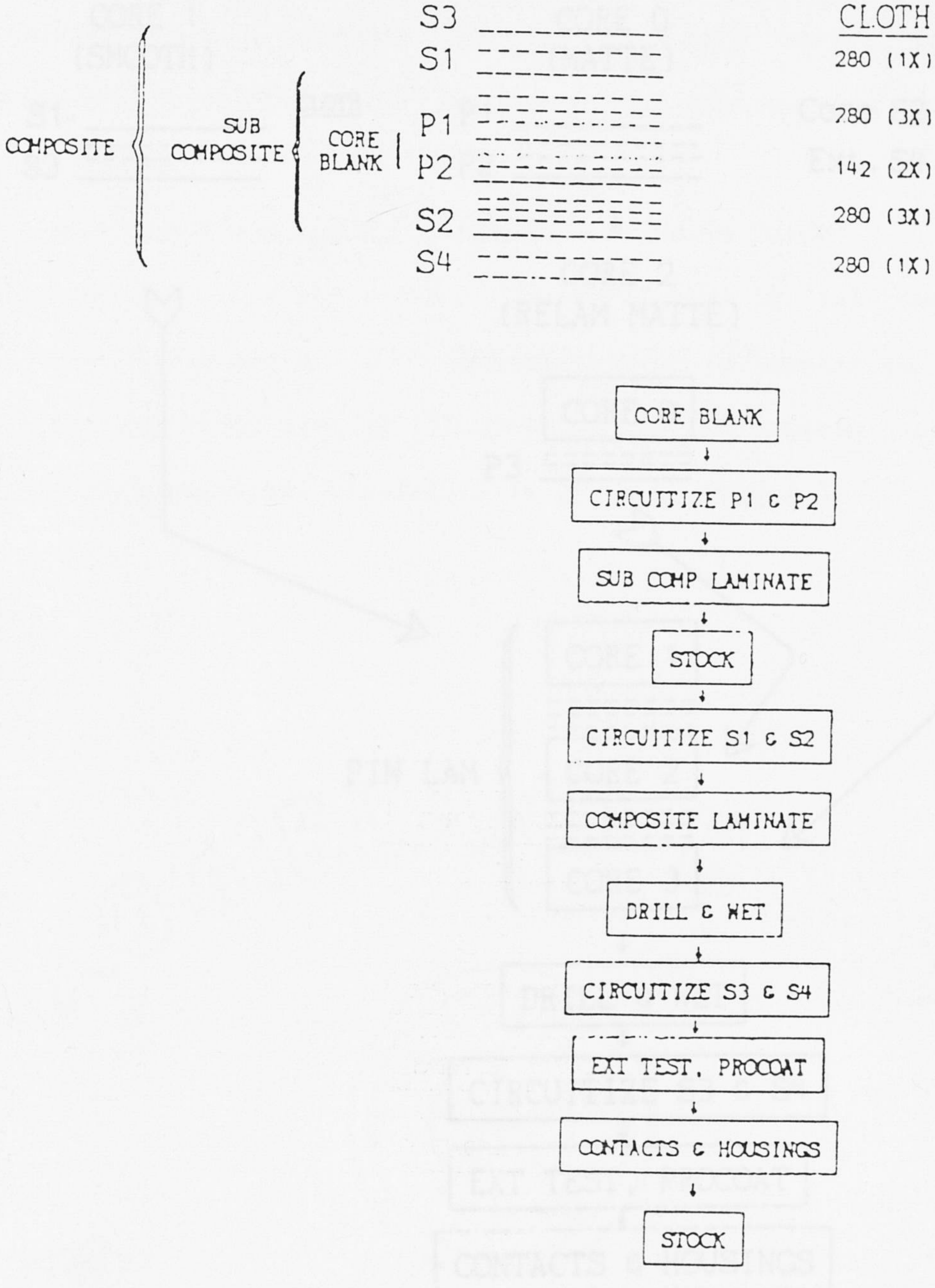


Figure 7: Typical Sequential Lamination (4S2P panel)

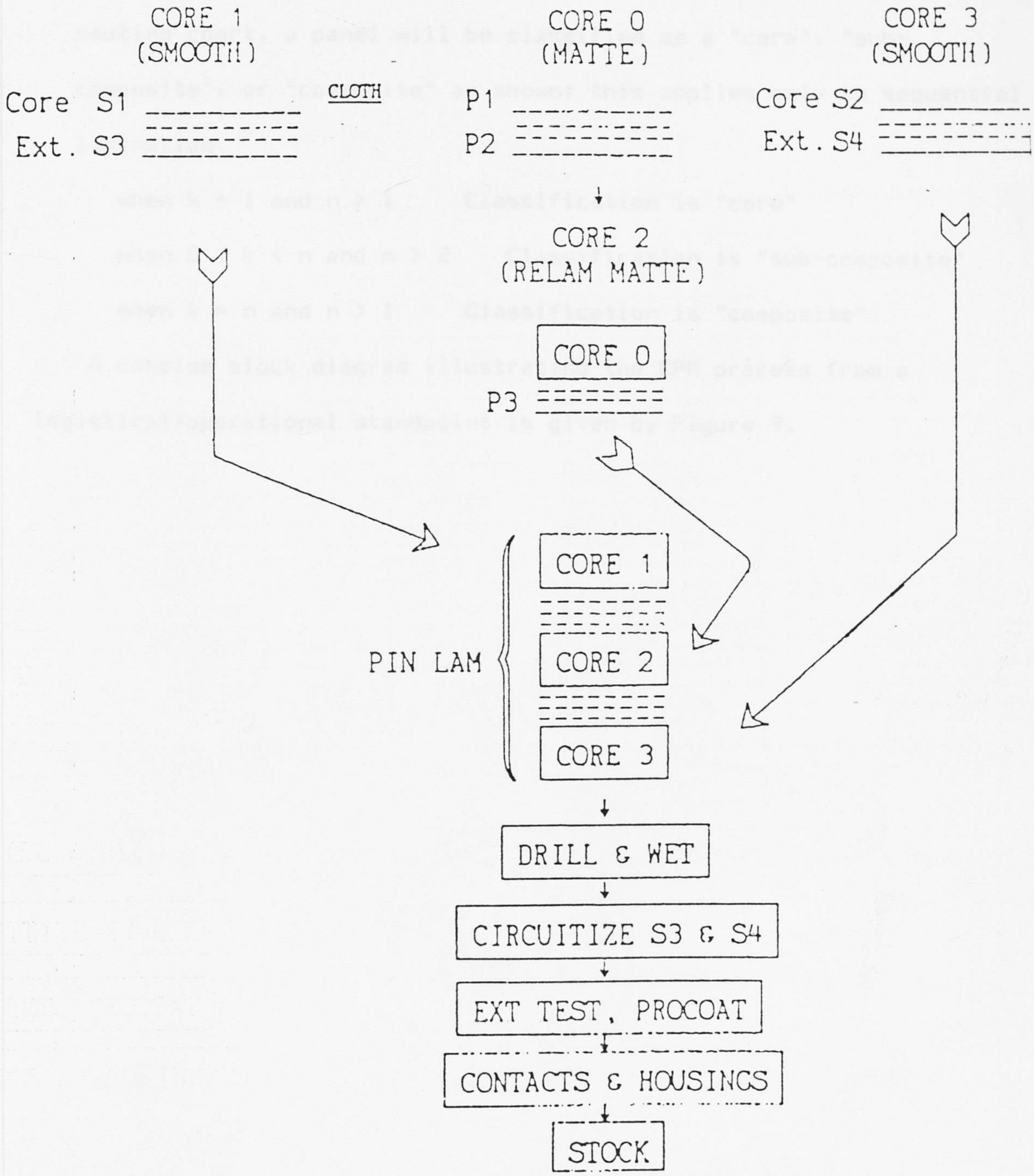


Figure 8: Typical Pin Lamination (4S3P panel)

passes (k) versus the number of total passes (n), as required by the routing chart, a panel will be classified as a "core", "sub-composite", or "composite" as shown; this applies only to sequential lamination.

when $k = 1$ and $n > 1$ Classification is "core"

when $2 < k < n$ and $n > 2$ Classification is "sub-composite"

when $k = n$ and $n > 1$ Classification is "composite"

A concise block diagram illustrating the CPM process from a logistical/operational standpoint is given by Figure 9.

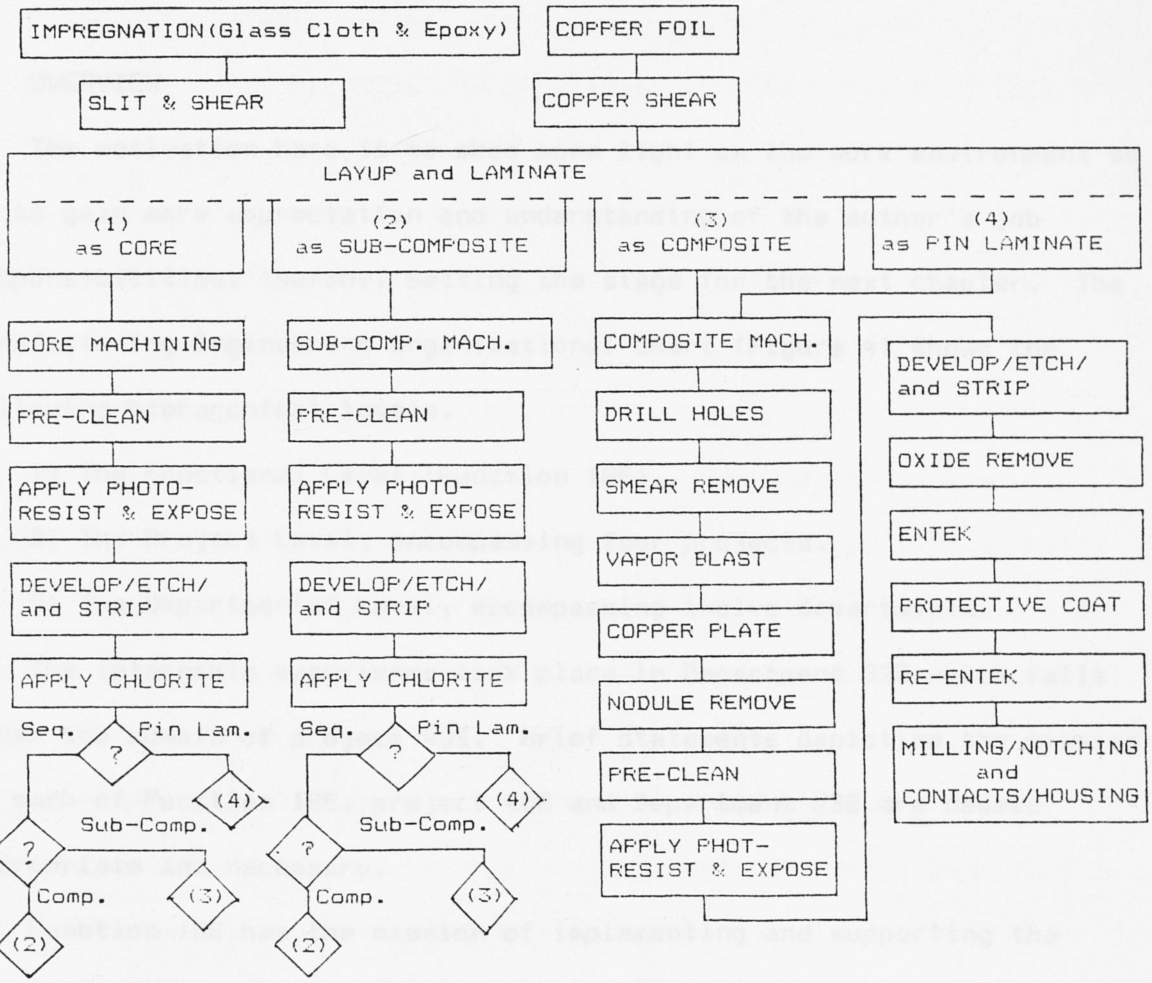


Figure 9: Manufacturing Process Flow

CHAPTER III

INTERNSHIP DESCRIPTION

A) OVERVIEW

The motivation here is to shed more light on the work environment so as to gain more appreciation and understanding of the author's job responsibilities, thereby, setting the stage for the next chapter. The Manufacturing Engineering Organizational Chart (Figure 4) shows the following hierarchical levels.

1) The Functional Level (Function 18E).

2) The Project Level, encompassing four projects.

3) The Departmental Level, encompassing twelve departments.

The internship experience took place in Department 23E which falls under the domain of project 40E. Brief statements depicting the mission of each of Function 18E, project 40E and Department 23E are deemed appropriate and necessary.

Function 18E has the mission of implementing and supporting the manufacturing processes, equipment and associated systems for STD Austin.

The mission of project 40E is to:

1. Coordinate the tool plan between M.E. and planning groups.
2. Provide site toolroom services.
3. Provide packaging engineering to STD products.
4. Develop an automation strategy and coordinate all Austin automation projects.
5. Write the equipment specifications, acquire, or design and build, install, and debug all capital equipment.

Finally, Department 23E has the mission of:

1. Writing process equipment specifications.
2. Acquisition, installation, and debug of this equipment.
3. Development and coordination of automation strategies such that they are consistent with Continuous Flow Manufacturing (CFM).
4. Providing CPM packaging engineering.

The functional procedure for acquiring Capital Process Equipment is given in Appendix A.

B) WORK POSITION AND SCOPE:

The internship commenced in June, 1984, when the author was recruited by the company as a Senior Associate Engineer. The author's academic background (B.S.M.E., M.S.M.E., and D.E. candidate) qualified him for this position which is normally held by engineers with many years of experience.

At that time, STD/Austin was committed to modernizing its CPM facilities. The focus was on improving productivity and yields by the concurrent implementation of Automation and Continuous Flow Manufacturing (CFM) strategies. Many automation projects were underway at various stages of completion, and more were to be initiated and justified. While automation was the responsibility of M.E., CFM was driven by a special task force.

As an equipment engineer, the author became actively involved in the automation effort. He developed an automation strategy, coordinated an automation project, and participated in other activities as well. The nature of the position as an equipment engineer required interaction and interfacing with other departments within and outside the M.E. function. Hence, it was necessary for the author to have proficient understanding of the product, the manufacturing process, and the operating procedures of the company. Additionally, these responsibilities enhanced the author's learning process, and gave him a broad exposure to the various aspects of a manufacturing environment.

CHAPTER IV

INTERNSHIP PROJECTS

A) INTRODUCTION

This chapter covers all aspects of internship participation during the period (June 1984-August 1985) with the IBM Corporation in Austin, Texas. During the course of the internship, the author was involved with two major projects and other smaller tasks. The assignments are presented in the order in which they occurred. At times there were several activities going on simultaneously.

Prior to his first assignment, the author was allowed an orientation period during which he had to:

1) become familiar with the overall corporate approach, philosophy, and culture, and
2) learn about the STD/Austin plant, its products, and the manufacturing process used.

The first objective was achieved by attending a one-week professional orientation program designed specifically for new employees. It provided a historical perspective of IBM, its basic beliefs, policies, and practices.

Even though there are two orientation programs designed to help employees who are new to STD Austin to become familiar with the business as well as the technical sides of the facility, none was being offered at the time. Therefore, the author had to achieve the second objective through personal effort. His sources were basically two: the local library, and fellow employees. The personal effort was augmented by temporarily assigning the author to assist Clint Brinkoeter (Sr. Assoc. Engineer/Equip. Engineering Dept.) in his efforts to develop a detailed flow chart (loop analysis) depicting the manufacturing process. This analysis provided information regarding the routing for each of the product families, classification and mode of each operation, and quantitative data as may be necessary. Once completed, the loop analysis would form the basis for formulating new automation plans, implementing CFM strategies, and simulating current processes as well as proposed plans. The author's participation, though limited to the initial stages of this project, has provided him with a unique opportunity to learn about the product and better understand the manufacturing process.

B) DEVELOPMENT OF "CORE CIRCUITIZE" AUTOMATION PLAN

Prior to commencement of this internship, a strategic objective to improve productivity and yields was set for STD/Austin. Moreover, CFM and automation were selected as the strategies most instrumental in realizing the aforementioned goal.

As mentioned earlier in this report, a special task force had the responsibility of implementing CFM while automation was to be driven by manufacturing engineering. Even though CFM was free of capital expenditures, automation was heavily dependent upon it. Hence, unlike those for CFM, automation plans were subjected to stricter requirements and were required to take current and future business needs into consideration.

Due to its magnitude and presence of unknown dependencies, it was almost impossible to establish a well-defined overall automation strategy. Instead, a modular approach was adopted where automation plans for different manufacturing centers were developed separately and then integrated together. Uniformity was to be assured by making the separate plans conform to guidelines set forth by the overall strategy.

This project was assigned to the author shortly after his internship commenced. As the principal investigator, he had the full responsibility of developing an automation plan for the "Core Circuitize" Manufacturing Center. Such a plan was to provide for improved productivity and yields, enhanced CFM, and compatibility with known guidelines of the total system strategy.

B.1) APPROACH

The steps of change, including change induced by automating an existing process, are:

1) know where you want to be,

2) determine where you are now, and

3) head toward your goal--building on the positive aspects of the current situation.

The first step can be derived from the goal as stated by the overall strategic direction, i.e., higher volumes, higher quality, and lower costs. Also stated "the above to be achieved through the concurrent implementation of CFM and Automation."

The second step is to analyze and fully understand the existing process. Only such a detailed study will allow us to differentiate the positive aspects from the negative ones. The loop analysis mentioned earlier is an excellent tool for this purpose.

Once the first two steps are well defined, the third becomes easier to accomplish--a problem well defined is a problem half solved. The remaining task is to use innovation and good judgment in defining the new process configuration, justifying it, and recommending an action plan. Development of the automation plan may be broken into the following phases:

1) Defining elements of existing process

2) Analyzing existing process

3) Developing new proposal/plan

4) Capital justification of the proposed plan

5) Implementation plan

B.2) DEFINITIONS

The objective of this phase is to become familiar with the manufacturing center (physical layout, equipment, product mix, etc.). The center consists of the following sub-divisions (in process order):

1) Pre-clean area: This is the staging area from where panels enter the Core Circuitize Manufacturing Center. This area contains 4 pre-cleaning machines. Each pre-cleaner consists of an automatic loader, 4 rinse chambers, $CuCl_2$ chamber, HCl chamber, and a mechanical scrubber.

2) Resist-Lamination area: This space is where photo-resist is laminated on panels that have been pre-cleaned. It contains 6 variable resist laminators with an automatic loader for each.

3) Hole pierce/Hole burnout: Punching registration holes in blank cores and burning of photo-resist covering the registration holes in sub-composites take place in this room. This area occupies 2 hole pierce presses and 3 hole burnout fixtures.

4) Diazo preparation area: This is where the circuit artwork is copied onto diazo films. This area contains 2 expose machines, 4 inspection benches, and the Glass Master Library.

5) Expose area: This is where the circuit pattern is generated on

panels coated with photoresist by exposing them to ultraviolet light. Twelve expose machines occupy this area.

6) Develop/Etch/Strip area: This is where the unexposed photoresist is dissolved by the developer, thus allowing for the copper underneath it to be etched. Finally the remaining (exposed) photo-resist is dissolved in the stripper. D.E.S. is the last value-add operation in the "Core Circuitize" Center. This area contains 4 D.E.S. lines.

7) Entrance area: is where the clean-room coats are stored. Also it is the entrance to area numbers 2, 3, 4, 5 and 6. The coats are needed because these areas are classified as Class 100 clean rooms. Moreover, special yellow lighting is used in these areas.

A dimensioned physical lay-out of Core Circuitize is shown in Figure 10. Figure 11, presents the equipment/operator layout for the existing process. While some machines are independent of product mix (expose, D.E.S.), others exhibit machine/product dependencies. Table 1 provides a breakdown of product types, the percentile composition of each, and the machine/product dependencies that exist. As seen from Table 1, each operation exhibits different degrees of dependencies. The following is a brief explanation of each dependency and the reasons for it.

1) Pre-clean: three processing modes exist:

*Power blank cores are double tracked with narrow edges leading.

*Signal blank cores are single tracked with wide edge leading.

*Sub-composites are double tracked with wide edges leading

The main reason behind this dependency is machine limitations (both physical and functional). The physical limitation is due to the fact that two of the four pre-cleaners have narrow scrubbers and single feed

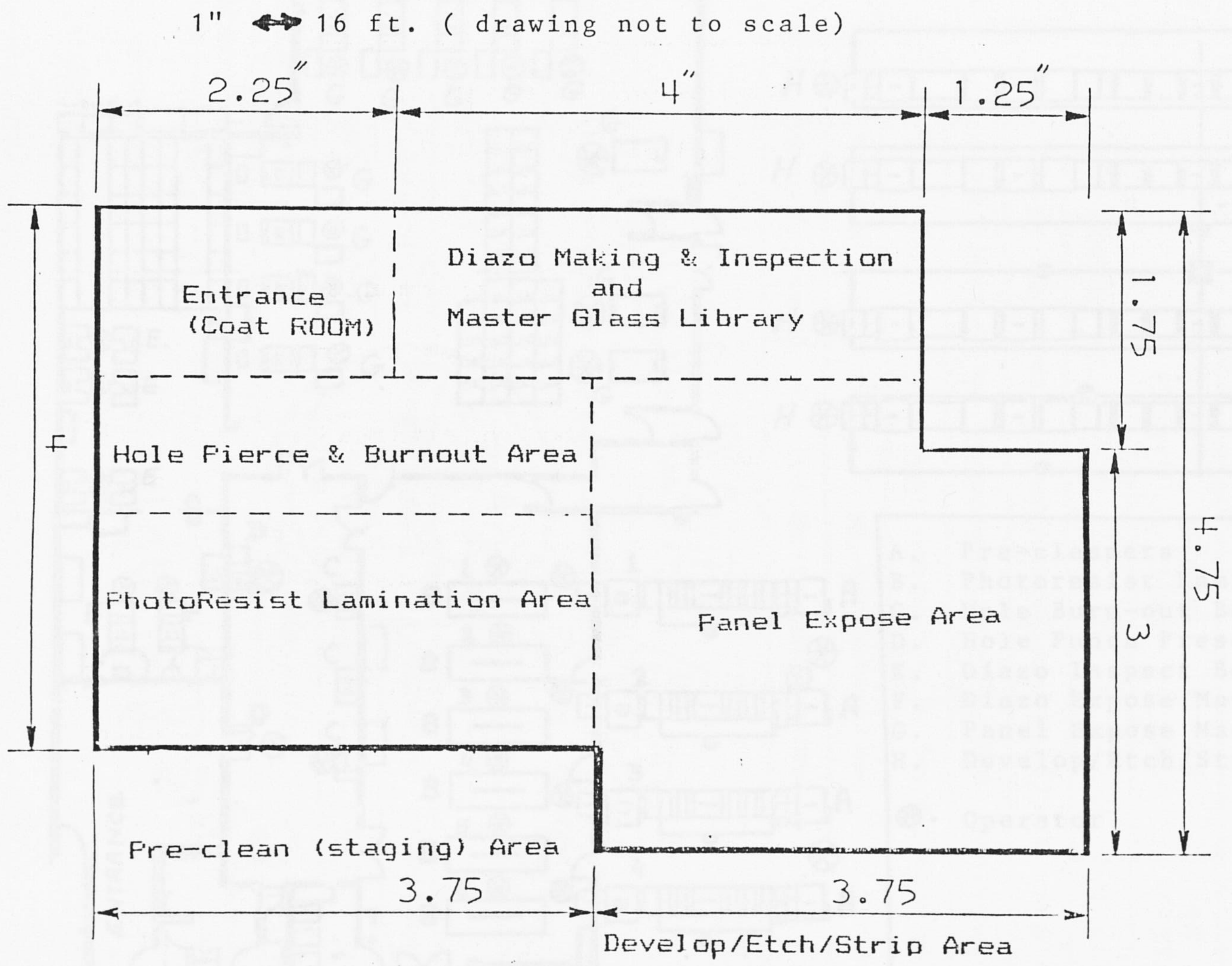


Figure 10: Dimensioned Layout of Core Circuitize Process Center

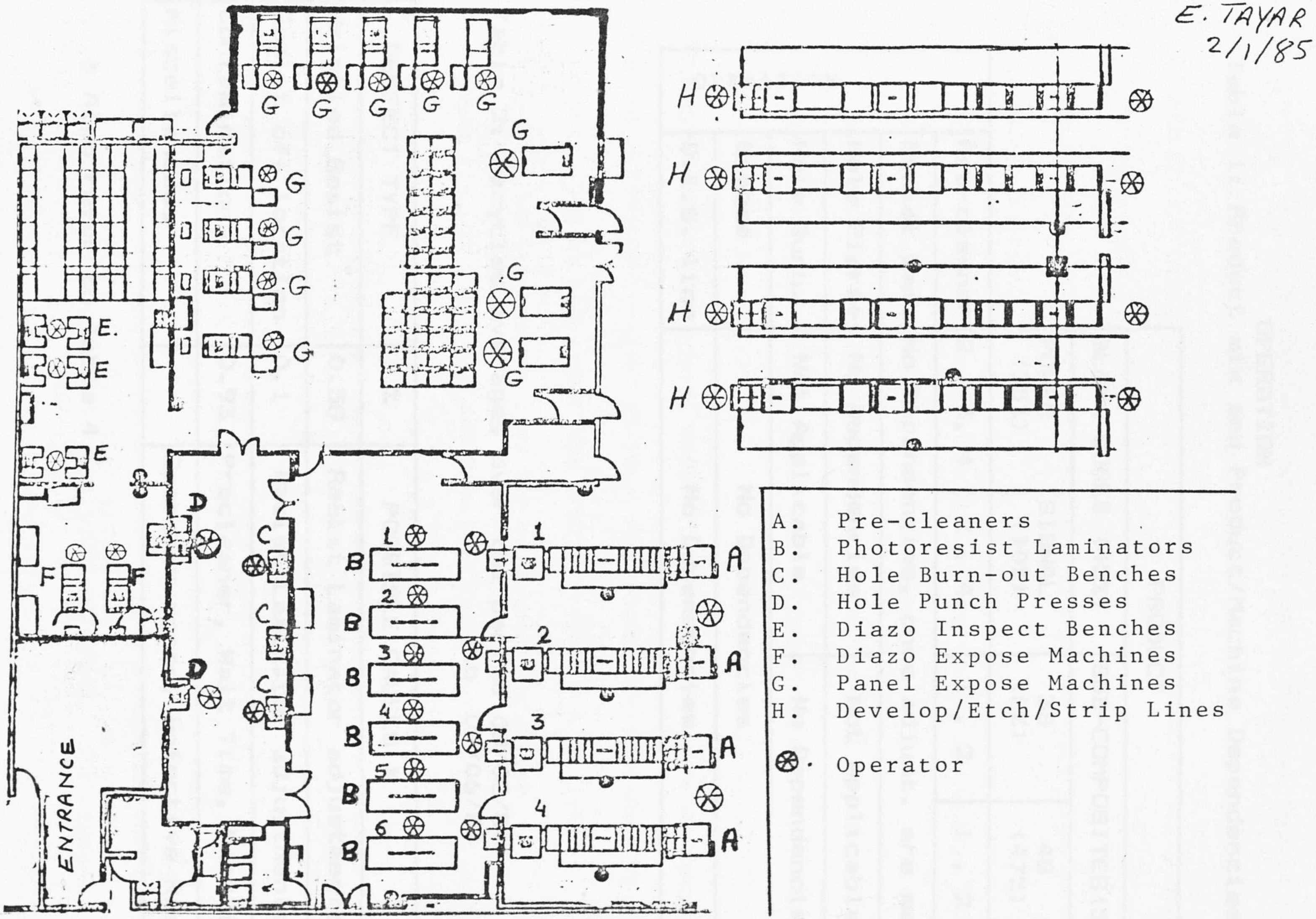


Figure 11: Core Circuitize -- Equipment/Operator Layout

OPERATION

Table 1: Product mix and Product/Machine Dependencies

		PRODUCT			
		BLANK CORES (45%)		SUB-COMPOSITES(55%)	
		POWER (35%)	SIGNAL (10%)	3S (8%)	4S (47%)
OPERATION	Pre-cleaner	2, 3, 4	2, 4	1, 2	1, 2
	Resist Lam.	No Dependencies, once adjust. are made			
	Hole Pierce	No Dependencies		Not Applicable	
	Hole Burn.	Not Applicable		No Dependencies	
	Expose	No Dependencies			
	D.E.S. line	No Dependencies			

Table 2: Recycles averages over the period 08/02/84 to 09/06/84

DEFFECT TYPE	%	POSSIBLE CAUSES *
Wrinkled Resist	0.58	Resist Laminator adjustments
Resist off location	0.1	Resist Laminator adjustments
Contamination	0.93	Precleaner, Wait Time, Handling
Miscellaneous		Operator error, Defective Resist

* Also refer to Table 4

capabilities. The functional limitation is due to the lower first pass yield resulting from bent and jammed panels inside the scrubber when thin panels (blank cores) are processed in a manner similar to that for the thicker sub-composites.

2) Resist lamination: There are two dependencies associated with this operation:

*The first is physical and is due to the slight difference in sizes between blank cores and sub-composites.

*The second is functional and due to the variation in the lamination speeds required for each of blank cores (thin) and sub-composites (thick).

The variable resist laminators, however, can be adjusted to different speeds and different conveyor widths. Therefore, the dependencies are not critical in this case, and they result only in a time penalty (increased set-up time) every time the adjustments are made.

3) Hole pierce: This operation is performed on blank cores only.

4) Hole burnout: is performed on sub-composites (and lately, only on 3S product) and on some blank core recycles.

Finally, panel handling devices and containers are described in this phase. Panels arrive at the staging area (pre-clean area) in totes which are placed in tote carts. The contents of each tote may not exceed 30 for signals and 50 for powers. Once pre-cleaned, panels are stacked vertically in wire carts with vertical slots. They remain in wire carts throughout the remaining operations and are transferred into totes only after passing through the D.E.S. lines.

B.3) ANALYSIS

The first step in the analysis process is data gathering. For this project, data collecting comprised all aspects of the manufacturing process, such as:

1) Equipment (qualifications/product dependencies, adjustments, major or frequent problems, availabilities, base capacities, actual capacities, etc.)
2) Queues (size, average waiting time, max. allowable waiting time, etc.)
3) Process parameters (panel handling methods and requirements, curing times, machine speeds and temperatures, process controls, tolerances, etc.)
4) Recycles (percentages, causes, handling, etc.)
5) First pass yields (per operation, defect causes, etc.)
6) Other (cost/operation, panel movements, etc.)

Such an effort required interaction with a multitude of people in various departments and functions such as manufacturing, maintenance, process engineering, cost accounting, industrial engineering, etc. To simplify the data gathering task, a questionnaire was developed and used by the author. The data was instrumental in constructing a detailed process flowchart; it was also used by a special simulation group from IBM/Boca Raton, Florida, in developing a simulation model for the "Core Circuitize" center. Due to confidentiality requirements, the basic process flow (details omitted) is presented here. Figure 12, reflects the mode of operation which existed during the first few months of this project's life. The subsequent implementation of a change resulted in the elimination of the hole burn out operation for 4S sub-composites. The modified process flow is given by Figure 13; it is also noted in Table 1. All the elements in each of Figures 12 and 13 may be

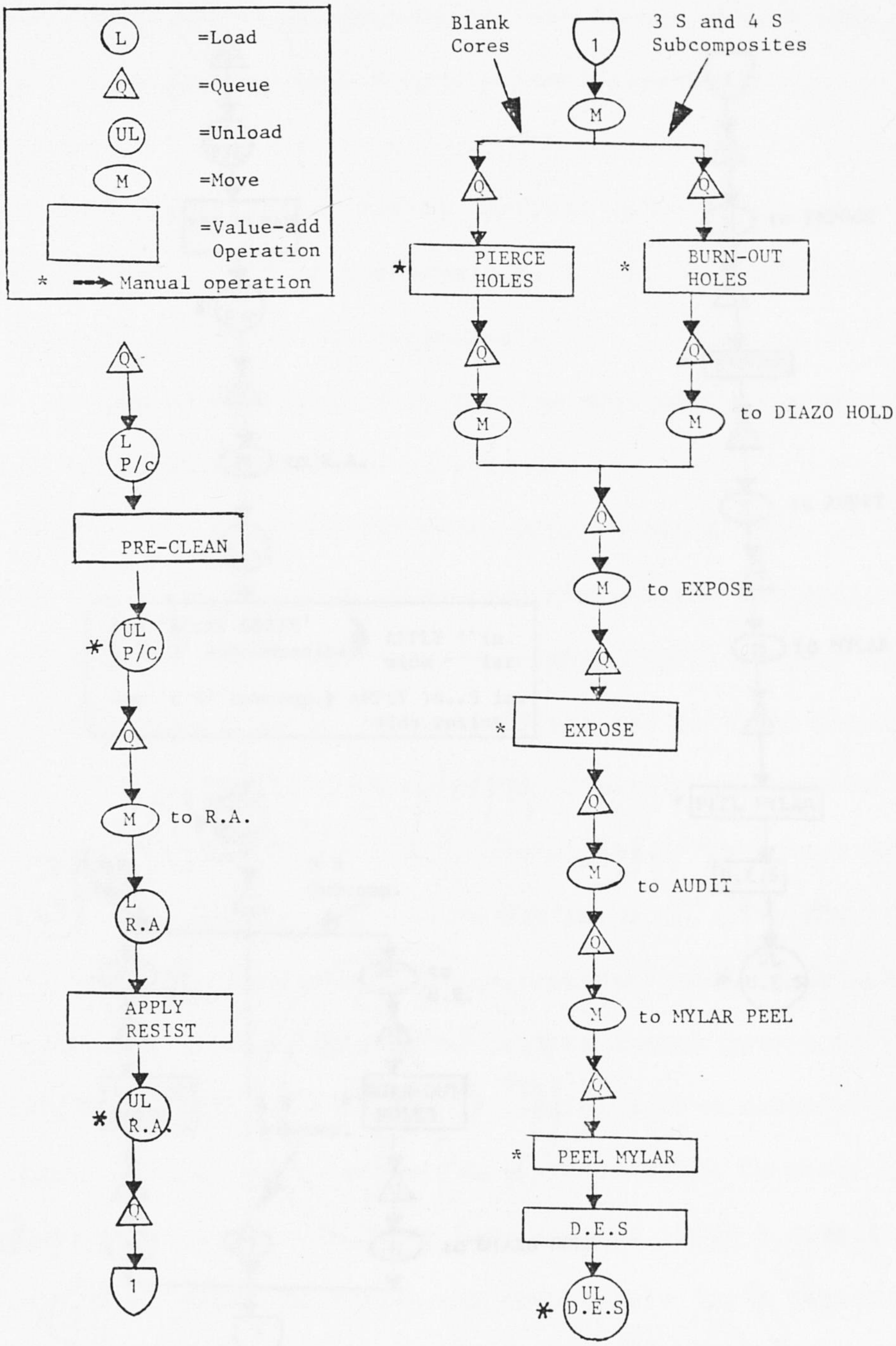


Figure 12: Original Mode of Operation -- Core Circuitize.

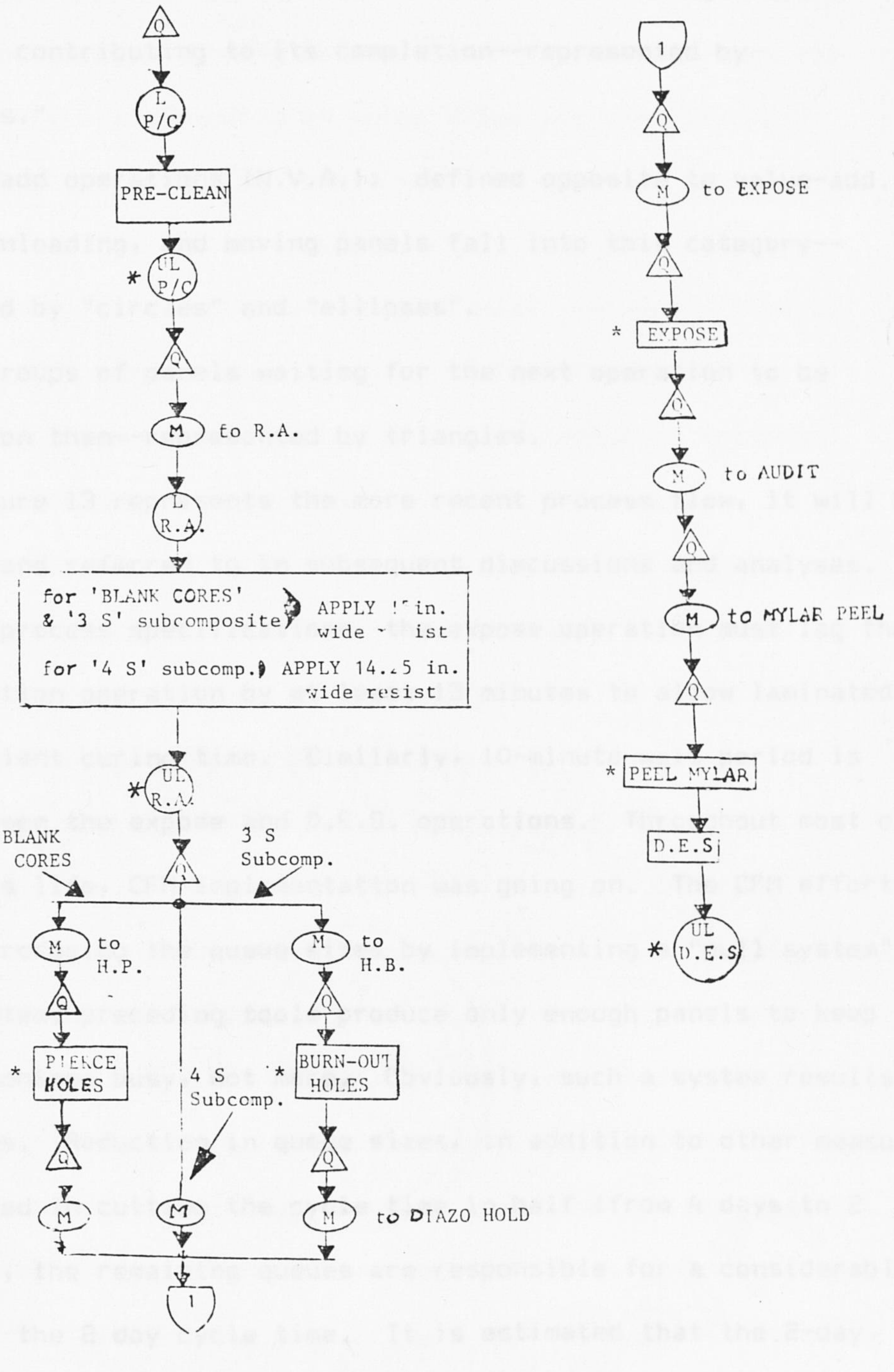


Figure 13: Current Mode of Operation -- Core Circuitize

categorized as follows:

1) Value-add operations: are operations that induce change into a panel thus contributing to its completion--represented by "rectangles."

2) Non-value-add operations (N.V.A.): defined opposite to value-add. Loading, unloading, and moving panels fall into this category--represented by "circles" and "ellipses".

3) Queues: groups of panels waiting for the next operation to be performed on them--represented by triangles.

Since Figure 13 represents the more recent process flow, it will be the one used and referred to in subsequent discussions and analyses. According to process specifications, the expose operation must lag the resist-lamination operation by at least 15 minutes to allow laminated panels sufficient curing time. Similarly, 10-minute wait period is required between the expose and D.E.S. operations. Throughout most of this project's life, CFM implementation was going on. The CFM effort was aimed at reducing the queue sizes by implementing a "pull system". In such a system, preceding tools produce only enough panels to keep succeeding machines busy, not more. Obviously, such a system results in smaller queues. Reduction in queue sizes, in addition to other measures taken, resulted in cutting the cycle time in half (from 4 days to 2 days). Still, the remaining queues are responsible for a considerable percentage of the 2 day cycle time. It is estimated that the 2-day cycle time may be divided as follows:

50% due to queues

35% due to N.V.A. operations and inspections

15% actual processing time

Naturally, to make the process more efficient further reduction in queues and N.V.A. operations is required.

Analysis of data pertaining to recycles revealed that they are processed differently depending on which value add operation was performed last. The following is a summary explanation of the processing sequence of various recycles:

1) Pre-cleaned recycles (prior to resist lamination) are processed through the HCl and scrubber chambers of the pre-cleaner

2) Laminated recycles (prior to expose) are processed as follows:

   a) through developer and scrubber--for recent laminates

   b) through developer, $CuCl_2$, HCl, and scrubber--for aged laminates

3) Exposed recycles (prior to D.E.S.) are processed through the developer, stripper, $CuCl_2$, HCl, and scrubber.

Charted and tabulated data pertaining to recycles are made available, to whoever requests them, through "yield reports". The data in these reports is broken down by defect type only. A similar breakdown by operation would have been also helpful for the purposes of this analysis. Due to the sensitivity of the manufacturing process and its dependence on a multitude of parameters, yield levels are continuously changing and sometimes are even unpredictable. A sample yield report has been summarized and rearranged for the purpose of presenting it here; this is given in Table 2. It is worthwhile noting that the levels of recycles given in yield reports were consistently lower than the estimates given by the operators, through the questionnaire mentioned earlier. The discrepancy may be justified by the following:

1) Verbal data provided by operators was at best an estimate, and

Table 3: Machine Parameters

TOOL NAME	BASE CAPAC. Pan./Hr	TRUE CAPAC. Pan./Hr	BASE AVAIL. %	TRUE AVAIL. %	MACHINE ADJUSTMENTS and MONITORED CONDITIONS
Precl	IBM Confid.	IBM Confid.	90	87	feed rates, spray and brush pressures, sump levels & concentrations
Res. Lam.	Confid.	Confid.	90	94	cure-roll temp., feed-roll & cure-roll speed, slack bar tension,etc.
H.P.	Confid.	Oper. depend.	99.9	99.9	None
H.B.	Confid.	oper. depend.	99.9	99.9	None
Exp-ose	Confid.	Confid.	99	99	Light intensity, exposure time
D.E.S	Confid.	Confid.	90	92.6	Spray Pressure and temp.,feed rate, sump levels & concentrations

2) Tendency by operators to neglect documenting and reporting every recycled panel. On one occasion it was discovered that operators failed to stamp some recycles. The stamp is necessary to determine whether a panel has been recycled more times than is permitted by the process specifications.

The author personally believes that the actual level of recycles is slightly higher than what is indicated in the yield reports.

In conclusion, a concise presentation pertaining to equipment capabilities and other related parameters is given in Table 3. Two remarks, in reference to the capacities of the pre-cleaners and resist laminators will follow:

1) The base capacity of the precleaners is dependent on whether the product is power core, signal core, or sub-composite (not only cores vs. sub-composites as suggested in Table 3). However, due to their low percentage compared to other product types, signal cores are treated as though they were power cores by tool planners.
2) The base capacity of the resist laminators was increased by 14% for blank cores and by 20% for sub-composites. This change was requested by the author when he discovered that there was a discrepancy between what was in the plan and what was actually happening on the manufacturing floor. The request for change is included in Appendix A.

B.4) DEVELOPMENT OF THE PLAN--PHASE I

The automation strategy to be developed was subject to the following ground rules:

1) Compatibility with associated strategies (larger panel, total tote, CFM, and product identification).

2) Higher efficiency (higher volumes, improved yields, lower cost).

3) Flexibility (modularity, less machine/product dependencies).

Unfortunately, such strategies as larger panel, total tote, and product I.D. remained undefined throughout the life of this project. Therefore, assumptions pertaining to each of them (except CFM) had to be made. The basic rule followed was to assume the most prevailing trend in each strategy, and to assume the current case in the absence of such a trend. Hence, current panel size and totes were assumed for the "larger panel" and "total tote" strategies, respectively. The "panel I.D." strategy, on the other hand, was found to have insignificant impact on development of the automation plan and, hence, no I.D. assumptions were made.

Through identification of some critical factors within the "Core Circuitize" process center, it became apparent that three somewhat natural and independent entities existed: 1) pre-expose, 2) Diazo make and panel expose, and 3) post-expose. At this point, general plans and recommendations were to be made for each of the entities. Since the best way to come up with a good idea is to start out with lots of ideas, the author held frequent brainstorming sessions that included key individuals from each of "Equipment Engineering", "Equipment Design and Build", "Process Engineering", and "Line Support". Additionally, the author held separate meetings or one-to-one sessions with people in Manufacturing, Industrial Engineering and others. After considering all possible options, the following were concluded:

1) Recommendations concerning "pre-expose" operations included:

a-Establishment of "double-tracking/wide-edge-leading" panel processing capability in all pre-cleaners.

b-Elimination of all N.V.A. operations and external handling between the pre-clean and resist lamination operations, also between resist lamination and hole-pierce operations.

c-Automation of H.P. operation.

d-Automation of all loading/unloading operations and providing tote handling capacity.

e-Automation of brush-pressure control in each of the scrubbers.

2) The "Diazo Make and Panel Expose" entity was identified by CFM and simulation analyses as being the bottleneck (gate) of the Core Circuitize process center. The method used was cumbersome, costly, and inefficient. Moreover, simple automation and/or modification of the existing process was judged to be ineffective (from a cost/benefit standpoint) and was not recommended. Instead, replacement of the present expose method with a data-generated scanning expose technique was an objective favored by all. Unfortunately, such a "Utopia" direct imaging system was still in development stages. Hence, the recommendations were summarized as follows:

a-keep on using the present method and continue implementation of the "clam shell" project to reduce cycle time.

b-replace with the new "Direct Imaging" system when it becomes available for on line implementation.

3) For "Post-Expose Operations", on the other hand, the following were recommended:

a-Continue implementation of "Automatic Mylar Peel" to demonstrate its feasibility and reliability.

b-Once proven, redesign the loader of the auto Mylar peel machine to establish commonality with the pre-clean loaders and to provide tote handling capability.

c-Automate D.E.S. process controls.

d-Automate the unloading of D.E.S. lines.

In addition to the above, automatic end-of-job detection capability and implementation of job carts for use as panel transportation medium within this process center (excluding interfaces with other centers) were also recommended for all three entities. This strategy would result in a process flow such as that shown in Figure 14. The strategy was to be implemented in three phases:

Phase I - Details and justification of "pre-expose" plan

Phase II - Details and justification of "post-expose" plan

Phase III - Details and justification of "Diazo Make and Panel Expose" plan

Since the implementation of each of the phases was to be sequentially dependent, the following implementation and justification details pertain only to Phase I of the automation plan.

B.5) DESIGN CONCEPT/IMPLEMENTATION DETAILS - PHASE I

Again, brainstorming meetings were held for the purpose of identifying and evaluating different design concepts pertaining to the implementation of Phase I. The alternative to be selected was the one that would meet the stated objectives while exhibiting reliability and simplicity. The following discussion pertains to the attributes and configuration of the proposed plan, also refer to Figure 15.

The main points of the plan include:

1) Replacement of the existing pre-clean loaders with automatic loaders that feature the following:

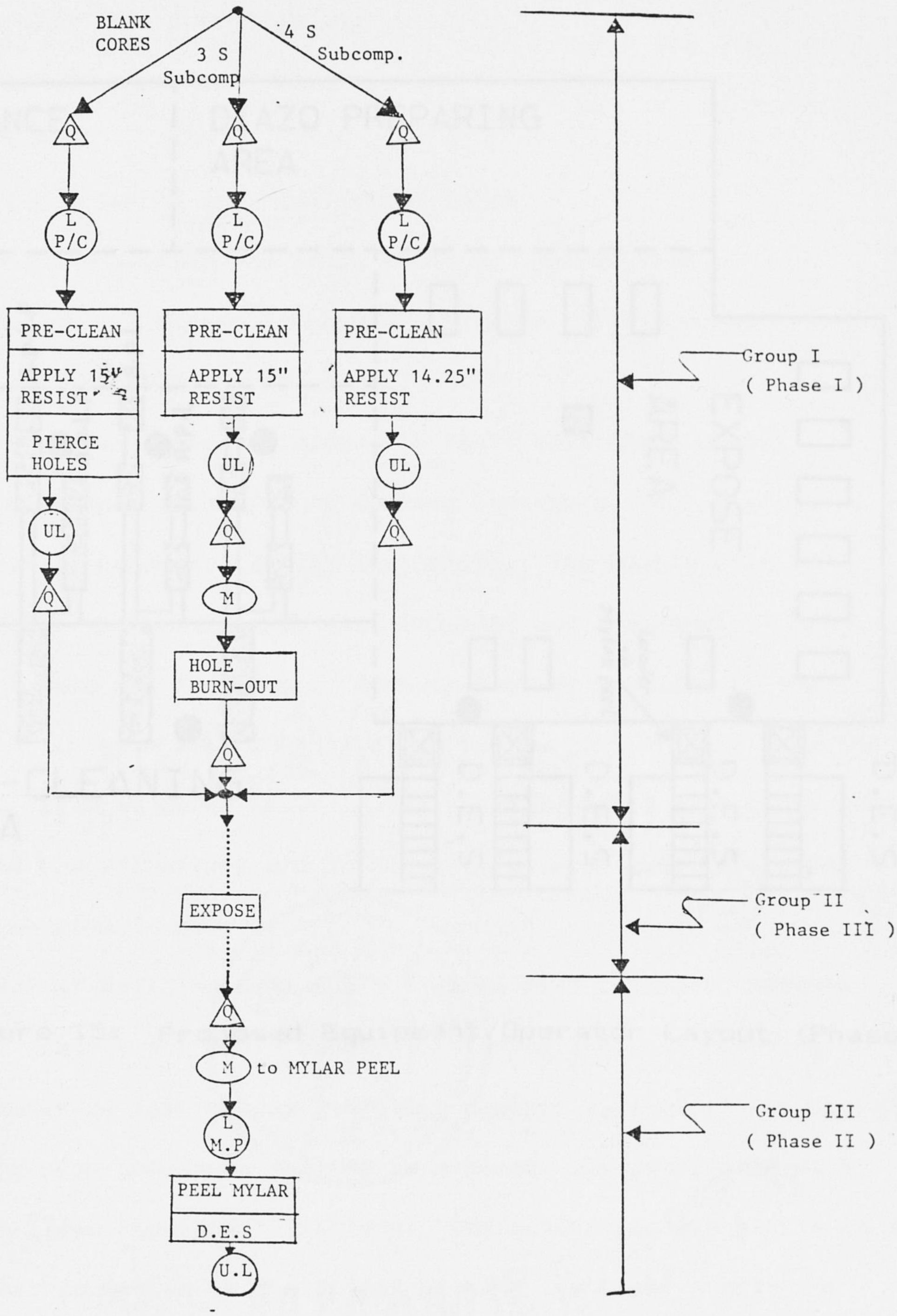


Figure 14: Proposed Mode of Operation -- Core Circuitize

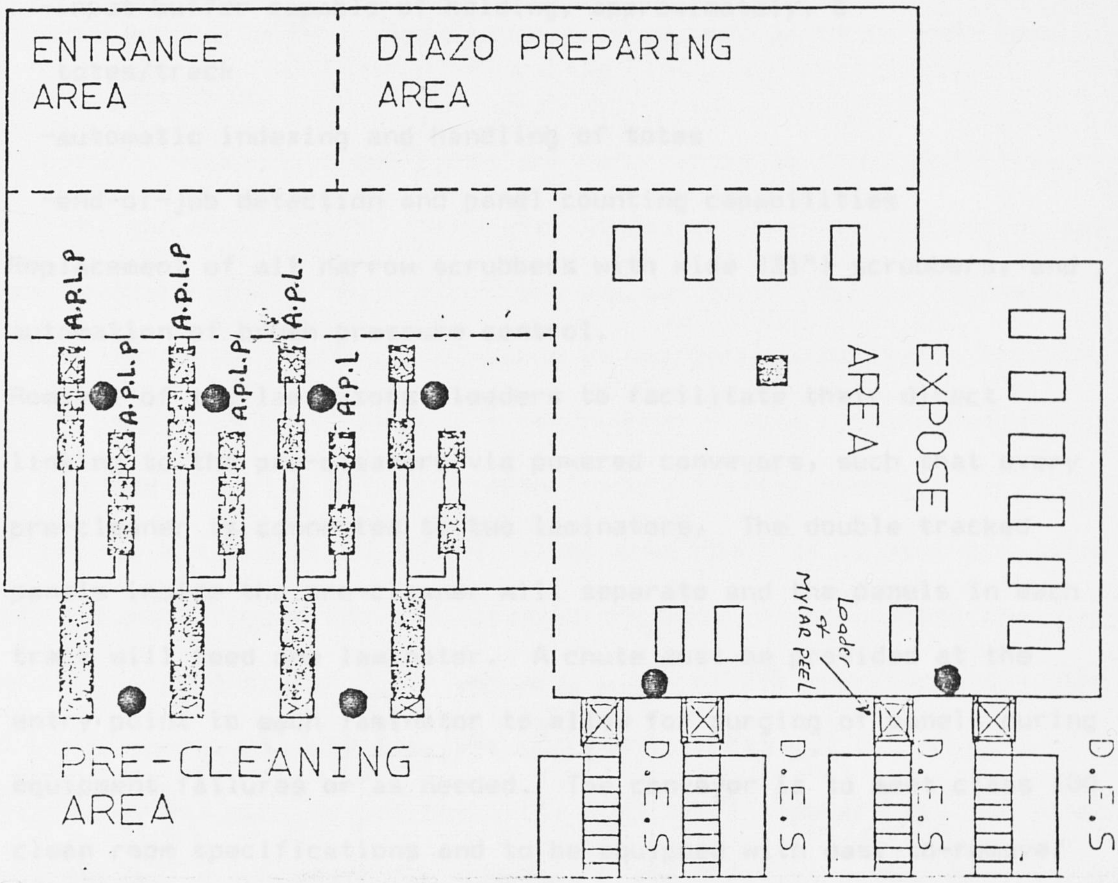


Figure 15: Proposed Equipment/Operator Layout (Phase I)

-double-compartment with double but independent feeding of panels with wide edges leading

-input buffer capable of holding, approximately, 5 totes/track

-automatic indexing and handling of totes

-end-of-job detection and panel counting capabilities

2) Replacement of all narrow scrubbers with wide (31") scrubbers, and automation of brush pressure control.

3) Removal of the laminators' loaders to facilitate their direct linking to the pre-cleaners via powered conveyors, such that every pre-cleaner is connected to two laminators. The double tracked panels inside the pre-cleaner will separate and the panels in each track will feed one laminator. A chute must be provided at the entry point to each laminator to allow for purging of panels during equipment failures or as needed. The conveyor is to meet class 100 clean room specifications and to be equipped with easy-to-remove/ see-through plastic covers.

4) Replacement of existing hole punch presses with automatic presses that will feature automatic panel positioning and hole punching within specified tolerances, disabling capability that allows panels to pass through unpunched when so is desired, and compliance with class 100 clean room specifications. The automatic hole pierce is to be directly connected to the output of each laminator processing blank cores.

5) Installation of automatic unloader at the exit of each of the hole punch presses (for lines processing blank cores), and of the resist laminators (for lines processing sub-composites). The unloaders

would be similar in design to the pre-clean loaders; however, unlike the loaders, each unloader will have a single compartment and a single output buffer. Additionally, they must be class 100 clean room compatible.

Lines processing blank cores are referred to as "Auto Pre-Clean, Laminate, and Hole Pierce" (A.P.L.P.) lines, while those processing sub-composites are called "Auto Pre-Clean and Laminate" (A.P.L.) lines.

Based on unit/hour (U/H) calculations it was determined that 4 A.P.L.P. (2 auto loader, 2 pre-cleaners, 4 laminators, 4 hole punch presses and 4 auto unloaders) and 2 A.P.L. (1 auto loader, 1 pre-cleaner, 2 laminators, and 2 auto unloaders) lines were required to meet projected daily volumes, Figure 15. The assumptions used in calculating the U/H included: current plan daily volumes, a mix of 27% sub-composites and 73% blank cores, 2% recycles, 95% operator efficiency, 90% machine efficiency, 90% machine availability, 0.25 hours time/set-up, 500 panels lot size, and 5 operators per 4 A.P.L.P. and 2 A.P.L. lines.

In formulating this automation plan, the author had to address many concerns some of which will be mentioned here. Yield data was analyzed and used to justify the elimination of panel inspection at the output of each pre-cleaner. Staggering of the laminators was devised to overcome space restrictions related to safety, maintenance, and operational requirements. To improve line balancing in the proposed plan, uplifting the base capacity of each laminator was necessary. The author identified several process and product parameters that impact the lamination speed. These factors include: cure rolls pressure and temperature; panel topography, thickness, and temperature; and contamination and oxidation of panel surfaces. Furthermore, the author suggested that panel temperature is an important factor in the equation and that it must be evaluated. Based on some references consulted, he recommended that a test be conducted to study the panel-temperature/laminator speed relationship. The recommended test parameters were to include:

1) Four samples (50 panels each) of sub-composites
2) Two cure roll speeds: a) 4-5 ft/min 200 panels/hr.
   b) 8-9 ft/min 360 panels/hr.
3) Two panel temperatures: a) room temperature
   b) 130 F

The following design of the experiment was recommended:

	Control sample #1	Control sample #2	Control sample #3	Control sample #4
apply roll speed (ft/min)	4-5	4-5	8-9	8-9
panel temperature (F)	room	130	130	room

The author believes that the experimental results would match the qualitative trend shown in Figure 16. Because some objections to the implementation of the proposed plan were based on existing machine/process problems, the author identified and recommended solutions, Table 4.

B.6) JUSTIFICATION OF THE PLAN--PHASE I

The proposed plan was justified by enhanced CFM, increased capacity, and a favorable Return on Investment(ROI). The following is a brief discussion pertaining to each.

Enhanced CFM was a by-product of combining the various operations. This resulted in eliminating all the queues between pre-clean/resist

Table 4: Problem Identification and Diagnosis

PROBLEM	SUSPECTED CAUSE	RESPONSIBILITY
For Pre-cleaners		
1) Panel jamming inside scrubber	a- Loose/worn pinch & back-up rollers	Maintenance
	b- Jerky conveyyor motion	Maintenance
	c- Need for guide rolls in conveyor	Engineering
2) Uneven/improper scrubbing	a- Same as in (1a)	Maintenance
	b- Improper brush adjustment	Engr./ Operator
	c- Worn brush	Maintenance
3) Panel bending inside scrubber	a- Improper panel support while in scrubber	Engineering*
4) Panel adhesion during pick-up	a- Need for a vacuum-breaking mechanism	Engineering*
5) Spotting on panels	a- Contaminated rinse	Engr./Operator (Not a critical problem)
	b- diluted and/or depleated Hcl bath	
	c- Inadequate drying	
For Resist Laminators		
6) Wrinkled resist	a- Slack bar tension adjustment	Engr./Operator
	b- Cure rolls speed/pressure adjustment	Engr./Operator
7) Off-set resist	a- Panel misallignment	Engr./Maintenance
	b- Timers and sensors adjustments	Engr./Maintenance

* Action was taken on both of these items.

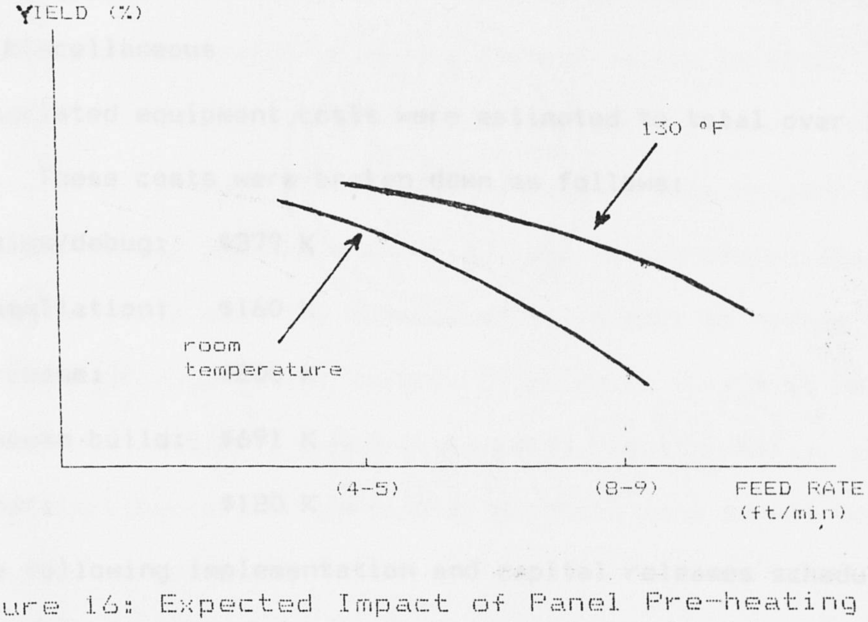


Figure 16: Expected Impact of Panel Pre-heating on Yield and Speeds --- Resist Lamination

lamination and between resist lamination/hole pierces. Additionally, the proposed job carts will reduce the remaining queues dramatically.

The increase in capacity (determined by U/H calculations) was due to eliminating N.V.A. operations, reducing recycles, and reducing set-up times (approximately 15 to 20% increase could be achieved).

Being a capital project, ROI analysis constituted the single most important justification element. Such an analysis involves three main components, U/H calculations, costs, and schedules. The U/H calculations were performed for both cases (with and without panel pre-heating). Costs included incurred as well as avoided equipment costs. An equipment list will include:

a) Automatic pre-clean loaders (3)

b) Powered, clean room, conveyor units (120' total)

c) I.D. readers (12)

d) Automatic hole punch presses (4)

e) Automatic unloaders (4)

f) Miscellaneous

Associated equipment costs were estimated to total over 1.5 million dollars. These costs were broken down as follows:

Design/debug:	$379 K
Installation:	$160 K
Purchase:	$200 K
Inhouse build:	$691 K
Other:	$120 K

The following implementation and capital releases schedules were also assumed:

Date	1/86	4/86	9/86	11/86	6/87	8/87
Event	$400 K <u>release</u>	$450 K <u>release</u>	$700 K <u>release</u>	PRS Line #1 <u>(A.P.L.P.)</u>	PRS Line #2 <u>(A.P.L.P.)</u>	PRS Line <u>#3 (APL)</u>

The Return On Investment was found to be 42.5% (details omitted for confidentiality reasons). In addition to the above justifications, other (minor) merits including improved quality and more efficient floor space utilization were to be derived also.

C) AUTOMATIC LAY-UP AND TEARDOWN--LAMINATION PROCESS CENTER

The manufacture of circuit boards requires the sequential or pin lamination of a dielectric between sheets of copper foil. The standard products require two to four sequential lamination cycles. In STD/Austin, the Lamination Center contains five presses for the lamination process. Each press comprises fifteen openings and each opening will accept one book of lamination products. The number of pages constituting a book is a function of the thickness of the product construction and, therefore, varies by product type. Each page contains four panels and each panel is ten by fifteen inches in size.

Originally, two manual lay-up stations and one manual teardown station existed for each press. The purpose of this project was to automate the lay-up and teardown of 2S, 3S, 4S sub-composites and composites on press #2. The automation tools must be highly flexible and sensitive because of the variety of products that must be assembled and the tenuous nature of some of the parts. Additionally, the following complimentary or peripheral projects were to run concurrently with auto lay-up/teardown:

1) Clean Room Upgrade

2) Lamination Carts & Lift Tables

3) Single-Ply Reusable Press Pad

4) Wessero Upgrade

The last project above (wessero upgrade) comprised the automation of brush pressure adjust and the conversion to no-pallet operation. It was completed prior to the date when the author was assigned to the auto lay-up/teardown project and, hence, it was not included in this report.

C.1) PROJECT DESCRIPTION

Auto Lay-up/Teardown and its complimentary projects were initiated in January, 1984. The projected completion data was set for January, 1985, with the peripheral projects to be completed at various times prior to that date. Considering its scope and budget, the project was a major and significant automation effort.

The Auto Lay-up station comprised an integrated system consisting of one IBM 7540 Robot, an IBM 7547 Robot, an automatic "OMK" collator, and material-handling carts. In addition to interfacing all system components, the system had to interface with the lamination press and with the operator. Auto Teardown, on the other hand, comprised a single IBM 7547 Robot that was to interface with the operator, the press, and with material handling carts. An overall lay-out of the system components relative to the lamination press is given in Figure 17. Additionally, a more detailed, three-dimensional representation of each of the Lay-up and Teardown stations is given by Figures 18 and 19, respectively. Because of security classification (IBM confidential), the equipment specification document cannot be included here. Instead, an edited version of that document is given next (refer to Figure 17 for locating positions):

1 - One Automatic "OMK" collator (position 1)

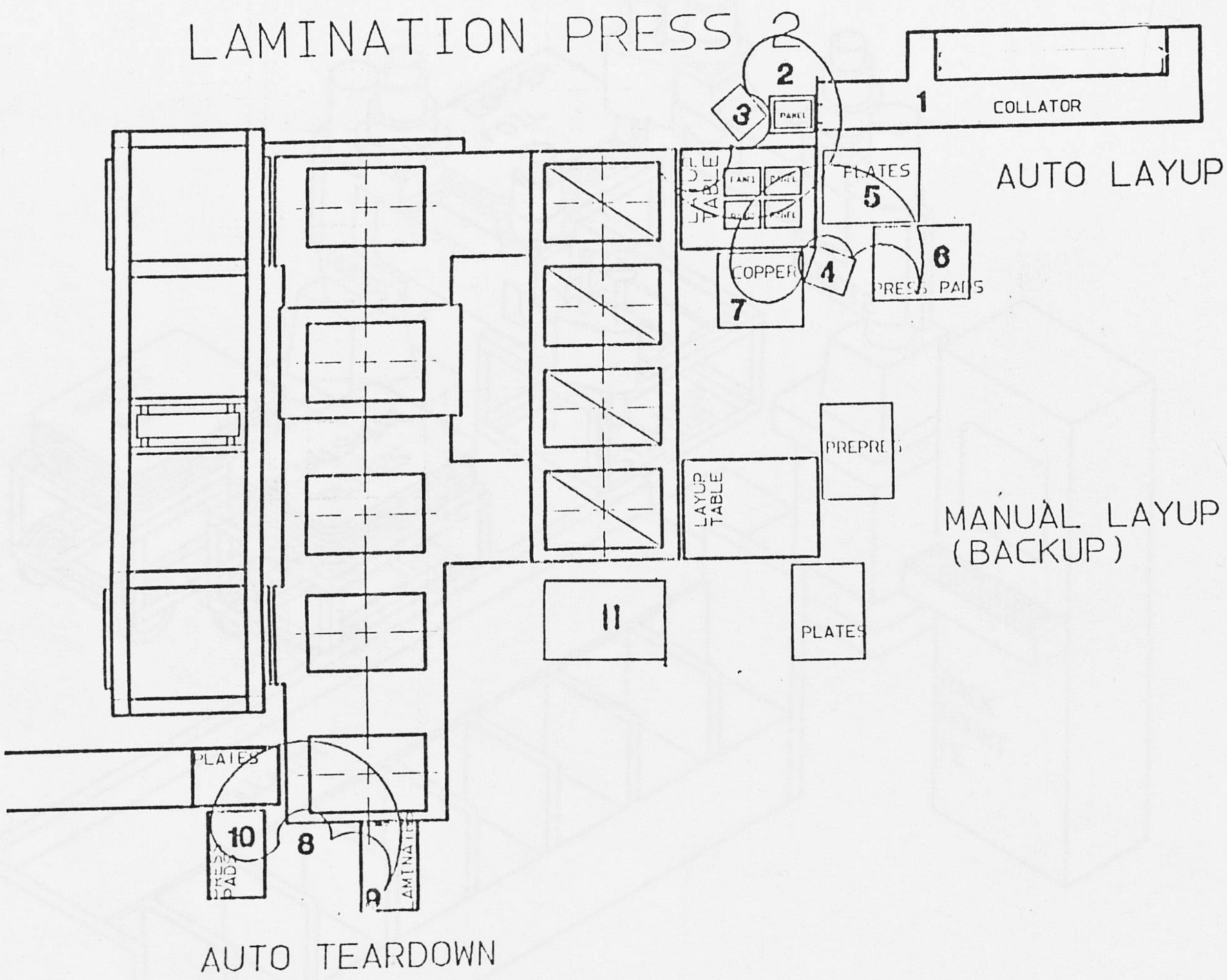


Figure 17: Auto Layup/Teardown -- Equipment/Press Layout.

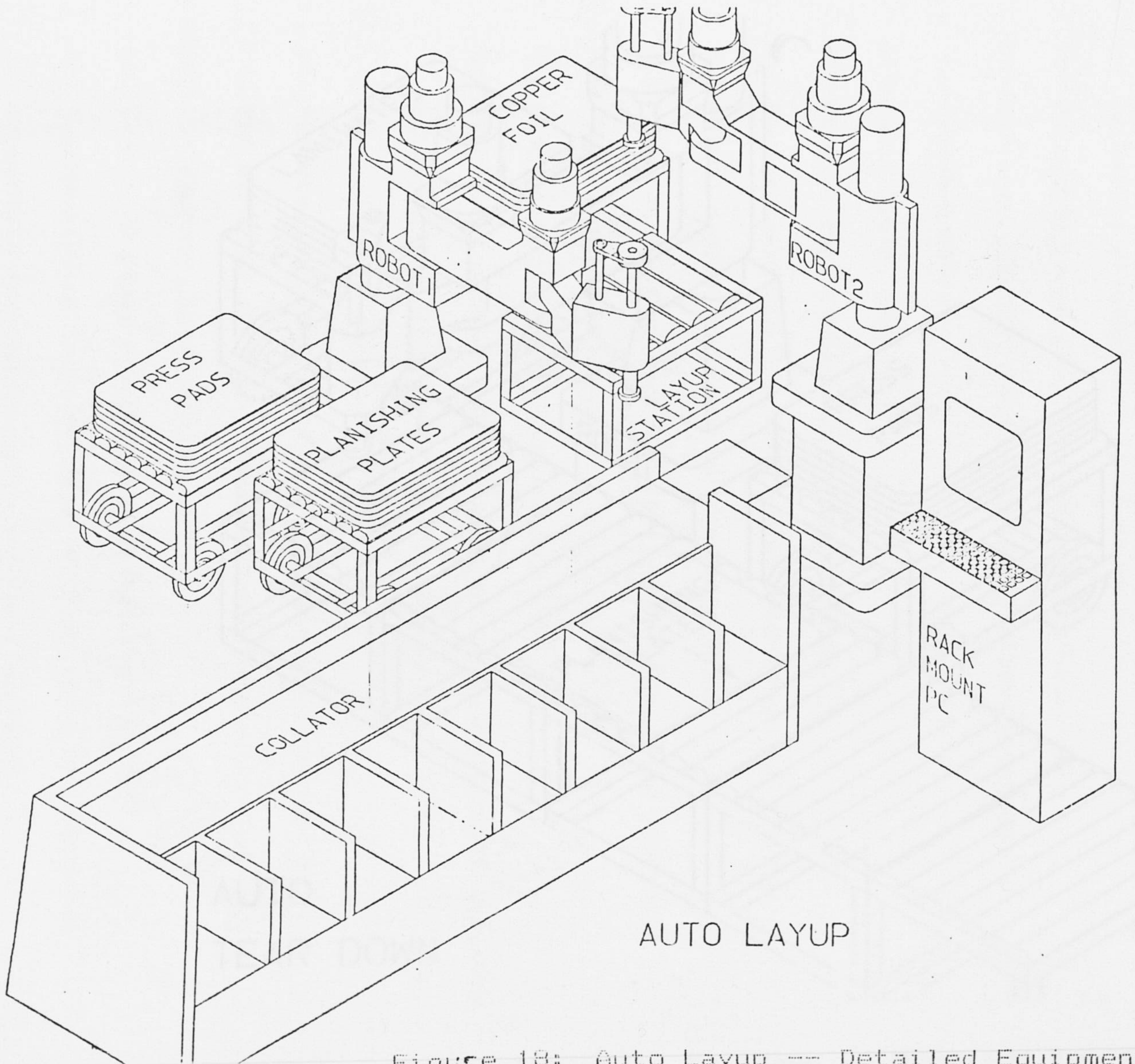


Figure 18: Auto Layup -- Detailed Equipment Layout.

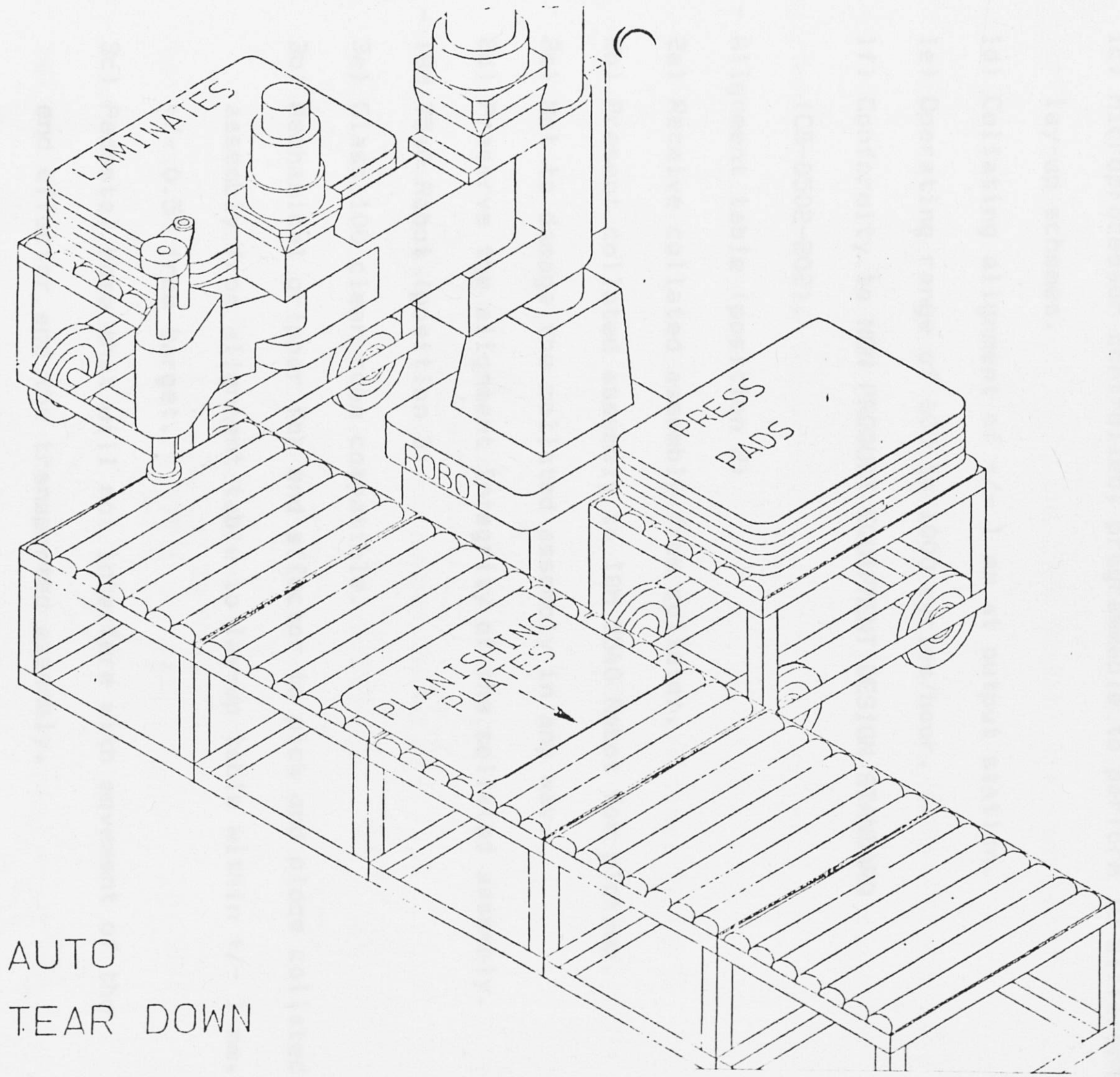


Figure 19: Auto Teardown -- Detailed Equipment Layout

1a) nine bins to be loaded with prepreg and laminates, selectively.

1b) Missing and double sheet detection.

1c) Microprocessor controlled, programmable to perform 10 different lay-up schemes.

1d) Collating alignment of +/- 1 mm at output station.

1e) Operating range of 600 to 1000 cycles/hour.

1f) Conformity to NON PRODUCT EQUIPMENT DESIGN STANDARD (CB-0502-202).

2 - Alignment table (position 2)

2a) Receive collated assembly from collator.

2b) Present collated assembly to IBM 7540 Robot for pick-up.

2c) Not to damage the collated assembly in any way.

2d) Preserve the alignment integrity of the collated assembly.

3 - IBM 7540 Robot (position 3)

3a) Class 100 clean room compatible.

3b) Mechanical gripper for end effector to pick and place collated assembly from alignment table to lay-up table within +/- 1 mm, +/- 0.5° from target.

3c) Pedestal base that will not interfere with movement of the end effector and the transported assembly.

4 - IBM 7547 Robots (positions 4 and 8)

4a) Class 100 clean room compatible (position 4 only).

4b) Vacuum pick-up (suction cups) with built-in compliance to compensate for non-leveled cart/floor surfaces.

4c) Robot (position 4) to interface with lamination carts (positions 5, 6, and 7), lay-up table, and a tack cloth fixture for wiping planishing plates.

4d) Robot (position 8) to interface with lamination carts (positions 9 and 10) and with the output conveyor of the press

4e) Two robot bases, similar to that in item 3c.

5 - IBM Personal Computer (PC), two disk drives, and associated hardware/software accessories.

Other equipment used in transporting and presenting products fell within the scope of the "Lamination Carts" peripheral project. Such equipment included the following:

1 - Fifty Lamination Carts

1a) To interface with Auto layup/teardown (positions 5, 6, 7, 9, and 10), with the Lift Tables at "Copper Shear", and with manual layup/teardown stations.

1b) Positive locating carts to transport planishing plates, press pads, laminates, and copper foil.

1c) Cart location repeatability of +/- 0.5 mm.

1d) Rubber roller tops for rolling payload on and off. Rubber not to shed or contaminate product.

1e) Carts to have wheel and roller brakes.

2 - Thirty Copper Pallets

2a) To stack copper foil at Copper Shear machine.

2b) To interface with Auto layup (position 7) and with manual layup.

2c) Pallet to be hand moveable from copper shear to cart and from cart to layup lift table.

2d) Pallet to be securely located in cart while moving.

2d) Pallet not to contaminate or damage product.

3 - Eleven Roller Tops to be installed at Copper Shear machine, and manual layup stations.

4 - Eleven Lift Tables to interface with Lamination Carts and Roller Tops at Copper Shear and manual layup stations.

Activities associated with the above included purchase, design, build, debug, installation, documentation, spare parts, acceptance criteria, and engineering support.

C.2) ASSUMPTION OF RESPONSIBILITY

The author was assigned to this project on January, 1985 - one year past its initiation date. At the time, the project was characterized as being: 1) late, 2) over cost, and 3) inflicted with a multitude of technical and communication problems. In short, it had all the signs of "a project in trouble".

As the new project leader, the author had management directives to:

1) Assess the status and needs of the project, and

2) Strive to meet the revised completion date of 4/30/85 (committed by the author's predecessor) - irrespective of resource concerns.

In order to lead effectively, the author had to become familiar with the project (goals, equipment, people and process). Meanwhile, he also had to learn about project management techniques and leadership skills. And since time was of the essence, the author had to achieve the above in the shortest possible time.

C.2.1) PLANNING AND SCHEDULING

The second step involved the planning and scheduling phases. This included the identification of all milestone activities as well as the smaller tasks. This was achieved by developing a checklist of outstanding milestone activities, estimating their durations, and identifying their predecessors (see Table 5). Moreover, Equipment Design and Build were seen as the most critical activities that required immediate and special attention. Hence, a detailed and complete checklist of all outstanding design and build tasks was developed. The checklist provided provisions for identifying: a) the person in charge, b) problem definition and dependencies, c) action taken or suggested, and d) completion time estimates. Based on data obtained above, and using PERT (Project Evaluation and Review Technique), the author constructed a new schedule for the project. The new schedule proved the fears of many that the committed completion date (4/30/85) was too aggressive. In compliance with management's desire to strive and save the committed date, the author went through various scenarios (such as re-allocating resources, introducing overtime, changing sequence of events, etc.) that resulted in successive compressions of the schedule. The following is a summary of the author's findings:

1) Given normal progress, 7/9/85 represented the most likely completion date for the project.
2) Given smooth sailing, proper managerial leadership, and a blank check, a completion date of 5/9/85 was possible.
3) As of 1/31/85, the project was almost 50% complete.
4) As of 1/30/85, the project's budget was over 75% expended.
5) Immediate resolution of critical technical issues was necessary.

On the human side, the author's main objective was to restore confidence, create a team spirit, and raise morales. These qualities were lost or diminished due to past failures, existing conflicts, and mismanaged interfaces. The author realized that such a task can be achieved only by practicing the following:

Table 5. Milestone Activity List -- Auto Layup/Teardown

AUTO LAYUP and TEARDOWN -- ACTIVITIES LIST			
#	ACTIVITY DESCRIPTION	DURATION (DAYS)	PREDECESSOR ACTIVITIES
1	equipment build /B805	20	none
2	equipment debug/B805	24	1
3	pre-qual. test/B805	3	2
4	contamination test	3	3
5	acceptance test	4	4
6	docum. acceptance	10	5
7	docum. release	10	6
8	spare parts release	10	6
9	clean room upgrade	10	none
10	site preparation	6	9
11	equip. installation	11	10,5
12	MES signoff	5	11
13	equip. debug /B60	7	12
14	manuf. process specs.	15	5
15	maintenance training	12	2
16	process debug	10	13,14,15
17	safety signoff	1	16
18	operator training	10	4
19	contamination test	5	17
20	qualification	5	19
21	PRS	1	20

1) Giving individuals a sense of responsibility, achievement, and above all, ownership, by allowing them to manage their work and to participate in decision-making pertaining to their work.
2) Encouraging upward, downward, and lateral communications so as to resolve conflicts and strengthen interfaces between individuals as well as groups.
3) Facilitating the work of individuals by listening to their needs, making timely and responsible decisions pertaining to their work, and by resolving exposures and dependencies.
4) Giving praise when deserved and support when needed.

Adopting such a collective decision-making policy proved successful from the very beginning. In formulating the project's schedule, the author used the Transactional (Quantitative/Micro) estimating technique which:

1) Takes into account the knowledge and experience of workers assigned to the project.
2) Uses estimates based on individual work activities.
3) Allows for estimating through negotiation.
4) Promotes motivation and commitment through involvement.

By doing so, the same individuals who initially resented having to meet what they perceived to be an impossible (4/30/85) schedule became supportive of the not-very-different "new" schedule.

Having completed the planning/scheduling phase, the author held a kick-off meeting that was attended by all those associated with the project, including management. The purpose of this meeting was to reflect on the project's status and to present the new schedule. In addition, the meeting served a motivational purpose by describing the challenges ahead, defining the expectations, and expressing confidence in the abilities and desires of those involved to make this project a success.

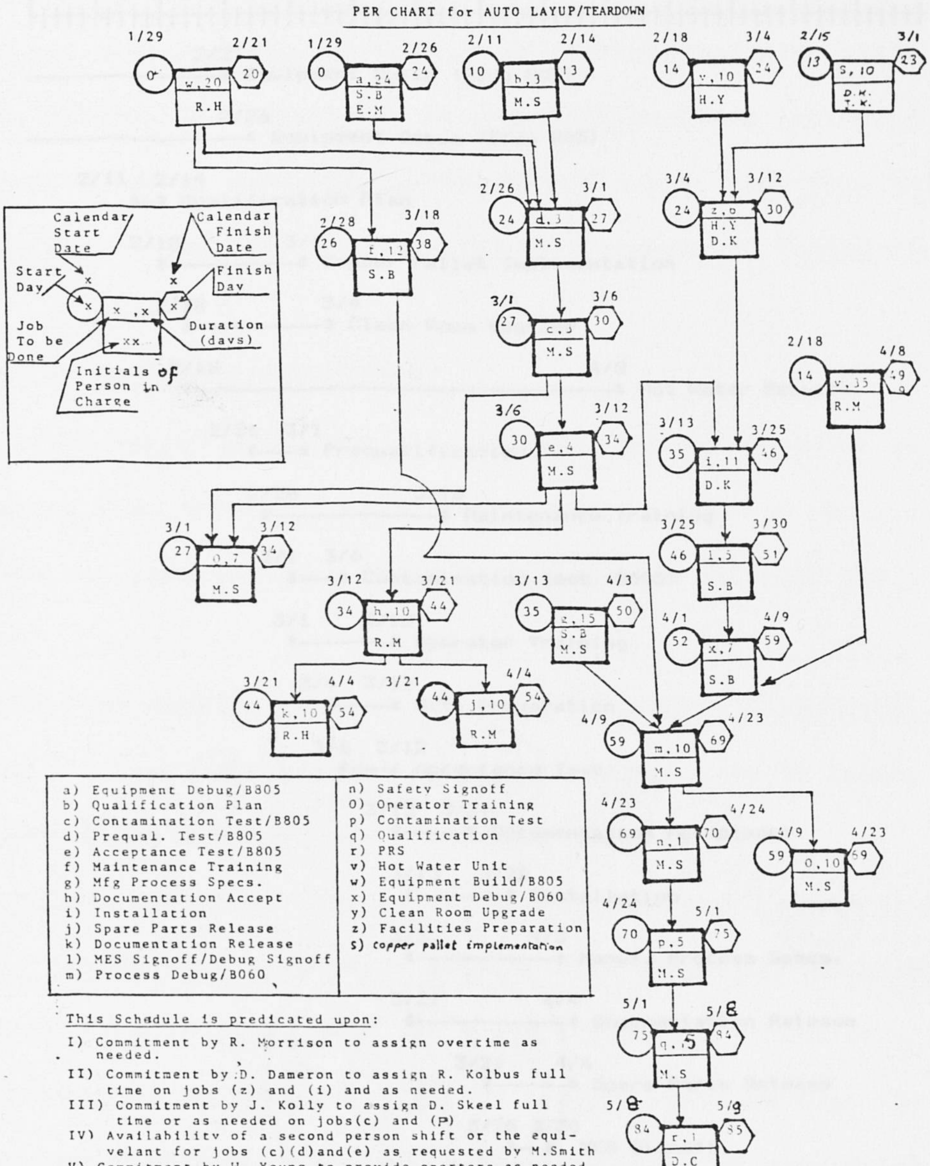
C.2.2) TRACKING AND CONTROL

Tracking the progress of a project is an essential project management task. Actual progress is measured and compared to the planned progress as given by the schedule. To ensure that individuals were aware of the target dates and of their responsibilities, copies of the following were given to each person involved with the project:

1) An overall PERT network (Figure 20) highlighting the following:
   a) Activity description and initials of person in charge.
   b) Duration and start/finish dates for each activity.
   c) Dependencies (predecessors and successors).
   d) Critical path (activities along this path have zero slack time).
2) An overall GANTT chart sorted in a chronological order. (Figure 21).
3) Personal GANTT charts that describe the activities each group leader is responsible for.

Because of time constraints imposed upon those working on the project by the tight schedule, no status reports were required from the group leaders. Instead, weekly status meetings were held and used for tracking as well as controlling purposes. The meetings focused on the following:

1) Measuring progress (checkpoints and milestones) with focus on critical activities.
2) Reporting and resolving problems.



a) Equipment Debug/B805
b) Qualification Plan
c) Contamination Test/B805
d) Prequal. Test/B805
e) Acceptance Test/B805
f) Maintenance Training
g) Mfg Process Specs.
h) Documentation Accept
i) Installation
j) Spare Parts Release
k) Documentation Release
l) MES Signoff/Debug Signoff
m) Process Debug/B060
n) Safety Signoff
O) Operator Training
p) Contamination Test
q) Qualification
r) PRS
v) Hot Water Unit
w) Equipment Build/B805
x) Equipment Debug/B060
y) Clean Room Upgrade
z) Facilities Preparation
S) copper pallet implementation

This Schedule is predicated upon:

I) Commitment by R. Morrison to assign overtime as needed.
II) Commitment by D. Dameron to assign R. Kolbus full time on jobs (z) and (i) and as needed.
III) Commitment by J. Kolly to assign D. Skeel full time or as needed on jobs(c) and (P) made more.
IV) Availability of a second person shift or the equivelant for jobs (c)(d)and(e) as requested by M.Smith
V) Commitment by W. Young to provide opertors as needed for training in concurrence with jobs(d)(e) and (m).
VI) 6 days/wk for jobs w,a,i,l, and x. All other jobs are based on 5 days/wk.

Figure 20: Activity Network -- Auto Layup/Teardown (schedule)

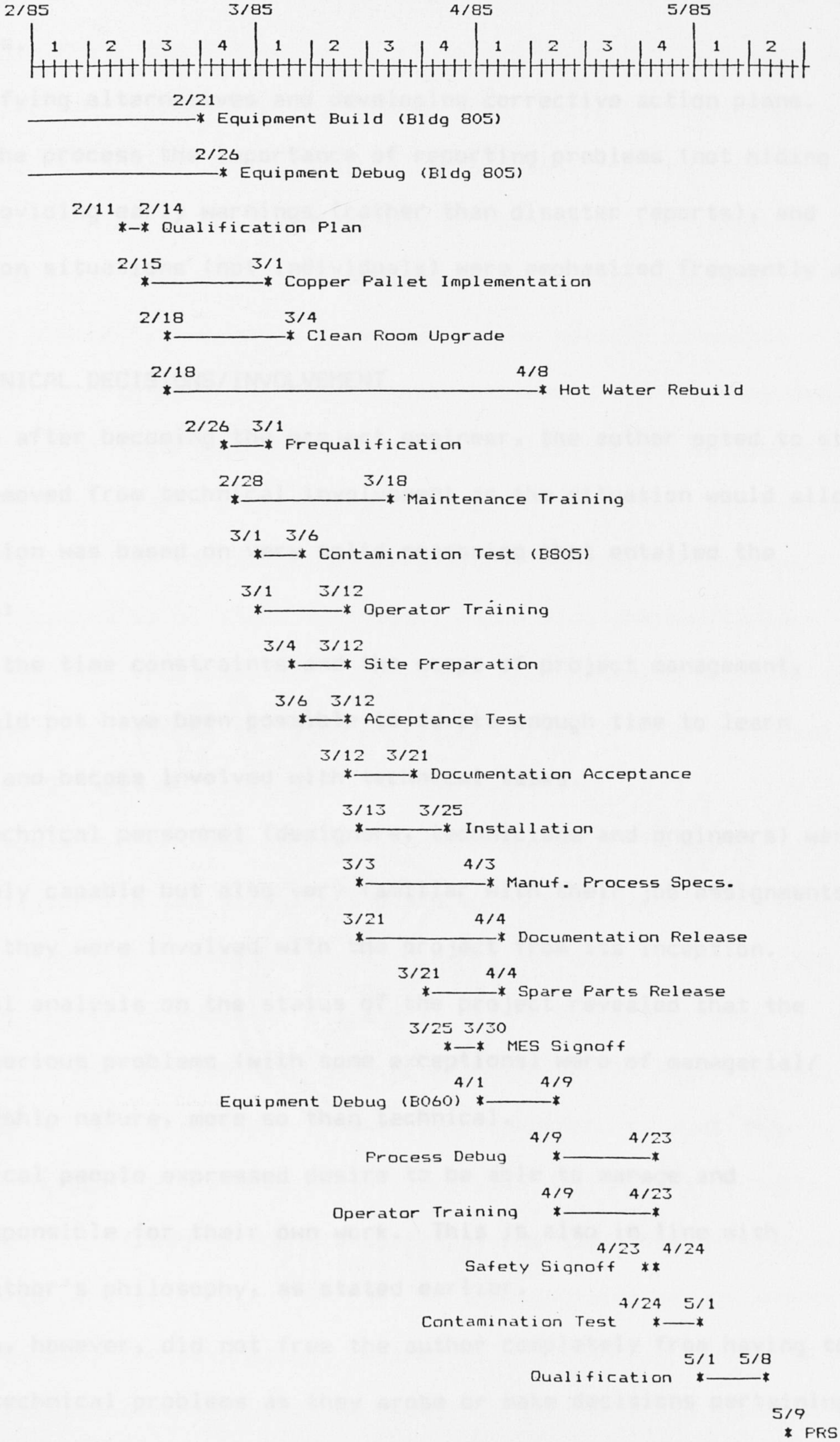


Figure 21: GANTT Schedule -- Auto Layup/Teardown

3) Identifying variances and determining their causes and effects.

4) Identifying alternatives and developing corrective action plans.

In the process the importance of reporting problems (not hiding them), providing early warnings (rather than disaster reports), and focusing on situations (not individuals) were emphasized frequently and often.

C.3) TECHNICAL DECISIONS/INVOLVEMENT

Soon after becoming the project engineer, the author opted to stay as far removed from technical involvement as the situation would allow. His decision was based on very solid reasoning that entailed the following:

1) Given the time constraints and the scope of project management, it would not have been possible to devote enough time to learn about and become involved with technical tasks.

2) The technical personnel (designers, technicians and engineers) were not only capable but also very familiar with their job assignments since they were involved with the project from its inception.

3) Initial analysis on the status of the project revealed that the most serious problems (with some exceptions) were of managerial/ leadership nature, more so than technical.

4) Technical people expressed desire to be able to manage and be responsible for their own work. This is also in line with the author's philosophy, as stated earlier.

This, however, did not free the author completely from having to address technical problems as they arose or make decisions pertaining to technical issues when needed.

The first impasse entailed the definition and qualification of a 1-ply reusable Press Pad. This was a peripheral project driven by process engineering. Such a pad was required so that it can be handled by the robot's vacuum pickup. Even though a target qualification date was set for 7/1/84, such a pad was never defined. Because of its impact on the robot's end effector, and on a wiper mechanism for the wiping of planishing plates, it became a critical problem needing immediate resolution. The author, the area process engineer, and the lead design engineer tackled this issue. Based on a suggestion given by the author, the solution entailed the stitching together of individual pad sheets used in the existing manual layup operation. The newly defined pad, therefore, consisted of eight individual paper pads and one tedlar release sheet stitched together in a manner that prevents drooping of the pad when lifted with the vacuum pickup. Moreover, the stitching was limited to the nonfunctional areas of the pad.

Another occasion that necessitated the author's involvement on a technical issue was the decision pertaining to the cancellation of development work on a vision system intended for auto teardown. The author justified his decision based on: 1) the functional need for a vision system was not demonstrated and established, 2) high cost vs. little benefit to be derived, 3) budgetary concerns, 4) available alternatives, and 5) a strong belief in simple designs and concepts. The initial justification for the vision system was based on low cost estimates as well as a desire on part of the equipment design and build group to develop the technology, neither of which was applicable at the time the cancellation decision was made. In addition, the intended function of detecting, and directing the robot to pick up dropped laminates was neither necessary nor feasible to the extent desired. Upon completing the equipment build and design activities, it was demonstrated that the vision system would have been a redundant addition.

One last illustration of the author's technical involvement entailed the "OMK" automatic collator. Under the original design, the package delivery mechanism at the output end of the collator's conveyor consisted of a push bar, bottom finger bars, and top leaf springs. As the collated assembly is pushed out with the push bar mechanism the finger bars and the leaf springs exert pressure on the top and bottom faces of the package so as to keep the various layers of the package well aligned. However, due to dynamic factors (inertia load) some slippage was taking place resulting in misalignment and misregistration that exceeded the tolerances required by the process specifications. Due to time and budgetary constraints, a quick, reliable, and cost effective solution was needed. The author became personally involved only after frequent attempts to remedy the situation merely by changing conveyor speeds, stiffness of the springs, and other operation and design parameters failed. As a last resort, technical personnel suggested the implementation of a major design change that required replacement of the above mechanism with a cylinder actuated mechanical gripper that would have to be interfaced with the collator's cycle. They estimated five to six weeks and over $8000.00 in implementation, time and cost. These estimates were not acceptable to the author, instead he took upon himself the task of finding an alternative solution. Relying on his academic preparation in statics, dynamics, and machine design he conceptualized, designed and implemented a replacement mechanism that proved to be accurate and reliable. The technique can best be described as a cam-driven mechanism that generates a compound angled surface suitable for the alignment and positioning of the collated assembly. A complete description of the make-up of the new technique is given in the Appendix (also refer to Figure 22).

C.4) INACTIVE STATE (PROJECT ON HOLD)

Effective March 15, 1985, all work activities on the project were halted due to:

1) Unexpected quota volumes that prevented manufacturing from releasing the presses for installation/qualification of the equipment

2) Need for additional capital funding to continue installation and subsequent activities.

The high quota volumes were to continue beyond the June, 1985 date. In fact, it was almost certain that manufacturing would not be able to release the presses until late summer of that year. Hence that provided the author with the opportunity to evaluate the budgetary status and to act on requesting additional funds.

It was known all along that additional funding would be needed. However, no such request was initiated then due to management directives to put budgetary concerns aside and concentrate on technical progress. By first demonstrating the technical feasibility of the project, a request for additional funding would stand a better chance for being approved because:

1) The project could be defended with more conviction, and its feasibility could be demonstrated to those in charge of approving the request.

2) The dollar amount requested could be estimated more accurately.

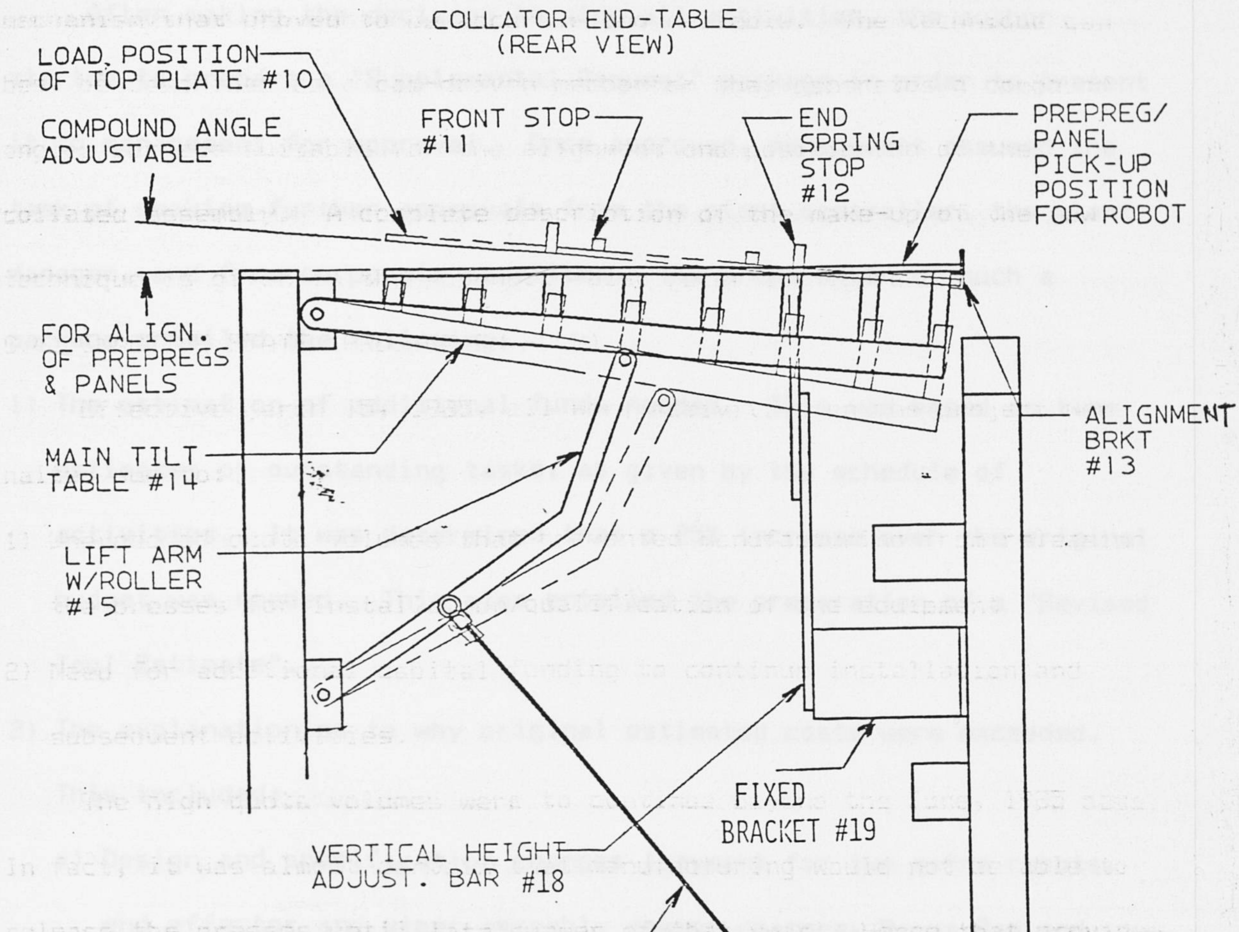


Figure 22:
Teflon-Coated/Spring-Loaded, Compound-Angle Mechanism

After making the decision to stop all activities, the author started to prepare a "Supplemental Request" package in order to present it to management for approval. Once approved, management assumed the task of seeking further approvals from the plant controller, the plant manager, and from corporate committee. The preparation of such a package entailed the following:

1) The estimation of additional funds needed. This was based on time estimates of outstanding tasks, as given by the schedule of activities. It was determined that a 25% increase over the original budget was needed. This also entailed the preparation of a "Revised Tool Estimate".
2) The explanation as to why original estimated costs were exceeded. This included:
   a) Design and specification changes (payment for two extra robots, end effector and wiper assembly design changes, Press Pad and collator problems, vision system development cost, etc.)
   b) Low initial estimates.
3) The justification as to why the Supplemental Fund Request should be approved. This encompassed the following:
   a) Return on Investment (ROI) analysis
   b) Impact of deferral (headcount, safety, capacity, and similar considerations).

C.5) RESUMPTION OF ACTIVITIES/RELINQUISHING RESPONSIBILITIES

The supplemental funds requested were released on July 27, 1985. Moreover, after repeated negotiations with Manufacturing and Industrial Engineering, Manufacturing committed to release the presses on September 21, 1985 to allow for installation and qualification of the equipment.

At that time, the author had to relinquish his responsibilities in order to spend the fall semester in residence at Texas A&M as per the requirements of the Doctor of Engineering program. Hence, he updated the project's schedule to reflect the new dates and transferred all technical responsibilities to the team leaders. Also, the manufacturing manager of the lamination process center assumed the responsibility of conducting weekly status meetings to ensure timely progress of activities as per the schedule.

D) OTHER PROJECTS

In addition to the two main projects described above, the author was involved with smaller tasks and other activities. This section will touch on the significant ones to provide a glimpse of each.

D.1) LAMINATION CARTS PROJECT

As mentioned earlier, this was a complimentary project to Auto Layup/Teardown. The equipment for this project was described and listed in section C.1. The equipment was designed, built, and shipped prior to the author's appointment as the project leader for Auto Layup/Teardown. Again, it was necessary for the author to study the objectives and status of this project. The findings could be summarized as follows:

1. The purpose of this project was to: a) Provide better and more accurate means of presenting product to and interfacing with the robots at the Automatic Layup and Teardown stations, and b) To replace fork lift trucks with lamination carts for transporting product between and within Process Centers.
2. Like Auto Layup/Teardown, the Lamination Carts project was behind schedule and over cost.
3. The remaining activities included floor leveling and equipment

installation as follows:

a. Conversion of the two copper shear stations to allow the use of new copper pallets for the stacking of copper foil. This required the installation of one cart collar, one hydraulic lift table, and one roller top per each station.

b. Conversion of nine manual layup stations to interface with the new copper pallet. This involved the installation of equipment such as described in part a.

c. Conversion of two Thompson Press stations to interface with the lamination carts. This entailed the installation of one conveyor and one lift table at each station.

The author constructed the implementation schedule of Figure 23. However, due to budgetary concerns, only those activities that were critical to Auto Layup/Teardown were implemented. Hence, one copper shear station was converted as per the schedule. Moreover, in order to provide operators with the opportunity to use the new pallets and get accustomed to their tighter tolerances prior to introducing them to Auto Layup, two manual Layup stations (on Press #3) were also converted.

D.2) EXPERT "PROJECT MANAGEMENT" SYSTEM

This assignment constituted the development of a computer-aided methodology suited for the management of projects of technical nature. In addition to serving as a teaching tool for the less experienced project engineer, such a methodology would also serve the purpose of establishing commonality and uniformity in planning, scheduling, tracking, and controlling such projects. The suggested methodology was given in a report that touched on all aspects and elements of project management (except financial). While the report in its entirety is

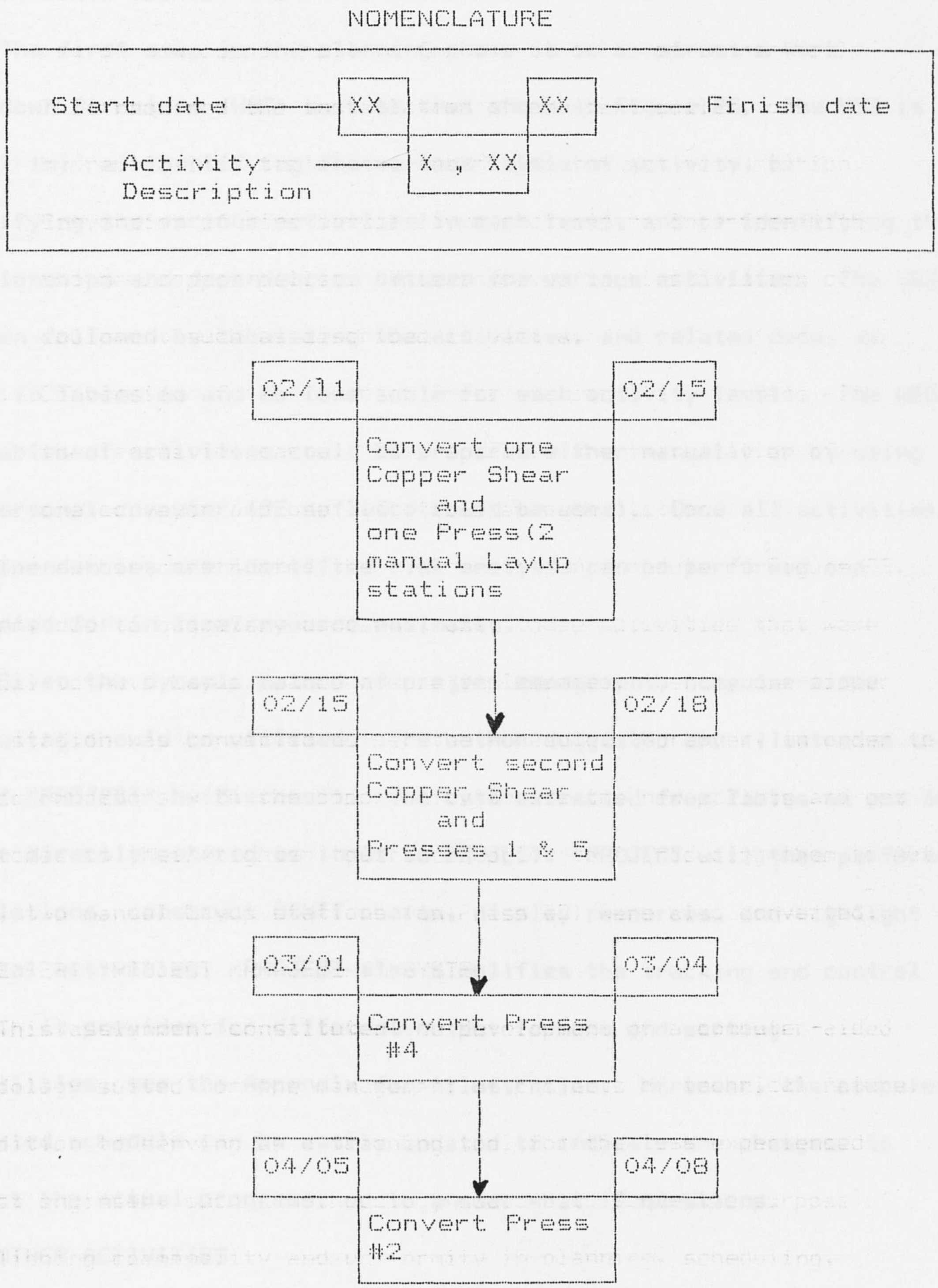


Figure 23: Activity Network -- Lamination Carts (Schedule)

included in the Appendix, a brief highlight of its main contents will follow next.

The first step in the planning phase is to construct a Work Breakdown Structure (WBS) such as that shown in Figure 25. The WBS is useful in: a) identifying the various levels of activity, b) identifying the various activities in each level, and c) identifying the relationships and dependencies between the various activities. The WBS is then followed by tabulating the activities, and related data, as shown in Tables 6a and 6b (one table for each activity level). The WBS and tables of activities could be prepared either manually or by using the personal computer (PE software could be used). Once all activities and dependencies are identified risk analysis can be performed and accounted for in time/resource estimates.

Given the dynamic nature of project management, computer-aided scheduling should be utilized. The author suggested and illustrated the use of "PROJECT" by Microsoft. The data extracted from Tables 6a and 6b can be directly entered as input to PROJECT. PROJECT will then perform calculations, construct GANTT charts, display resources, and highlight critical activities. PROJECT also simplifies the tracking and control tasks. It provides for different output formats and sorting capabilities, see the Appendix for illustration. Moreover, the computer generated schedule can be easily updated to indicate any changes, to reflect the actual progress, or to answer what if questions.

D.3) OTHER ACTIVITIES

As a team member, the author actively participated in the task of developing "Process Equipment Specification" GUIDELINE. The purpose of this task was to establish guidelines pertaining to the format and contents of a "Process Equipment Specification" Document. In addition to establishing commonality and uniformity, these guidelines simplify and enhance the task of preparing such a document. It assists the new or not very experienced equipment engineer in preparing the equipment specification document necessary in the acquisition of machines. Original input was enhanced and supplemented with excerpts extracted from existing equipment specification documents, as applicable. The result was a complete and easy to use reference document. This GUIDELINE document is included in the Appendix.

Another task in which the author was involved in as a team member entailed a study on "Failure Mode and Effect Analysis" (FMEA). The study, was being directed by Dr. Joe Foster of the Texas A&M Industrial Engineering Department. The purpose of this study was to establish a methodology to be used by the manufacturing engineer in evaluating equipment design from a reliability/maintainability standpoint and in recommending preventive maintenance schedules. The author's participation was limited to the last two weeks of his internship.

CHAPTER V

SUMMARY AND CONCLUSIONS

A. SUMMARY

The motivation here is to relate the intern activities to the internship objectives. One objective may be addressed by several activities and one activity may relate to more than one objective. A sincere effort will be made in sorting the relationships between the two.

One objective, Orientation, has been realized through:

1) Professional Development courses as well as attending seminars and, attending and participating in weekly Automation/CFM meetings.
2) Assisting in the Loop Analysis depicting Process Flow; providing data base for use in computer simulation of the Core Circuitize Center and, evaluating the validity of the simulation results.
3) Interfacing with the various departments as per the RASI chart (see Appendix) while developing the automation plan for the Core Circuitize Process Center. This project encompassed the first three phases (Initiation, Definition, and Justification) outlined in that chart.
4) Management of the Auto Layup/Teardown and Lamination Carts Projects. The author's involvement here encompassed the last two phases (Acquisition, Qualification).

The second objective, Contribution, was fulfilled by:

1) The development of a sound and complete automation plan. The data gathering and systematic analysis proved useful in shaping and

promoting the computer simulation effort. Many elements of the plan were indirectly helpful to CFM implementation, process and equipment troubleshooting, and tool planning in the Core Circuitize Center.

2) Transforming Auto Layup/Teardown from a high risk project to a low risk project. This in turn resulted in the approval of additional funds, without which the project could have been terminated.
3) The development of the "Process Equipment Specifications Guideline" and the "Project Management Guideline" provided reference documents that will enhance and simplify the task for equipment engineers.
4) The technical contributions which were known for simplicity and cost effectiveness. These contributions resulted in three Cost Effectiveness Awards and the submission of one invention disclosure.

The third and last objective, Development, was accomplished by:

1) The interfacing necessitated by the two main projects. This interfacing helped develop the author's interpersonal skills.
2) The enriching of the author's technical abilities. This was due to participating in and supervising the progress of technical projects.
3) Improving leadership and administrative skills by coordinating the activities of professionals representing various disciplines. This was apparent in the responsibilities associated with the author's role while assigned to the two main projects.
4) The author's participation in meetings and seminars as well as taking professional development courses offered by IBM and by outside organizations.

As a result of these assignments, the author had every opportunity to contribute, develop and learn about the organizational procedures and approach to problems.

B. CONCLUSION

The author's internship with IBM Corporation exposed him to unfamiliar fields and new challenges in one of the most respected and successful companies in corporate history. The nature and scope of the assignments afforded the author with the opportunity to experience leadership and technical roles in a high pressure and dynamic production environment. In a high technology company, the author observed, it is not only how well you perform that counts but also how well you can adapt to rapid and continuous change to product, processes, and every other aspect of the business.

In conclusion, the material presented in this report demonstrates that the internship experience was enriching, challenging and rewarding. It allowed the author to contribute to the internship firm and, at the same time, improve his personal and professional skills. The author strongly believes that the internship fulfilled his own objectives as well as those set forth for the Doctor of Engineering program. Most of all, the internship was a successful and enjoyable experience due largely to the positive attitude of the people with whom the author worked.

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APPENDIX (A)

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE
FOR ACQUIRING CAPITAL PROCESS EQUIPMENT

07-05-1985

STD Equipment Engineering
Department 23E/Building 045
Austin, Texas

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

OBJECTIVE/SCOPE

The OBJECTIVE of this document is to provide the normal procedure by which capital process equipment is conceived and implemented by Manufacturing Engineering (M.E.) and to define area responsibilities, support and communication within and external to M.E.

The SCOPE of this procedure covers all capital process equipment (tools) acquired by Manufacturing Engineering for Manufacturing use.

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PREFACE

This procedure divides the activities required to conceive and implement capital process equipment into five phases, each of which must be completed prior to the start of the subsequent phase. These are listed and described briefly on page 4 of this document.

Within each phase, many individual tasks must be completed. Listed on subsequent pages of this procedure are the major activities for each phase. Each phase is given a separate matrix on its own page. Within the matrices tasks that are printed in the upper case are listed in order of performance. Tasks that are printed in the lower case are in general order of performance but may, in practice, be performed concurrently or in any order with respect to each other.

For each of these tasks/activities the involvement of applicable M.E. departments and support groups is indicated on the matrix. All groups that may be involved are indicated; not all groups will be involved as indicated on every project due to differences in individual project scope/complexity. That involvement has been divided into three general categories that are listed and described below:

- RESPONSIBLE (R)

  This is the group that has ultimate accountability for the performance of the task. In the process of performing the task, this group is required to secure the cooperation of the support groups (indicated on the matrix by "S") that must assist them in completing their task. The responsible body must also keep other appropriate bodies informed of their activities (indicated on the matrix by "I"). Finally, this group must obtain approval of their work from all appropriate groups, both formal and informal. These approvals are not indicated on the matrices within this document. They are, however, inherent to the tasks listed on the following pages. That is, in the course of providing support to the responsible group, each support group will have ample opportunity to express approval or disapproval. Many approvals are also requirements of other formal Operating Procedures and, hence, are not redundantly included here.

- SUPPORTIVE (S)

  A group with this designation is one that must assist the responsible group in the performance of their task. Input/assistance from these groups will be solicited by the responsible group when needed. In the course of providing that input/assistance to the responsible group the support group(s) will inherently be giving approval to the actions of the responsible group. Sometimes that approval will be formalized, as specified by other Operating Procedures. See comments above concerning approvals.

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

- INFORMED (I)

  Any group on the matrix with this label has a "need to know" the actions of the responsible group and will be kept informed by the responsible group of those actions, either informally (ex. telephone) or formally (ex. memo or meeting) as deemed necessary by a mutual understanding between the groups.

Below is a key to the department/group abbreviations that appear on the following pages:

- EQ ENG Equipment Engineering
- PRO ENG Process Engineering
- FAC ENG Facilities Engineering
- MFG Manufacturing
- REL Reliability
- ES Equipment Services
- CS Chemical Services
- PUR Purchasing
- IND ENG Industrial Engineering
- SAF Safety
- IH Industrial Hygiene
- QUA ENG Quality Engineering
- INF SER Information Services
- FIN Finance

FIVE PHASES OF CAPITAL PROCESS EQUIPMENT ACQUISITION

- PHASE 1 -- INITIATION

  The inception of a project occurs due to one or more of these reasons: Safety, Quality (Yield improvement), Cost reduction, Capacity increase, Automation/Continuous Flow Manufacturing (CFM), New product, Equipment replacement, New process, Strategic directive.

- PHASE 2 -- DEFINITION

  The project requirements are stated in terms of three situations:

  - A specific equipment type and source (replacement or replication)
  - A specific equipment function, but no type or source known
  - A specific process problem, but no equipment function/concept, type or source known

  This phase includes the creation of detailed project specifications, budgetary estimates/schedules and capital planning

- PHASE 3 -- JUSTIFICATION

  Budgetary estimates/schedules are refined into commitments and documented via the Capital Equipment Commitment document. Capital funding for the project is justified, requested and released. The final project schedule is determined.

- PHASE 4 -- ACQUISITION

  The equipment is sourced, ordered, designed and built. The site is prepared and the equipment is installed. Safety approval is acquired. The equipment is debugged. Interim documentation and training are supplied to Equipment Services. Training of Chemical Services and Manufacturing also is provided.

- PHASE 5 -- QUALIFICATION

  The process specifications are written (MPS/QPS) and the process is debugged. The process goes through a Qualification and, upon passing Qualification, "Production Run Start" (PRS) occurs. The final documentation for the equipment is released. Seventy-five days after PRS, a total project audit is held to discuss outstanding issues and their solution. The equipment is "Maintenance Accepted" by Equipment Services. The project is closed.

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PHASE 1 -- INITIATION

KEY: R = RESPONSIBLE, S = SUPPORTIVE, I = INFORMED												
ACTIVITY	DEPARTMENT(S) OR GROUP(S)											
	EQ ENG	PRO ENG	FAC ENG	MFG	REL	ES CS	PUR	IND ENG	SAF IH	QUA ENG	INF SER	FIN
ESTABLISH NEED	S	R		I	I	I		I	I	I	I	
Develop Proposed Project Schedule	S	R	I	I	I	I		I		I	I	

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PHASE 2 -- DEFINITION

KEY: R = RESPONSIBLE, S = SUPPORTIVE, I = INFORMED

ACTIVITY	DEPARTMENT(S) OR GROUP(S)											
	EQ ENG	PRO ENG	FAC ENG	MFG	REL	ES CS	PUR	IND ENG	SAF IH	QUA ENG	INF SER	FIN
WRITE PROCESS REQUIREMENTS SPECIFICATION	S	R		S	S	S			S	S		
DEVELOP INITIAL EQUIPMENT CONCEPT	R	S	I	I	S	I		I	I		S	
DEVELOP BUDGETARY EQUIPMENT ESTIMATE AND SCHEDULE	R	S	S	I	S	S	S				S	
DEVELOP BUDGETARY PROJECT ESTIMATE AND SCHEDULE	S	R	I	S	S	S		I		I	I	I
INPUT TO CAPITAL PLAN	S	R	I	I				S			S	S
Write Environmental Impact Assessment or Negative Impact Statement	I	R	S	I					S			
Write Process Equipment Design and Performance Specification	R	S	I	I	S	S		I	I	I	S	

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PHASE 3 -- JUSTIFICATION

KEY: R = RESPONSIBLE, S = SUPPORTIVE, I = INFORMED

ACTIVITY	DEPARTMENT(S) OR GROUP(S)											
	EQ ENG	PRO ENG	FAC ENG	MFG	REL	ES CS	PUR	IND ENG	SAF IH	QUA ENG	INF SER	FIN
PREPARE CAPITAL EQUIPMENT COMMITMENT DOCUMENT	S	R	S	S	S	S		S	S	S	S	S
DEVELOP CONDITIONAL EQUIPMENT SCHEDULE	R	S	S		S	S	S				S	
DEVELOP CONDITIONAL PROJECT SCHEDULE	I	R	I	I	I	I		I	I	I	I	I
PREPARE AND PRESENT CAPITAL JUSTIFICATION	S	R	I					S			S	S
RELEASE FUNDS	I	I	I	I				I				R
DEVELOP AND COMMIT TO FINAL PROJECT SCHEDULE	S	R	S	S	S	S	S	S	S	S	S	S

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PHASE 4 -- ACQUISITION

KEY: R = RESPONSIBLE, S = SUPPORTIVE, I = INFORMED

ACTIVITY	DEPARTMENT(S) OR GROUP(S)											
	EQ ENG	PRO ENG	FAC ENG	MFG	REL	ES CS	PUR	IND ENG	SAF IH	QUA ENG	INF SER	FIN
SOURCE DECISION	R	S			I	I	S				I	
Request and review vendor quotations	R	S	I	I	S	S	S					I
WRITE FACILITIES ENGINEERING SERVICE REQUEST(S), FESR(S)	R	S	S	I								S
Place vendor order	S	I			I	I	R					S
Hold equipment design and build review(s)	R	S	I		S	I	S		S	I	I	
PREPARE SITE	S	S	R	S	S	S		S	S		I	
ACCEPT EQUIPMENT BUILD	R	S		I	S	S	S		I		I	
INSTALL AND OBTAIN FIRST SAFETY SIGN-OFF (M.E.S.)	R	S		S	S	S			S			
DEBUG EQUIPMENT	R	S		I	S	S				I	S	
Provide interim documentation package	R	I			S	S						
Train Equipment Services	R	S		S	S	S					S	
Train Chemical Services	S	R	S	S	S	S			I			

STD MANUFACTURING ENGINEERING FUNCTIONAL PROCEDURE

PHASE 5 -- QUALIFICATION

KEY: R = RESPONSIBLE, S = SUPPORTIVE, I = INFORMED

ACTIVITY	DEPARTMENT(S) OR GROUP(S)											
	EQ ENG	PRO ENG	FAC ENG	MFG	REL	ES CS	PUR	IND ENG	SAF IH	QUA ENG	INF SER	FIN
DEBUG PROCESS	S	R		S	S	S		I		S	S	
Obtain final safety sign-off	S	S	S	R	S	S			S	S		
Train Manufacturing	S	R		S	S	S						
Write Manufacturing Process Specification (M.P.S.)		R		S				S	S	S	S	
Write Quality Process Specification (Q.P.S.)		S		S				S	S	R		
Develop Qualification Plan	I	R		S	I	I				S		
QUALIFY PROCESS	S	R		S	I	I				S		
Issue Qualification Acceptance Tag and notice	I	I		I	I	I		I	I	R		
Maintenance Accept equipment (Conditional)	S	I		I	R	S				I		
START PRODUCTION (P.R.S.)	I	S	I	R	S	S		I	I	I	I	I
CONDUCT 75 DAY POST-P.R.S. AUDIT	R	S	S	S	S	S	S	S	S	S	S	S
RELEASE FINAL DOCUMENTATION	R	I			I	I						
MAINTENANCE ACCEPT (FINAL)	S	I		I	R	S						

APPENDIX (B)

TITLE

Cam-Actuated/Spring Loaded, Compound Angle, Mechanism for the Accurate Registration & Alignment of Automatically Collated, Multi-Layered Stacks of Prepreg and Copperclad Laminates.

PROBLEM SOLVED

This Technique was successfully implemented on an Automatic OMK Collator to rectify misallignment and misregistration problems encountered by the automation of the Layup operation in the manufacturing of circuit boards.

DESCRIPTION

The Automatic Layup station consists of Robots, Carts, and a Collator. The system Collator presents collated stacks of base laminates and prepreg to the system Robot that places these stacks onto the Layup table. The accurate alignment and registration of these stacks is key to the Layup process.

The new technique provided better and more accurate method of presenting the collated stacks to the system Robot. It replaced the original mechanism that was provided with the OMK collator. The new mechanism employs concepts of gravity, friction, and spring forces for the accurate positioning and alignment of the collated packages. In addition to outperforming the original mechanism, this technique exhibits advantages over other methods such as "Tilted Shake Tables" and "Cylinder-Actuated Grippers".

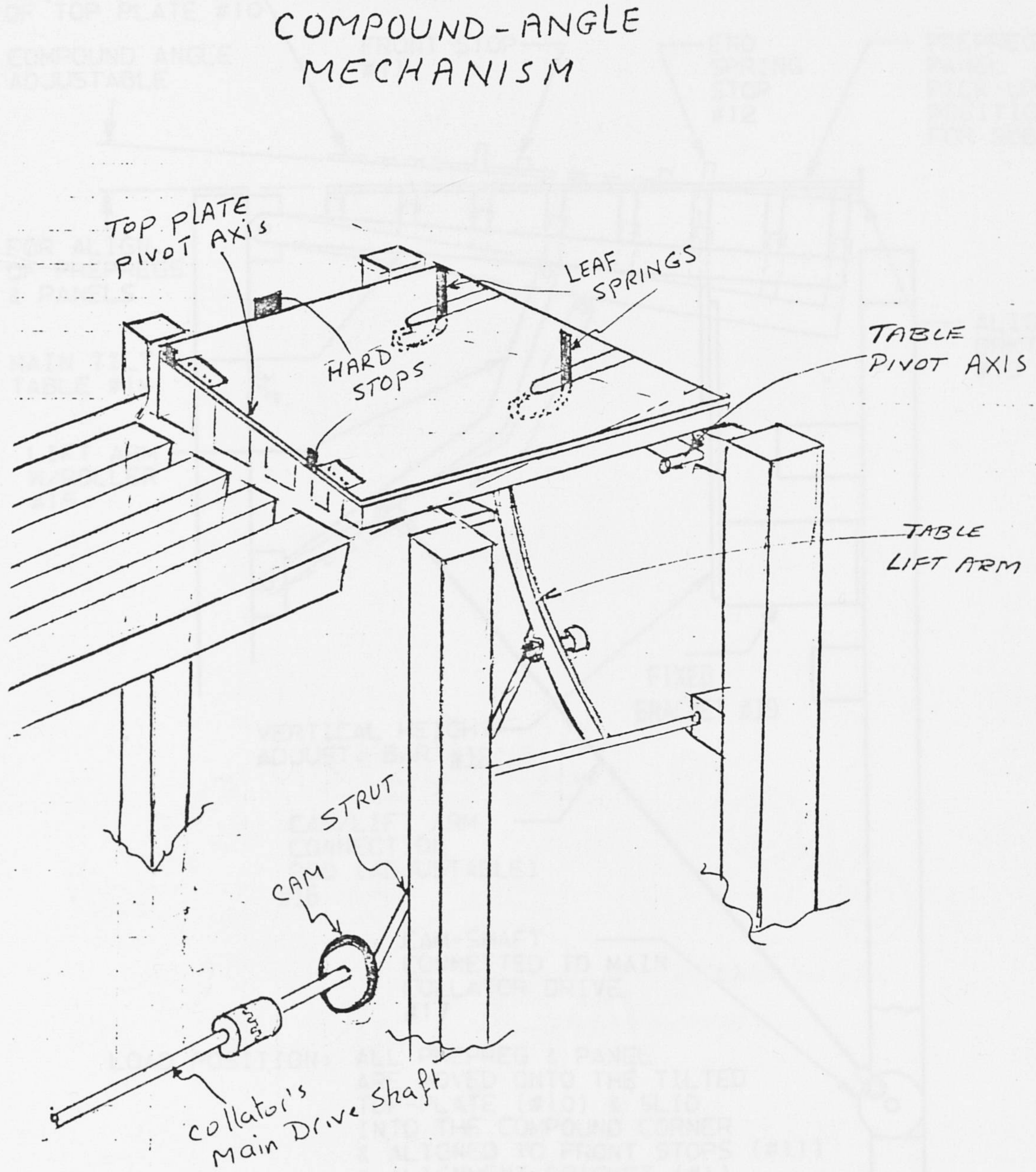
The new mechanism is directly linked to the main shaft drive of the collator via a strut that is connected to a cam at the output end of the shaft. With each Collator cycle, the mechanism undergoes one cycle that can be decomposed into the following phases:

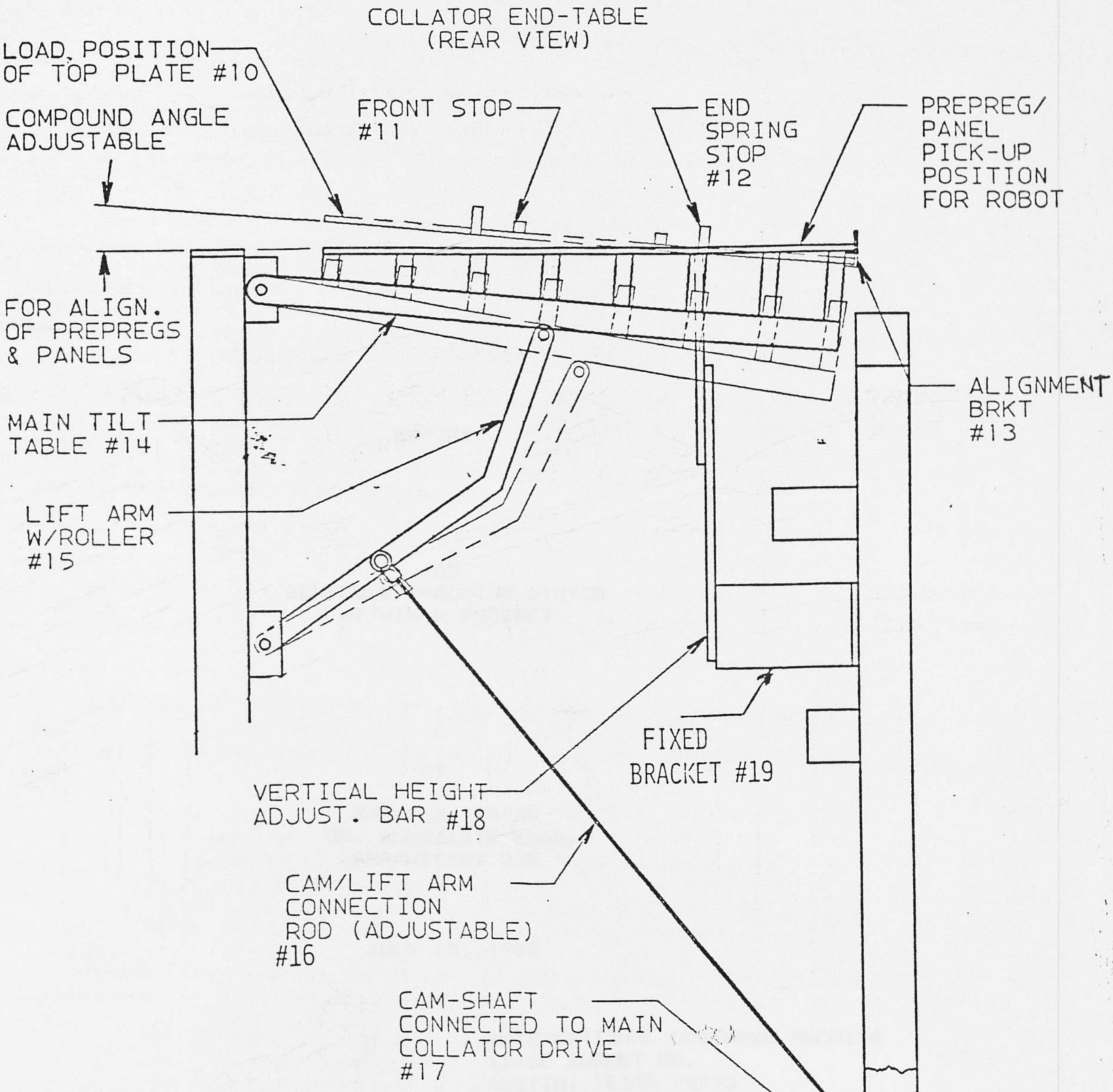
1) Loading Phase:
   Main Lift-Table (#14) drops down to same level as the Collator's feed conveyor. Simultaneously, top plate #10 assumes acompound angle configuration. While in this position, a collated stack is fed onto the top plate.
2) Dwell Phase:
   Top plate #10 dwells in the compound angle configuration for a short period of time. This allows for the downslide, and hence, the registration and alignment of the fed package.

3) Unload Phase:
   The tilt table lift and assumes a horizontal position. Simultaneously, the top plate assumes a horizontal configuration with the collated stack resting on top of it.

The top plate #10 is hinged to the front end of the tilt table #14. The motion of the tilt table is directly linked to that of the Collator's main drive shaft via cam #17, strut #16, and lift arm #15. The vertical bar #18 is rigidly mounted to fixed bracket #19 which allows for vertical and horizontal adjustments. When the tilt table is lowered, the vertical bar prevents the back end of the top plate from dropping with it and thus causing it to rotate about the front hinges thereby generating a compound angle surface. When in the compound angle configuration, a collated package is fed onto the top plate, overpassing the front stops #11. Almost instantly, the package starts to slide down the bi-directional incline of the top plate. The sliding process is enhanced and accelerated by Teflon-coating the surface, to minimize frictional forces, as well as by the spring forces exerted by leaf springs #12. The sliding package finally rests against the front and side stops #11 and #13 ensuring its accurate registration. Moreover, the change in the momentum of the package results in improved alignment.

This new method has been successfully implemented. It constituted a reliable and cost effective solution for the alignment/registration of automatically collated stacks. Its direct mechanical linking to the collator ensured a synchronous operation with negligible impact to the availability or cycle time of the total operation


COMPOUND-ANGLE
MECHANISM
TOP PLATE
PIVOT AXIS
LEAF
SPRINGS
HARD
STOPS
TABLE
PIVOT AXIS
TABLE
LIFT ARM
STRUT
CAM
collator's
Main Drive Shaft



LOAD POSITION: ALL PREPREG & PANEL ARE MOVED ONTO THE TILTED TOP-PLATE (#10) & SLID INTO THE COMPOUND CORNER & ALIGNED TO FRONT STOPS (#11) & ALIGNMENT BRACKET (#1)

PICK-UP POSITION: AS CAM (#17) ROTATES & LIFT ARM (#15) IS MOVED UPWARDS BY CONNECTION ROD (#16) IT FORCES MAIN TILT TABLE #14

Figure 22:

Teflon-Coated/Spring-Loaded, Compound-Angle Mechanism

REPORT

JOB
SCHEDULE/TRACKING SYSTEM
WITHIN A PROJECT

BY

EMILE J. TAYAR
SR. ASSOCIATE ENGR.
DEPARTMENT 23E

JULY 25, 1985

INTERNATIONAL BUSINESS MACHINE
11400 BURNET RD.
AUSTIN, TEXAS 78758

ABSTRACT

Good quality product, on time, and within budget are the stated objectives in almost every project. Thus, the performance of a project leader is measured by his (her) ability to meet or beat these objectives.

As a result, Project Management has evolved as a discipline that provides the project leader with the necessary tools to do the job. Many techniques became available. Some techniques are better suited for certain applications than others. Moreover, due to the complexity of some projects as well as the dynamic nature of project management, Computer-Aided techniques were developed. This gave the project leader the power to handle the task more efficiently.

This report focuses on selecting the project management technique that is best suited for projects of technical (engineering) nature. To be more precise, the purpose is to develop a "Schedule/Tracking system within a project" by integration and implimentation of selected manual and computerized techniques.

INTRODUCTION

Successful management of a project starts at the project's beginning. The project's goals, purpose, constraints, and specifications must be clearly defined. A well defined project should have:

° An established start date
° A well defined purpose
° An established business case (justification)
° A well defined end product
° Well defined design points (performance, reliability, etc)
° An established end point and completion criterea

Project management consists of four elements. Arranged in the order in which they should be accomplished, these elements are:

1) Planning (the project plan)
2) Scheduling (time, resource)
3) Tracking (measurement of progress)
4) Control (corrective actions as needed)

Even though the purpose of this report is to develop "a job Schedule/Tracking system within a project", it will be inadequate and even impossible to do so without some coverage of the constituents of "Planning" and "Control". Based on all information obtained in the planning stage, a project schedule can be established. This schedule will provide the project engineer with the means to track the progress of the project. Subsequently, the tracking data is used in controlling the project.

The tasks of Scheduling and then Tracking a project can be handled either manually or using computers (see appendix A). However, manual handling of such tasks can get extremely difficult, if not impossible, for the following reasons:

° Some projects are large (too many activities) and complex (too many dependencies)
° Impossible to do instant revisions of the schedule. Changes may be necessary for many reasons--mistake in defining the activities
  --mistakes in estimating resources
  --desire to ask what if questions
  --update schedule to reflect actual progress
  --to level or re-allocate resources
  --etc.

° Impossible to do timely sorting to reflect the perspectives that might be of interest to the project engineer at a particular point in time. Activities may be rearranged (sorted) in terms of----------critical path
---start dates
---finish dates
---slack time
---duration
---etc

To overcome the above drawbacks, and to provide greater flexibility and speed, computer-aided scheduling/tracking techniques were developed. A literature survey shows that the number of computer programs developed for project management purposes is bountiful. In this report, one such program "PROJECT" (by Microsoft) has been selected for use. PROJECT is based on the CPM method- this method is illustrated in appendix.

PLANNING

Planning is the first and most important step, it serves two main functions:

- ° It enables the project engineer to better understand the project requirements and how to satisfy them.
- ° It provides the basis for scheduling, tracking, and control.

It starts by defining a set of specific tasks (activities) that constitute the project. Proper definition of these activities is essential for the successful completion of the project. A Work Breakdown Structure (WBS), see fig. 1, is extremely helpful in preparing the activities list (brief explanation of WBS is given in appendix).

The second step is to input some key information for each activity. Depending on the need, this may include:

- ° Description of each activity.
- ° Duration of each activity in days (how long it takes).
- ° Predecessors for each activity (which other activities must be completed before this one can start).
- ° Start date of each activity.
- ° Resource estimate for that activity (only number of people and the skill type for each)--- $ estimates will not be considered here.

Usually it is easier to estimate the number of people required to complete an activity (man hours) than to estimate duration; hence , duration is often derived from the estimate of the people. Appendix contains a brief discussion on the subject of estimation.

RISK ANALYSIS

Since planning/estimating deals with the future, there will always be an element of risk associated with any plan. It is necessary that the project engineer be able to identify and evaluate that risk so as to apply the proper contingency factors and buffers to the plan.

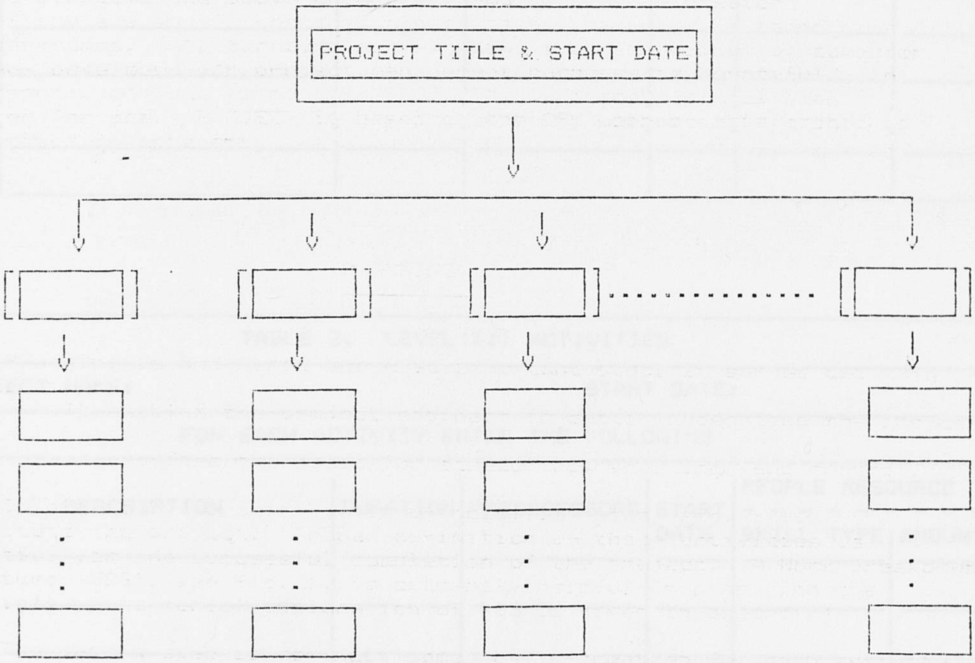
To learn how to do risk analysis, other references must be consulted. The process, however, involves the following basic steps:

° Examine "plan/Estimates" to identify areas of risk:

- New architecture.
- New technologies.
- Inexperienced people.
- Inavailability of a good data base.
- Dependencies.
- Exposures.

° Classify risk as "high, meduim, or low".
° Develop a plan to manage:
  - High and meduim risk to low (extend dates, add resources, develop backup plans).
  - Exposures to dependencies (get written commitments from all the people on whom you are dependent).

Fig. 1, Work Breakdown Structure (WBS)



Where: indicates level(I), major, activities

and

indicates level(II), minor, sub-activities

For the purpose of scheduling/tracking projects of technical/engr. nature, two levels of activities suffices.

TABLE 1. LEVEL(I) ACTIVITIES						
FOR EACH ACTIVITY ENTER THE FOLLOWING						
#	DESCRIPTION	DURATION	PREDECESSORS	START DATE	PEOPLE RESOURCE SKILL TYPE	AMOUNT
1						
2						
3						
.	.	.	.	.	.	.
ETC						

TABLE 2. LEVEL(II) ACTIVITIES						
PROJECT NAME:				START DATE:		
FOR EACH ACTIVITY ENTER THE FOLLOWING						
#	DESCRIPTION	DURATION	PREDECESSORS	START DATE	PEOPLE RESOURCE SKILL TYPE	AMOUNT
1						
2						
3						
.	.	.	.	.	.	.
ETC						

Note: if the start date for an activity is the same as the latest of the finish dates of the predecessors (ie- ASAP), then it need not be entered.

Microsoft "PROJECT"

Capability

PROJECT is an interactive program that can be used at three different levels:

1° To draw a schedule and calculate the critical path.
2° To allocate resources(people).
3° To analyze and control costs.

The last item will not be of concern to us and, therefore, will not be covered. The greatest benefit, however, is in providing the ability to quickly "Rearrange Activities for Effective Scheduling".

Contents

PROJECT consists of three major components (screens):

1° Activity screen: is where you enter information about the individual activities that make up a project and where the schedule itself is displayed.
2° Calendar screen: is where such things as holidays, vacations, The normal work week, the starting year and length of the project, are specified.
3° Resource screen: is where you enter resouce capacity and costs, and where graphical representation of the allocated resources can be viewed.

More detailed information about the contents, capability, and the use of "PROJECT" can be found in the documentation provided by Microsoft.

SCHEDULING -- using "PROJECT"

Scheduling is the task of calculating the start and finish dates for each of the activities, identifying the critical activities (ie- those that must be completed on time in order to meet a deadline), calculating the slack time for each of the non-critical activities, allocateing resources, etc.

setting up a schedule using Microsoft PROJECT is either a two-step or three-step process, depending on your needs:

1° Set the calendar for your project using the Calendar screen
2° Set your project's start date and enter activities on the schedule (see table 1). This you do from the Activity screen.
3° Finally, if you wish, you can assign resources to activities (from the Activity screen) and then specify resouce capacity (from the Resource screen).

TRACKING -- using "PROJECT"

In project management, "tracking" is the condition of being aware of the progression of a project. It constitutes the following:

° Measuring the actual progress. This may entail:
  * Status Reports ┐
  * Charts ┘ —(written)
  * Status meetings——(verbal)

° Comparing that measurement with the base Plan (without buffers or contingencies), which is represented by the schedule.

In addition, good tracking provides the project engineer with an "early warning system" because it allows him(her) to predict potential problems before they occur. In addition to being the basis upon which project "Control" is excercised, Tracking data should be kept for project history and for future estimates.

A good tracking system is one which will provide the needed information about a project, for the right person, at the right time.

PROJECT's ability to instantly update a schedule, recalculate dates, re-sort activities, identify the critical path, etc. renders the tracking task achievable even for complex projects. In addition to keeping schedule information up to date, it provides for personalised selection of reports to suit individual needs:

° Table form
° Gantt (bar) Chart in sorted sequence (many selections)
° Detailed form (for each activity and its dependencies)

CONTROL

The purpose of control is to ensure the achievement of the project's objectives (quality product, on time, and within budget). The process involves analysis of tracking data and taking action on all variations. Control can be classified as preventative, concurrent, and post control. It is desirable to excercise preventative control, and only a good tracking system makes this possible.

Once progress is measured and compared with the schedule (Tracking), the following control activities should take place:

° Identify variance
° Determine effect
° Identify alternatives
° Develop action plan
° Communicate and get approvals for the plan
° Ensure that action is taken to recover

It is necessary to have a " written change control procedure ". Such a procedure will ensure that a change request is in writing. Change requests may contain information as to:

° Why a change is necessary.
° What activities are affected.
° Impact of the change on resources and commitments.
° Recommended action

If needed, change requests are submitted to management. Management may approve or disapprove the request, or even return it to the project engineer for further analysis and study. Regardless of the procedure followed, critical problems should be reported immediately.

TASK REVIEW AND OUTLINE

A schematic summary of the major steps involved in a project management task, and the sequence of their flow, is given in (fig.2). The following is an outline of these major steps and their contents:

I) PLANNING

* a- Establish "Start Date" for the project.
* b- Construct the (WBS) for the project, see fig 1.
* c- Prepare the "Activities List" (complete Table 1 and/or 2) using the WBS as a guide.
? d- Analyze plan: - Identify and Classify risk
 - Develop risk managemnt plan
 ° Manage risk to low
 ° Manage exposures to dependencies

The WBS and the Activities list (b & c) can be prepared either manually or using the computer. I recommend using the "Personal Editor" (a "PC" software).

II) SCHEDULING-- using Microsoft "PROJECT"

* a- From the Calendar screen, set the project's calendar.
* b- From the Activity screen, set the project's start date and enter activities on the schedule-- using "Table 1 or 2".
? c- If required, enter resource information from the Activity screen (using table 1 or 2), and resource capacity from the Resource screen.

III) TRACKING

While placing emphasis on the critical activities, the following are points to consider:
* a- Measure the actual progress.
* b- Compare the actual vs. the base plan.
* c- Report and communicate the variances, if any.
? d- Try to spot potential problems / give early warnings.

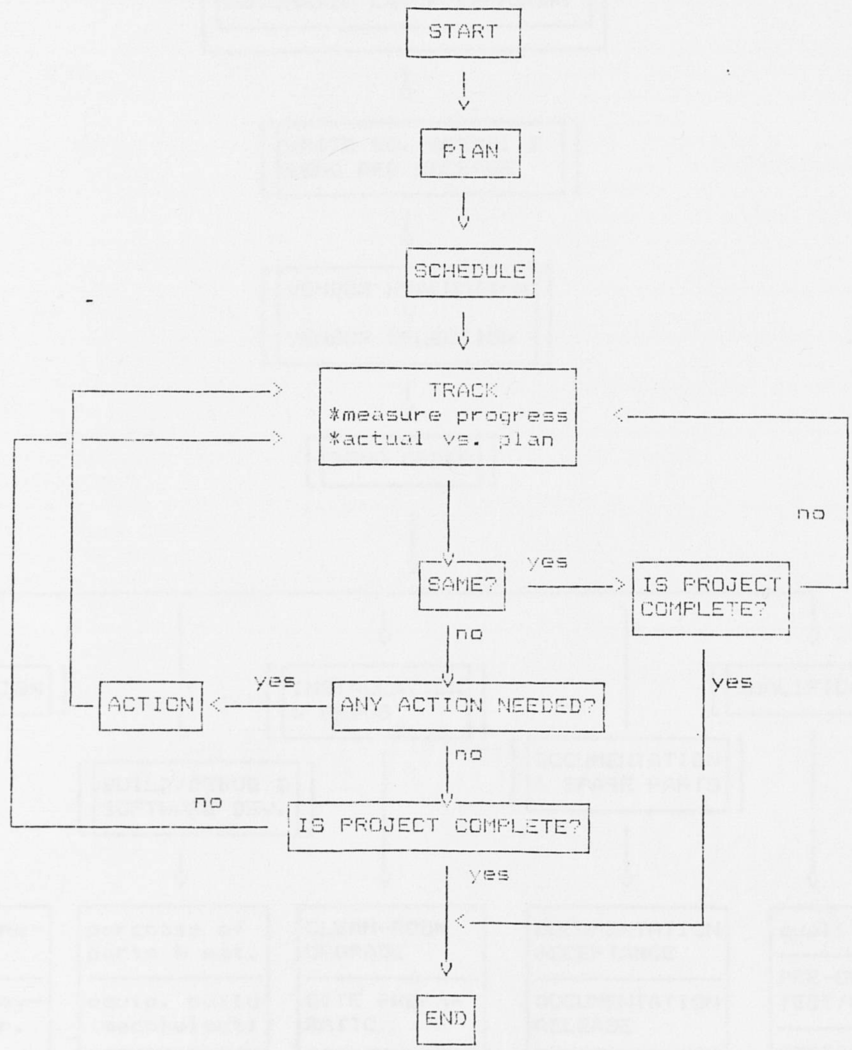
IV) CONTROL

* a- Analyze the variance (causes and effects).
* b- Decide on a remedial action plan (change original plan, re-allocate resources, etc.).
? c- Write a change request: -- why change.
 -- impact of change.
 -- recommended action.
? d- Communicate your action plan and get approvals.
* e- Execute your action plan.
* f- Update the plan and schedule to reflect any changes.

---

* means required action item ? means recommended action item

Fig. 2, PROJECT MANAGEMENT ACTIVITIES DIAGRAM



EXAMPLE
(AUTO LAYUP & TEARDOWN)

Introductory Statement:

The purpose of this project is to automate the layup & teardown operation at press 2, in the lamination center of building 060. For the sake of simplicity, past due dates, interruptions, and completed activities will not be considered here. Furthermore, some of the estimates given in this illustration are purely hypothetical. The objective of this illustration is to demonstrate the use of this Scheduling/Tracking system in projects similar to this one. This can be accomplished as follows:

a) Construct a macro schedule consisting of level(I) activities. Such a schedule provides a useful summary concerning the progress of the overall project.
b) Construct a detailed (micro) schedule of the outstanding activities of level(II). These are the "CAPITALIZED" activities inside the boxes (see the WBS diagram below). Such a detailed schedule provides the basis for detailed tracking and is usefull when reporting the project status to other team members.

1) WORK BREAKDOWN STRUCTURE(WBS)

- AUTOMATIC LAYUP/TEARDOWN
  - WRITE EQ. SPECS. & SEND RFQ PACKAGE
  - VENDOR EVALUATION & VENDOR SELECTION
  - SEND ORDER
    - DESIGN
      - input gathe- ing
      - concept lay- out & engr. analysis
      - preliminary des. review
      - intermidiate des. review
      - final design review
    - BUILD/DEBUG & SOFTWARE DEV.
      - purchase of parts & mat.
      - equip. build (mech&elect)
      - equip. debug (mech&elect)
      - software development
      - software debug&doc.
    - INSTALLATION & DEBUG
      - CLEAN-ROOM UPGRADE
      - SITE PREPA- RATIO
      - EQUIPMENT INSTALLATION
      - MES SIGNOFF
      - EQUIP. DEBUG (MECH&ELECT)
      - SOFTWARE & SYSTEM DEBUG
    - DOCUMENTATION & SPARE PARTS
      - DOCUMENTATION ACCEPTANCE
      - DOCUMENTATION RELEASE
      - SPARE PARTS RELEASE
      - maintenance training
    - QUALIFICATION
      - qualif. plan
      - PRE-QUALIF. TEST/B 805
      - contamination test/B 805
      - ACCEPTANCE TEST/B 805
      - OPERATOR TRAINING/B060
      - MANUFACTURING PROCESS SPEC.
      - PROCESS DEBUG
      - CONTAMINATION TEST/B 060
      - SAFETY SIGNOFF
      - QUALIFICATION & PRS

Notes: a) all level(I) activities will be included in the macro schedule

b) "CAPITALIZED" level(II) activities are those that are yet to be completed. For sake of brevity, only these activities are included in the detailed schedule.

2) ACTIVITIES LISTS

TABLE 1. LEVEL(I) ACTIVITIES

PROJECT NAME: AUTO LAYUP & TEARDOWN START DATE: 01/07/1985

FOR EACH ACTIVITY ENTER THE FOLLOWING

#	DESCRIPTION	DURATION (days)	PREDE-CESSORS	START DATE	PEOPLE RESOURCE SKILL TYPE	AMOUNT
1	Eq. Spec.& RFQ package	30				
2	Vendor Éval.&Selection	10	1			
3	Place Order	5	2			
4	Design	60	3			
5	Build/Debug & Software Development	110		04/29/85		
6	Clean Room Upgrade & Site preparation	15		09/23/85		
7	Installation & Debug	25	6			
8	Qualification	20	7			
8	Document./Spare Parts	6	5			

TABLE 2. LEVEL(II) ACTIVITIES

PROJECT NAME: AUTO LAYUP & TEARDOWN START DATE: 09/03/1985

FOR EACH ACTIVITY ENTER THE FOLLOWING

#	DESCRIPTION	DURATION (days)	PREDECESSORS	START DATE	PEOPLE RESOURCE SKILL TYPE	PEOPLE RESOURCE AMOUNT
1	prequal. test / B805	3		09/03/85	proc. engr	1
2	acceptance test/ B805	4	1		proc. engr	1
3	docum. acceptance	10	2		maint.	1
4	docum. release	10	3		designer	1
5	spare parts release	10	3		designer	1
6	clean room upgrade	11		09/23/85	fac. engr.	1
7	site preparation	6	6		eq. engr	1
8	installation in B060	11	2,7		eq. engr	1
9	MES signoff	5	8		maint.	1
10	equipment debug /B060	7	9		elect.engr technician	2 1
11	manuf. process specs.	15	2		proc. engr	1
12	process debug / B060	10	10,11		proc. engr	0.9
13	safety signoff	1	12		safety eng	1
14	operator training	10	12		proc. engr	0.1
15	contamination test/B60	5	13		cont. engr	1
16	qualification	5	15		proc. engr	1
17	PRS	0	16			

3) CREATE THE SCHEDULE -- using Microsoft "PROJECT"
(see instructions under "Task Review and Outline")

To illustrate the capability of "PROJECT", the following sample outputs (print-outs) are included:

A) SCHEDULES
- "GANTT" output
- "TABLE" output
- "DETAIL" output

B) RESOURCES
- "HISTOGRAM" outputs
- "DETAIL" outputs

"SCHEDULE" (Gantt) output
level(II) activities
Auto Layup & Teardown

```
Sep'85  1111   11112  22222  3 Oct'85  11  11111  22222
23456   90123  67890  34567  01234  78901  45678  12345
```

1. prequal. test / B805
2. acceptance test / B805
3. docum. acceptance
4. docum. release
5. spare parts release
6. clean room upgrade
7. site preparation
8. installation
9. MES signoff
10. equip. debug / B060
11. manuf. proc. specs.
12. process debug
13. safety signoff
14. operator training
15. contamination test
16. qualification
17. PRS

```
33 Nov'85  11111  11222  222  Dec'85  1111   11112  22
011  45678  12345  89012  567  23456   90123  67890  34
```

prequal. test / B805 1
acceptance test / B805 2
docum. acceptance 3
docum. release 4
spare parts release 5
clean room upgrade 6
site preparation 7
installation 8
MES signoff 9
equip. debug / B060 10
manuf. proc. specs. 11
process debug 12
safety signoff 13
operator training 14
contamination test 15
qualification 16
PRS 17

"TABLE" output
level(II) activities
Auto Layup & Teardown

Project: AUTOLAY2.ACT Date: 09/03/1985

#	Activity	Duration (Days)	Early / Late Start	Early / Late Finish	Slack Avail	Critical
1	prequal. test / B805	3	09/03/1985 10/04/1985	09/05/1985 10/08/1985	23	
2	acceptance test / B805	4	09/06/1985 10/09/1985	09/11/1985 10/14/1985	23	
3	docum. acceptance	10	09/12/1985 11/19/1985	09/25/1985 12/04/1985	48	
4	docum. release	10	09/26/1985 12/05/1985	10/09/1985 12/18/1985	48	
5	spare parts release	10	09/26/1985 12/05/1985	10/09/1985 12/18/1985	48	
6	clean room upgrade	10	09/23/1985 09/23/1985	10/04/1985 10/04/1985	0	*
7	site preparation	6	10/07/1985 10/07/1985	10/14/1985 10/14/1985	0	*
8	installation	11	10/15/1985 10/15/1985	10/29/1985 10/29/1985	0	*
9	MES signoff	5	10/30/1985 10/30/1985	11/05/1985 11/05/1985	0	*
10	equip. debug / B060	7	11/06/1985 11/06/1985	11/14/1985 11/14/1985	0	*
11	manuf. proc. specs.	15	09/12/1985 10/25/1985	10/02/1985 11/14/1985	31	
12	process debug	10	11/15/1985 11/15/1985	12/02/1985 12/02/1985	0	*
13	safety signoff	1	12/03/1985 12/03/1985	12/03/1985 12/03/1985	0	*
14	operator training	10	12/03/1985 12/05/1985	12/16/1985 12/18/1985	2	
15	contamination test	5	12/04/1985 12/04/1985	12/10/1985 12/10/1985	0	*
16	qualification	5	12/11/1985 12/11/1985	12/17/1985 12/17/1985	0	*
17	PRS	1	12/18/1985 12/18/1985	12/18/1985 12/18/1985	0	*

"DETAIL" output
level(II) activities
Auto Layup & Teardown

Activity: #1 prequal. test / B805 Date: 09/03/1985

Early Start: 09/03/1985 Early Finish: 09/05/1985
Late Start : 10/04/1985 Late Finish : 10/08/1985

Resources Allocated:

Name	Duration (Days)	Amount used	Cost	Cost Basis	Cost to Complete
proc. engr	3	1.0	$0.00	Day	$0.00
Total					$0.00

Predecessors:

# Activity:	EARLY FINISH	LATE FINISH	SLACK AVAIL
NONE			

Successors:

# Activity:	EARLY START	LATE START	SLACK AVAIL
2 acceptance test / B805	09/06/1985	10/09/1985	23

"DETAIL" output
level(II) activities
Auto Layup & Teardown

CRITICAL

Activity: #13 safety signoff Date: 09/03/1985

Early Start: 12/03/1985 Early Finish: 12/03/1985
Late Start : 12/03/1985 Late Finish : 12/03/1985

Resources Allocated:

Name	Duration (Days)	Amount used	Cost	Cost Basis	Cost to Complete
safety engr	1	1.0	$0.00	Day	$0.00
Total					$0.00

Predecessors:

# Activity:	EARLY FINISH	LATE FINISH	SLACK AVAIL
12 process debug	12/02/1985	12/02/1985	0

Successors:

# Activity:	EARLY START	LATE START	SLACK AVAIL
15 contamination test	12/04/1985	12/04/1985	0

"HISTOGRAM" output
level(II) resources
Auto Layup & Teardown

Project: AUTOLAY2.RES   Date:09/03/1985

Resource: proc. engr

```
        Sep'85  1111   11112  22222  3 Oct'85  11   11111  22222  2233 No
        23456  90123  67890  34567  01234  78901  45678  12345  89011
  2.0|
     |
     |
  1.5|
     |
     |
  1.0| ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
  0.5| ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
     | ****  *****  *****  *****  ***
  0.0--****--*****--*****--*****--***------------------------------------
```

"HISTOGRAM" output
level(II) resources
Auto Layup & Teardown

Project: AUTOLAY2.RES   Date:09/03/1985

Resource: proc. engr

```
     Nov'85  11111  11222  222    Dec'85  1111   11112  22       33 Jan'
      45678  12345  89012  567    23456  90123  67890  34       01123
  2.0|
     |
     |
  1.5|
     |
     |
     |                                          ***  *
  1.0|                                          ***  **
     |            *  *****  ***    *            ***  **
     |            *  *****  ***    *            ***  **
     |            *  *****  ***    *            ***  **
  0.5|            *  *****  ***    *            ***  **
     |            *  *****  ***    *            ***  **
     |            *  *****  ***    *            ***  **
     |            *  *****  ***    *****  *****  **
  0.0-------------*--*****--***----*****--*****--**-------------------
```

Project: AUTOLAY2.RES Date: 09/03/1985

"DETAIL" output
level(II) resources
Auto Layup & Teardown

Resource: proc. engr

#	Activity	Duration (Days)	Early Late Start	Early Late Finish	Amount used	Slack Avail
1	prequal. test / B805	3	09/03/1985 10/04/1985	09/05/1985 10/08/1985	1.0	23
2	acceptance test / B805	4	09/06/1985 10/09/1985	09/11/1985 10/14/1985	1.0	23
11	manuf. proc. specs.	15	09/12/1985 10/25/1985	10/02/1985 11/14/1985	1.0	31
12	process debug	10	11/15/1985 11/15/1985	12/02/1985 12/02/1985	0.9	0
14	operator training	10	12/03/1985 12/05/1985	12/16/1985 12/18/1985	0.1	2
16	qualification	5	12/11/1985 12/11/1985	12/17/1985 12/17/1985	1.0	0

APPENDIX

PROJECT MANAGEMENT TECHNIQUES

There are many tools available for the project engineer to help him(her) perform the task of coordinating projects efficiently. A brief description of each tool will follow:

°GANTT CHART	-	Also known as bar or milestone chart
	-	Does not show the dependencies between activities
°PERT	-	Event oriented (events on nodes)
	-	Activities assumed to be on arrows
	-	Allows for three duration estimates (optimistic, most likely, pessimistic)
	-	Duration estimates shown on arrows
°CPM	-	An extension of pert
	-	Activity oriented (Activities shown on arrows)
	-	Focuses on optimizing schedule
°PRECEDENCE NETWORK	-	Outgrowth of PERT/CPM
	-	Activity oriented (activity on the node)

WORK BREAKDOWN STRUCTURE

It is a "family tree" of all the activities that constitute the project. Proper definition of these activities is the most important single step in completing a project successfully. Nothing can ever compensate for inadequately or inaccurately defined activities. A work breakdown structure serves to:

° Identify and define the activities.
° Identify the interrelationships between activities
° Identify the levels of the activities

A work breakdown structure can have as many levels of detail as dictated by the complexity of the project. It begins with the major heading that defines the project. This will be followed by defining the major activities that constitute the project. The third and subsequent levels of detail reflect further subdivision of the major activities defined at the second level. Most projects can be clearly defined by three levels of detail.

The activities defined at the lowest level of a work breakdown structure are usually called "work packages" . They correspond to the activities typically used by both CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique). These work packages form the basis for scheduling, tracking, and controlling the project.

Keep in mind, when defining work packages, that both CPM and PERT analysis assume that a work package cannot be subdivided and must be completed without interruption. It is also assumed that all resources assigned to a work package are required for the entire duration of the activity. If one of the activities does not satisfy either of the above assumptions, that activity should be subdivided further until both assumptions are met.

The degree of completion of each work package is often not tracked as a project progresses. Frequently, only the beginning and end of each activity are monitored. Hence, defining work packages with short durations is desirable and wise.

ESTIMATING

Even though no universal formula or model for estimating purposes exists, it is possible to do a good job of estimating. Estimating is not an art, knowlege, or science, yet it contains elements of all of the above.

Estimating can be characterised as:

- ° Qualitative---largely verbal
- ° Quantitative--largely numeric
- ° Micro (bottom up)--estimate for the whole is assembled from estimates of the parts
- ° Macro (top down)--arrived at for whole without examining the parts

The most known estimating techniques are:

- ° SEAT OF THE PANTS (Quantitative/Macro)
  - -- Used in time pressure situations
  - -- Based on personal experience
  - -- Often overlooks details
  - -- Useful for : * Short range projects
    * Sizing of large projects
- ° SCENARIOS (Qualitative/ Macro)
  - --Generally used for long-range planning to provide basis for preliminary sales estimates and future product forecasts
- ** ° TRANSACTIONAL (Quantitative/Micro)
  - --Takes into account the knowledge and experience of workers assigned to the project
  - -- Used to estimate individual work activities
- ° PROJECTIVE (Quantitative/Micro-Macro)
  - --Based on statistical analysis of completed projects (requires historical data)
- ° DELPHI (Quantitative/Macro)
  - -- An interactive and systematic polling of the opinions of "experts"
  - -- Used most often where no historical data is available
  - -- Based on group opinion and interaction

It will be impossible to discuss these techniques in more detail here, the project engineer will have to do his(her) own research on as needed basis.

** This estimating technique is the most suitable one for the majority of projects handled by the Department of "Equipment Engineering".

CPM PROCESS EQUIPMENT SPECIFICATION GUIDELINES

BY

EMILE TAYAR
DAVID WALKRER
HOWARD GEISE

04/25/1985

CPM PROCESS EQUIPMENT DESIGN AND PERFORMANCE SPECIFICATION
FOR
"Project's Name"

"Date"

"Engineer's Name" / Equipment Engineer
STD Equipment Engineering
Department 23E/building 045
IBM Corporation
11400 Burnet Road
Austin, Texas 78758

"Tel. Number"

CPM PROCESS EQUIPMENT DESIGN AND PERFORMANCE SPECIFICATION
FOR
"Project's Name"

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CPM PROCESS EQUIPMENT DESIGN AND PERFORMANCE SPECIFICATION
FOR
"Project's Name"

IBM CONTACTS

1. IBM Purchasing Representative

IBM Corporation
"Name"
Dept. 33G/814
P.O. Box 10258
Austin, TX 78766

"Tel. Number"

2. Equipment Engineer

IBM Corporation
"Name"
Dept. 23E/045
11400 Burnet Road
Austin, TX 78758

"Tel. Number"

3. Process Engineer

IBM Corporation
"Name"
Dept. 23E/045
11400 Burnet Road
Austin, TX 78758

"Tel. Number"

All communications with IBM must be through the above listesd persons.

CPM PROCESS EQUIPMENT DESIGN AND PERFORMANCE SPECIFICATION
FOR
"Project's Name"

I. SCOPE AND OBJECTIVE

Provide a concise but complete narrative description of the intended useof the equipment. Short paragraphs describing the function of the proposed equipment and the goals to be attained.

II. REFERENCE MATERIAL

Provide any documents, Prints, or Specifications which may affect the buid or design of this equipment, such as:

1. IBM NON-PRODUCT DESIGN STANDARD C-B-3-0502-202 BOOKLET
2. MANUFACTURING PROCESS SPECIFICATIONS (MPS), if available.
3. QUALITY PROCESS SPECIFICATIONS (QPS), if available
4. ENVIROMENTAL IMPACT ASSESSMENT statement, if needed
5. Other

III. GENERAL REQUIREMENTS

FACILITIES:
Identify all factors pertaining to this equipment, such as: water temperature, pressure, flow rates, power input requirements, weight limits on the floor in question, space limitations, etc.

CONTAMINATION:
Specify the maximum allowable levels of contamination (usually dictated by the clean room class). Also identify the areas, on the surface of the product, that allow handling without damaging or contaminating the product.

SAFETY:
Identify all safety features that are not covered in item 1 of the reference list, such as: safety covers, interlocks, and EPO locations.
ENVIRONMENTAL:
Identify all environmental elements the equipment will be exposed to, such as: humidity, chemicals, dust, temperature, etc. Also, list all restrictions that may apply to the equipment; this includes: exhaust temperature, discharge of chemicals, harmful waste, noise levels, and others (in addition to the items given by the EIA).

OTHER:
Specific any unique requirements not covered in the above statements, such as:

- ° Quantities of each tool
- ° Spare Parts supply (six months supply)
- ° Confidentiality requirements
- ° Contractor approval by IBM Purchasing Dept.

IV. SPECIFIC REQUIREMENTS

CAPACITY REQUIREMENTS:
Specify required throughput and list all factors that influence it, such as: Machine Base Capacity, Machine Availability, Machine Efficiency, Handling, Set-up time, and Operator Efficiency using the IBM Unit/Hour formula:

$$\text{Unit Hour} = \frac{\left(\dfrac{1}{\text{Base Capacity}} + \dfrac{\text{Set-up Time}}{\text{Lot Size}}\right) \times (\text{\# of operators})}{(\text{Operator Efficiency})(\text{Machine Efficiency})}$$

CONTROLS:
Specify all required controls and set their limits (Operating and Process limits). This may include: temperature/pressure/and speed settings, mechanical and electrical adjustments, chemical levels and concentrations, etc.

AUTOMATION:
List any desired features for the equipment that will enhance automation and be compatible with CFM, such as:

- ° Auto Process Controls
- ° Dedicated, Flexible, and Modular tools
- ° Maintainable, compatible, and user friendly software
- ° Product I.D. recognition

PRODUCT:
Specify the following:

- ° Dimensions and relevant characteristics of the product
- ° Product orientation, spacing, and registration requirements
- ° Product handling devices and containers that will interface with the equipment

OTHER:
Any and all required hardware (mechanical/electrical) features not covered in reference item 1.

V. DOCUMENTATION:

Specify the type and format of the required documentation; consult Operating Procedure 106 for details. Documentation will include:

- ° Electical, Mechanical, Hydraulic, and Pnuematic drawings as applicable to the specific machine.
- ° Operator and Maintenance manuals.
- ° Spare Parts List.

GLOSSARY

Artwork:	Layout of printed circuitry which is photographically reproduced for manufacture of panels.
Book:	Laminate material contained between two carrier plates for pressing in the laminating press.
Clean Room:	An enclosed area with a controlled environment, particularly a dust-free atmosphere.
Composite:	A name for any panel that has completed its laminating press sequence.
Core Panels:	Core is the term used to describe the internal layers of a multi-layer circuit panel. The core construction is generally two sheets of copper foil bonded together by prepreg plys.
CPM:	Circuit Package Manufacturing.
Developer:	Machine used to develop photoresist after expose.
Epoxy:	A non conductive plastic type material generally used in the impregnation process and protective coat process.
Epoxy Glass:	Glass impregnated with epoxy resin, whether partially cured (prepreg) or fully cured.
Etching:	Removal of unwanted copper by dissolving it chemically; leaving behind the desired circuit pattern.
Expose:	Process in which panels coated with photoresist are exposed to ultraviolet light to produce the desired circuit pattern.
Glass Master:	Sheet of glass coated with a photograghic emulsion that is exposed to artwork and developed to produce an image of desired circuitry to which panels coated with photoresist are exposed.
Lamination:	Process using heat and pressure to bond together multiple layers of similar or dissimilar material.
Layup:	Process of putting together prepreg, copper foil, core panels, face sheets, planishing plates, etc. in the proper order for insertion into the lamination press.

Multilayer:	A printed circuit board with alternate layers of conductors and dielectric bonded together and interconnected with plated-through holes.
Page:	One single layer of constituent laminate material between two planishing plates.
Photoresist:	Material used to produce circuit images by the glass master or method; it is highly light sensitive and can be used openly only in yellow or red light. When exposed to white light it becomes chemically resistant and is therefore used as an etching or plating mask.
Planishing plates:	Approximately 1/8 inch thick stainless steel plates used to separate the individual pages of a laminate "book".
Plated-through Holes:	Connections between insulated layers of circuit foil formed by holes. Hole walls are chemically metalized and then electroplated to the desired thickness.
Pre-Clean:	Series of chemical baths used to clean panels prior to a plating or circuitizing.
Prepreg:	Glass cloth impregnated with partially cured epoxy resin, produced by the impregnation process
Press:	Machine used to laminate material under heat and pressure.
Press load:	Work to be laminated in a press; usually consists of from 1 to 15 books, each of which has from 5 to 9 pages.
Process:	Sequence of operations required to manufacture a finished product.
Process Center:	Number assigned to identify a group of manufacturing operations within a department.
Registration:	The position of circuit phototools with respect to their desired location on a board or panel.
Strip:	Removal of the resist film from the etched printed circuit panel.
Subcomposite:	A core panel with additional layers of prepreg and copper laminated to it. A subcomposite has more laminating and circuitizing steps to go through before it becomes a finished composite board.

Teardown:	Process of dissassembling laminate books after they are removed from the presses.

VITA

Name:	Emile Joseph Tayar
Born:	Nov. 5, 1954
Parents:	Mr. Joseph Tayar and Mrs. Elaine Tayar
Wife:	Adrianne Courtney
Children:	Joseph and Jacqueline
Education:	B.S., Mechanical Engineering, Univ. of Tulsa, May 1978.
	M.S., Mechanical Engineering, Michigan Technological University, May 1981.
Experience:	June 1984 - August 1985 Engineer (Doctor of Engineering Internship) International Business Machines, Austin, Texas
	September 1982 - May 1984 Lecturer Texas A&M University (Mechanical Engineering Department).
	September 1978 - May 1982 Graduate Teaching Assistant Michigan Technological Univ. (Mech. Engineering Dept.).