THE DEVELOPMENT OF FLEXIBLE BUSINESS PROCESS REENGINEERING IN PCB MANUFACTURING

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JULY 2001

ABSTRACT

The new management concept of Flexible Business Process Reengineering (FBPR) is developed by a combination of three management tools – Positioning, Continuous Improvement and Business Process Reengineering (PIR). By combining and employing the three management tools, it forms a complete management concept rather than solely continuous improvement or reengineering. However, the changes could be slightly less "radical" than the conventional BPR, but in exchange, it is relatively less risk-taking and can facilitate continuous learning and improvement.

The objective of this research is to increase the productivity and to decrease the Through-Put-Time (TPT) of a Printed Circuit Board (PCB) manufacturing company located in Hong Kong through the use of both linear and non-linear improvement scheme of FBPR. In this research, a Value Delivery System (VDS) is developed to provide a systematic approach for project implementation. A number of supporting tools such as strategic planning, performance analysis, action description table, relational diagram, process decomposition, analysis development, preventive analysis, Design Of Experiment (DOE), benchmarking, prototype testing, computer simulation model and process analysis are utilized to accelerate the effectiveness of FBPR.

The implementation of the FBPR is presented in three independent case studies, the process level, the operational level and the organizational level. The process level is considered to be the least complex during the implementation and the organizational level is considered to be the most complex. The scope of process-level FBPR is limited to within a

process. Therefore, its degree and course of improvement is considered linear. In contrast, the scope of organizational-level FBPR has extended to the whole organization. Due to its high complexity and extensive target of enhancement, the degree and course of improvement is considered non-linear.

The first case study is to apply process-level FBPR on the silkscreen printing process to linearly improve its productivity and its TPT. Two additional supporting tools, action description table and relational diagram are utilized. Action description table is used to illustrate the value adding and non-value adding activities. Relational diagram is used to illustrate the workflow of the activities. The result of this project shows an average of greater than 30% increase on both the productivity and the TPT of the silkscreen printing process.

The second case study is to apply operational-level FBPR on the post-Hot-Air-Solder-Leveling (post-HASL) baking operation. The objective of this project is to eliminate the entire post-HASL baking operation so as to reduce this non-value adding operation and to promote the concept of preventive action. The post-HASL baking operation, as a corrective action, is used to reduce the ionic contamination created from the former operations such as the solder masking operation and HASL operation. Two additional supporting tools, process decomposition and analysis development, are used to identify the root cause of the ionic contamination. The result of this project shows that the entire post-HASL operation is eliminated. This reduced the total TPT, increased the quality of product, and reduced the possibility of making manual errors.

The third case study is to apply organizational-level FBPR in redesigning the PCB panel size. This project aimed to improve the total manufacturing TPT, decrease the quality variances, and decrease the total production cost. A number of supporting tools, such as DOE, benchmarking, prototype testing, computer simulation model and process analysis, are used to control and monitor changes. The result of this project shows that the productivity of various manufacturing operations has increased up to 25% and 103%.

Keywords

Flexible Business Process Reengineering, Positioning, Continuous Improvement, Business Process Reengineering, Value Delivery System, Printed Circuit Board.

Acknowledgements

I owe a tremendous debt of gratitude to those individuals at Carven Circuits Ltd. (CCL) who assisted me in my research and who provided me unique access to the company's working environment. I also owe a debt of gratitude to the funding body (i.e. HKSAR) that have supported my research throughout the development period of FBPR. I would also like to thank CCL for funding part of my research. Without these generous funding, I would never be able to gather the data and information for this research study.

I would like to thank the intellectual debt I owe to Dr. K.C. Yung, who was my supervisor at Hong Kong Polytechnic University (HKPU). I also would like to thank the fellow staff at PCB Technology Unit of the HKPU, who assisted my research. Not only are they excellent scholars, but also they have been good friends and great collaborators.

Finally, I need to thank and acknowledge the managing director, Mr. Albert Mok, and factory manager, Mr. Gary Ngan, of CCL for their valuable contributions. I thank them for teaching me how to work, for inspiring in me a sense of self-confidence, for being my intellectual guide and mentor, and for teaching me how to think and reason. I would like to thank the quality manager, Mr. Thomas Lau, who provided valuable assistance during my research in developing the Value Delivery System and for managing the data gathering process at CCL and as well as external parties for performance benchmarking.

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Glossary of Abbreviations and Terms

BAM	Business Activity Mapping
BPR	Business Process Reengineering
CA	Corrective Action
CI	Continuous Improvement
DBPR	Dynamic Business Process Reengineering
DOE	Design Of Experiment
FBPR	Flexible Business Process Reengineering
HASL	Hot-Air-Solder Leveling
PA	Preventive Action
PAR	Positioning And Business Process Reengineering
PCB	Printed Circuit Board
PDSA	Plan-Do-Study-Act
PIR	Positioning, continuous Improvement and business process Reengineering
RSD	Relational System Development
SP	Strategic Planning
TPT	Through-Put-Time
VDS	Value Delivery System

Action Description Analysis

Analysis development

Benchmarking (Performance, Internal, and External)

Computer Simulation

Cost Analysis

Linear Improvement Scheme

Non-Linear Improvement Scheme

Operational-Level Reengineering

Organizational-Level Reengineering

Performance Analysis

Performance Improvement Cycle

Process Analysis

Process Decomposition

Process-Level Reengineering

Prototype testing

Relational Diagram

Synergy

CHAPTER ONE: INTRODUCTION

1.1 Scope and introduction of Flexible Business Process Reengineering (FBPR)

Most manufacturing today are so used to working according to conventional methods that they rarely ask themselves why they have to perform tasks in such ways. As a result, they are becoming decreasingly competitive when dealing with unpredictable changes. This situation is worsening since the business world is becoming increasingly complicated and globalized. In order to sustain their competitiveness in this global manufacturing era, enterprises need to continuously adopt both linear improvement scheme such as continuous improvement and non-linear improvement schemes such as reengineering (Ng et al., 1999).

Reengineering has been a popular topic for discussion and research. Like all new activities, it has been given a wide variety of names; they include streamlining, transforming and restructuring. However, regardless of the name, they all share a common goal: increase the ability to compete through cost reduction and through increase in profit margin. Market economics is the force that most often motivates reengineering. Therefore, management and engineering methodologies must keep up with new demands from the marketplace.

Conventional definition of Business Process Reengineering (BPR) has identified that reengineering cannot be carried out in small and continuous steps. It is an all-or-nothing proposition that should produce dramatic and impressive results. Stoddard and co-workers (1995) explained, "BPR is about changing the engines of a flying airplane." Most manufacturing organization will not consider the conventional reengineering methodology as their only optimal approach for implementing a radical improvement project, due to the high failure rate and the need to start everything from scratch. After realizing the constraints and shortcomings of the conventional reengineering method, Flexible Business Process Reengineering (FBPR) is introduced which keep the conventional all-or-nothing proposition but simultaneously promote continuous learning and improvement. All FBPR projects must be well-positioned before implementing either reengineering or continuous improvement. As a result, outcomes of FBPR projects could be both evolutionary or revolutionary. In exchange, the implementation of FBPR would be relatively less risk-taking compare to the solely BPR. After all, one still needs to cautiously choose the right engine for the right flying airplane.

The scope of FBPR projects denote to the level and area of improvement – for example, whether the impact of change should be limited to process-level, operational-level or organizational-level. Hammer and Champy (1993) and Venkattaman (1994) define that BPR spans mainly on organizational-level. In contrast, FBPR spans on all three aforementioned levels of change. However, there seems to be a wide disparity in how narrowly or broadly a process is viewed from one reengineering initiative to another – this results in different degrees of scope of the reengineering effort. Therefore, in order to effectively and efficiently apply a FBPR project, it is important to develop a systematic project management concept – Value Delivery System (VDS) and apply Strategic Planning (SP) on all FBPR projects. Together with both VDS and SP, they will increase organization's competitiveness and on reducing the performance gap. At the same time, as the complexity of the FBPR project increases, the deeper the planning is needed.

As mentioned earlier, the scope of FBPR span on three levels. They are process-level reengineering, then, operational-level reengineering and finally the most challenging organizational-level reengineering. The objective of process-level reengineering concentrates on re-structuring the processes' activities; thus, it aims to linearly improve the effectiveness and the efficiency of the manufacturing processes and manual performance. In this study, it aims to redesign the silkscreen printing process in PCB manufacture for enhancing the process effectiveness and efficiency, and minimizing the non-value adding activities within the production process.

The operational-level reengineering targets to re-design manufacturing operations; thus, it aims to enhance the effectiveness and to re-define the value of the operations. Therefore, there is a possibility that the FBPR project may involve more than one department (for instance, cross-departmental and inter-departmental), Therefore, a relatively more complex positioning plan is needed if compare to the process-level FBPR project. Illustrating this level of FBPR as a case study, the Post-Hot-Air-Solder-Leveling (Post-HASL) baking operation is redesigned. This operational-level reengineering project attempts to eliminate the entire Post-HASL baking operation with appropriate modification on other manufacturing operation. This eliminates a non-value adding operation and to promote the concept of preventive operation.

Finally, organizational-level reengineering is used to re-think, to re-learn and to reengineer the organizational activities by employing the concept of fundamental rethinking. This enhances the company's performance, improves internal and external customer satisfaction, and promotes the concept of a learning organization. Again, this level of FBPR is illustrated in a case study, the panel size of the Printed Circuit Board (PCB) is redesigned. This increases the effectiveness of the entire production cycle. Since the organizational-level reengineering project directly affects the entire manufacturing system, the project is more challenging and more complex.

1.2 Objectives

The aim of this research project is to implement and to analyze Flexible Business Process Reengineering (FBPR) in a Printed Circuit Board (PCB) manufacturing organization. The following objectives are targeted:

(A) To investigate and to determine the applications, the constraints and the limitations of the newly introduced FBPR methodologies by developing a Process Model for the Value Delivery System;

(B) To concurrently implement the concept of Positioning, continuous Improvement and business process Reengineering (PIR) in a PCB manufacturing organization with the aid of additional supporting tools, they include strategic planning, performance analysis, action description table, relational diagram, benchmarking, process decomposition, analysis development, preventive analysis, Design Of Experiment (DOE), prototype testing, computer simulation model and process analysis.

(C) To linearly and non-linearly enhance the organization's performance and manufacturing effectiveness in various level of FBPR; and,

(D) To quantify and to qualify the effects of the planned reengineering changes, thus, to be able to determine and to forecast the potential effects of the future processes alterations.

After the completion of the research projects, the targeted organization would have a better ground on predicting and on controlling any potential effects caused by process alterations.

1.3 Research methodologies and deliverables of FBPR

The methodology of FBPR is a combination of three well-known management tools; they include Positioning, Continuous Improvement and Business Process Reengineering (PIR). Positioning can aid in identifying the business areas that have the potential to receive the greatest improvements after implementing FBPR changes, while locating other business areas that might be sub-optimized if changes are taken place, and initiate appropriate modifications. Continuous improvement is utilized to linearly improve the business processes that have not yet optimized. Business Process Reengineering is implemented to dramatically and non-linearly improve the manufacturing performances of the organization's operations where there are great performance gaps.

To enhance the flexibility of implementing FBPR projects, an appropriate model for achieving the business strategy should be developed. In this research study, Value Delivery System (VDS) is developed and employed that based on four characteristics: Process Intent, Process Model, In-process Control and Evaluation, and Design of New Learning System. Detailed methodologies and analyses are illustrated in Chapter three. Since VDS is a system that delivers values to the customers, the system was designed to deliver high performance, responsiveness, quality and cost to value in customers' perspective. In other words, VDS is designed to deliver customer-focused products and services.

After the VDS has been developed, the six principles that can gather factual and accurate information feedback is then identified to enhance the effectiveness of FBPR projects. In this research, the methodologies of FBPR are applied in a PCB manufacturing organization. The implementation of FBPR is conducted in three levels; they include process-level, operational-level and organizational-level.

CHAPTER TWO: LITERATURE REVIEW

2.1 The motive for developing Flexible Business Process Reengineering (FBPR)

The overextension and misuse of the conventional BPR methodology have resulted dissatisfaction and have raised many concerns. Altinkemer and co-workers. (1999), Tinnila (1995), Hammer and Stanton (1995), and Hammer and Champy (1993) estimated that between 50 to 70 percent of the reengineering efforts were not successful in achieving the desired breakthrough performance. Various reasons have been given for this; most of the failures are attirbuted to mis-management of projects and to difficulties faced while attempting in meeting strategic objectives (Tinnila, 1995; Morris and Brandon, 1993). While implementing changes in an organization, BPR could be a very demanding and challenging assignment if it is to stand alone to manage the changes. Therefore, in order to accelerate the effectiveness and efficiency of the changes, positioning must be implemented prior to and simultaneously with BPR; as a result, the reengineering team would have a better idea on the potential effect and criticality of the areas on where they implement changes (Morris and Brandon, 1993).

The concept of Flexible Business Process Reengineering (FBPR) originate by the author is to some extent similar to the combination of two management methodologies: they are Dynamic Business Process Reengineering (DBPR) originated by Morris and Brandon in 1993 and the well-known Continuous Improvement (CI) concept. DBPR is an improvement methodology that utilizes the concept of both Positioning and Business Process Reengineering (BPR). By combining these two methodologies, the extent of performance improvement will be greater than the conventional CI, yet, the degree of risk creates from the FBPR project will be much less than the conventional BPR. As mentioned earlier, FBPR and DBPR are to some extent similar because they both share two major management methodologies – Positioning and Business Process Reengineering (PAR), but FBPR also brings in the concept of Continuous Improvement. In brief, FBPR has developed a new management concept of integrating Positioning, continuous Improvement and business process Reengineering (PIR). Moreover, they do not share common supporting tools, DBPR stipulates users to mainly implement the Relational System Development "RSD" and the Business Activities Mapping "BAM" as the spine of their reengineering projects. On the contrary, FBPR does not restrict users to implement any specific supporting tools, because different industries in different locations might need different kinds of reengineering supporting tools. Though, FBPR suggests to develop a Value Delivery System (VDS) to effectively and systematically identify and control the planned change.

The fundamental philosophy of BPR is an innovative approach to change, resulting in best practices. However, Hammer and Champy (1993) states that it is unnecessary to gather information concerning the current business operation. Hammer and Champy (1993) also declares that gathering excessive information may be a waste of time. If one spent an excessive amount of time on the original process, one can possibly lose one's fresh and creative inspiration. On the other hand, if insufficient amount of information are gathered, the implementation of FBPR project might not be efficient. Thus, it leads to an unsatisfactory result.

The term Business Process Reengineering first came to prominence in the early 90's by Michael Hammer and his book (Hammer and Champy, 1993) have consolidated their pivotal position in what might reasonably be called the BPR movement. In addition, Hammer's definition of reengineering has become largely synonymous with the term BPR:

> Re-engineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed. (Hammer and Champy, 1993)

On top of the Hammer's definition on BPR, one assumption is made regarding the 'results' achieved by reengineering. The reengineering literature always report 'radical' and 'order of magnitude' improvement without anyone actually setting a clear definition of how radical 'radical' is. The following definitions defined by Jarrar and Aspinwall (1999):

(1) Radical - in excess of 60% improvement over the initial work activities.

(2) Major - between 30 and 60% improvement over the initial work activities.

(3) Incremental - less than 30% improvement over the initial work activities.

The concept of reengineering challenges managers to rethink their traditional methods of doing work, commit themselves to a customer-focused process and enhance the concept of continuous learning. Many outstanding organizations have achieved and maintained their leadership through the application of both continuous improvement and reengineering (Oakland, 1995).

2.2 Strategic planning

While determining a FBPR project, it is essential to understand every business function as units of strategic planning and therefore acknowledges the need to connect them closer to the business strategies and the process intent (Tinnila, 1995; Mosscrop, 1994; Oakland, 1994). Therefore, process model, strategic level decisions and organizational changes can then be positioned as the starting point for any FBPR project.

Previous researches have listed different activities as examples of potential reengineering processes. Typically, core or key processes in need of greatest attention are considered to be strategic. Other processes are classified as supporting and non-strategic processes (Morrow and Hazell, 1992). To add the difficulty in defining processes, there remains the fact that most business processes are never designed in the first plan, but have evolved over time to meet changing circumstances and fix problems that have occurred in due course. Similarly, Hammer (1993) and Hammer and Champy (1993) states that many of the procedures of processes are not designed at all, they just happened.

Therefore, to optimize the effectiveness of a FBPR project, it is important to consider every business operations as an object of strategic planning, to connect all activities to capability-based strategy (Stalk et al., 1992) and to abruptly redesign the Value Delivery System (VDS). Concurrently, the building blocks of corporate strategy is not the final product nor business operation but what customer values. These key concepts have to be transformed into strategic capabilities while providing superior value to customers.

2.3 Scope of change: determining the tactics of change

The pace of change is dependent on the scope of, and the commitment to FBPR project – tactics or techniques used to encourage an organization's staff to commit and to participate a proposed change. A change that complies with current organizational values and norms, skills, structures, and incentive systems is inherently evolutionary. In contrast, change that challenges or undermines the status quo, creates new vision, and accomplishes fundamental change in values and norms, work practices, and structures is revolutionary change (Orlikowski, 1993).

The basic supposition for managing change in FBPR is simple: different initiatives require different change management tactics depending on the scope and the type of FBPR project. One of the change tactics of FBPR is to apply linear improvement scheme at the organization's activities. Linear improvement scheme is essential in the early stage of FBPR to increase the top management commitment. With top management commitment, the tactics of change of FBPR project can be enhanced from an evolutionary change approach to a revolutionary change approach. In the FBPR works reported here, evolutionary change approach is implemented on the process-level FBPR project. Revolutionary change approach and non-linear improvement scheme is applied at the operational-level and organizational-level FBPR project to receive a greater scope of improvement.

2.3.1 Linear improvement scheme – an evolutionary change approach

Evolutionary change approach assumes that change is adapted to the pace and capacity of people and then widespread to others. Continuous training and learning are the key tactics to enable incremental change and continuous improvement. Evolutionary change concept also assumes that improvement cannot be fully planned at the outset and those who will be affected by the change must lead and participate in the change process (Leonard-Barton, 1988). Broad participation from various levels in an organization indicates that the pace of change has been adapted to the capacity of the least changeable element or group in the organization.

As such, evolutionary change concept suggests a gradual, staged socio-technical change approach. The change tactics derived from this view reflect two basic assumptions about change; firstly, changes are continuous and are best accomplished in small increments at a time, and secondly, changes are recursive adaptation process between the technology and the user environment (Wood and Finch, 1994).

2.3.2 Non-linear improvement scheme – a revolutionary change approach

According to the conventional BPR methodology, a revolutionary change cannot be accomplished piecemeal, gradually, or comfortably. Rather, the change must be unfolded rapidly. The creation of new forms and processes requires difficult compact revolutions. Although researchers of revolutionary change theories acknowledge the existence of incremental changes during periods of stability (i.e. at equilibrium), they argue that any major change could only come as a result of revolutionary upheaval (i.e., "big bang") (Gersick, 1991). As revolutionary change delivers radical and non-linear improvement, it can only be applied once in the entire organization's operation until the process intent is shifted to another target or goal.

2.3.3 FBPR - combining evolutionary and revolutionary change concepts

There exist a number of similarities and some major differences between the linear and non-linear improvement scheme. FBPR select, combine, and employ the best improvement concept from both of the improvement schemes. Therefore, enterprise that sufficiently employ FBPR gains a continuous self-learning and self-improvement working environment to increase enterprise's competitiveness, while promotes fundamental perception of re-thinking and re-structuring. FBPR applies rigid milestones for both the linear and non-linear improvement scheme and also suggests to employ linear improvement at the preliminary stage of the newly redesign Value Delivery System (VDS), due to its high flexibility and the respectively low degree of complexity.

2.4 Merging with additional supporting tools

An empirical validation of some of the suggestions and prescriptions in conventional BPR's critical success factors and pitfalls are provided through a content analysis from the annual reports of a number of companies that have reported success in their reengineering projects (Altinkemer et al. 1999). The analyzed results suggest that many companies were not implementing BPR alone, but implement BPR as one of the components of a set of change approaches such as strategic rethinking of business direction or less radical process improvement. The analyzed results also suggest that BPR should not be evaluated alone but as part of a strategic change-set due to the different complexity for different FBPR projects (Altinkemer et al., 1999). Therefore, various management tools should be used to support the implementation of FBPR project and to decompose the organization into different sectors for better adaptivity.

In the three different levels of FBPR project, various management tools are used to support their preparation and implementation. For the process-level FBPR project, tools such as performance analysis, action description tables and relational diagrams are used to identify and to improve the production activity within the process. For the operational-level FBPR project, process decomposition, analysis development and preventive analysis are used to redesign the operation. These tools are chosen due to the FBPR project's cross-departmental quality concern. Therefore, it is important to acquire tools that can decompose operation's process and promote preventive action. For the organizational-level FBPR project, the fundamental concept of DOE, benchmarking, prototype testing, simulation model and process analysis are used to visualize the manufacturing performance and to improve its capabilities by running designate experiments. There is no universal tool or management method for all three levels of FBPR project, they are proficient as long as they can achieve the intention of the FBPR project.

2.5 Performance analyses

With no exception, performance measurements and analyses are important parts for all FBPR projects. By applying such measurements and analyses prior and during the implementation of FBPR projects, organizations will be in a better position both to monitor and to benchmark the degree of success in the business redesign projects, to learn and to improve the entire business function according to the customers' perspective.

To this end, Guha and co-workers (1993), Jones (1994), Rummler and Brache (1995), and Kaplan and Murdock (1991) propose an integrated set of performance indicators encompassing all the business processes within an organization. Since most manufacturing processes within an organization are inter-related, there exist potential risks of optimizing one activity but worsening others if performance measurements and analyses are not being appropriately applied.

To determine the competitiveness of the organization within its industry, a solid method for performance benchmarking is needed. Performance benchmarking can be classified into four stages (Swartz, 1994). They include:

(1) Comparing present performance to past performance or internal standards:

e.g. past year sales, profit, Return On Investment (ROI), performance to budget, etc.

(2) Comparing customers' perceptions versus their expectation or needs:

e.g. customer complaints, comment cards, surveys, focus groups, etc.

(3) Comparing our performance to the performance of our best competitors:

e.g. competitive benchmarking.

(4) Comparing present performance to ultimate possible performance.

A performance benchmarking model is illustrated in Figure 1.

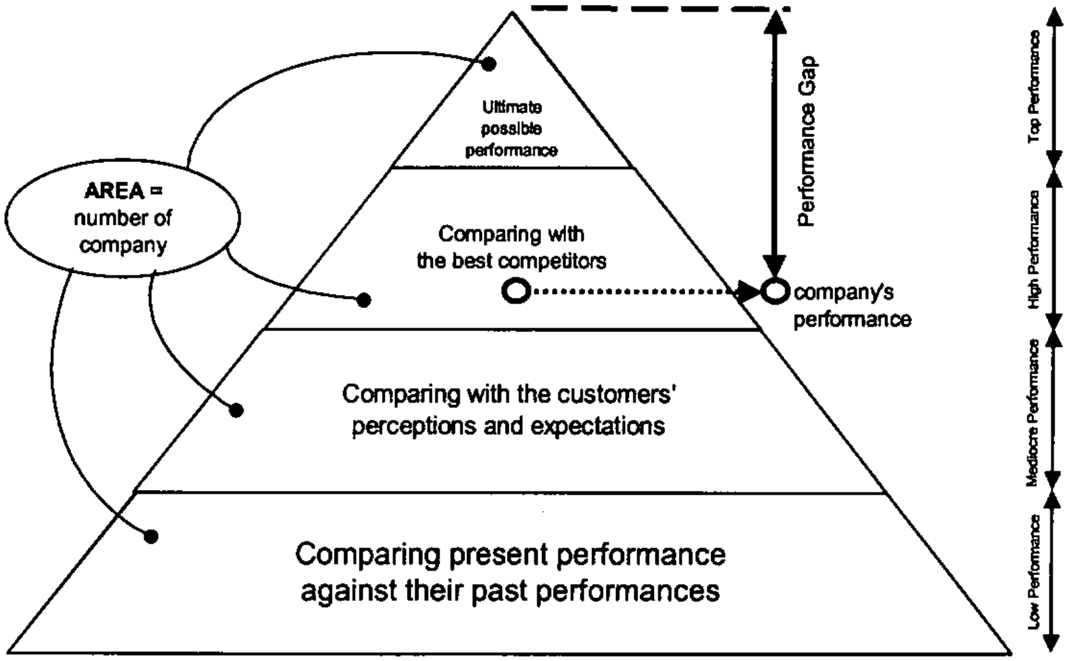


Figure 1: Performance benchmarking model

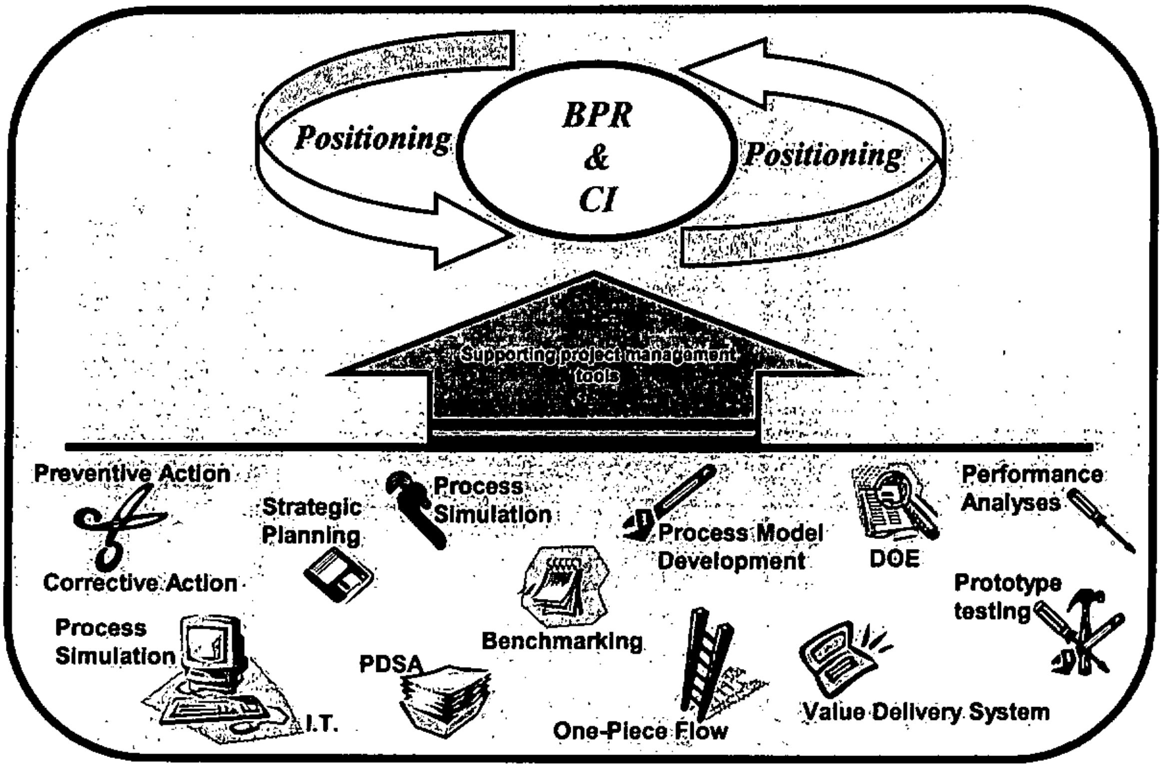
As illustrated in Figure 1, the "AREA" indicates the number of company within its performance region. The number of company reduces as the organization's performance increases. In other words, there are more less-competitive companies than the best performed companies. Therefore, organization must continuously and effectively improve their performance to reduce their performance gap. Performance gap is the difference between the present organization's performance and the ultimate possible performance. The organizations that have competitive edge continually measure themselves against the ultimate performance within the same frame of reference. They realize that if their performance gap is large, either they have to close that gap or risk that a competitor will exploit their weakness. Concurrently, if performance gap is large, this usually indicates that the company must dramatically increase its rate of learning and improvement. In other words, linear or continuous improvement will not be sufficient to close up the extensive gap; therefore, the system must be redesigned and apply non-linear improvement scheme.

Consequently, a higher level of transformation, Value Delivery System redesign is necessary in achieving dramatic improvement.

People or companies do not usually realize that they have a large performance gap unless they get into deep trouble, and by the time they realize that competitors are ahead of them, it takes them much longer to recover than it takes the competitors putting them out of business. One of the critical success factors for improving the competitiveness within an organization is, to continuously employ both linear and non-linear improvement schemes. A company can also enhance its competitiveness by determining suitable process intent, minimize all non-value adding activities and optimize value-adding activities.

2.6 The development of Flexible Business Process Reengineering – Positioning, Continuous Improvement and Business Process Reengineering - PIR

To avoid proliferating new definitions of "reengineering," it is best to confine the use of the term to the redesign of business processes and the implementation of non-linear improvement scheme. However, to enhance the scope of this conventional definition and yet discuss other activities, additional project management tool must be employed with linear and non-linear improvement schemes to deliver their principal benefit – competitive advantage (Altinkemer et al., 1999; Tinnila, 1995; Morris and Brandon, 1993). This project management tool is "positioning." It addresses a higher-level view and set of concerns and uses both continuous improvement and reengineering to implement its directives. Positioning aids in determining what should continuously be improved and what should be reengineered; and at the same time, initiates ancillary activities and side changes that can enhance the effectiveness of the FBPR project without sub-optimizing other business activities.



BPR = Business Process Reengineering
CI = Continuous Improvement
I.T. = Information Technology
DOE = Design Of Experiment
PDSA = Plan Do Study Act

Figure 2: The Flexible Business Process Reengineering model

Figure 2 illustrates the relationships between Positioning, Continuous Improvement (CI) and Business Process Reengineering (BPR) with the supporting project management tools under the Flexible Business Process Reengineering (FBPR) model. CI and BPR remain as the central piece of FBPR project while positioning determines the scope of FBPR project for different types of business activities. In addition, positioning also identify and initiate appropriate modifications to the areas that could potentially be sub-optimized if changes are to be implemented in other business activities. The illustrated supporting project management tools are only some of the tools that FBPR can use. Any tools can be compatible as long as it fits the project's intent.

2.6.1 Positioning - Decomposing an organization into a multi-model structure

Positioning is a set of activities that provides the input and strategic planning framework for both continuous improvement and business process reengineering. It helps to accelerate the implementation of both the linear and non-linear improvement scheme. An organization can be viewed as a collection of interacting processes. Production processes, engineering processes, quality assurance processes, and accounting processes are some of the interacting processes within an organization. If restructuring each process independently without considering its interaction with others, the improvement is likely to be sub-optimal (Ormen, 1998). One of the principal elements of Positioning is decomposition. Decomposition often serves as basis of any business activity. Since, the higher the complexity of FBPR projects, the higher the chance of making mistakes, Ormen (1998) suggests that organizational activities should be decomposed into smaller tasks to prevent un-necessary complexity.

Morris and Brandon (1993) suggests that positioning should begin by gathering data about the company, which are to be used to compare the initial operating processes with the re-designed operating processes. This comparison can be done by exercising the methodology of performance benchmarking or any other appropriate frame of references (Simpson et al., 1999).

The second major element of positioning is to gather information about the way the business is conducted. This information provides a framework for change. It defines the relationships among the company's business units and its business processes. Concurrently, it provides a baseline against which future changes will be measured, and it supports the analysis of improvements in terms of cost and effectiveness.

The third element of positioning is to create an environment in which FBPR project can be implemented quickly, effectively, and without sub-optimizing other operations within the organization. Hence, the rate of changes in business is certain to increase. Change can therefore no longer be treated as an enemy, but an ally.

Positioning is conducted in two stages, they are process analysis and process redesign. The main purpose of process analysis is to define the current business operations and identify other areas of activities that could be affected by the FBPR project. The core purpose of process redesign is to develop an enhanced process after each phase of FBPR (Gaughan, 1996). The enhanced process is re-designed with recommendations during the implementation phase of FBPR. Then cultural, organizational and training issues that represent obstacles to implementation are sufficiently identified. In addition, measurements should continually be established during different phases of FBPR projects.

Ng and co-workers (1999) and Lin and Cochran (1987) have stated that it is often conceived that the workflow system and simulation technology are major tools to support non-linear improvement scheme that aims at redesigning an existing process into a more efficient process. A key to apply the workflow system to the non-linear improvement scheme is to analyze and to evaluate the performance such as customer satisfaction, of the newly redesigned processes in advance. Most existing business activities, however, do not surpass the level of satisfaction defined by their customers and markets (Armistead and Rowland, 1996).

2.6.2 Continuous improvement – Endless learning and involvement

The conventional concept of continuous improvement is to continuously monitor and enhance business activities that are sub-optimal (Morris and Brandon, 1993). Continuous improvement delivers linear changes to all operations within internal business operations and external customer-supplier communications (Monden, 1998; Swartz, 1994). Therefore, systematic approach must be defined to further understand the concept of continuous improvement. Four stages of changes are illustrated as follow:

(1) Constant monitor by applying performance measurement and performance benchmarking;
(2) Focus on processes that exhibit a increasing trend on performance gap;
(3) Continuous training and learning; and,
(4) Employ linear improvement to the targeted business processes.

As illustrated above, implementation of continuous improvement can be characterized into four stages. The primary stage is to constantly monitor and analyze one's performance gap, so that one will be able to identify the areas that need greater improvement. The second stage of continuous improvement should target at various improvement schemes to those business activities that have an increasing trend of performance gap. The third stage should provide adequate training and further promoting the concept of self-learning. Finally, after sufficient training is provided to the related staff, linear improvement scheme should target at business activities.

Continuous improvement can be achieved by applying linear improvement scheme

(Swartz, 1994). Constant and effective application of linear improvement scheme aid an organization to incrementally improve its performance and to reduce its performance gap. Though, if the performance gap is relatively large, non-linear improvement scheme is essential to radically improve its performance.

2.6.3 Business process reengineering – Fundamental rethinking

Unlike the Japanese continuous improvement concept, the conventional BPR concept is to unlearn, then rethink an operation, develop a well-thought-out reengineering plan, and finally, radically and non-linearly improve the organization's performance. Some of the attributes Mohanty (1998); Maull et al. (1995); Hammer and Champy (1993); Morris and Brandon (1993) define for BPR are:

1) Assumes a clean slate change approach;
2) Focuses on end-to-end processes;
3) Redesigns Value Delivery System;
4) Restructures the organization by defining its Process Intent;
5) Develops a suitable Process Model;
6) Enhances flexibility,
7) Results in non-linear improvement.

Reengineering can on the other hand be named non-linear improvement because it makes a dramatic breakthrough with past thinking and believe. Organizations that have implemented the non-linear improvement scheme are very flexible; they are champions of change. The business that has successfully implemented reengineering look beyond past performance and beyond what would satisfy customer today. They look beyond what their best competitors are doing today. They are guided by ultimate standards of performance. In other word, they anticipate and act before they experience trauma.

A reengineering project could be over-challenging if the project leader do not have a very well planned objective. A very thoroughly planned objective must include the hardware, software, organizational activities, and human behavior. Armistead and Rowland (1996) define their meaning of "operating disciplines' as emphasizing the message that organizations should not aim to be "lean and mean" but to be "lean and happy". To achieve the "lean and happy" working environment, three information feedback factors must be defined. The first factor is that the organization's objective of change should be understood throughout the company. The second factor is that major types of resistances to change should be realized. The third factor is constant monitoring and enhancement on internal and external communications. A more detailed explanation is explained as follow:

Factor one - Objective of all changes

During the planning stage of non-linear improvement projects of FBPR, the objective and target of the expected result should be clearly and quantitatively established. This can provide a clearer picture on the type and the scope of change to staff that are to be involved. Alternatively, project leaders must be totally objective toward all operational procedures. This can enhance the change agent to have a clearer vision on how the job "Is" currently being done and "Should" be done (Gaughan, 1996).

Factor two - Resistance to change

Middle Management is more likely to resist changes (Hammer and Champy, 1993). Some of the reasons are that they are comfortable with the way their activities are currently carrying out. Therefore, they rarely thought of improving this mal-performed management system. They may also assume reengineering means additional work or even downsizing. Hence, during the planning and the implementation stages of a FBPR project, all staff must constantly be informed, so as, to provide them adequate training and sufficient self-confidence and to prepare them for upcoming changes.

Factor three - Internal and external communications

Morris and Brandon (1993) have stated that most staff concerned more about themselves than others. Therefore, inter-departmental communication can be considered to be one of the weakest links within an organization, especially during the process of reengineering. In order to break the communication barrier, additional activities such as scheduled communication training, periodic team competitions, etc., should be performed to increase the team spirit. Alternatively, two-way communication should also be enhanced both internally and externally. During the implementation of a FBPR project, there is a potential that the product quality and service be affected. Therefore, to minimize any negative effect from non-linear improvement project (if any), customers should also be informed about the changes. Simultaneously, organization should also inquire customer feedback, such as product quality trend and customer surveys.

2.7 Benefits of Reengineering

Before implementing a FBPR project, measurable improvement targets must be determined (Hammer and Stanton, 1995). After the targets are identified, the FBPR team would have a clearer vision on where to implement non-linear changes. The targets of the FBPR project should focus on the types of benefit on which the organization could possibly receive. Mohanty (1998) states that one of the potential benefits which implementation of a reengineering project can provide is, the development of innovative ideas from both the reengineering team and the organization's staff. This promotes and aids the employees to develop self-improvement and self-initiative. With the increase in employees' abilities and initiatives, the productivity and the efficiency of work activities could increase. Therefore, it will aid in enhancing the process Through-Put-Time (TPT). Concurrently, organizational and process flexibility, and the responsiveness will also be improved. Hence, it leads to cost reduction and increase in the profit margin. With the increase of competitiveness, the service and product quality would simultaneously be enhanced. The financial performance and the value delivery performance would also be improved. To conclude, the final destination of all the improvement will end up to an increase in customer satisfaction and organization's competitiveness.

2.8 Comparing CI, BPR and FBPR

The similarities and the differences between the three management methodologies – CI, BPR and FBPR is illustrated in Table 1:

Table 1: Similarities and Differences between CI, BPR and FBPR

CI	BPR	FBPR
Continuous small steps	Infrequent big leaps	CI + BPR
Start with what you have	Start with "clean sheet"	CI + BPR
Change what you have learned	Forget and re-learn	Continuous learning and involvement
Eliminate non-value added processes	Selective, one at a time	Whichever that fit the process intent
Simultaneous processes	Minimize inputs, add value to processes	Output focused
Not under competitive pressure to take immediate action	The company has the resources to handle the transformation	Constant and systematic improvement management system
People involved in the operations	BPR project team	Involve both the direct labor and project team

2.9 Synergy for FBPR

After the theory of FBPR is understood throughout the organization, the synergy of FBPR is developed to enable a systematic method of implementing an efficient and effective reengineering project. Where as, the term "synergy" can be defined as the combination of improvement changes. The synergy of FBPR contains a seven steps performance improvement cycle. This seven steps performance improvement cycle provide a trend and a systematic method for FBPR project implementation. The seven steps of performance improvement cycle are illustrated as follow:

Step 1: Gain top management's commitment and support for employing both linear and non-linear change.

Step 2: Re-delineate a shared vision and mission of the business and what changes are required, and then identify the process intent for upcoming changes.

Step 3: Determine measurable objectives as being the quantifiable indicators of success in terms of the FBPR project, and then create a process model.

Step 4: Develop the mission based on its Critical Success Factors (CSFs) and process intent; subsequently develop a Value Delivery System.

Step 5: Breakdown the CSFs into key or critical business processes and optimize process ownership, and promote and develop preventive operations.

Step 6: Decompose the critical processes into multiple processes, activities and task and form the FBPR team around these, then employ either linear improvement scheme or non-linear improvement scheme.

Step 7: Re-align, monitor and analyze the redesigned activities, apply corrective action if any problem arises. Re-employ performance measurement and analysis to benchmark and to position the degree of improvement compare to the initial performance. Once the defined process intent is met, the project can be considered completed. Alternatively, when the market demand shifts, the process intent must be revise and the process model must then be regenerated by repeating step 2 to 7.

The multiple-steps relationship and the synergy of FBPR have been illustrated in Figure 3 and Figure 4 respectively.

With the mentioned seven steps of performance improvement cycle and the synergy of FBPR being properly defined, understood and implemented, organization will be able to continuously enhance its industrial competitiveness.

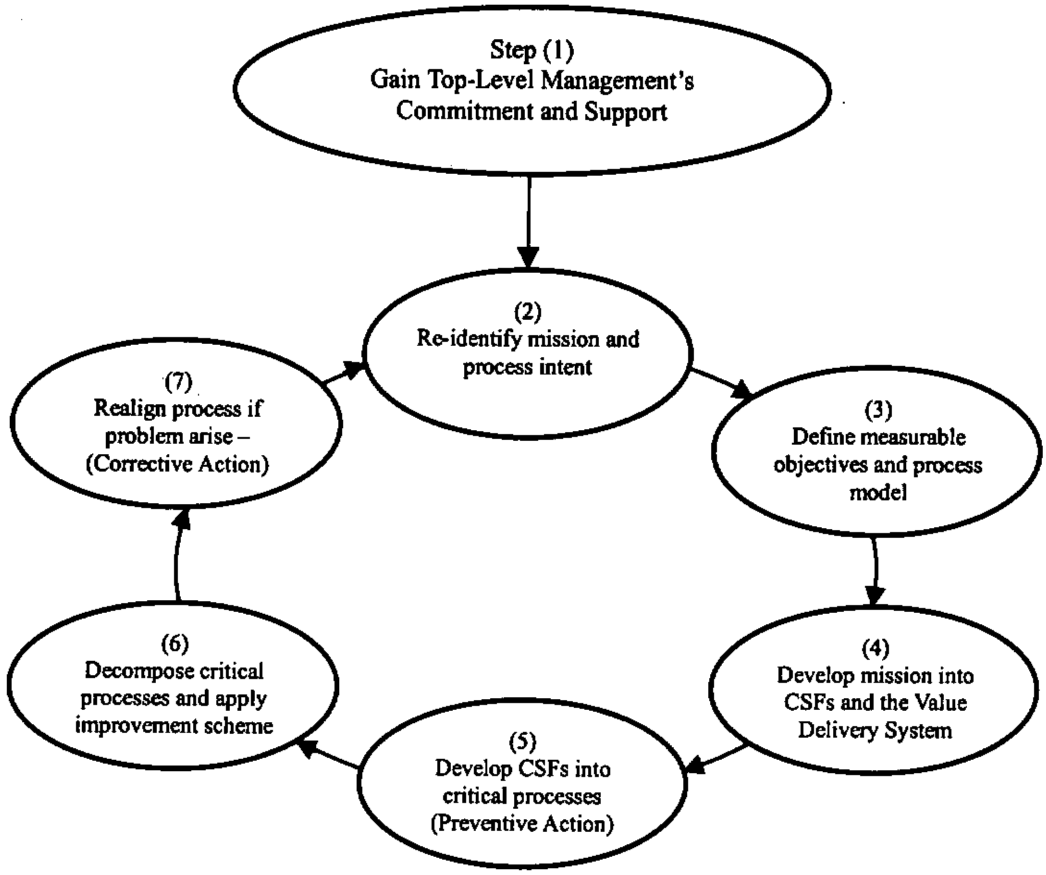


Figure 3: Performance improvement cycle of Flexible Business Process Reengineering

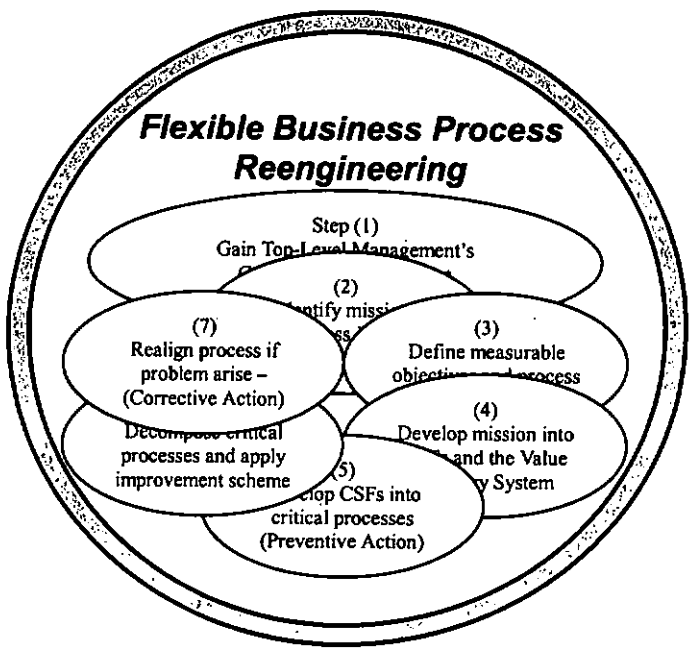


Figure 4: The "Synergy" of Flexible Business Process Reengineering

CHAPTER THREE: THE FBPR PROJECT MANAGEMENT METHODOLOGY – VALUE DELIVERY SYSTEM (VDS)

Reengineering is an approach to planning and controlling change. Business reengineering means redesigning business processes and then implement new processes with new methodology. If full measure of positioning is done beforehand, reengineering projects will have their goals set and their environment prepared (Morris and Brandon, 1993). Alternatively, implementing positioning by using the fundamental concept of PDSA cycle (Plan Do Study Act cycle) of continuous improvement can aid the FBPR team to enhance the effectiveness of performance analysis during both the linear and the non-linear improvement scheme.

The combination of the three concepts – Positioning, continuous Improvement and business process Reengineering (PIR) – is important for several reasons. Firstly, the scope of positioning is best set very broadly. The entire enterprise, or one independent business unit may be an optimal target. Continuous improvement is best when its scope is limited to a process or group of operations. Alternatively, since conventional BPR has already frightened connotations among the working levels; therefore, positioning at the early stage of a FBPR project can accelerate the efficiency and effectiveness of change process. Positioning specifically set a favorable and trusting environment, it can therefore greatly increase the effectiveness of the subsequent improvement efforts. By clearly identifying its goals and process intents; staff will have a greater confidence and sense of security during the change process. Lastly, by constantly implementing positioning during the FBPR projects, all information concerning product quality, manufacturing performance, etc. can be kept up-to-date.

The concept of PIR is flexible enough to be used for either an entire enterprise or a single business unit. Because they divide the business into manageable parts, there is neither upper limit nor lower limit on the size of the business to which positioning can be applied. The smallest unit of a large business that can use them would be a single business activity. Any business process will, however, generally be cross-organizational and will typically touches many parts of the units in a business. This causes the scope of any single reengineering project to be organizationally independent.

3.1 Value Delivery System (VDS)

To identify or re-modify the objective and target of an organization during a non-linear improvement scheme, Value Delivery System (VDS) is one needed. A VDS consists of all people, processes, procedures, facilities, and machines that provide a group of products, services or information to customers (Swartz, 1994). VDS should be designed to deploy optimally the strategies of the business. VDS have four characteristics: Process Intent, Process Model, In-Process Control and Evaluation, and Design of New Learning System. Once a business strategy is determined, the initiator of the VDS could then determine the process intent.

VDS is a system that delivers values to customers. For instant, from the time material leaves the mines, oil fields, or farms, or from the time information leaves its source, it is a continuous value-adding process until it gets to the final customer. From the moment a creative idea is generated until the time that idea turns to a new product or service, the Delivery System is adding value.

Process intent is what the process is intended to do. To be competitive, a VDS must be designed for customer response, customer quality, and customer's perception of a high value-to-cost ratio. The Process intent of the system is considered in terms of performance requirements, responsiveness, quality level to be achieved and cost of adding value. Competitive organizations often redesign the VDS abruptly, non-linearly changing process intents and process models, thus to enhance the flexibility of the organization to adapt to the constant changing market and customer demand.

As mentioned previously, flexibility is essential to increase competitiveness. Flexibility is essential due to its abilities to anticipate the need to change and its abilities to change or adapt to changes. Competitive organizations are flexible and they constantly develop new strategies to win customers.

There are no universal good process models. Their suitability is determined by how well they meet the Delivery System's process intent, develop a VDS design, determine strategic options and minimize Through-Put-Time (TPT). Through-Put is the quantity of products or services that flow completely through a Delivery System. The most effective way to improve the TPT is to increase the rate of production at the worst bottleneck in the Delivery System.

A business must have to develop a Delivery System that excels in all three performance categories – response, quality, and value-to-cost ratio. To develop an adequate VDS, the design should be analyzed in an organizational level point of view. For instant, during the implementation of a Preventive Action (PA) one must be able to "see the forest instead of trees." During the phase of realizing the hidden and potential problems, one must have to adjust one's perception to be able to see the forest – organizational level.

Once the FBPR methodology and VDS are successfully established and implemented, the VDS model allows management to try new process designs before they are implemented. Each business process can be studied, analyzed, and modified by corporate managers and project leaders. The results are: a well-designed business process, a clear picture of the impact of changes and a well-developed knowledge of the process. The key to apply VDS to the FBPR projects is to determine the vital ground for analyzing and evaluating the performance of the newly redesigned process in advance (Bae et al., 1999).

3.2 Developing the Value Delivery System for FBPR

As mentioned earlier during this chapter, VDS is one of most important elements to be developed during the application of FBPR. The development of the VDS is separated into four steps. The Value Delivery Model is illustrated in Figure 5 and briefly described in following sub-section.

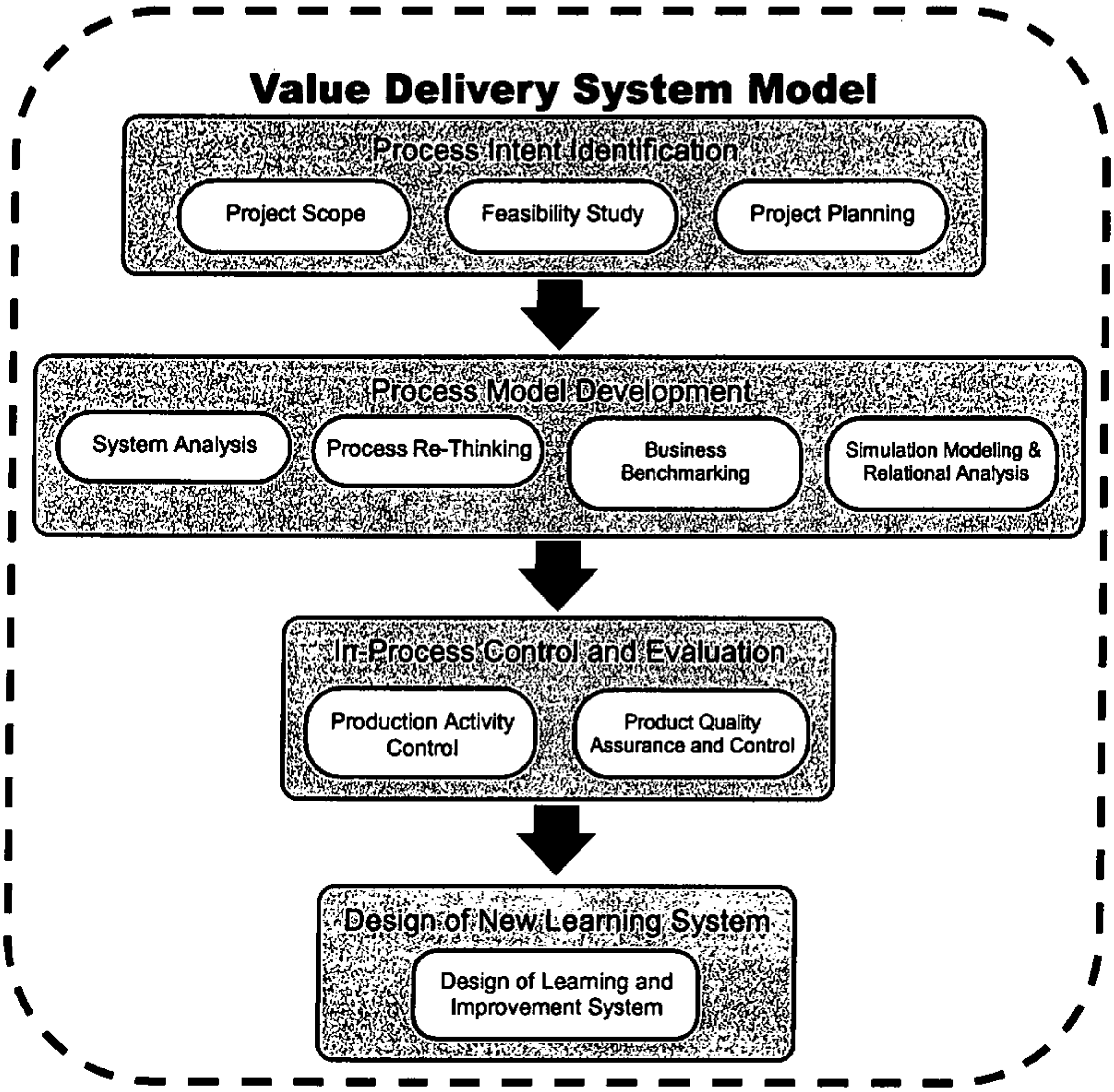


Figure 5: The Value Delivery System model

3.2.1 Process intent identification

An FBPR project begins with business activities planning and positioning. This is a blueprint that organizes the resources and directs any future activities involved in the project. The three activities consist of project scope, feasibility study and final project plan. The details can be elaborated as follows.

Project scope identification

An initial study to identify scope is conducted in order to arrive at a problem definition. The reengineering team must first identify what is to be benchmarked/redesigned and determine a method for performance analysis. Thus, the reengineering team would be able to re-define the scope of the project and set goals against which the alternate design is evaluated. The reengineering team can then perform process analysis and determine the business areas that have the greatest performance gaps or business sectors that have the least improvement for a lengthy period of time, before employing either linear or non-linear improvement schemes. Alternatively, the operating requirement and the processing requirement can also be obtained as input for the feasibility study.

Feasibility study

Determination of the constraints and controls is needed for any FBPR project. These are carefully examined in order to decide whether the preliminary requirement defined in the earlier stage can be fulfilled. Process intent should be re-determined if needed, and functional goals should be redesigned and sufficient training should be provided before initiating FBPR projects.

Project planning

Process model and corporate strategies should be developed once the process intent is defined. The process model and corporate strategies specify the scope, the system performance, the timing and the resources allocated to the FBPR project. A FBPR program is introduced to organize and to control the resources and the activities. Simultaneously, specific actions to monitor progress should be implemented by applying performance analysis.

3.2.2 Process model development

The development of process model calls for analyzing and redesigning of the existing state of business activities while implementing the concept of Preventive Action (PA). It begins with preliminary analysis and the business operations and problems are studied in greater details. The process model includes four types of analysis and testing which are elaborated as follows:

System analysis

The process model initiators must be completely familiarized with the current working system by periodically auditing its flexibility, efficiency, capability, limitations and connectivity. Initiators must also realize that current working systems that are sub-optimized. Any problems that are inherent in the system can be fully understood and clearly defined. Testing and analysis scheme such as Design Of Experiment (DOE) and relational diagram can be employed to map out the relationship between business activities. Simultaneously, applying FBPR changes to one business activity while isolating others may consequently affect other business activities. Therefore, in order to prevent this, the reengineering team must recognize the business activities that could be affected and initiate appropriate actions to accommodate the FBPR movements.

Process re-thinking

Process re-thinking involves recognizing potential solutions, and then seeking and recognizing obvious or latent problems that may be solved. The process model initiators should challenge the assumptions that underlie current business activities in order to generate ultimate process model where appropriate. Thus, a set of new processes can be achieved for process benchmarking.

Business benchmarking

Benchmarking is usually considered as a continuous improvement tool. As for the non-linear improvement, benchmarking can be applied to gain information regarding the company's relative position in key business activities, core competencies and performance gaps. The reengineering team can use this technique to create an industry context for the goals set. This provides the company with examples of best practices in terms of new processes and the approach during FBPR project implementation.

Computer simulation modeling and relational analysis

Simulation modeling and relational analysis can be used to visualize and to evaluate the redesigned processes generated by both linear and non-linear improvement schemes. These provide the reengineering team with appropriate tools for evaluating the current performance and capabilities and potential improvements for new business activities. Discrete-event computer simulation and animation can then be applied in understanding the general over-view of each business activity.

3.2.3 In-process control and evaluation

Production activity control

Production activity control is the nuts and bolts within the Cost Effectiveness Analysis (CEA). In order to recognize the effectiveness of each process, relationships between production activities and job-costs, specific management objectives and control must be developed during the FBPR project; the characteristics for CEA are illustrated as follow:

(1) Provide realistic job costs budgets and estimates;

(2) Control the costs of jobs;

(3) Monitor the progress of jobs through the production processes; and

(4) Provide actual cost variance reporting.

Production capability planning is necessary for a manufacturing organization. With appropriate simulation model and relational analysis, the FBPR team can easily monitor the progress of operations throughout the production facility. Since no operation can be considered "perfect", intensive Corrective Action (CA) is essentially important during the implementation of a FBPR project. After these have been done, detail description of the manufacturing processes can then be provided to monitor the rate of improvement versus the goal and target of improvement.

Product quality assurance and control

The optimal target of all manufacturing organization would include a "Build-in Quality" system within all their imminent products and services. Therefore, quality assurance and control are particularly important while implementing an FBPR project. During the planning stage and implementation stage of a FBPR project, process performances and activities may be affected. As a result, continuous processes assessment and analysis should be conducted. In the work reported here, reliability analysis has been conducted to monitor the continuous changing process. A more detailed description on reliability analysis applied is illustrated in chapter 7.

3.2.4 Design of learning and improvement system

In order to maintain and constantly improve the organization's global competitiveness, the organization must not only endlessly search for new management methodologies and the most updated technologies, but also constantly develop and enhance existing working methodologies. Thus, the organization has to design the ultimate learning and improvement system at times. To become and remain competitive within the industry, it is essential to *transform one self's mind and then the business in order to maximize the rate and quality of learning and improvement.* In other words, optimal performances can be achieved by un-learning those already known and re-learning the essentials.

3.3 Six FBPR principles that can increase reengineering projects' effectiveness

At the planning stage of a FBPR project, specific methodologies and principles are developed before project implementation. They are crucial because that they can provide factual and accurate information feedback instead of the theoretical assumption. The six principles that can enhance a FBPR project's effectiveness is illustrated as follow:

(1) Since the customers pay for the product outcome, any FBPR project should base its intention on organizing around outcomes instead of tasks which many former reengineering projects aimed at.

(2) During process simulation stage, testing stage and actual implementation stage, staffs who usually perform the processes should carry out the redesigned activities at all time to increase the accuracy of data and information. Since different staff contain different performances, it is important to get the right staff for the right task.

(3) Information must be captured at the source where activities are carried out, thus provide up to date information without any mis-communication.

(4) Subsuming information-processing work into the real work that produces the information, rather than the theoretical data and information, thus factual information can be obtained.

(5) Position the decision point where the activities are performed and build control within processes to promote an information feedback and feed-forward system. A sufficient feedback system can reduce time-to-detect and can improve quality of feedback information. A sufficient feed-forward system can reduce time-to-correct and can improve the quality of problem solving processes.

(6) Parallel activities should be linked instead of integrating and analyzing their results. Thus avoid optimizing one business area and sub-optimizing others.

3.4 Three levels of FBPR in Hong Kong PCB manufacturing company

Flexible Business Process Reengineering projects can be applied in three levels within any organization. They included process level, operational level which covers cross-departmental activities, and organizational level which includes all business operations.

To enhance the practicality of FBPR, the work reported here was carried out in a Hong Kong manufacturing company. Factual operating and performance data and information were obtained. The work was conducted in Company "C". Company "C" is a Small and Medium size Enterprise (SME) who manufactures Printed Circuit Boards (PCBs) for the automotive, telecommunication and general appliances industries with customers in USA and a number of European countries.

In the development stage of finding appropriate linear and non-linear improvement projects, one project for each level of FBPR is identified. They are the silkscreen printing process at the process level; post-Hot Air Solder Leveling (post-HASL) baking at the operational level; and lastly, production panel size at the organizational level. While positioning the organization, it has been identified that silkscreen printing process is one of the bottleneck among all manufacturing processes. At the same time, it has also been realized that if linear improvement is to be applied in the silkscreen printing process, it may result a relatively larger improvement in both productivity and efficiency; since the process involves a relatively large amount of labor and machineries comparing to other PCB manufacturing processes. At the operational level, post-HASL baking operation is eliminated with appropriate re-modification and analysis on other operation's activities. At the organizational level, optimizing the production panel size is conducted by employing non-linear improvement scheme.

CHAPTER FOUR: APPLICATION OF FBPR IN PROCESS LEVEL – SILKSCREEN PRINTING PROCESS

There are a number of production operations in manufacturing PCB. The solder masking operation is considered as one of the main bottlenecks and it affects to the quality of the PCB. The main processes in the solder masking operation are silkscreen printing, baking, U.V. exposure, and solder mask developing. The most crucial process among the four is the silkscreen printing process, as it directly impacts the quality and the reliability of the PCB. The solder mask serves as an insulative and protective coating to protect the PCB from damages caused by factors such as mal-soldering, humidity, heat, oxidation, scratches, etc.

To improve the productivity of the silkscreen printing process, additional supporting tools such as action description table and relational diagram have been utilized to enhance the effectiveness of the FBPR project. There are a total of 31 steps within the silkscreen printing process as presented in the action description table in Figure 6 and the relational diagram in Figure 7.

The process-level FBPR project for silkscreen printing process is carried out in approximately eight months. After the development of the project's methodology and the analysis of the initial findings, the implementation is conducted in five phases and a final analysis. To prove the effectiveness of the reengineering effort, measurement and analysis of the performance before and after the changes are essential. Alternatively, Preventive Action (PA) and Corrective Action (CA) must also be considered during the implementation of the linear improvement project, thereby eliminating the side effects possibly resulting from the process changes.

As shown in Figure 6, there are at most 31 steps in the silkscreen printing process. Due to the different pre-treatments for different types of PCB, Gold (Au) and Tin (Sn) PCB have slightly different process activities. However, steps 1 to 4 occur only on the first unit of Gold PCB for each production lot. Steps 5 to 9 are the value-adding steps in silkscreen printing. Steps 10 to 15 and steps 17 to 22 are handling activities. Step 16 is the visual inspection for every unit of PCB to ensure that every panel is of good quality. Steps 23 to 30 are procedures for the treatment of the silkscreen.

4.1 The aim of applying FBPR in the process level

This linear improvement project aims to reduce the Through-Put-Time (TPT) of the silkscreen printing process by applying FBPR. Peppard and Rowland (1995) states that "business reengineering aims to increase performances by redesigning the processes through which an organization operates, maximizing their value adding content and minimizing everything else." Therefore, by minimizing the non-value adding activities within the silk-screen printing process, the value-adding ratio is maximized. Meanwhile, the process is restructured so that the activities can be performed simultaneously. As a result, the manual productivity and efficiency of the silkscreen printing process will increase while the TPT is decreased. As for the non-value adding activities that cannot be eliminated, they have been restructured in such a way that they operate in parallel with the value-adding activities. Consequently, the effects of the non-value adding activities could be minimized.

4.2 Supporting tools for process level FBPR – Action description table and Relational diagram

It is advantageous to use external project management tools to enhance the effectiveness of a FBPR project. In this FBPR project, the action description table and the relational diagram are developed and utilized. They are used to model the SSP process; thereby, to increase the visibility of the actual process' activities and to benchmark the process. On the other hand, in order to maintain all factual data up-to-date and to monitor the rate and trend of improvement, the action description table and the relational diagram are re-analyzed after each phase of process-level FBPR.

4.2.1 Action description table

As a fundamental tool in process analysis, the action description table is used to illustrate the information of the process' manufacturing activities. The action description table consists of seven elements. They include: the number of steps, the action time, the determination of value addings, the descriptions of the activities, the chance of occurrence, the average action time per panel and the content of each activity.

The activities are divided into four categories: the decision activity, the handling activity, the quality control activity and the operation activity. The three former activities are known as the non-value adding activities, and the last activity is the only type that delivers value to the customer. The average time needed per panel is calculated by the multiplying the time needed per action by the chance of occurrence. The content is used to reason the purpose of each of the activities. Various stages of the action description tables are illustrated in Figures 6, 8, 10, 12, 14 and 16.

4.2.2 Relational diagram

The relational diagram is developed and used to illustrate the activities flow of the silkscreen printing process during the process of linear improvement. Within the relational diagram, there are five different types of symbols. They include the beginning and the ending symbol (hexagon), the decision symbol (diamond), the quality control symbol (oval), the rework symbol (documentation), and the operation and handling symbol (rectangular). Various stages of the relational diagrams are illustrated in Figure 7, 9, 11, 13, 15 and 17. With a clear illustration and understanding of the silkscreen printing process, the effectiveness of the implementation of process-level FBPR is enhanced.

4.3 Testing and comparing design alternatives

Positioning the process activities is one of the most crucial elements before implementing linear improvement in the SSP process. By continuous learning and challenging the process intent of the SSP process, the activities that should be eliminated and restructured can be identified clearly. Performance analysis is then needed to realize the relationship between all value adding and non-value adding activities. After evaluating the performance of the SSP process, a number of questions are raised. The entire SSP process operates in succession. Hence, one of the methods to maximize the efficiency is to restructure the activities in such a manner that they can be operated simultaneously. Alternatively, the visual inspection should be minimized without sacrificing the product's quality since it is non-value adding to the production cycle. Nevertheless, a minimal rate of inspection has to be maintained to prevent and to correct any sporadic losses and to ensure the quality output of the silkscreen printing process.

When challenging the activities within the SSP process, it is found that having every PCB panel visually inspected at step 16 in Figure 2 and Figure 3 does not add any value to the SSP process. Rather, it adds an additional layer to the process flow. Furthermore, ensuring that the panels are well secured on the newly engineered fixture at the beginning of the process can avoid the 100% visual inspection. On the other hand, since the SSP process is operated semi-manually, manual errors should be taken into consideration. Therefore, visual inspection cannot be eliminated but can only be minimized on step 16.

4.4 Five phases of implementation

During the implementation stage, a number of activities must be carried out prior implementing the process-level FBPR to the silkscreen printing process. As mentioned previously, benchmarking and analyzing the process activities before and after employing linear improvement are part of the essentials. Therefore, factual data and information concerning the silkscreen printing process are obtained before employing changes. Meanwhile, the performance analysis is applied for future comparisons.

After data collection and performance benchmarking, implementation of the new process activities is carried out in five phases.

Phase I

There are initially a total of 31 steps to the silkscreen printing process. Most manufacturing activities are carried out subsequence to each other. In phase one, the original TPT for each PCB panel is 22.0 sec and 25.5 sec for Tin and Gold PCB respectively. The primary phase of silkscreen printing process is illustrated in Figure 6 and Figure 7.

STEP	Time (sec)	Value Added?	Description	Chance of Occurance	Average time (sec needed per cycle)	Content
0			START			START
1	0		Decision	100%	0	Cleaning for every unit
2	1.5	N-VA	Handling	100%	1.5	
3	2	VA	Operation	100%	2	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2	
6 – 9	7	VA	Operation	100%	7	Actual Silk Screen Printing
10	1	N-VA	Handling	100%	1	Handling
11	0		Decision	100%	0	Rework twice for approximately every 250 units
12	0		Decision	1.67%	0	
13	2	N-VA	Handling	0.67%	0.01	
14	2.5	N-VA	Handling	100%	2.5	Handling
15	4.5	N-VA	Q.C.	100%	4.5	Visual Inspection
16	1	N-VA	Handling	100%	1	Handling
17	1	N-VA	Handling	100%	1	
18	0		Decision	100%	0	
19	0		Decision	8.33%	0	
20	5	N-VA	Handling	5.00%	0.25	
21	30	N-VA	Handling	3.33%	1	
22	0		Decision	100%	0	Refill paint once for approximately every 150 units
23	15	VA	Operation	1.00%	0.15	
24	0		Decision	0.67%	0	Cleaning once for approximately every 150 units
25	2	N-VA	Handling	0.67%	0.01	
26	7	N-VA	Operation	0.67%	0.05	
27	2	N-VA	Q.C.	0.67%	0.01	
28	2	N-VA	Handling	0.67%	0.01	
29	0		Decision	0.67%	0	
30	0		Decision	100%	0	END
31			END			
			Total Time (Sn)		*22.00*	
			Total Time (Au)		*25.50*	

Figure 6: Action description for silkscreen printing process ~ phase I of process reengineering (initial state)

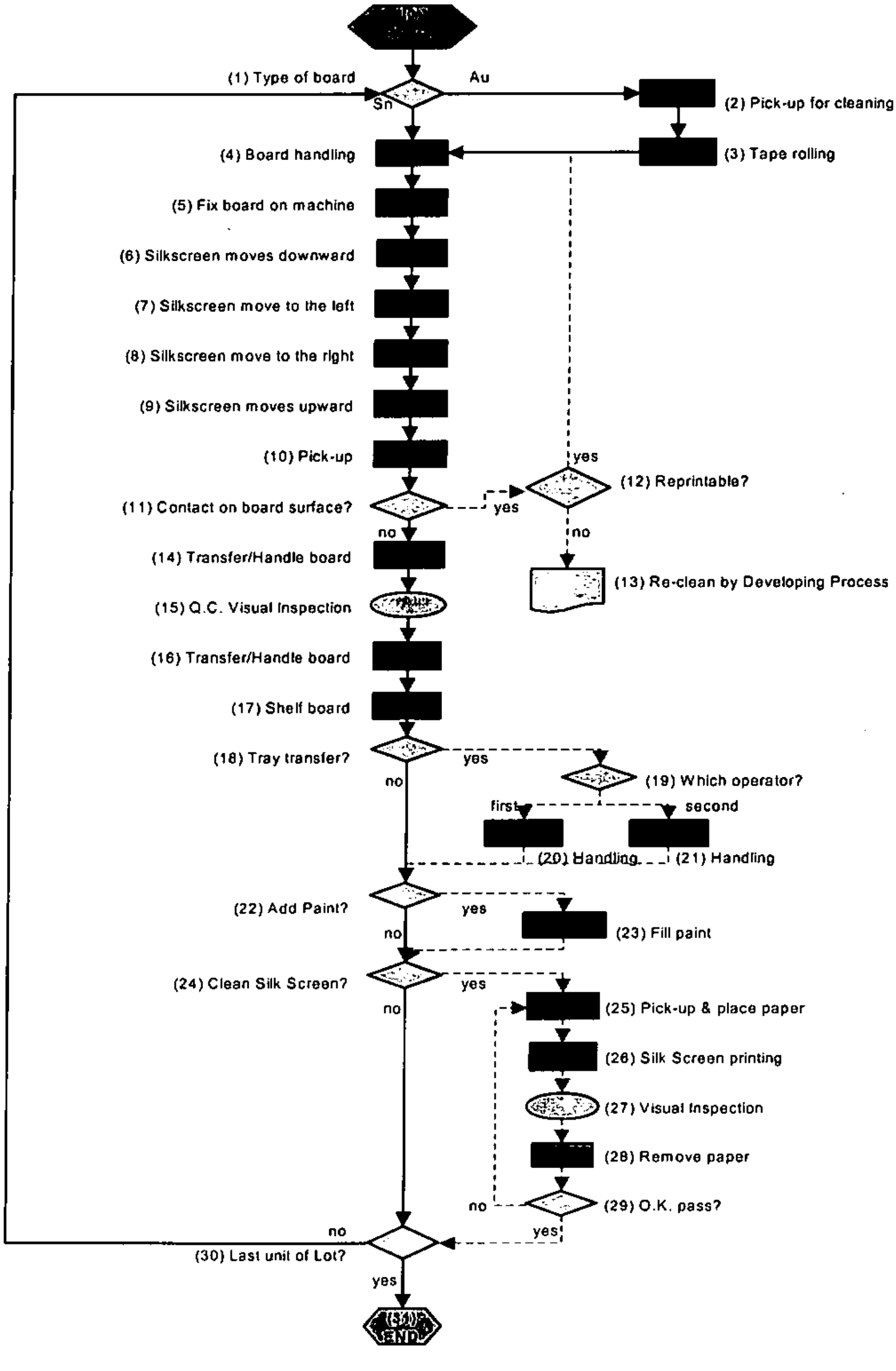


Figure 7: Relational diagram for silkscreen printing process ~ phase I of process reengineering (initial state)

Phase II

After applying the concept of fundamental rethinking, the Figure 8 and Figure 9 demonstrates that 100% visual inspection is unnecessary after a special redesigned silkscreen fixture is installed on the solder masking table. Therefore, the visual inspection procedure at step 16 is reduced from 100% inspection to approximately 3.3% due to level of necessity. The rate of 3.3% inspection is obtained by visually inspecting the first unit of every tray, where there exists 30 panels per tray. The visual inspection at step 27 is eliminated as well. The average TPT per panel at this stage is reduced from 22.0 sec to 17.6 sec and 25.5 sec to 21.1 sec, an increase in productivity of 19.8% and 17.1% for Tin and Gold PCB respectively. The reduction of visual inspection did not affect the high quality of the PCB due to the newly redesigned fixture in the silkscreen printing process.

STEP	Time (sec)	Value Added?	Description	Chance of Occurance	Average time (sec) needed per cycle	Content
0			START			START
1	0		Decision	100%	0	Cleaning for every unit
2	1.5	N-VA	Handling	100%	1.5	
3	2	VA	Operation	100%	2	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2	
6 – 9	7	VA	Operation	100%	7	Actual Silk Screen Printing
10	1	N-VA	Handling	100%	1	Handling
11	0		Decision	100%	0	Rework twice for approximately every 250 units
12	0		Decision	1.67%	0	
13	2	N-VA	Handling	0.67%	0.01	Handling
14	2.5	N-VA	Handling	100%	2.5	
15	0		Decision	3%	0.0	Visual Inspection
16	4.5	N-VA	Q.C.	3%	0.2	
17	1	N-VA	Handling	100%	1	Handling
18	1	N-VA	Handling	100%	1	
19	0		Decision	100%	0	
20	0		Decision	8.33%	0	
21	5	N-VA	Handling	5.00%	0.25	
22	30	N-VA	Handling	3.33%	1	
23	0		Decision	100%	0	Refill paint once for approximately every 150 units
24	15	VA	Operation	1.00%	0.15	
25	0		Decision	0.67%	0	Cleaning once for approximately every 150 units
26	2	N-VA	Handling	0.67%	0.01	
27	7	N-VA	Operation	0.67%	0.05	
28	2	N-VA	Handling	0.67%	0.01	
29	0		Decision	100%	0	END
30			END			
			Total Time (Sn)		***17.64***	
			Total Time (Au)		***21.14***	

Figure 8: Action description for silkscreen printing process ~ phase II of process reengineering

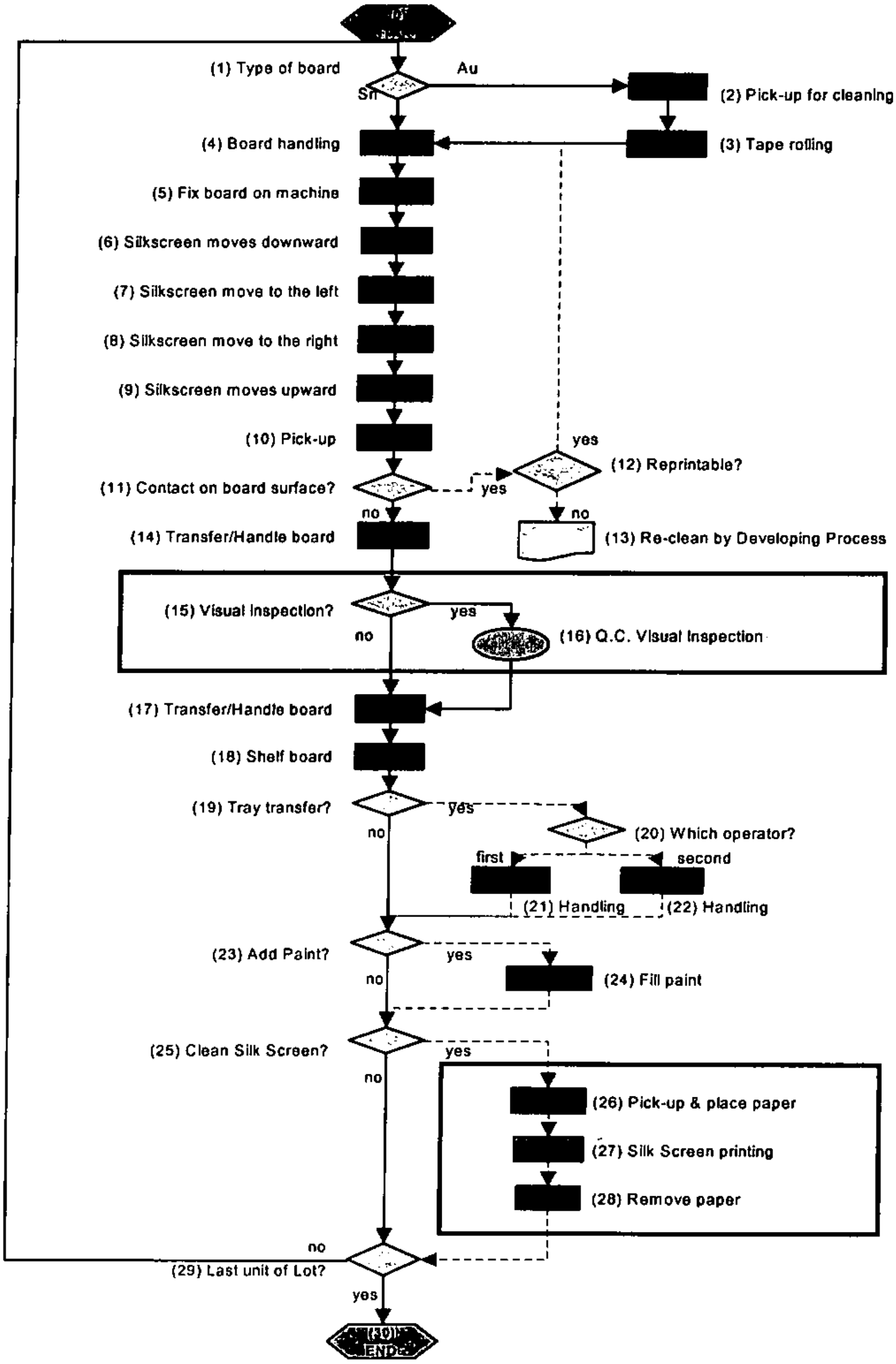


Figure 9: Relational diagram for silkscreen printing process ~ phase II of process reengineering

Phase III

The handling activities at steps 19 to 22 demonstrate in Figure 10 and Figure 11 operates in parallel to the operating activities rather than consecutively. Based on the concept of One-Piece-Flow, performing two activities simultaneously and reducing the operators' idle time during production could increase the productivity and the efficiency of manufacturing process. The concept of One-Piece-Flow is therefore initiated to maximize the silkscreen printing process productivity and efficiency. In return, the total handling time per panel is reduced from 8.0 sec to 6.0 sec and 9.5 sec to 7.5 sec, a cycle time reduction of 25% and 21% for Tin and Gold PCB respectively.

STEP	Time (sec)	Value Added?	Description	Chance of Occurance	Average time (sec needed per cycle	Content
0			START			START
1	0		Decision	100%	0	
2	1.5	N-VA	Handling	100%	1.5	Cleaning for every unit
3	2	VA	Operation	100%	2	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2	
6 – 9	7	VA	Operation	100%	7	Actual Silk Screen Printing
10	0		Decision	100%	0	
11	0		Decision	8.33%	0	
12	5	N-VA	Handling	5.00%	0.25	Handling
13	30	N-VA	Handling	3.33%	1	
14	1	N-VA	Handling	100%	1	
15	0		Decision	100%	0	Rework twice for approximately every 250 units
16	0		Decision	1.67%	0	
17	2	N-VA	Handling	0.67%	0.01	Handling
18	2.5	N-VA	Handling	100%	2.5	
19	0		Decision	3%	0.0	Visual Inspection
20	4.5	N-VA	Q.C.	3%	0.2	
21	1	N-VA	Handling	100%	1	Handling
22	1	N-VA	Handling	100%	1	
23	0		Decision	100%	0	Refill paint once for approximately every 150 units
24	15	VA	Operation	1.00%	0.15	
25	0		Decision	0.67%	0	
26	2	N-VA	Handling	0.67%	0.01	
27	7	N-VA	Operation	0.67%	0.05	Cleaning once for approximately every 150 units
28	2	N-VA	Handling	0.67%	0.01	
29	0		Decision	100%	0	
30			END			
			Total Time (Sn)		***17.15***	
			Total Time (Au)		***20.65***	

Figure 10: Action description for silkscreen printing process ~ phase III of process reengineering

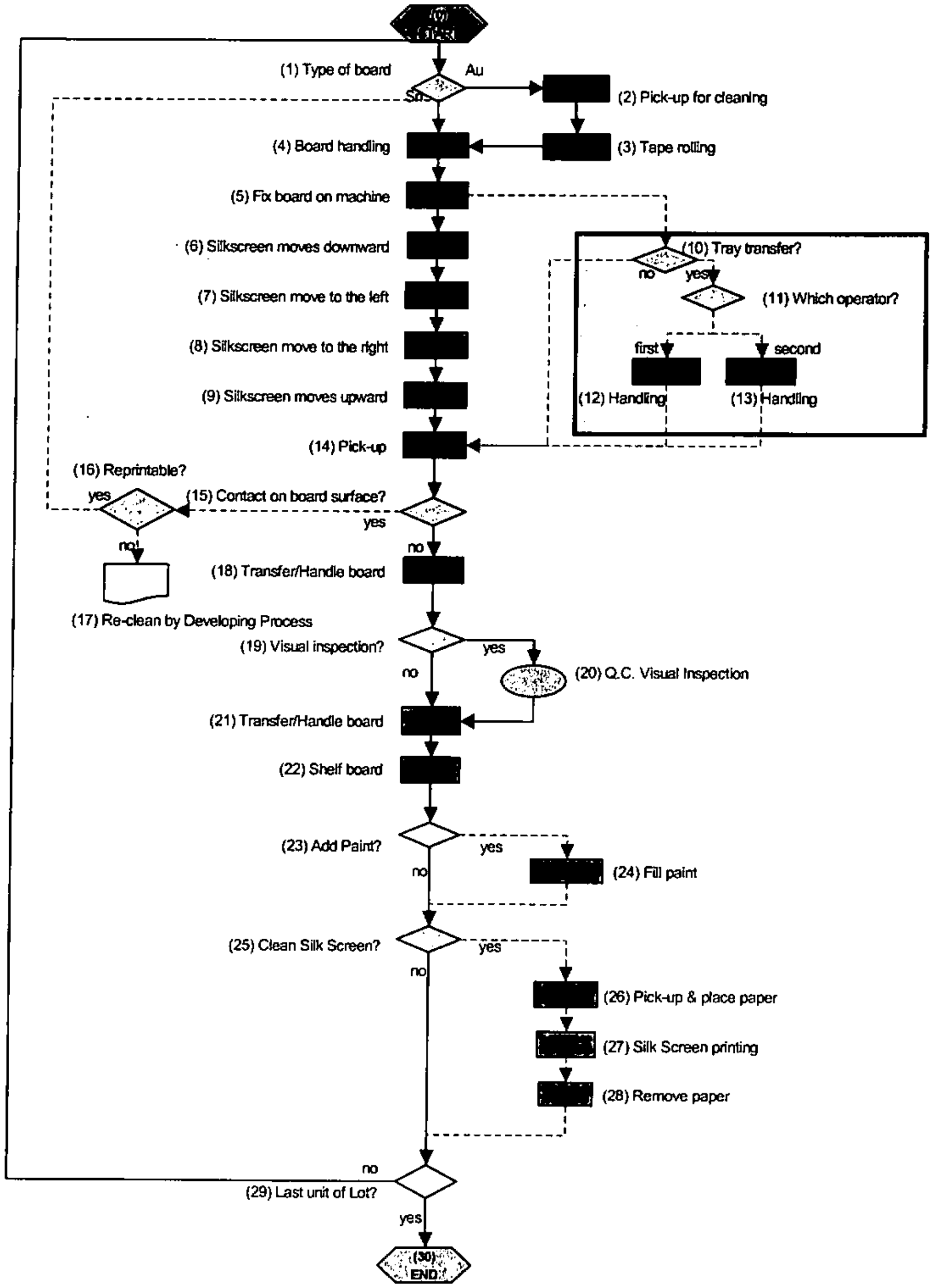


Figure 11: Relational diagram for silkscreen printing process ~ phase III of process reengineering

Phase IV

The handling activities at step 1 to step 3 presented in Figure13 operates in parallel to the silkscreen printing but before the tray transfer activities. Figure 12 shows that step 1 to step 3 are kept due to the first panel in every production lot. Therefore, the manufacturing process will not repeat step 1 to step 3 following after the initial production panel. By performing the handling activities and the operation activities simultaneously, the handling time is then further reduced from 7.5 sec to 7.0 sec, an additional improvement of 6.6% for Gold PCB.

STEP	Time (sec)	Value Added?	Description	Chance of occurance	Time (sec) needed	Content
0			**START**			START
1	0		Decision	0.5%	0	Been used only on the initial unit
2	1.5	N-VA	Handling	0.5%	0.0075	
3	2	VA	Operation	0.5%	0.01	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2.0	
6 – 9	7	VA	Operation	100%	7.0	Actual Silk Screen Printing
10	0		Decision	100%	0	Cleaning for every unit
11	0		Decision	100%	0	
12	1.5	N-VA	Handling	100%	1.5	
13	2	VA	Operation	100%	2.0	
14	0		Decision	100%	0	Handling
15	0		Decision	1.67%	0	
16	5	N-VA	Handling	5.00%	0.25	
17	30	N-VA	Handling	2.86%	0.857	
18	1	N-VA	Handling	100%	1.0	Handling
19	0		Decision	100%	0	Visual Inspection, one unit per tray 1/35
20	4.5	N-VA	Q.C.	3.33%	0.15	
21	0		Decision	100%	0	Rework twice for approximately every 250 units
22	0		Decision	1.67%	0	
23	2	N-VA	Handling	0.67%	0.013	
24	2.5	N-VA	Handling	100%	3	Handling
25	1	N-VA	Handling	100%	1.0	
26	0		Decision	100%	0.0	Refill paint once for approximately every 150 units
27	15	VA	Operation	0.67%	0.1	
28	0		Decision	100%	0.0	Cleaning once for approximately every 150 units
29	2	N-VA	Handling	0.67%	0.013	
30	7	N-VA	Operation	0.67%	0.047	
31	1	N-VA	Handling	0.67%	0.007	
32	0		Decision	100%	0	END
33			**END**			
			Total Time Minimum (Sn)		***15.99***	
			Total Time Maximum (Sn)		***17.53***	
			Total Time Minimum (Au)		***16.18***	
			Total Time Maximum (Au)		***17.82***	

Figure 12: Action description for silkscreen printing process ~ phase IV of process reengineering

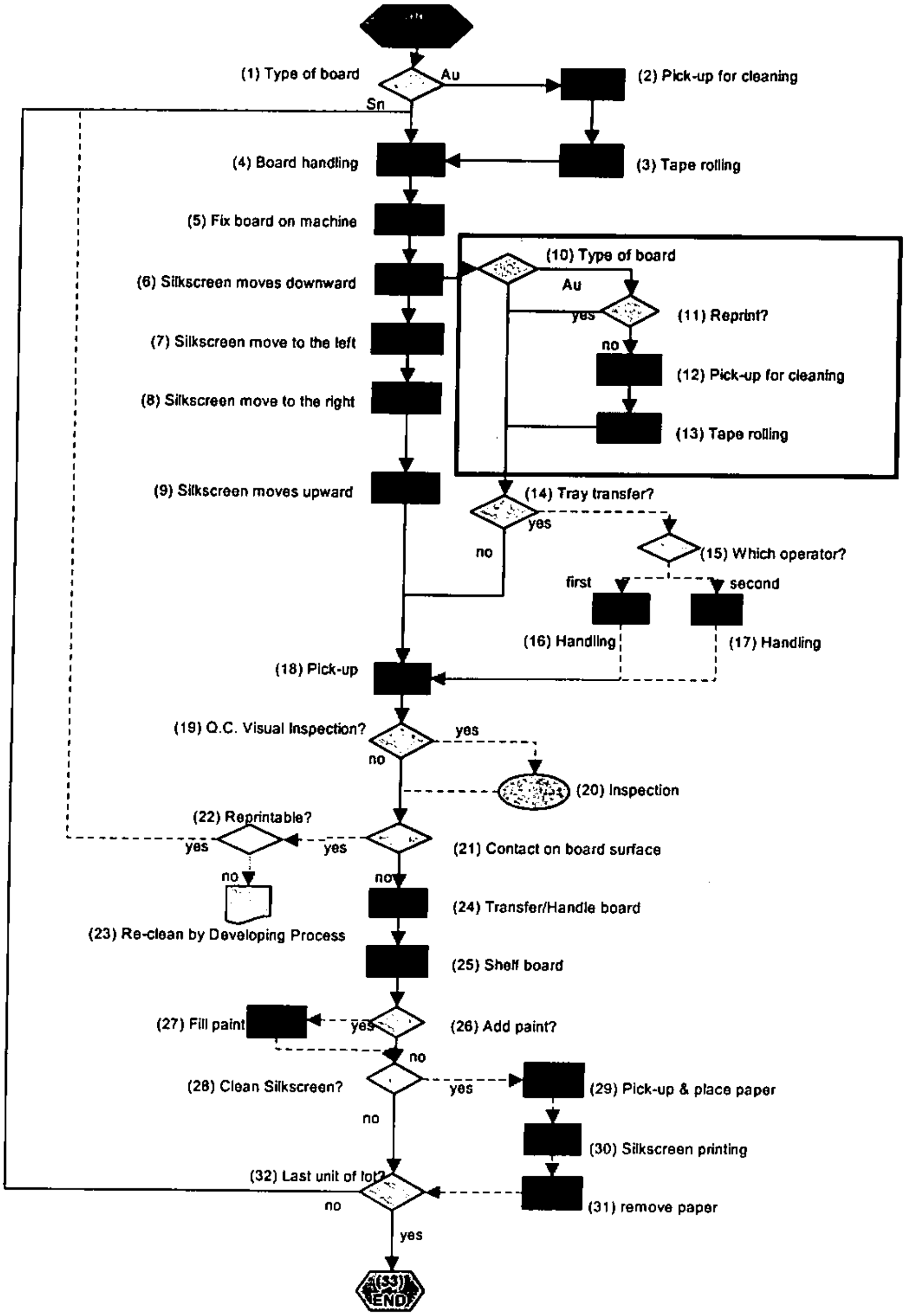


Figure 13: Relational diagram for silkscreen printing process ~ phase IV of process reengineering

Phase V

Phase five of the linear improvement scheme is illustrated at Figure 14 and Figure 15. The visual inspection activities at step 18 and step 20 are performed while the silk-screen printing is operating. By performing these two activities concurrently, the inspection time per production batch is again reduced by another 4.5 sec.

STEP	Time (sec)	Value Added?	Description	Chance of occurance	Average time (sec) needed per cycle	Content
0			START			START
1	0		Decision	0.5%	0	Been used only on the initial unit
2	1.5	N-VA	Handling	0.5%	0.0075	
3	2	VA	Operation	0.5%	0.01	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2.0	
6 – 9	7	VA	Operation	100%	7.0	Actual Silk Screen Printing
10	0		Decision	100%	0	Cleaning for every unit
11	0		Decision	100%	0	
12	1.5	N-VA	Handling	100%	1.5	
13	2	VA	Operation	100%	2.0	
14	0		Decision	100%	0	Handling
15	0		Decision	1.67%	0	
16	5	N-VA	Handling	5.00%	0.25	
17	30	N-VA	Handling	2.86%	0.857	
18	0		Decision	100%	0	Visual Inspection, one unit per tray 1/35
19	4.5	N-VA	Q.C.	3.33%	0.15	
20	1	N-VA	Handling	100%	1.0	Handling
21	0		Decision	100%	0	Rework twice for approximately every 250 units
22	0		Decision	1.67%	0	
23	2	N-VA	Handling	0.67%	0.013	
24	2.5	N-VA	Handling	100%	3	Handling
25	1	N-VA	Handling	100%	1.0	
26	0		Decision	100%	0.0	Refill paint once for approximately every 150 units
27	15	VA	Operation	0.67%	0.1	
28	0		Decision	100%	0.0	Cleaning once for approximately every 150 units
29	2	N-VA	Handling	0.67%	0.013	
30	7	N-VA	Operation	0.67%	0.047	
31	1	N-VA	Handling	0.67%	0.007	
32	0		Decision	100%	0	END
33			END			

Total Time Minimum (Sn)	*15.65*
Total Time Maximum (Sn)	*18.82*
Total Time Minimum (Au)	*16.06*
Total Time Maximum (Au)	*19.21*

Figure 14: Action description for silkscreen printing process ~ phase V of process reengineering

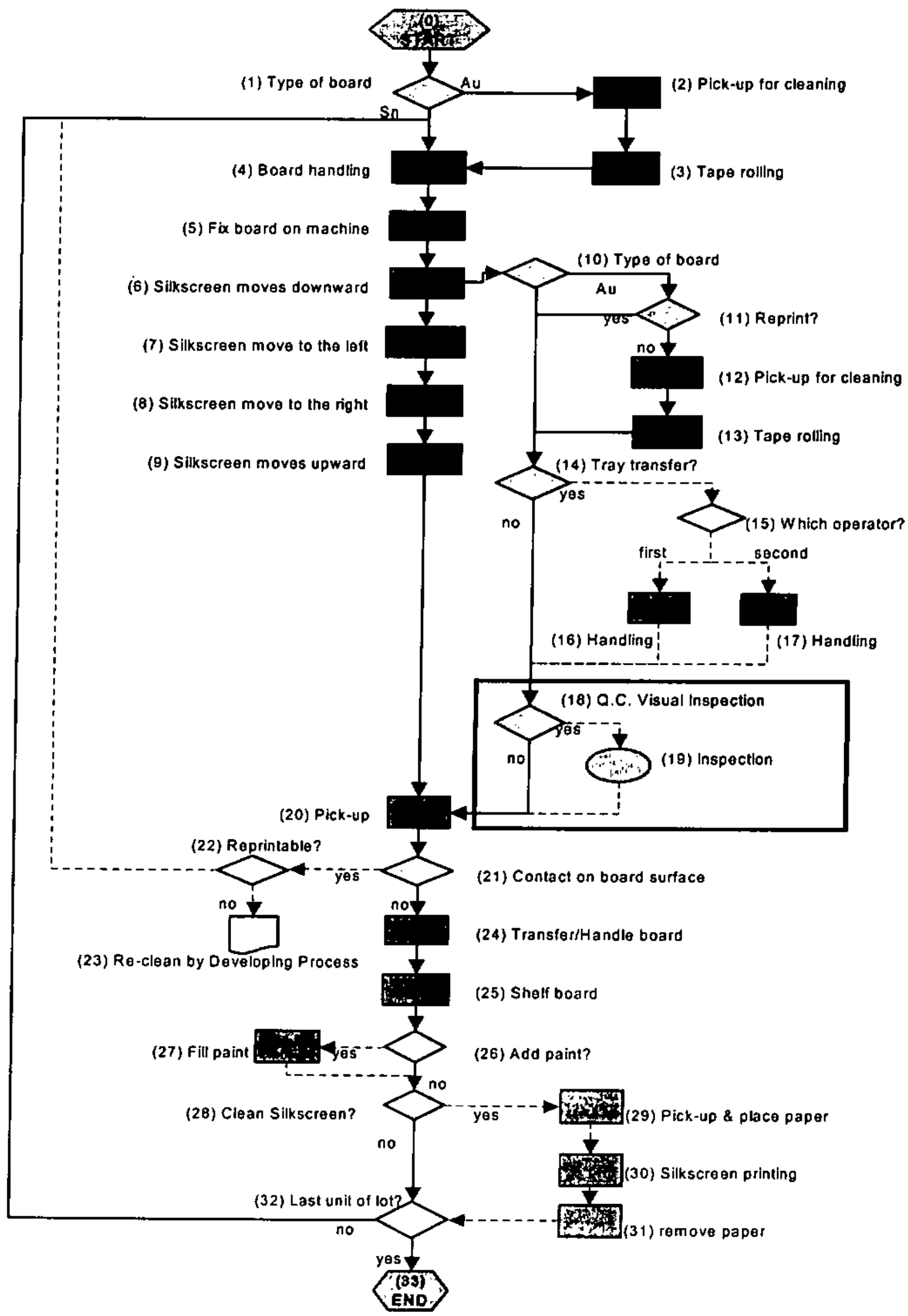


Figure 15: Relational diagram for silkscreen printing process ~ phase V of process reengineering

4.5 Findings

The process activities shown in Figure 16 and in Figure 17 are restructured in such a way that a number of activities are being performed simultaneously. By positioning and linearly improving the silkscreen printing process through the aid of the developed relational diagrams and action description tables, the performances are benchmarked and applied throughout the FBPR processes. The TPTs per panel are reduced from the initial 22.0 sec to 15.6 sec for Tin PCB, and from 25.5 sec to 16.0 sec for Gold PCB, a total productivity improvement of 29% and 37% respectively.

STEP	Time (sec)	Value Added?	Description	Chance of Occurance	time (sec) needed [illegible]	Content
0			START			START
1	0		Decision	0.5%	0	Been used only on the initial unit
2	1.5	N-VA	Handling	0.5%	0.0075	
3	2	VA	Operation	0.5%	0.01	
4	1.5	N-VA	Handling	100%	1.5	Handling
5	2	N-VA	Handling	100%	2.0	
6 – 9	7	VA	Operation	100%	7.0	Actual Silk Screen Printing
10	0		Decision	100%	0	Cleaning for every unit
11	0		Decision	100%	0	
12	1.5	N-VA	Handling	100%	1.5	
13	2	VA	Operation	100%	2.0	
14	0		Decision	100%	0	Handling
15	0		Decision	1.67%	0	
16	5	N-VA	Handling	5.00%	0.25	
17	30	N-VA	Handling	2.86%	0.857	
18	0		Decision	100%	0	Visual Inspection, one unit per tray 1/35
19	4.5	N-VA	Q.C.	2.86%	0.13	
20	0		Decision	100.00%	0	Refill paint once for approximately every 150 units
21	15	VA	Operation	0.67%	0.1	
22	1	N-VA	Handling	100%	1.0	Handling
23	0		Decision	100%	0	Rework twice for approximately every 250 units
24	0		Decision	1.67%	0	
25	2	N-VA	Handling	0.67%	0.013	
26	2.5	N-VA	Handling	100%	3	Handling
27	1	N-VA	Handling	100%	1.0	
28	0		Decision	100%	0	Cleaning once for approximately every 150 units
29	2	N-VA	Handling	0.67%	0.013	
30	7	N-VA	Operation	0.67%	0.047	
31	1	N-VA	Handling	0.67%	0.007	
32	0		Decision	100%	0	END
33			END		0	
			Total Time (Sn)		15.62	
			Total Time (Au)		16.02	

Figure 16: Action description for silkscreen printing process ~ Final state of process reengineering

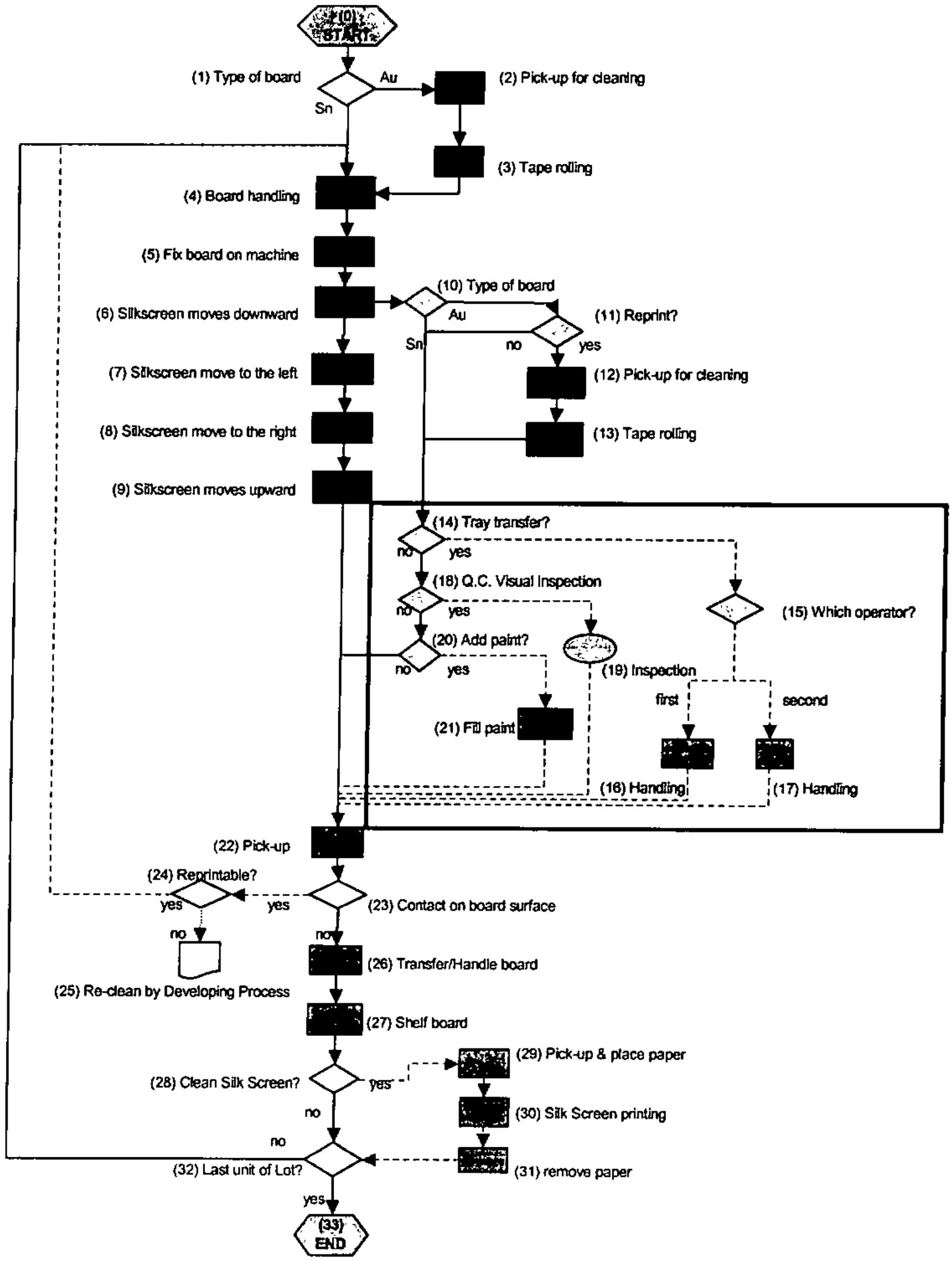


Figure 17: Relational diagram for silkscreen printing process ~ Final state of process reengineering

4.6 Performance improvement in process-level FBPR

4.6.1 Quantitative improvement

The silkscreen printing process flow as a result of positioning and linear improvement is shown in Figure 16 and Figure 17. The findings of the performance of the silkscreen printing process are measured using quantitative performance indicators. By utilizing the quantitative performance indicator, an average of 29 percent and 37 percent improvement in Through-Put-Time (TPT) for the Tin and the Gold PCB respectively are obtained. With the improvement in TPT, additional enhancements have also achieved due to the modification in the silkscreen printing process. Labor costs have reduced by greater than 35 percent. Aside from the drop in labor costs, the costs of reworks and scraps are also reduced due to the newly redesigned fixtures on the solder masking table. With the original process, there is on average six rework or scrap panels at each production lot, an immediate departmental quality yield of 97%. After linearly improving the process, the average number of rework panels per production lot is below two panels, an immediate departmental quality yield of greater than 99%. The result is therefore an improvement of greater than 66 percent in production effectiveness within the silkscreen printing process.

On the other hand, since the silkscreen printing process is originally one of the bottlenecks in PCB manufacturing within company C, the organization's production capability is limited. Therefore, with the improvement in the production performance within the silkscreen printing process, the organization's potential production capability is shifted positively. Not only are there major improvements in performance, but many informative findings are also obtained. These findings turns out to be the reason and baseline of the cultural changes across the company.

4.6.2 Qualitative improvement

In addition to the significant quantitative improvement in the silkscreen printing process after it has been linear improved, some qualitative achievements related to cultural changes are also identified. A clear and comprehensive understanding of an individual's own work is conducted to form a basis for comparison within industry practice. Across the company, there is a willingness to accept change and to adapt to new arrangements based on the process restructuring efforts. At the same time, there is also openness to new ideas and innovation to improve existing processes. In summary, the best type of improvement has been achieved, that is, continuous learning and endless self-challenging.

CHAPTER FIVE: APPLICATION OF FBPR IN OPERATIONAL LEVEL – POST-HASL BAKING PROCESS ELIMINATION

An FBPR project that involves cross-departmental is considered as operational-level FBPR. In this case, the post-Hot-Air-Solder-Leveling (post-HASL) baking operation is be eliminated. Post-HASL baking operation serves to reduce the ionic contamination caused by the previous manufacturing production operations, such as the solder masking operation and HASL operation. The post-HASL baking operation is performed by storing the PCB panels in a heated chamber with an elevated temperature of 155°C for a period of 65 minutes. During the post-HASL baking operation, the ionic contamination on the PCB panels tends to vaporize, thereby reducing the contamination concentration from up to 11.0μgNaCl/in^2 to an average of 5.0μgNaCl/in^2. Since the customer demands for the specification limit of ionic contamination lower than 8.0μgNaCl/in^2, the company C's have then set Statistical Process Control (SPC), the Upper Control Limit (UCL) for the ionic contamination is 6.4μgNaCl/in^2 and the Lower Control Limit (LCL) is 0.0μg.NaCl/in^2.

In order to eliminate the post-HASL baking operation, the root causes and source of ionic contamination are positioned. After conducting thorough research by applying process decomposition and analysis development, it is found that the ionic contamination is created within the HASL department and the solder masking department, since these are the two manufacturing operations that involve unwanted metallic ions. The contamination concentration, however is in average of 1.0μgNaCl/in^2 at both the entry point and the exit point of the solder masking operation and concurrently, the contamination concentration is in the average of 1.0μgNaCl/in^2 at the entry point and in average of up to 11.0μg.NaCl/in^2 at the exit point of the HASL operation.

Therefore, to eliminate the post-HASL baking operation, the location and root causes of ionic contamination shall be identified. The HASL operation is formed by the combination of three manufacturing processes,: the pre-HASL re-activating process, the HASL process, and the post-HASL cleaning process. The pre-HASL re-activating process is performed to re-activate the oxidized Copper (Cu) surfaces which are caused by the solder masking operation and the buffering period. In addition, the pre-HASL process will apply a flux coating on the PCB panel to protect it against over heating during the HASL process and to serve as a contacting agent. The HASL process is performed by applying a Tin/Lead coating on the exposed copper surface for further electronic device assemblies. The post-HASL cleaning process is performed by removing the excessive flux coating with pre-heated rinsing, fine-grinding and subsequent cleaning and drying of the PCB panels. On the other hand, the solder masking operation is developed by the combination of six processes: they include fine grinding process, silkscreen printing process, pre-baking process, Ultra-Violet exposure process, solder mask developing process, and final baking process. A more detailed explanation on the solder masking operation is illustrated in chapter four.

5.1 The aims of applying FBPR in the post-HASL baking operation:

Applying operational-level reengineering on the post-HASL baking operation aims to reduce the total TPT, to increase the ratio of value-adding operations, and to eliminate confusions caused from over-lapping production from the solder mask operation and the post-HASL baking operation. Due to various product requirements at the level of ionic contamination, there is a possibility of having to rework or scrap the PCB panel if the operators carry on incorrect activities subsequent to the HASL operation. Alternatively, it is discovered that the post-HASL baking operation is an operation that can increase the product quality because it can help reduce the level of ionic contamination. However, it greatly increases the manufacturing cost and establishes an ineffective workflow. Thus, in order to maintain a low contamination level and to minimize additional manufacturing cost, positioning is used to identify the root causes of the ionic contamination. Moreover, operational-level FBPR must be applied to dramatically improve the quality of the PCB.

5.2 Methodologies for operational-level FBPR

To reveal the root causes of the ionic contamination, all the parameters within the operations and production activities involved shall be identified. With the use of positioning, the development of ionic contamination is confined to two operations: the solder masking operation and the HASL operation. Consequently, the process decomposition and process analysis are carried into two sections. The primary section focuses on the HASL operation and the secondary section relates to the solder masking operation. During the primary section of the process decomposition and process analysis, a thorough research on the HASL operation is performed by utilizing process decomposition to identify the location of the elevation of ionic contamination. Simultaneously, benchmarking is also applied on the other organization's HASL parameters to serve as a baseline for further investigation and comparison. In the secondary section of the process decomposition and process analysis, the distribution of the ionic contamination is identified on various stage of manufacturing process.

5.3 Positioning, decomposition and analysis development within the HASL operation

The FBPR project initiator must identify and position all possible causes of ionic contamination prior to implementing reengineering changes to any processes or operations within the HASL operation and the solder masking operation. The HASL operation is targeted as the primary operation to benchmark and to analyze.

5.3.1 Positioning and decomposition

Positioning the operations is the primary stage prior to implementing any operational reengineering project. Since there are three manufacturing processes within one HASL operation, it is important to develop a methodology that isolates the process from each other. Therefore, a methodology is developed to analyze and position the contamination effects of each process activity individually.

After decomposing the HASL operation, the following activities and attributes are identified for each process that could have the potential to affect the level of contamination.

(1) Pre-HASL re-activating process

Within the Pre-HASL reactivating process, there are three activities. They are:

(a) Surface micro-etching

(b) Rinsing (Re-Generated water, Fresh City water, De-Ionized water)

(c) Flux coating

(2) HASL process

Within the HASL process, there are four activities. They consist of:

(a) Dipping time

(b) Elevated solder bath temperature

(c) Tin/Lead ratio

(d) Copper concentration

(3) Post-HASL cleaning process

Within the Post-HASL cleaning process, there are three activities. They include:

(a) Air-Cooling

(b) Water cleaning (with elevated temperature)

(c) Fine grinding

(d) Rinsing

(e) Drying

5.3.2 Analysis development

Assumption

Before proceeding with the contamination level analysis, assumptions need to be made. Before inserting the testing unit into the testing device (Omega Meter SMD-600), the testing unit must be assumed to be both dry and clean (flux-less and residue-less).

The ionic contamination analysis should include three conditions. They include the contaminated condition subsequent to solder masking operation, the conditions during the HASL operation, and the condition subsequent to the post-HASL baking process.

Table 2 illustrates the methodology used for ionic contamination testing on the HASL operation.

Table 2: Methodology for ionic contamination testing for HASL operation

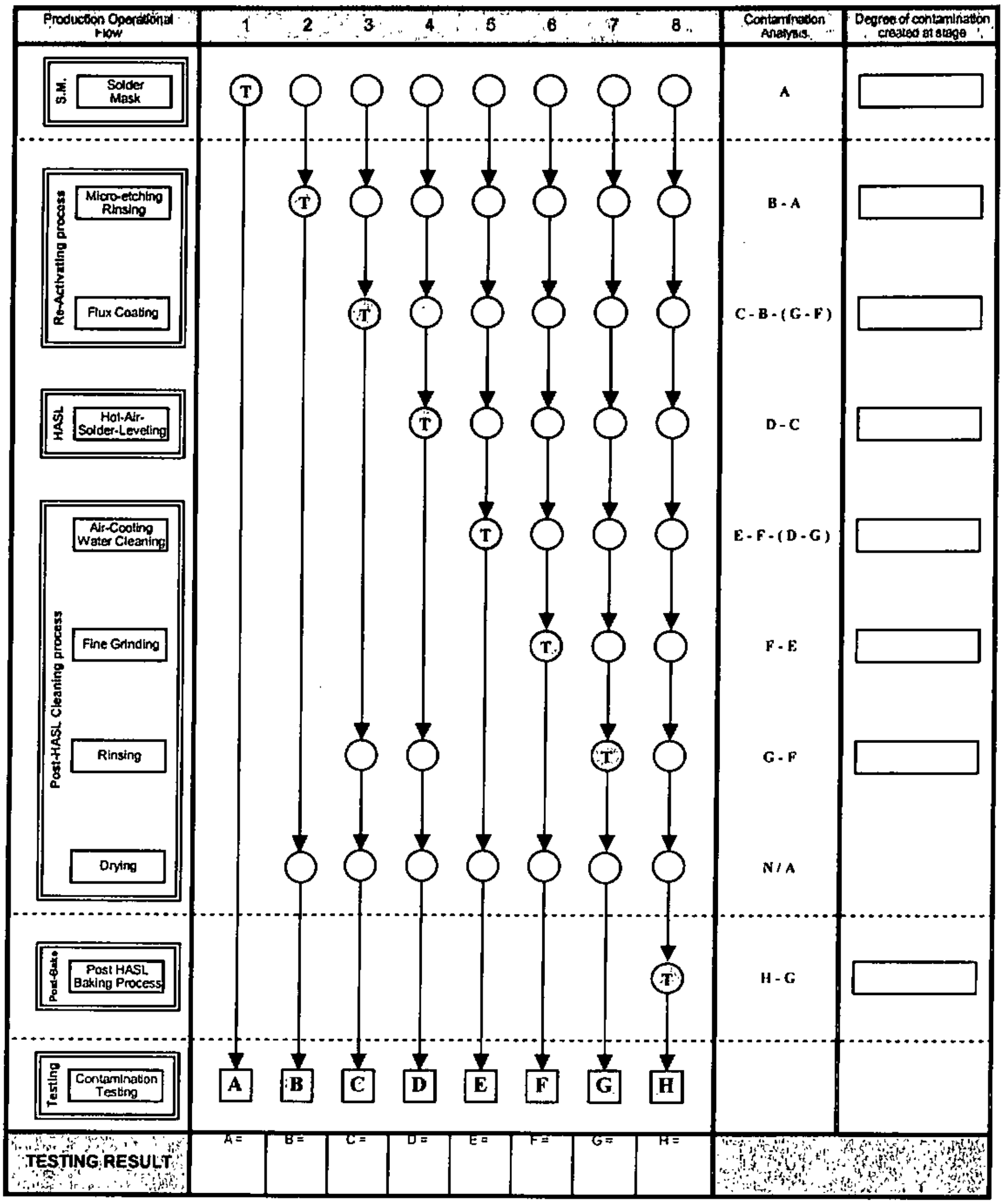


Table 2 illustrates the experimentation methodology for the ionic contamination test. There are four independent symbols used in the analysis. They include: 'activity', 'test point', 'flow', and 'contamination level'. The following are the characteristics of each of the symbols used.

○ Acitivity carried

Ⓣ Testing Point

↓ Production Flow

[x] Contamination level at stage x

Through the use of DOE, the newly developed experimentation methodology is able to identify the different levels of contamination for different production processes. Table 3 and Table 4 demonstrate the contamination index for two independent test samples. The resulted data for each test illustrated at the bottom of Table 3 and Table 4 are the levels of ionic contamination created by the combination of designated processes. The analyzed data illustrated on the right hand side of the Table 3 and Table 4 is the level of ionic contamination created by the left hand side process.

Figure 18 graphically demonstrates the total ionic contamination for a combination of various manufacturing processes. Figure 19 illustrates the degree of contamination created at each production process.

Table 3: Ionic contamination test I

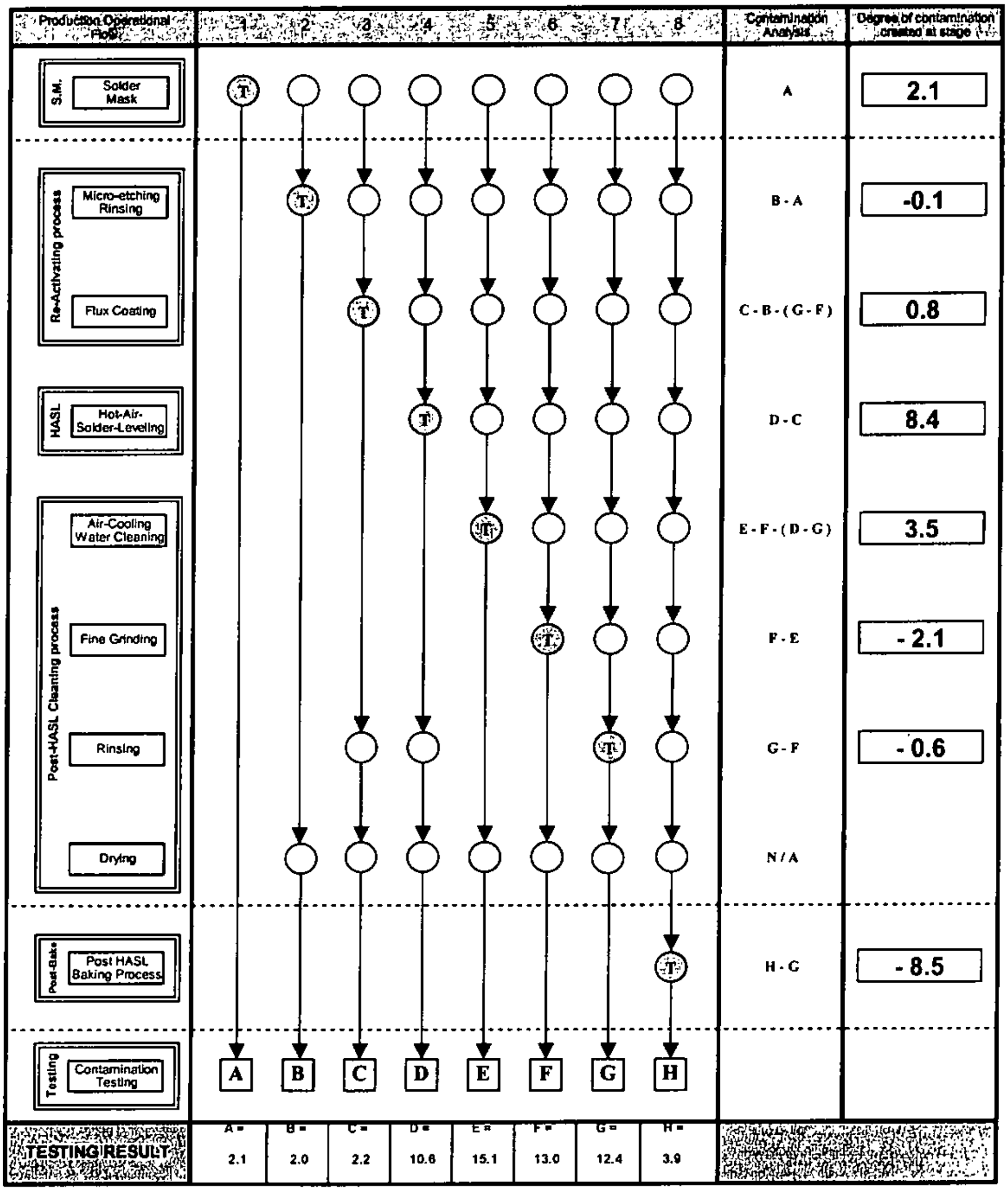


Table 4: Ionic contamination test II

	Production Operational Flow	1	2	3	4	5	6	7	8	Contamination Analysis	Degree of contamination created at stage
S.M.	Solder Mask	T	O	O	O	O	O	O	O	A	4.1
Re-Activating process	Micro-etching Rinsing		T	O	O	O	O	O	O	B - A	- 2.0
	Flux Coating			T	O	O	O	O	O	C - B - (G - F)	0
HASL	Hot-Air-Solder-Leveling				T	O	O	O	O	D - C	10.2
Post-HASL Cleaning process	Air-Cooling Water Cleaning					T	O	O	O	E - F - (D - G)	0.3
	Fine Grinding						T	O	O	F - E	- 0.9
	Rinsing			O	O			T	O	G - F	0.3
	Drying		O	O	O	O	O	O	O	N / A	
Post-Bake	Post HASL Baking Process								T	H - G	- 5.9
Testing	Contamination Testing	A	B	C	D	E	F	G	H		
TESTING RESULT		A = 4.1	B = 2.1	C = 2.4	D = 12.6	E = 12.6	F = 11.7	G = 12.0	H = 6.1		

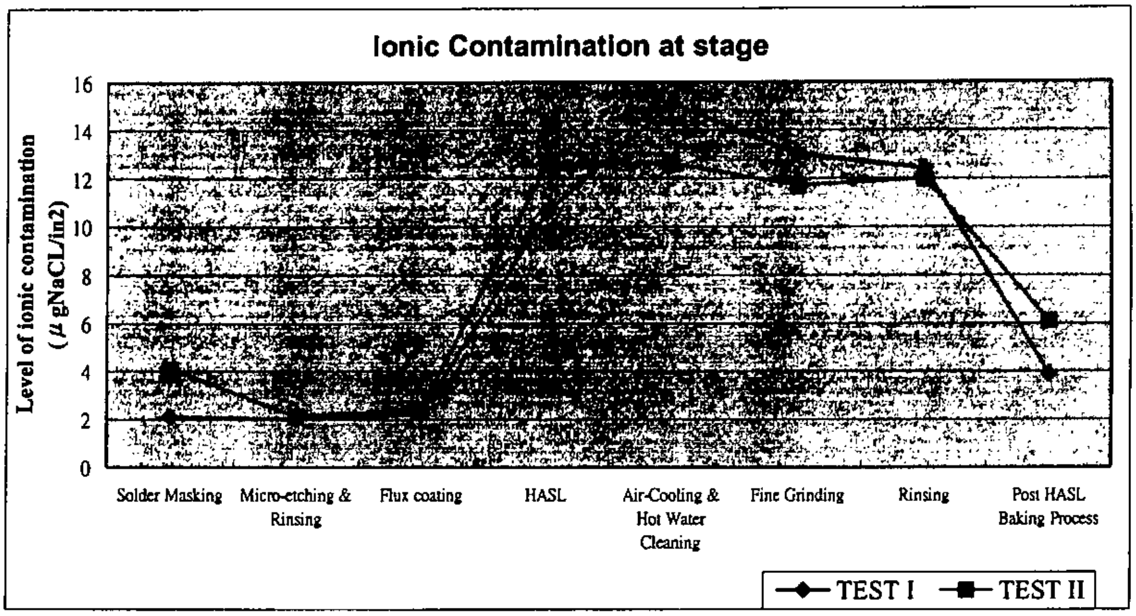


Figure 18: Ionic contamination at various stage

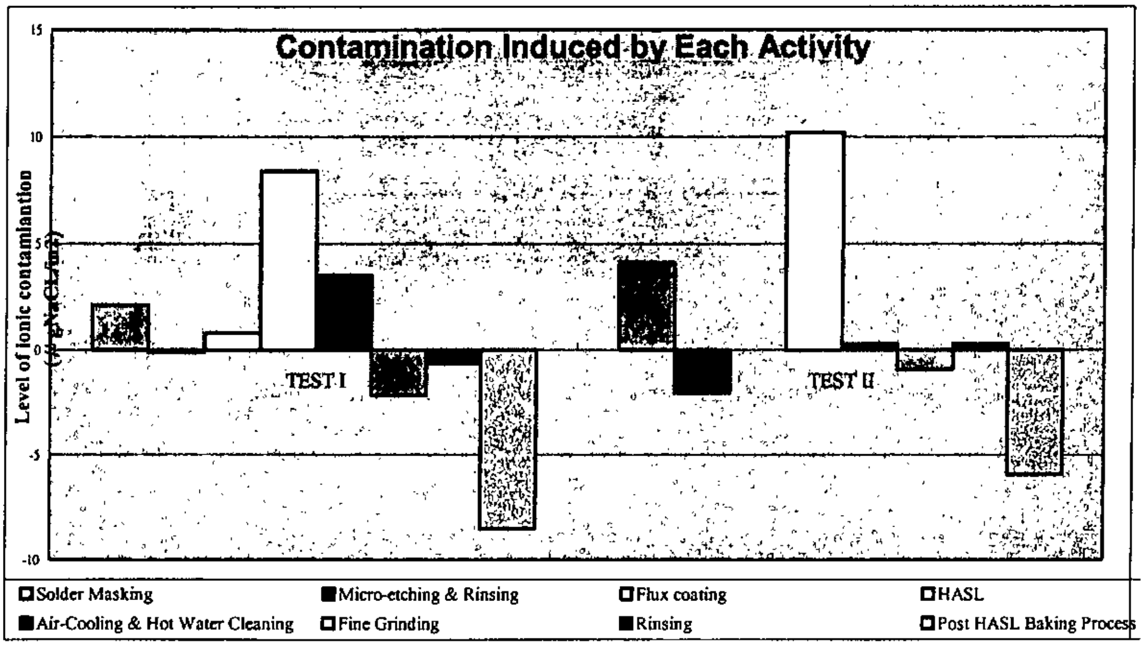


Figure 19: Contamination induced or deduced by each production activity

Figure 18 and Figure 19 clearly identifies that the ionic contamination is mostly introduced during the HASL process. Therefore, conventional corrective action taken across the industry is by introducing an additional manufacturing procedure: such as the post-HASL baking operation, the UV curing operation, and the solvent cleaning operation. A limited number of the PCB manufacturing organizations, however have realized that preventive actions should be taken in order to reduce the ionic contamination in the first place. To apply preventive action prior to the development of the ionic contamination, preventive analysis is conducted on the solder masking operation. The need to perform the analysis is due to the elevated temperature of 250°C to 270°C during the HASL process, which causes the compound of the solder mask to transform, thus increasing the ionic contamination of the PCB.

5.4 Process analyzing the solder masking operation

The second section of process decomposition and process analysis is applied on the solder masking operation. During this stage of process decomposition and process analysis, a hypothesis must be made on the process that can and cannot apply changes. The assumptions are as follows:

(1) Restructuring the fine grinding process, silkscreen printing process, UV exposure process, and solder mask developing process have minimal effects on the level of ionic contamination due to a number of manufacturing constraints.

(2) Re-modification of the manufacturing specification on solder mask baking process would have a relatively greater effect on the quality of the PCB due to its manufacturing flexibility.

As for the solder masking baking process, there are three dependent variables that can be re-modified. They include:

(1) Baking temperature

(2) Baking period

(3) Speed and rate of ventilation (at the entry point and the exit point)

The conventional definition of the baking process is that the baking temperature and the baking period are dependent on the level on solder mask curing. On the other hand, the ventilation system determines the curing distribution with the PCB. Yet with an in-depth research and analysis on the baking process, it is found that an effective ventilation system does not only provide an even curing distribution, but it also aids in reducing the level ionic contamination.

After revealing the effects of the baking ventilation system, experiments are conducted at the different levels of ventilation. By conducting the experiments in the laboratory, the findings of the tests shows that the ionic contamination in an effectively ventilated baking process can be reduced by greater than 50% compared to a mal-ventilated baking process. As a result, with the reduction of the metallic ion during the solder mask baking process, the quality of the PCB is able to surpass the ionic contamination requirement defined by the customers.

5.5 Findings of applying operational- level FBPR in the post-HASL baking operation

Serving as a corrective action, the post-HASL operation can aid in reducing the ionic contamination to an acceptable limit. Since corrective action is not the optimal strategy for the manufacturing industry, the organizational reengineering project promotes the concept of preventive operation through the use of process decomposition and process analysis. By initiating appropriate experiments on the HASL operation and the solder masking operation through laboratory testing and production testing, the causes of ionic contamination are then identified to provide adequate reengineering changes and to develop solution to surpass the targeted level of contamination. Which in result, the post-HASL operation can thus be eliminated.

After implementing operational-level FBPR on the post-HASL baking operation, a number of quantitative improvements are identified They include:

(1) Eliminating the possibility of production staffs from making mistakes such as mis-locating and mis-handling the PCB panels after the HASL operation,

(2) Eliminating a production operation thus, reducing the total TPT, and

(3) Reducing production costs, such as costs of power consumption, labor, additional inspection, manufacturing defects, rework.

In summary, the operational reengineering project tends to enhance the concept of applying preventive action rather than corrective action to minimize non-value adding activities. In conclusion, preventive application is always one of the ultimate strategies to maximize the value adding activities, to minimize the non-value adding activities, and to increase the competitiveness of manufacturing industries.

CHAPTER SIX: APPLICATION OF FBPR IN ORGANIZATIONAL LEVEL – PCB PANEL SIZE RE-MODIFICATION

PCB panel size is considered to be one of the most critical manufacturing factors among all organizational activities, since it affects both critically and directly the Through-Put Time (TPT) of the entire manufacturing cycle. Improvement of TPT can positively assist in ameliorating the production effectiveness and manufacturing capability. After the TPT is improved, the theory of Just-In-Time (JIT) can be more efficiently applied because the storage time of the raw material and the Work-In-Process (WIP) are reduced. Improved TPT not only improves the productivity of PCB manufacturing, but it can also decrease the possibility of over-production and the stagnation of semi-finished product.

6.1 The aims of applying FBPR in organizational level

The organizational reengineering project of this research is aimed to increase the manufacturing capability and to decrease the TPT of various operations. In order to surpass the set targets, the organizational reengineering project must concentrate on reducing the total manufacturing time for mass production while maintaining and enhancing the high quality of product. Since the scope and the complexity of an organizational-level FBPR project are relatively high compared to the two former FBPR projects, the application of the non-linear improvement scheme would be essential to improve the project effectiveness.

The JIT production theory and Lean/Leveled production (LP) methodology are some of the tools that could be used when considering of the limitations and the constraints of this organizational reengineering project. JIT is a tool that can be used to assist the organization from over-production and over-stocking. On the other hand, LP can be used to restructure the current push- and pull-system to a continuous production system.

The concept of a push-system is that the productivity at all production machineries and production lines should be maximized, thus to creating a buffer and Work-In-Process (WIP) for further production. The disadvantage of the push-system is that it will create a large amount of WIP and decrease the effectiveness of information feedback and feed forward.

In contrast, the pull system is a concept that the manufacturing throughput of the latter processes are always greater than the former processes, so that there will only be a minimum amount of WIP and the information feedback and feed forward time will be reduced. But the disadvantage of the pull system, however, is that the machine productivity can not be maximized since there will always be machines in the halting state.

Finally the continuous production system is a concept that all manufacturing processes should produce a sufficient amount of WIP to maintain a continuous production and to reduce the amount of inventory including both WIP and raw materials. As a result, the continuous production system is the combination of the advantages of both the pull system and the push system. Therefore, the efficiency and effectiveness of this organizational reengineering project can be elevated by merging both the JIT theory and the LP methodology into a non-linear improvement scheme.

6.2 Product quality assumptions

Prior to the implementation of an organizational-level FBPR project, it is important to form assumption regarding the quality effects caused by the FBPR project. Amplification of the PCB panel size may affect the quality of product due to the abilities and the capabilities of the production machineries and production lines. In the case of PCB manufacturing, the quality of product is assumed to be directly related to the production panel size. For example, as the panel size of a PCB increases, the control of manufacturing process should simultaneously increase to accommodate the variance caused by respectively larger panel size. Figure 20 demonstrates an ideal case with regards to product quality subject to a perfect process control.

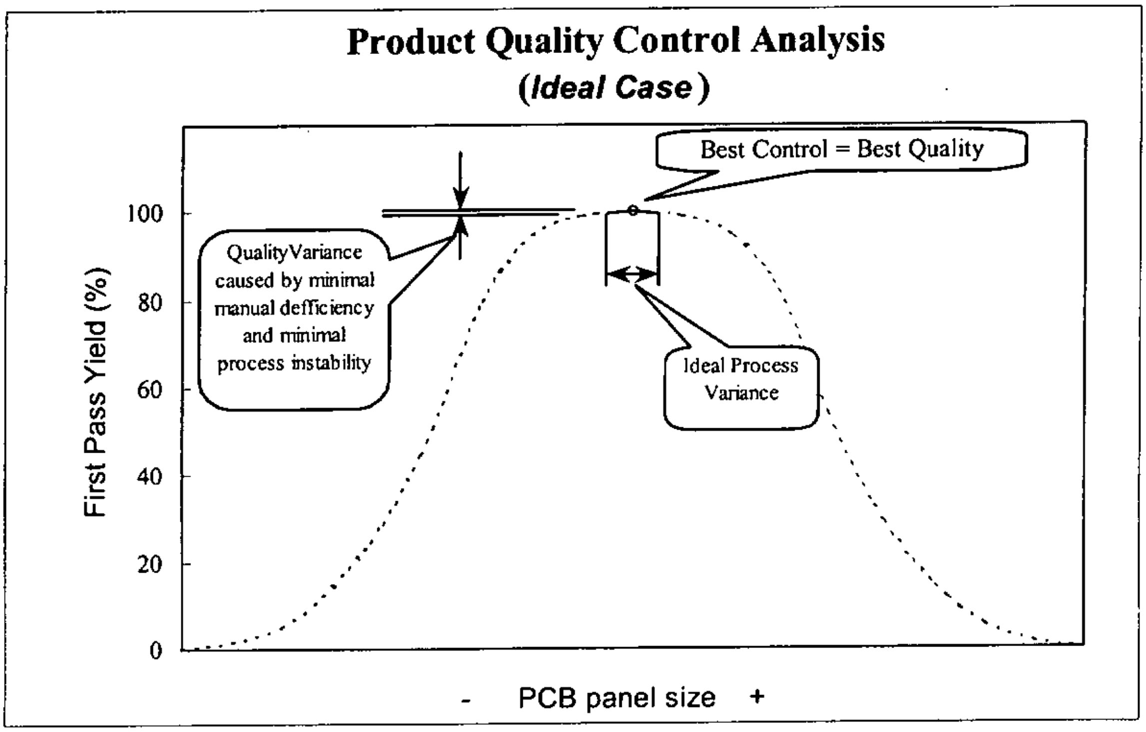


Figure 20: Relationship of product quality and process variance in an ideal condition

Figure 21 shows that theoretically if Total Quality Control (TQC) is implemented throughout the entire PCB manufacturing operations, including both manual control and machine process control, the average quality of output (product) would be relatively high. Nevertheless, due to chronic losses, it can never guarantee zero defect. In many cases of realistic manufacturing operations, however, the manual handling defects would be elevated and the process abilities would be truncated due to unpredictable incidents and sporadic losses such as human imperfection and time related deficiencies.

Figure 21 and Figure 22 demonstrate the relationship between product quality and process variance in a factual circumstance.

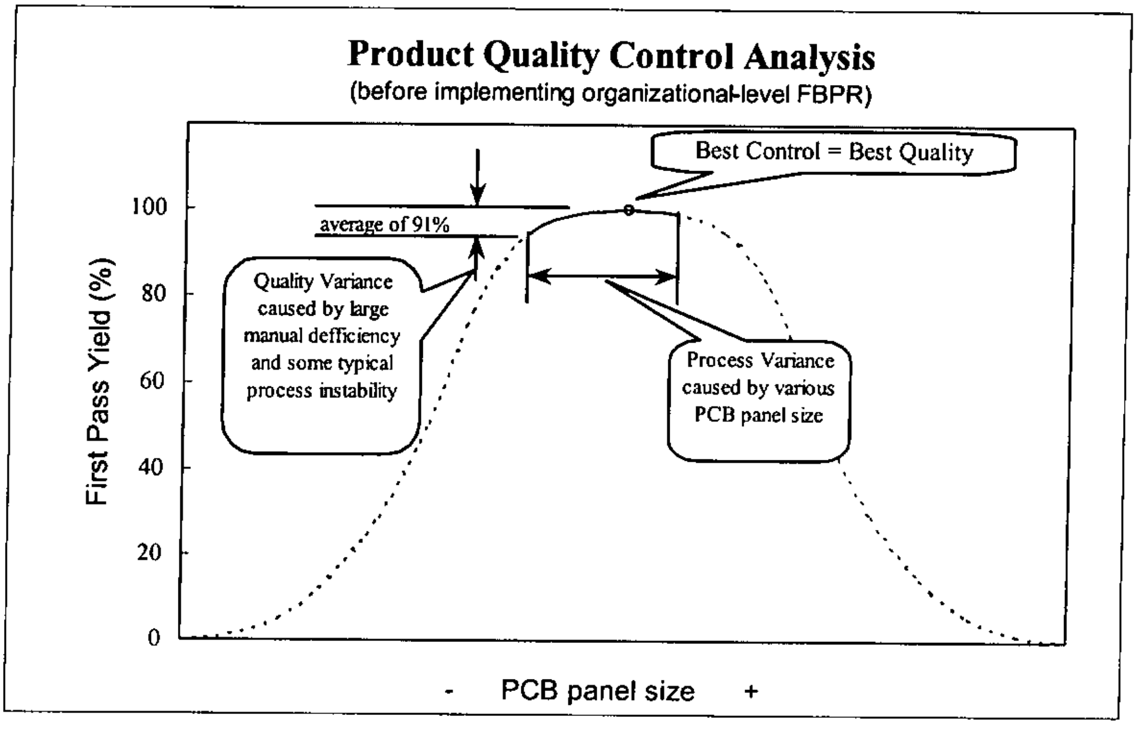


Figure 21: Relationship between product quality and process variance (before implementing organizational-level FBPR)

Figure 21 presents the relationship between product quality in the first pass yield and the PCB panel size before implementing organizational-level FBPR. As shown in the Figure 21, the process variance extends to the left and slightly to the right. The variance extended to the left is due to the relatively higher manual handling deficiencies and sporadic losses caused by a greater amount of manual handling of a small PCB panel. The variance slightly extended to the right is caused by the unstable manufacturing activities and the actual chronic losses.

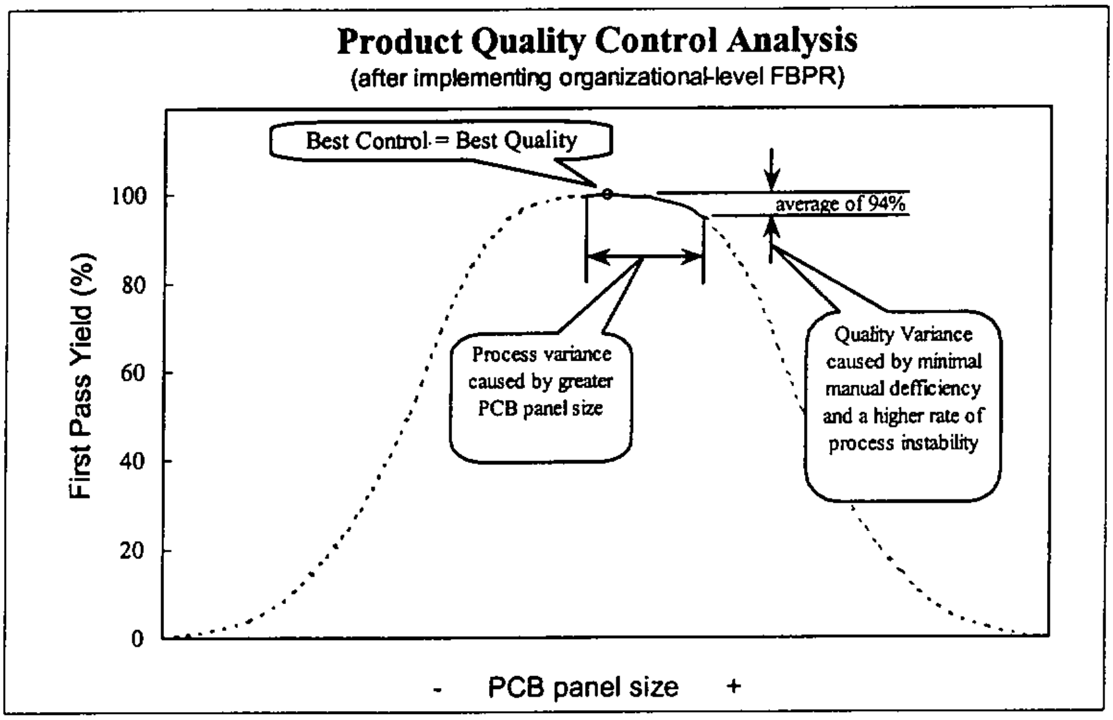


Figure 22: Relationship between product quality and process variance (with an increase in production panel size)

Figure 22 illustrates the relationship between product quality in the first pass yield and the PCB panel size after implementing organizational-level FBPR. Shown in Figure 22, the process variance is shifted from the leftly extended to the rightly extended. The variance extended to the left is demoted due to the reduction in the total amount of manual handling, therefore resulting in less manual handling defects. For example, if the panel size is doubled, the average number of manual handling per unit would then be halved, thus slashing the manual defects by approximately half. On the other hand, the variance extended to the right has slightly escalated due to the increase of potential in unstable manufacturing activities and process limitations, such as the machine manufacturers' suggested effective production abilities and capabilities.

Figure 21 and Figure 22 illustrate the quality effects of the increase in PCB panel size. As the PCB panel size increases, the process variance would shift to the right as indicated on the product quality control diagram. Therefore, the quality of the product can be affected.

Therefore, by combining both the simulation model analysis and the process quality effect analysis, the proximity of the organizational reengineering results would be closer to the actual reengineering results.

6.3 Using Design Of Experiment and PDSA in organizational level FBPR

One of the crucial steps in implementing non-linear changes to any operations is to manufacture prototypes by performing analysis using the fundamental concept of Design Of Experiment (DOE). The fundamental concept of DOE can aid in identifying a number of aspect involved during the prototype testing. They include the dependent and independent variables, criterion measure, correlation coefficient and interaction. Therefore, the basic principle, Plan Do Study Act (PDSA) of DOE isused simultaneously with prototype testing.

Figure 23 demonstrates the four stages of the PDSA model in prototype testing.

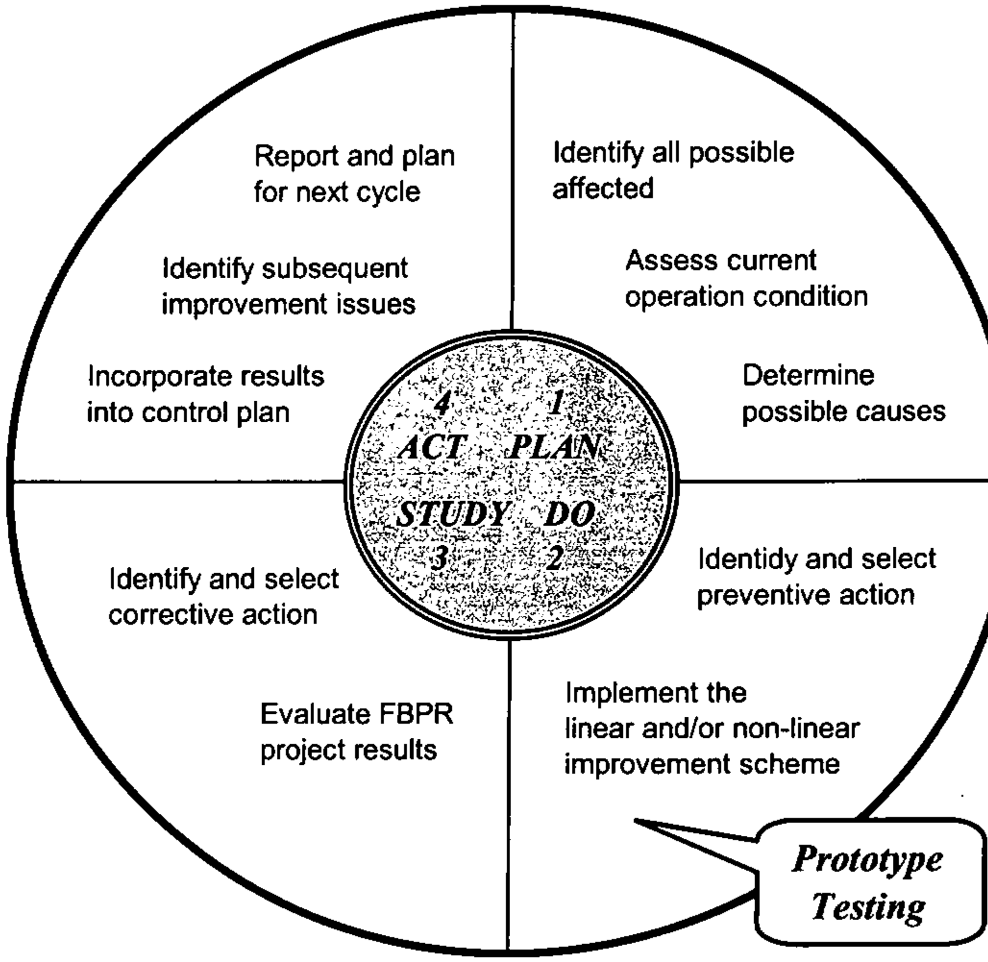


Figure 23: The PDSA model of DOE in prototype testing

The first stage of the PDSA model demonstrated in Figure 23 can assist in identifying the multiple potential affected aspects of the organizational reengineering changes and the non-linear improvement scheme. The planning stage of the PDSA cycle can be utilized to position the criteria variances from the newly re-designed operational processes. After the initial planning for product quality related characteristics is finalized, a number of aspects and causes are pinpointed. They include product design characteristics, such as PCB's circuitry's line-width and thickness, plating surface density and distribution, and complexity.

and production operational capabilities, such as permissible production panel size and chemical concentration vs. quality effectiveness.

The second stage of the PDSA model is used to initiate preventive action and to implement testing on the redesigned operations and activities. Prototype testing is practiced to simulate the actual and the potential effects of the PCB panel size amplification. A number of criteria are taken into consideration during the design of the prototype panel. They include various types of circuitry with the panel size such as 24"x36" because the design of the circuitry and the actual PCB panel size are the two major contributors of the product's quality. Once sufficient preventive action is carried, prototype testing is then launched.

The third stage of the PDSA model is used to study the effects of the organizational-level FBPR project, including both the effect on productivity and on quality. Various productivity enhancement are stated earlier in the research project. The reengineering change will mainly affect the quality of electro-plating operation and the UV exposure processes. Other operations are less affected in their quality effects and have less differentiations. The electro-plating operation will receive quality enhancement since there will be a reduction in panel to the panel distance. This would therefore lead to an improvement in plating distribution. The average quality improvements on the uneven-plating distribution on the panel edge is measured to be approximately 19% (1). On the other hand, the increase in the exposure area would lead to widened the UV light exposure distribution. This would result in a negative effect on the UV exposure operation if

(1) $$\frac{(2332\mu in + 2226\mu in)/2}{1908\mu in} - 1 = 19.44\%\ \text{improvement in plating variance}$$

no production machinery enhancement is achieved. To accommodate this deficiency, process engineering is harnessed. The reflective cap of the UV exposure is thus redesigned to increase the effectiveness of exposure to a larger area.

Finally, once all three stages of the PDSA are completed, all changes should be finalized, documented and implemented. This final phase is essential in noting all the affected variables, potential problems and the results of reengineering changes. After the PDSA cycle is completed, it can be used for further business activities enhancements and for gaining additional top management support and initiative.

6.4 Using simulation in organizational-level FBPR

As organizational-level FBPR is considered to be the most complex FBPR project in the implementation of FBPR, an additional tool must be integrated to support the positioning methodology. Therefore, simulation model is employed. A simulation model can be one of the best partners in positioning, since simulation models can serve as a reference in performance benchmarking. At the same time, it can predict the results if modifications are required on certain operations or processes (Murphy, 1994).

Simul8, a simulation software is used in the positioning model. One of the reasons for which Simul8 is been chosen for this FBPR project is its high cost effectiveness. The advantages of implementing Simul8 also include a strong support from the internet and compatibility of all the major features with PCB manufacturing simulation. The stated reason, therefore, can satisfy the concept of Low Cost Analysis (LCA). Alternatively, the

Simul8 programmer is able to create specific workstations for each PCB manufacturing process. The simulation model can thus be custom made.

As mentioned earlier, a simulation model is to be created at the earlier stage. Alternatively, it can be used to identify the current and the potential production capabilities of operations. After the basic simulation model is developed, all current information and data must constantly be kept up-to-date, thereby providing a factual simulated model at all times, and on the other hand, it could aid the reengineering team to identify the location of bottlenecks and potential improvements in related operations and activities.

After the quality effect assumptions of this organizational reengineering project are concluded, process capability analysis is then prepared. The operational process simulation model is one of the better tools for analyzing process capabilities. As for this FBPR project, Simul8 is utilized to develop a simulation model. The establishment of the PCB manufacturing simulation model is carried out in seven phases. The first and the most vital phase in creating a PCB manufacturing model is to develop the basic operations and the buffering/storage within the operations. After the basic model is created, detail information such as multi-process activities, Through-Put-Time (TPT), production machineries capabilities, limitation, downtime, and efficiencies, should then be analyzed.

Even though the primary phase of the seven phases simulation model is considered to be the most crucial among all the phases, neither detail data nor information is needed. The initial phase is only to develop the general PCB manufacturing operational flow. Nevertheless, a general PCB production flow must be obtained to cultivate the initial simulation model. Therefore, information on all production activities, such as production work stations, WIP buffers, manual handling, and WIP transportation, should be considered. Since Simul8 is a flexible simulation software that allows users to custom-made a simulation model, the graphics of the production activities can be developed according to its operations in order to provide a better visual understanding. Figure 24 demonstrates the phase one of the development of a PCB manufacturing simulation model.

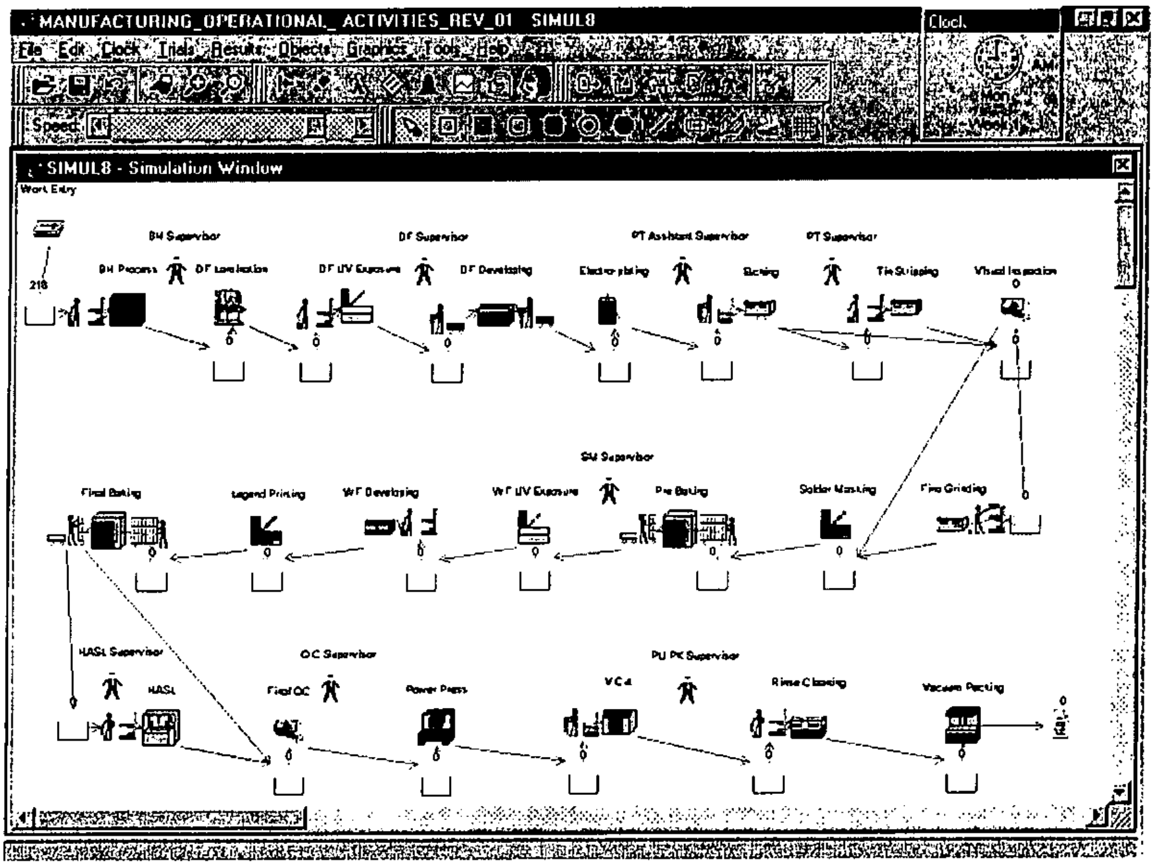


Figure 24: Phase I – General PCB manufacturing operational flow development

After the general PCB manufacturing operational flow is developed, additional information, such as processes activities at each manufacturing operation, should then be identified and integrated into the simulation model to increase its accuracy. Identification of processes at each manufacturing operations is important since it provides not only better accuracy but also opportunity for important in process ability and process capability. This potential process enhancement will be employed during the organizational reengineering project. Figure 25 identifies the phase two of the simulation by employing the process activities at all manufacturing operations.

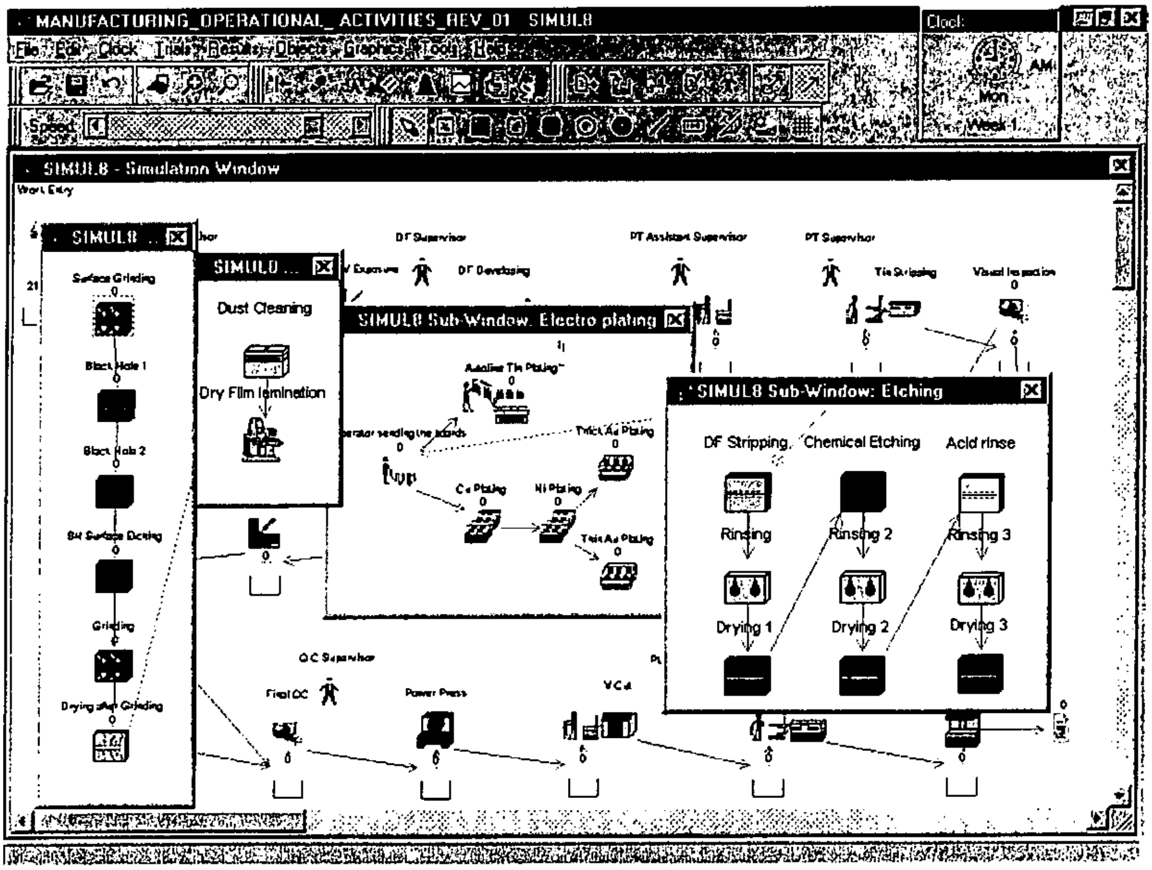


Figure 25: Phase II – Deploying production activities at manufacturing operations

Once the comprehensive PCB manufacturing simulation model is developed, data and information within each activity should be identified. Since the production rate or the production capability of all production machineries and production lines is assumed to be one of the most crucial factors for manufacturing productivities, and it can be used to determine the current or the potential bottlenecks of the entire production cycle, various processes manufacturing speed should be considered in the fundamental information manipulated by the simulation model. Figure 26 identifies the production rate of the "Black Hole 1" operation.

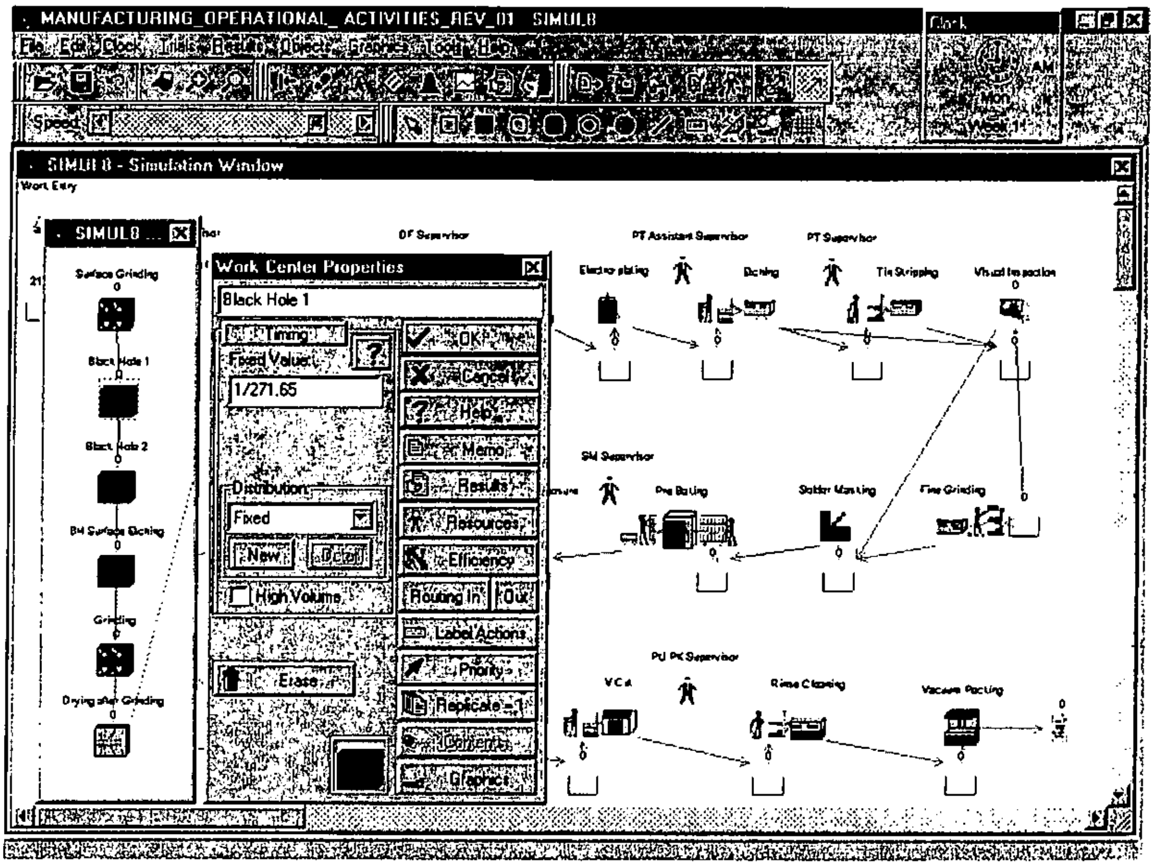


Figure 26: Phase III – Identification of production capability

The next crucial factor that would affect the manufacturing productivity after the manufacturing speed is the deficiencies in the production machineries, production lines, and the manual deficiencies. These deficiencies generate schedule machine downtime and unscheduled machine breakdowns. As a consequence, inefficiencies would be reduced by effectively applying preventive and corrective maintenance. Although manual imperfection is the most detrimental factor among the three types of deficiencies, the information and data deployed in the simulation model can only be estimated by previous quality data from the company. Figure 27 illustrates the normalized efficiency factor for the "Black Hole 1" operation.

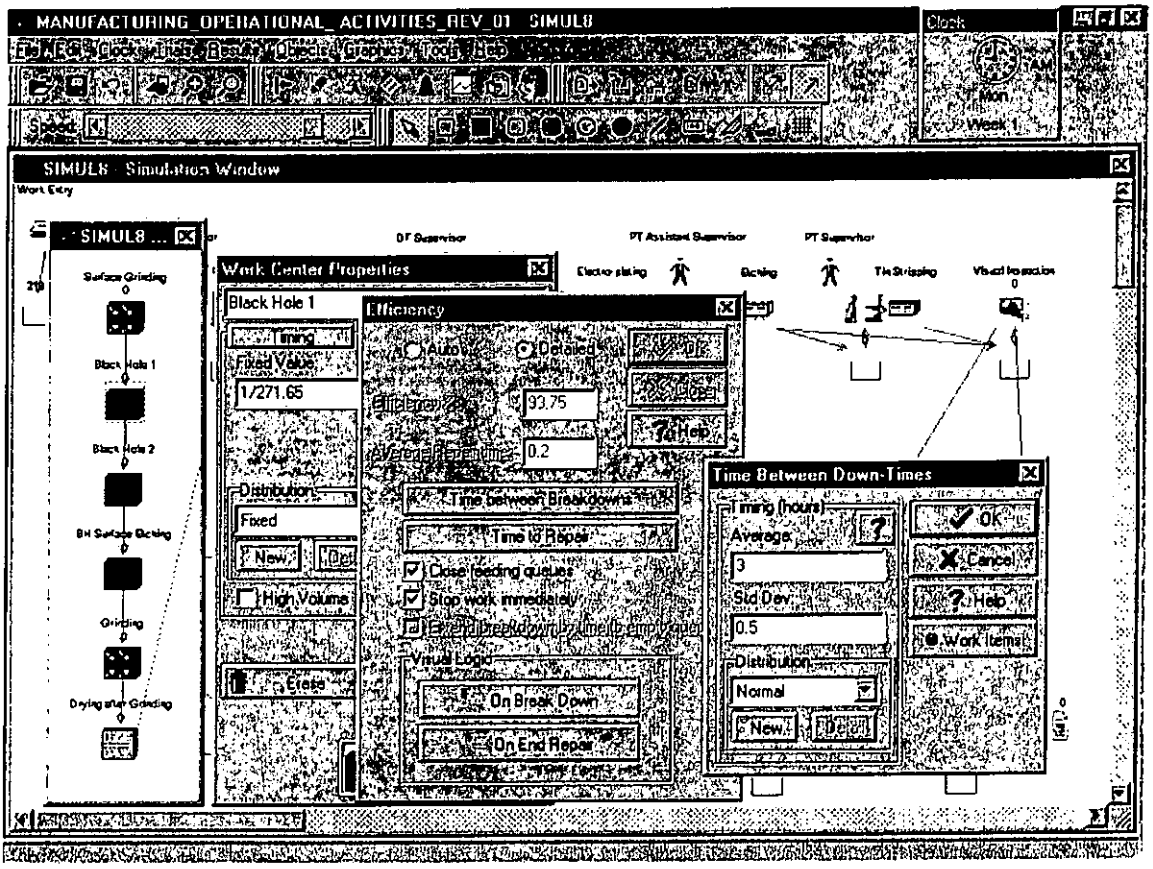


Figure 27: Phase IV – Identification of normalized efficiency for each production activity

Since every production machinery contains different manufacturing speeds and production capabilities, Lean Production (LP) and continuous production methodology cannot be employed in the current manufacturing operations. As the manufacturing speed varies, the departmental operation time also varies. In order to accommodate the various manufacturing speeds, human resources are used to control the departmental operation time and periods in the simulation model. Figure 28 illustrates the resources utilized in their respective department.

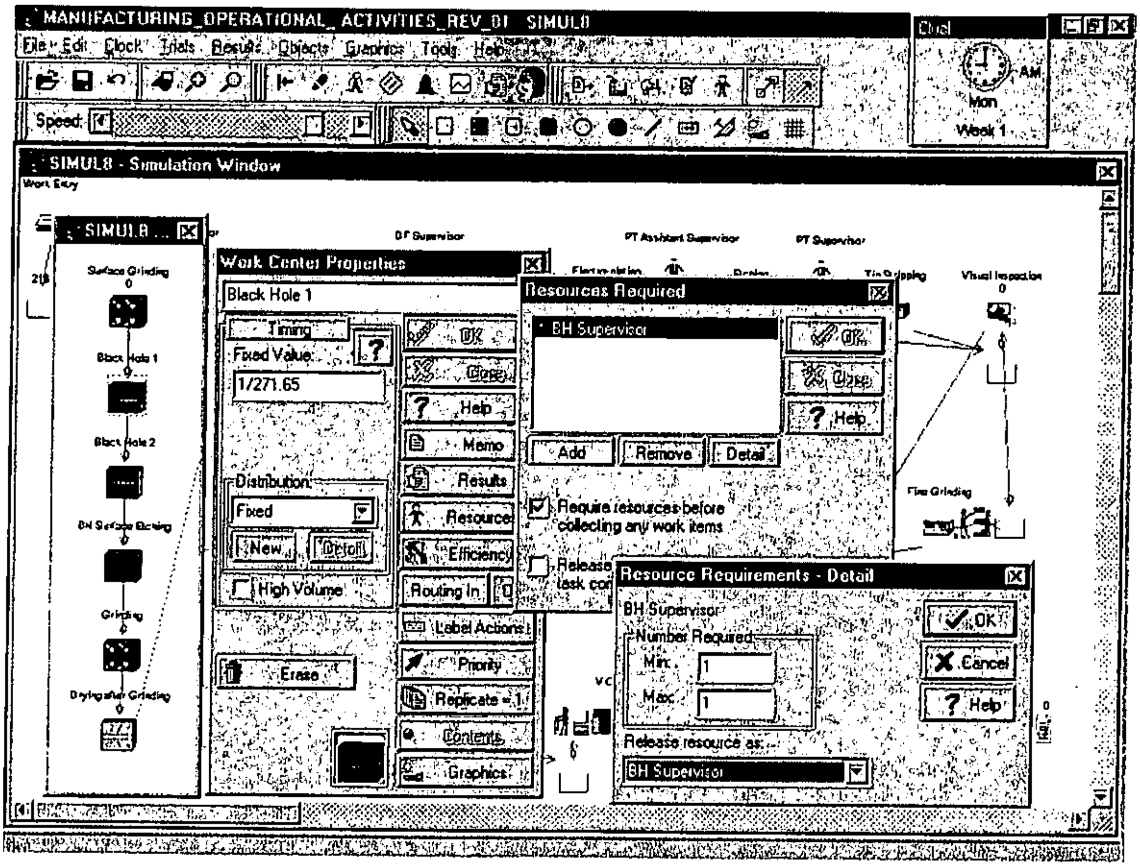


Figure 28: Phase V – Operation times controlled by the departmental resources

To simplify the simulation model, only two types of Double-Sized PCBs (work items) are considered since they consist of greater than 95 percent of the total production. The two types of Double-Sized PCBs are Gold (Au) panels and Tin (Sn) panels. The two types of work items have slightly different production route paths. The simulation model thus demonstrates a parallel path for their respective manufacturing processes, such as the electro-plating process, the etching process, and the HASL process. Since the two types of PCBs have different production route paths, they need to have different identifications for better product traceability. Therefore, the labeling function is exercised within the PCB manufacturing simulation model. Figure 29 illustrates the PCB labeling in the simulation model.

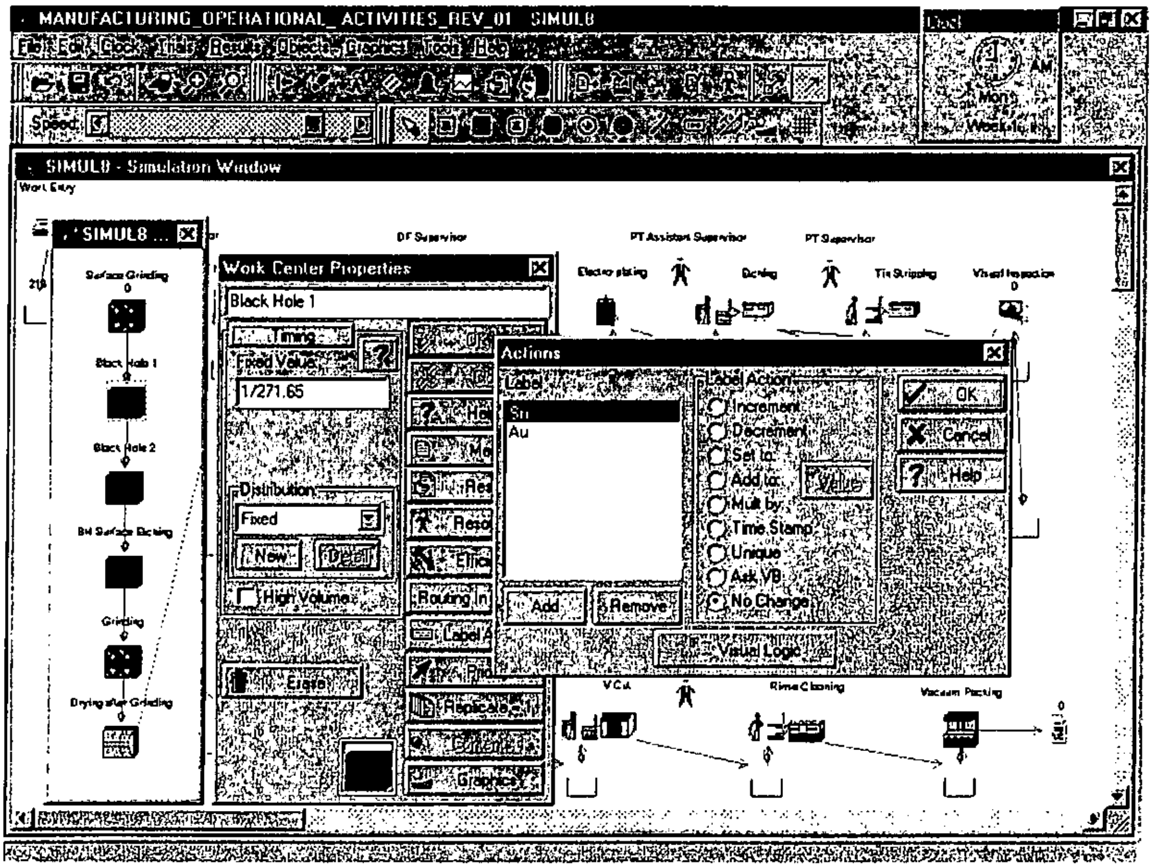


Figure 29: Phase VI – Labeling the work items as production route path identification

Finally, the last phase fin developing a PCB manufacturing simulation model is to identify the work entry volume for continuous production. Work entry can assist in positioning the current and potential production bottleneck. Since, the simulation model does not consider quality defects, the total output is equivalent to the total input after a certain period of time. The model can thus aid in determining the average TPT for each operation. After the TPT for each process is known, the organization can identify the average total production capability. Therefore, the company can have a better pre-production planning. Figure 30 demonstrates the production entry rate in the PCB manufacturing simulation model.

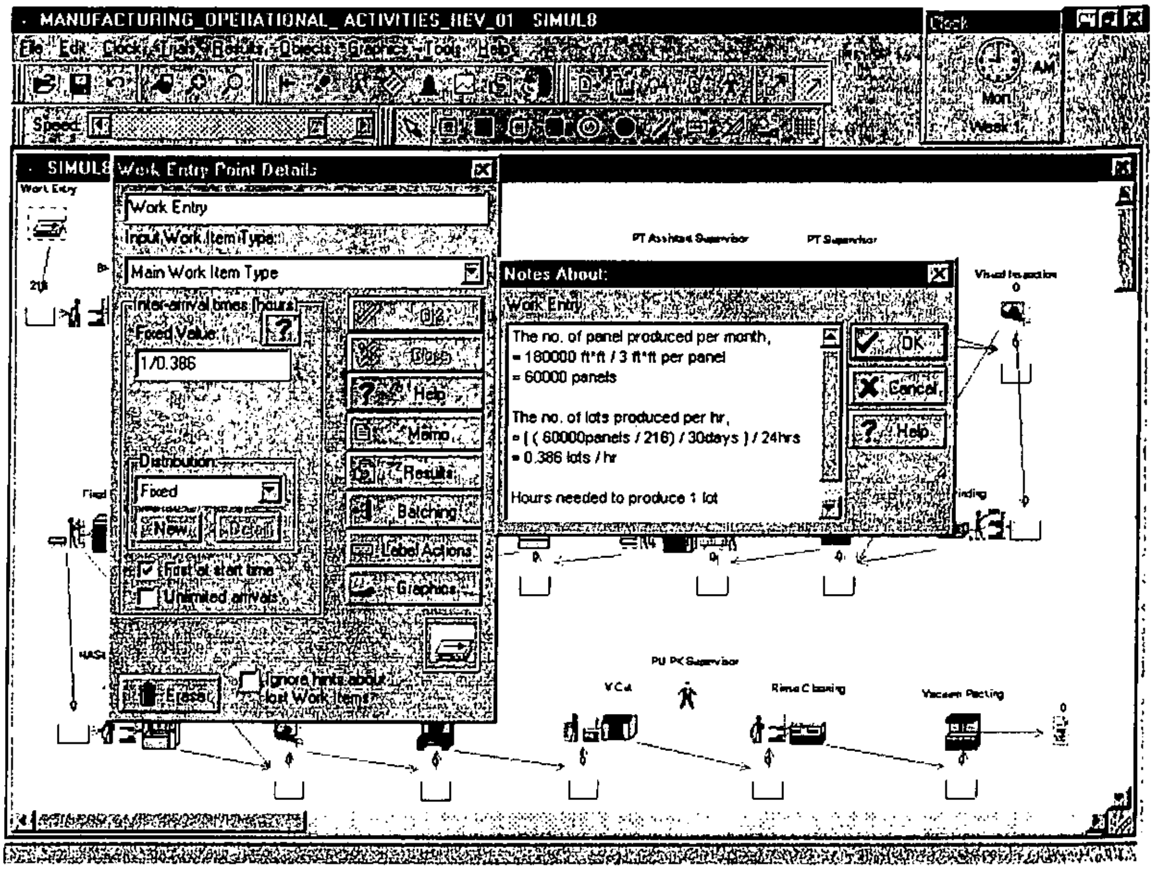


Figure 30: Phase VII – Production entry rate for the PCB manufacturing simulation model

After the PCB manufacturing simulation model is developed, the next task to be taken is to benchmarking to the organization. Benchmarking, in some extent, can aid in positioning and locating the operations that could receive maximum benefit in recognizing the performance gap with the minimum reengineering effort.

6.5 Benchmarking as a supporting tool

As an evolutionary improvement tool, organizational benchmarking is implemented during the stage of positioning. Applying both external and internal benchmarking into the non-linear improvement project can foster a baseline for the organization in utilizing performance measurement.

6.5.1 External benchmarking

External benchmarking can be targeted at direct competitors and also at similar industries. An example of external benchmarking is performance benchmarking. External benchmarking can be used to compare and to benchmark one's company's performance against direct competitors. External benchmarking can also assist in positioning competitive differences and performance gaps between industries. At the same time, it can identify potential improvement within the organization. Benchmarking against similar industries can help in brainstorming and importing new ideas and new technologies to the organization, thereby increasing the effectiveness of applying fundamental rethinking and promoting continuous learning.

6.5.2 Internal benchmarking

Internal benchmarking can be served as one of the better tools in identifying production capabilities and abilities of manufacturing operations. Internal benchmarking can be used to identify the bottleneck of production processes, quality related and cost related within one's business operation. As the objective of the organizational reengineering project is to amplify the PCB panel size, the quality output of a number of manufacturing operations are affected. During the internal benchmarking process, a number of aspects are noted. They include process operation speeds, maximum production size, machine productivities, and machine/operator ratio. Table 5 illustrates the manufacturing abilities and production operation capabilities in the initial state.

Table 5: Internal benchmarking the production operations' performance

Dept	Operation	Permissible Panel Size		number of production machine/line	type of panel		Manufacturing speed		number of operator	Maximum Productivity (ft*ft/hr)
		Width	Length		Au	Sn	m/min	panel/hr		
BH	Black Hole	24.5"		1	●	●	2.3		1	837
DF	Auto Laminator	24.0"		1	●	●	2.4		4	855
	Pattern printing	24.0"	32.0"	4	●	●		120		2560
	DF developing	21.5"		1	●	●	2.4		2	851
PT	Manual Au plating	22.5"	31.0"	1	●	○		48	2	144
	Auto Sn plating	24.0"	144"	1	○	●		160	2	480
	Etching (H/H)	26.0"		1	●	●	2.4		2	975
	Etching (1/1)	26.0"		1	●	●	1.6			650
	Tin Stripping	23.0"		1	○	●	1.5			512
SM	Fine Grinding	23.0"		1	○	●	3.3		1	1176
	Silk-screen printing	18.0"	24.0"	8	●	●		85	4	2040
	Legend printing	18.0"	24.0"	4	●	●		100		1200
	Solder-Mask Exposure	26.0"	34.0"	2	●	●		116	4	1426
	Solder-Mask Developing	24.0"		1	●	●	3.0		1	1069
	Pre-Bake			1	●	●		288	1	864
	Final Bake			3	●	●		162		1458
HASL	HASL	22.0"		1	○	●	2.5		2	908
PU/PK	Power-Press			18	●	●				
	V-cut			4	●	●				
	Cleaning and Packing			2	●	●				

Assumption - Average Production Panel Size: 18.0" x 24.0" (one production panel = 6 delivery panel)

6.6 Using process analysis as a supporting tool

Process capability analysis and ability analysis are the next crucial task to achieve the goal of the organizational reengineering project after benchmarking. As stated in the internal benchmarking section, the initial PCB panel size is 18" x 24". While the objective of the reengineering project is to reach a PCB panel size of 24" x 36". To achieve the FBPR project's objective, a number of factors should be considered, including process capability limitations. For instance, the machine manufacturers' suggested PCB panel size for all independent manufacturing processes must be reached. If any of the manufacturing process is not capable to meet such goal, adequate engineering modifications and decisions must be executed to meet the intention of Preventive Action (PA). Simultaneously, the process manufacturing speed also needs to be considered and analyzed to provide continuous production.

During the process of internal benchmarking, not all process capabilities and abilities can accommodate the increase in PCB panel size. Thus, in order to compensate for the mentioned deficiencies, reliability engineering analysis and cost analysis are performed.

6.6.1 Reliability analysis

Since the increase in PCB panel size would potentially affect the product quality, reliability engineering is used to analyze the quality variation for both the 18" x 24" panel and 24" x 36" panel. Prior to applying reliability analysis to the entire PCB manufacturing process, different types of production machineries must be identified and classified. They are the horizontal production line, the lateral production line and the solitary production machinery. Classifying the manufacturing processes into three categories can narrow down the magnitude of experimentations. Thus decreasing the time and the cost of analysis.

These three categories of manufacturing processes are described as follows:

(I) Horizontal Production Line

A) Black Hole Process
B) Dry Film Developing Process
C) Etching Process
D) Tin Stripping Process
E) Fine Grinding Process
F) Solder Mask Developing Process
G) Pre-HASL Re-activating Process
H) Post-HASL Cleaning process

The special characteristics for all horizontal production lines are that they all shared a different combination of four independent manufacturing activities, they include board grinding, chemical spraying, water rinsing and air-drying. All four manufacturing activities did not affect the quality of product provided that the production panel sizes are within the process capabilities. As for mistake proofing, if the horizontal production line is not capable to manufacture such panel size, the PCB panel will not be able to enter to the production line.

(II) Lateral Production Line

A) Manual and Auto-Plating Line

B) HASL Process

The characteristics of both plating line and HASL process are somewhat similar. The major production activity of both the plating operations and HASL process is to insert the PCB vertically into electro-plating baths and into a soldering bath respectively. If the PCB panel increases, the quality outcome after the electro-plating process is improved since the respective plating area distribution is improved. As a result, this creates better quality product. Alternatively, the quality outcomes of the HASL process remains constant due to its specific production method.

(III) Solitary Production Machinery

A) Auto-Dry Film Laminator

B) Pattern Printing (Dry Film exposure)

C) Silkscreen and Legend Printing

D) Solder Mask Exposure

E) Baking Process

The characteristics of solitary production machineries are distinct in manufacturing activities. Therefore, to accommodate the increase in PCB panel size, the solitary production machineries analyzed independently.

Similar to the horizontal production lines, the quality outcome of the auto-dry film laminating process, the dry film exposure process and the solder mask exposure process, are not been affected by the change in PCB panel size. Since there exists a build-in mistake-proofing approach. This menas, if the PCB panel can enter into the manufacturing process, the high quality of product will remain constant and stable.

On the other hand, the quality outcome of the silkscreen printing process is slightly affected. As the production panel size increases, the respective silkscreen dimension would also be increased. Since constant tension is applied on the silkscreen, the potential silkscreen deformation (elastic elongation) would exist. Therefore, as the size of the silkscreen increases, the elastic elongation would also increase. As a result, it would increase the potential of delivering an imprecise quality of PCB product. To compensate the mentioned defective, the Reliability Qualification Test Program (RQT) is launched. A number of factors are considered and analyzed in their dependent relationships during the RQT. They include the silkscreen's density, complexity and material/texture. The result of the qualification test shows that there is an interrelationship on the product output between the silkscreen density and the silkscreen complexity. The analyzed solution suggests that by increasing the silkscreen density, this would aid in increasing its stiffness and in reducing its rate of elongation. On the other hand, it also suggests that by decreasing the silkscreen complexity, this would aid in accommodating the effects caused by the change in silkscreen density while maintaining the high quality product outcome.

The quality outcome of the solder mask baking process is shifted positively because of the increase in ventilation effectiveness from the reduction in air-traps inside the baking chamber. The air-traps are caused by the manual mis-placement of two independent shelves on the PCB panels inside one compartment, and the air turbulence induced by the spaces between the two independent shelves. With the increase in PCB panel size, both the manual mis-placement and the spaces between the shelves will no longer exist since it allows only one shelf for each compartment inside the baking chamber, thus increasing the ventilation effectiveness inside the baking chamber.

6.6.2 Cost analysis

After analyzing the quality output and the reliability of the manufacturing activities, cost analysis is then applied. As observed from internal benchmarking, a number of manufacturing processes are not capable of producing PCBs with a radical increase in PCB panel size. Thus, purchase of new production equipments could be an alternative. The affected production equipments include dry film developing line, manual gold plating line, tin stripping line, fine grinding line, silkscreen printing machineries, UV exposure machineries and HASL production line. During the cost analysis, the initial cost and its period of cost recovery need to be identified. Since the cost of purchasing production machineries would be great, the non-linear improvement would consume a respectively larger amount of time.

Due to the essentiality of top management commitment, it is important to establish a target for initial cost vs. cost recovery period. Thus, the goal for the cost recovery period is set at five years after the installation of each of the production equipments. Since company C can foresee the constant change in the market demand. In other words, if the period of cost recovery for the new production machinery expands over five years, the purchase of new production machinery might not be feasible, given that there will be no dramatic change on the external factors, such as new technology that not likely will not be introduced within a short time of period, quality enhancement related, and health and safety related factors.

As mentioned earlier, this organizational reengineering project would be a long-term investment. Thus, there will be time variation with regards to different process changes. To define the order of the process changes, a number of conditions have been positioned, which include potential bottlenecks, the initial cost, and the quality impact. Since bottlenecks are the factor that limits the production capability, it is primarily considered. Furthermore, given that company C is a Small and Medium size Enterprise (SME), there would be a capital investment limitation as well; The initial investment is therefore considered next. Finally, as the quality output of the production process is directly related to the cost of production equipment, the quality impact is taken into consideration.

The primarily non-linear improvement section that will be discussed is the Wet Film Ultra-Violet (UV) Exposure operation. It is the major bottleneck among the manufacturing operations. At the same time, the production capability of the operation is below the requirement of the non-linear improvement project. With these two constraints, it is the factor that necessitates the foremost FBPR change. Before amending and replacing the production machinery, a number of criteria should be considered, which include the permissible production area and the average production TPT, since they are the principles that define the manufacturing productivity. After the criteria are benchmarked, the UV exposure is then replaced and amended. The permissible production panel size is induced from 26"x34"to 34"x42", achieving a 62% of improvement in production effectiveness. Alternatively, due to the limited ability of the manufacturing under UV exposure process, the production cycle time is increased from an average of 31 seconds to an average of 38 seconds reaching a 23% increase in TPT. By combining both the effectiveness improvement and the ability limitation, a 25%(2) productivity enhancement is generated with approximately three to four years of cost recovery period.

The second non-linear improvement that is implemented on the organizational-level FBPR project is the dry film developing process since it is also one of the major production bottleneck and one of the major contributions to defects. This bottleneck is caused by the limitation in production panel size, which in turn leads to defects caused by the unstable production equipment and accessories. After three months of operational engineering and operational augmentation analysis, a newly redesigned dry film developing line is established. The manufacturing speed of the new dry film developing line is enhanced by approximately 46%, from 2.4m/min to 3.5m/min, and its permissible production panel size is increased by approximately 40%, from 21.5" to 30". This presents a total productivity improvement of 103%(3). Meanwhile, the cost recovery period is estimated to be two to three years. With the mentioned radical productivity improvement and the respectively shorter period of cost recovery, the dry film developing process is then considered for further improvement.

The third operational improvement is applied to the HASL operation as it is next again production bottleneck. Similar to the dry film developing process, the limitation of production panel size greatly affects the TPT of the entire PCB manufacturing. Therefore, a

(2) $$\left[\left(1+\frac{34x42-26x34}{26x34}\right)x\left(1-\frac{38-31}{31}\right)-1\right]x100\% = 25.1\%\text{productivity enhancement}$$

(3) $$\left[\left(1+\frac{3.5-2.4}{2.4}\right)x\left(1-\frac{30.0-21.5}{21.5}\right)-1\right]x100\% = 103.5\%\text{productivity enhancement}$$

new HASL operation is needed to accommodate the increase in PCB panel size. Meanwhile, since the original HASL operation has high quality output, no drastic reengineering design is required. Therefore, after one month of redesigning the HASL operation, a new operation design is established. The quality output of the new HASL operation remains constant. The manufacturing speed, however, is has increased by 28%, from 2.5m/min to 3.6m/min, and the new permissible production panel size is increased by 25%, from 22.0" to 24.0". This presents a total productivity enhancement of 57%[4]. The cost recovery period for the entire HASL operation is projected to be approximately three to four years.

Since the organizational-level FBPR changes are considered to be longitudinal, a complete organizational reengineering implementation will expand more than two years. A limited number of reengineering changes thus are executed within the period of the reengineering project. Therefore, in order to create initiative for continuous reengineering implementation within company C, the continuous process improvement concept and objective are implemented into the company C's scope with the top management's commitment. To obtain the support from the top management, a manufacturing prototype is produced.

6.7 Performance and productivity enhancement in organizational-level FBPR

The implementation and the ongoing results of the organizational reengineering project had been measured to be successful, even though the full implementation is not yet

(4) $\left[\left(1+\frac{3.6-2.5}{2.5}\right)x\left(1+\frac{24.0-22.0}{22.0}\right)-1\right]x100\% = 57.1\%$ productivity enhancement

completed. A number of analyzes are conduced during the process of organizational-level FBPR which include simulation of manufacturing operations, external and internal benchmarking and process analysis relating to costing and reliability. After the analyzes are carried out and partial of the full implementation is done, the gap from reaching the target and the objective of Just-In-Time (JIT) and Lean Production (LP) are reduced. After the implementation of organizational-level FBPR, TPT, the manufacturing efficiency, effectiveness and capabilities are enhanced.

With the assured quality improvement and productivity enhancement from the executed prototype testing, top management is willing to initiate continuous FBPR changes to areas that require non-linear improvement. As illustrated in the internal benchmarking, various production operations must be amended or replaced to accommodate the complete organizational-level FBPR project. Due to time and resources limitations, only three of the operational changes are implemented. On the other hand, operational changes on the tin stripping process, the fine grinding process, and the solder mask printing process will continuously be implemented subsequent to this proposed reengineering project. In addition, the manual electro-gold plating production operation will not be redesigned due to the relatively high initial capital investment and the feasibility of capability and productivity improvement.

After the complete organizational reengineering project is implemented and its results are estimated, the final stage of internal benchmarking is carried out. Table 6 illustrates internal benchmarking after the organization-level FBPR project is partially implemented and estimated.

Table 6: Internal benchmarking the result after implementing organizational-level FBPR

Dept	Operation	Permissible Panel Size		number of production	type of panel		Manufacturing speed		number of	Maximum Productivity
		Width	Length	machine/line	Au	Sn	m/min	panel/hr	operator	(ft*ft/hr)
BH	Black Hole	24.5"		1	●	●	2.3		1	837
DF	Auto Laminator	24.0"		1	●	●	2.4		4	855
	Pattern printing (from SM)	26.0"	34.0"	1	●	●		120		737
	Pattern printing (initial)	24.0"	32.0"	4	●	●		120		2560
	DF developing	30.0"		1	●	●	3.5		2	1733
PT	Manual Au plating	22.5"	31.0"	1	●	○		60	2	291
	Auto Sn plating	24.0"	144"	1	○	●		160	2	480
	Etching (H/H)	26.0"		1	●	●	2.4		2	975
	Etching (1/1)	26.0"		1	●	●	1.6			650
	Tin Stripping	26.0"		1	○	●	2.4			975
SM	Fine Grinding	30.0"		1	○	●	3.3		1	1548
	Solder Mask related coating	24.0"	36.0"	2	●	●		82	4	984
	Silk-screen printing	18.0"	24.0"	8	●	●		85		2040
	Legend printing	18.0"	24.0"	4	●	●		100		1200
	Solder-Mask Exposure	34.0"	42.0"	1	●	●		95	2	892
	Solder-Mask Exposure (initial)	26.0"	34.0"	1	●	●		116	2	713
	Solder-Mask Developing	24.0"		1	●	●	3.0		1	1069
	Pre-Bake			1	●	●		288	1	864
	Final Bake			3	●	●		162		1458
HASL	HASL	24.0"		1	○	●	3.6		2	1426
PU/PK	Power-Press			18	●	●				
	V-cut			4	●	●				
	Cleaning and Packing			2	●	●				

Process criteria and productivities assumption for various manufacturing operations

Table 6 demonstrates the productivity enhancement after the organizational-level FBPR implementation is complete. A number of operations are successfully improved during the implementation. They include enhancements on the solder mask exposure process, the dry film developing process, and the HASL operation. However, the reengineering processes for the tin stripping process, the fine grinding process and the solder mask printing process are not yet implemented due to time and cost constraints. Thus, the results of the three planned reengineering operations and processes can only be estimated by utilizing cost analysis and reliability analysis on their potential abilities and productivities.

It is found that there are quality improvement and productivity enhancement during the implementation of the organizational-level FBPR project. The quality outputs of the Tin electro-plating operation and UV exposure process have shifted slightly. The quality variance between the plating edges and the plating center is improved by approximately 19% due to better electro-plating distribution caused by the reduction in space between production panels during the Tin electro-plating operation. Alternatively, the quality variances of the UV exposure process are slightly increased. Engineering change is therefore adapted to accommodate with increase in quality variances. Finally, it is assumed that there would be negligible quality effects from other affected manufacturing operations compared to the dry film developing process and the HASL operation.

During the implementation of the organizational-level FBPR project, various productivity enhancements are realized and assumed. From the primary stage to the final stage of the organizational-level FBPR project, three non-linear improvements scheme are emplyed and three other non-linear improvements are assumed due to time limitation. The first FBPR change is applied to the UV exposure process. The result shows that the manufacturing productivity is increased by 25%. Although the improvement is not dramatic, the rate of improvement shifts the major bottleneck from UV exposure to other operations and is being minimized later. On the other hand, manufacturing productivity is increased due to the increase in PCB panel size. The second non-linear improvement is applied to the dry film developing process. The result of the FBPR implementation shows a 103% improvement in TPT. Finally the third non-linear improvement is applied to the Hot-Air-Solder-Leveling (HASL) operation. After the implementation is completed, a 57% of operational TPT improvement is achieved on the HASL operation. In addition, the cost recovery periods are estimated to be two to four years after the implementation of the each independent reengineering change.

Three non-linear improvements will be carried out after the FBPR research is concluded. Therefore, the results of the expected changes are estimated and summarized. The potential productivity enhancement for the Tin stripping process is presumed to be 90%. The potential enhancement is calculated and tested by applying chemical laboratory experimentation. The potential TPT improvements for the fine grinding process and silkscreen printing process are measured to be 32% and 93% respectively. The TPT improvement originates from related machineries design specification.

In summary, the direct actual and estimated improvements for the implemented and planned non-linear improvements on the organizational reengineering project are demonstrated on Table 7.

Table 7: Manufacturing performance enhancement after completed organizational-level FBPR

Dept	Business Activities	Productivity Enhancement	Period of Cost Recovery	Status
SM	UV exposure process	25%	3-4years	Implemented Improvement
DF	DF developing process	103%	2-3years	
HASL	HASL operation	57%	3-4years	
PT	Tin stripping process	90%	<= 4years	Planned Improvement
SM	Fine grinding process	93%	<= 4years	
SM	Silkscreen printing process	32%	<= 4years	

In addition to the above enhancements, there are also indirect productivity improvements to a number of business activities, such as electro-Gold plating operation, and lateral production lines. Indirect productivity improvements are instigated due to the increase in PCB panel size while no additional changes are needed due to their specified production methodology. For example, the manufacturing activities for electro-Gold plating operation is to amend one PCB panel at a time. Therefore, if the panel size is increased from 18" x 24" to 24" x 24", productivity will be enhanced by 33% due to the increment in 18" and 24".

6.8 Regenerate the manufacturing simulated model

The details of the manufacturing simulated model must constantly be updated, since the model can provide the company a general view of the most current and potential manufacturing productivity for every operational process. The degree of accuracy of a simulation model can be enhanced as the information and data approximates to factual conditions. The analysis output of the model can merely serve as an assumption, since no computed manufacturing simulated model can be 100% accurate.

CHAPTER SEVEN: RESULT AND DISCUSSION

Flexible Business Process Reengineering (FBPR) develops wisdom and initiates commitments and actions to enhance competitiveness, while transforming the Value Delivery System (VDS) through the use of both linear and non-linear solution. The rate and quality of learning and improvement can thus be maximized. A number of literatures such as, Andrews and Stalick (1994), Davenport (1993), David and Henry (1995) and Hammer and Champy (1993) have stated that a higher number reengineering project did not reach their expected goal because of its overextension, misuse, mal-planning and mainly lack of commitment.

To accommodate with the management gaps, Altinkemer and co-workers (1999), Swartz (1994), and Morris and Brandon (1993) suggest that positioning, continuous process improvement and additional management tool must be applied with reengineering to optimize the effectiveness and flexibility of the radical improvement projects. The results of this research indicate that when FBPR is implemented, the effectiveness of the improvement effort is increased; thus, decreased the hidden and potential risk caused by the implementation of FBPR projects. Meanwhile, FBPR also demonstrates various techniques and tools to support the implementation for both linear and non-linear improvement. By decomposing different layer of activities in a manageable size and developing the process model, FBPR therefore, is less problematic to implement than both the conventional BPR and DBPR due to the increase in flexibility, different implementation techniques and the vision of change.

One of the objectives for FBPR is to redesign the VDS, while the core of VDS is the process intent identification and process model development. Process intent is used to identify the Critical Success Factors (CSFs) for the company at time. Therefore, as the market changes and the customer demand shifts, the process intent will also be alternated. After the process intent is defined, the process model can thus be determined by targeting the modified goal to the CSFs amendment and to the performance gaps. Alternatively, due to the constant change in market demand, there are no universally good process models. Their suitability is determined by how well they meet the process intent at time, and develop a VDS design and capability to determine strategic options. The process intent for this FBPR research is endeavored on manufacturing productivity enhancement. Therefore, the objective of all three independent FBPR projects aimed at increasing the effectiveness, efficiency and flexibility of the manufacturing operations through the use of linear and non-linear improvement solution.

Not all FBPR projects employed the concept of "clean slate," or "greenfield" type of implementation due to the nature and scope of changes. The FBPR concepts implemented for the projects include optimizing the value adding activities, redesigning the manufacturing activity flows, minimizing the TPT, maximizing the return on investment and competitiveness; while alternatively, sustaining high quality in product and customer-supplier relationship. FBPR generally keep and linearly improve the existing operation (evolutionary tactics) by applying the concept of continuous improvement, while alternatively, promoting non-linear improvement solution to the existing activities (revolutionary tactics) by applying the concept of BPR, aligned process intent with strategy, and designed process model that optimally achieve process intent.

As the fundamental concept of FBPR, it is important to start a FBPR project that is the least complex to implement; thus, the initial FBPR results can be used in changing the mindsets, mental models, and measures of the top management. After the top management is committed to and ready for the non-linear solution, the scope of FBPR project and process model can thus be enhanced as the improvement initiative increased.

Three independent case studies are utilized to illustrate the procedures and methodologies adopted in this implementation are of general interest to any prospective process redesign practitioner. Three levels of FBPR scheme, process-level, operational-level, and organizational-level were adopted and actual implementations are carried out in different phases. In general, if changes are within a process, process-level reengineering should be applied. If on the other hand, changes involve inter or cross-departmental, operational-level reengineering should be applied. Lastly, if changes involve the entire organization, organizational-level reengineering should be applied. Various aspects of positioning, continuous process improvement and business process reengineering (PIR) are considered and employed, they include:

(1) Align Process Intent with strategy and productivity enhancement;
(2) Exploit a Value Delivery System (VDS);
(3) Apply performance measurement;
(4) Benchmark and analyze the initial business activities to identify the performance gaps;
(5) Decompose the value adding activities and the non-value adding activities;
(6) Develop both linear and non-linear improvement scheme;
(7) Simulate the manufacturing activities;
(8) Redesign and restructure the workflow system; and
(9) Implement FBPR project.

7.1 Silkscreen printing re-design - Process level FBPR

The primary FBPR project applied process-level FBPR on the silkscreen printing process by utilizing the linear improvement scheme. Since the scope of process-level FBPR project has been limited to a process or a business activity, the complexity of the project is relatively narrowed and the period of design, implementation and analyses are also short. Thus, in turns, it consumes relatively less time for employing the entire FBPR cycle on the process reengineering project. By setting the target on reducing manufacturing TPT, the reengineering project provides a clear understanding and an apparent vision on where to position the linear improvement scheme and evolutionary changes.

During the stage of positioning, process analysis is employed in realizing and supporting the current and potential possible manufacturing productivity within the silkscreen printing process. Once process analysis is successfully employed, both value adding activities and non-value adding activities are then identified. Non-value adding activities include activities such as manual handling, transportation and inspection. By realizing the essentials within the silkscreen printing process, appropriate changes are identified to meet the defined process intent. Various aspects are considered, analyzed and implemented during process-level FBPR, they include minimizing the non-value adding visual inspection by redesigning a fixture for better quality production, reducing manual handling time by operating multiple activities simultaneously, restructuring manufacturing process flow etc.

The process-level FBPR project is implemented by employing both evolutionary change tactics and linear improvement scheme, the concluded result of productivity enhancement is of satisfactory. The TPT performance is improved by an average between 29 to 37 percent. Due to the reduction in TPT, the labor cost is reduced and the production capability for the silkscreen printing process is significantly increased by approximately 35 percent. In addition to the quantitative improvement, qualitative achievements are also gained, such that operational process are studied, analyzed, and enhanced. The utilization of manpower is maximized by reducing their idle time during production. A clear and comprehensive understanding of how an individual's own work is conducted to form a basis for comparison with industry practices. With the initiatives and involvements of the direct labors, the implementation is successfully implemented and a learning environment is developed; thus, the target and the objective of continuous learning, continuous challenging and continuous improvement are promoted.

As for further improve the effectiveness of all manufacturing processes within the organization, process-level FBPR should be applied to all manufacturing processes that demand relatively great amount of labor. Since the methodology employed for this process-level FBPR project mainly aims at improving the productivity by identifying and minimizing the non-value adding activities, employing relative time study, restructuring the process flow, and utilizing performance analysis, similar methodology could thus be able to apply to all process level activities for further performance enhancement.

7.2 Post-HASL baking elimination - Operational level FBPR

The second reengineering project has been implemented on the post-HASL baking operation. The incentive for targeting the reengineering project on the post-HASL baking operation is that it directly affects the TPT and it also significantly affects the quality of the PCB product. Ionic contamination is considered to be one of the major quality control aspects during the PCB manufacturing. The initial level of ionic contamination for the Tin production panel after the HASL operation are measured to be in an average of 11.0μgNaCl/in^2 which is considered to be out of the Statistical Process Control (SPC); the SPC for the ionic contamination has a range between 0.0μgNaCl/in^2 to 6.4μgNaCl/in^2. Thus, in order to reduce high level of ionic contamination after the HASL operation, additional corrective operation is needed to regain the quality of the PCB. In this case, post-HASL baking operation had been introduced. The post-HASL baking operation is able to reduce the ionic contamination from an average of 11.0μgNaCl/in^2 to an average below 5.0μgNaCl/in^2.

Serving as a Corrective Action (CA), post-HASL baking operation is able to reduce the level of ionic contamination to a desire scale; but alternatively, the additional operation introduced additional problems; they include excessive manual handling, longer TPT, and incoherent operational workflow. Incoherent operational workflow generated supplementary manual handling, reworks, defects, etc. Therefore, in order to maintain exceptional product quality, operational reengineering project is launch to improve the ionic contamination at the operations that have the potential in elevating the level of ionic contamination.

By studying the possible operations that could introduce the ionic contamination, two major ionic contamination contributors are realized; they include the solder masking operation and the HASL operation. During the stage of positioning the root causes of the ionic contamination, DOE is employed in two sections. The primary section of DOE is applied on the HASL operation, and the second section is carried on the solder masking operation.

During the application of DOE on the HASL operation, the concept of decomposition is utilized to identify and to independently breakdown the activities within each of the manufacturing process of the HASL operation. After decompositioning and analyzing the results of the HASL operation, it is realized that the ionic contamination was being elevated after the HASL process. Thus it leads to a trend that the compound inside the solder mask had been transformed due to the elevated temperature of above 245°C, thus delivered excessive ionic compound to the surface of the solder mask on the PCB.

After realizing the ionic contribution within the HASL operation, the second DOE is employed on the solder masking operation. During the analysis of the solder masking operation, hypothesis is used to identifying the limitations and constraints of the manufacturing process within the solder masking operation. Subsequently, solder mask baking operation is considered to be ionic compound related and had demonstrated that it will greatly effect the level of ionic contamination. To promote the concept of preventive operation, appropriate engineering modifications is made on the baking system to improve the quality and to reduce the level of ionic contamination.

The result of the operational reengineering project is that the post-HASL baking operation is eliminated. Thus, a number of quantitative improvements is identified; they include reduction in TPT, in cost of production and cost of manufacturing defects and reworks.

The concept of operational reengineering cannot only be applied in eliminating non-value adding operations; it can also be used in enhancing other business activities such as inter-departmental communications, production layout, etc. Enhancing the inter-departmental communication can improve the information feedback, information feed forward and trouble shooting if any problem occurs; thus, be able to reduce the period of correction and prevention and to improve quality of manufacturing and quality of product and service. Alternatively, employing the concept of operational reengineering in production layout may be able improve the manufacturing efficiency and effectiveness due to the reduction in transportation and the increase in manufacturing flexibility. Therefore, operational reengineering can constantly be applied to the any business activities within an organization when appropriate.

7.3 PCB panel size modification - Organizational level FBPR

To achieve the overall non-linear improvement, the final reengineering project is piloted on the PCB panel size. As the scope of the organizational reengineering project is considered to be the broadest and the most complex compare to the other two former implemented reengineering projects, both the complexity of the change and the complete implementation period for the project are thus relatively increased. Alternatively, the overall production TPT will be dramatically enhanced and the quality variance caused by manual handling and operational design will also be improved.

During the planning stage of the organizational reengineering project, the concept of Just-In-Time (JIT) and Lean/Leveled Production (LP) are utilized to identify the initial and potential capability and bottleneck of all manufacturing activities. The JIT and LP concept can aid in restructuring the initial semi-push and pull-system to a later continuous manufacturing system. By maximizing the productivity of selected manufacturing operations, improving the operation response time, and reducing the Work-In-Process (WIP); continuous production and the manufacturing output rate could thus be enhanced.

On top of applying JIT and LP, the basic concept of Design Of Experiment (DOE) is utilized on designing the benchmarking method, initiating quality variance assumptions, developing manufacturing simulation model, process analysis, etc. The application of DOE enhances the effectiveness by implementing reengineering changes and prototype testing thus to be able to systematically experiment changes rather than utilizing Trial-and-Error experimentation.

After the DOE is initiated, organizational-level FBPR project has than been instigated. The primary step employed for this complex non-linear improvement change is made on quality variance assumptions, since there would be a potential that quality of product could be affected. To accommodate with the mentioned, quality assumptions is made for further enhancement to ensure that the quality could be remained and/or enhanced. The initial quality variance assumption is made in on the relationship between quality of product vs. manual defects and process ability. The initial analyses are that the quality variances are mainly triggered by manual defects and process abilities limitations, where manual defects are the crucial defects among the two.

After the initial analyses are done, further quality assumptions are made concerning the quality shift after implementing organization reengineering. The assumption is that as the size of production panel increases, the number of manual handling will decrease. The ratio of manual defects will therefore improve. Alternatively, as the production panel size increases, there will be a potential that the initial manufacturing processes may not have the ability to produce the same level of quality. Therefore, in order to maintain or improve the current high quality of product, cost analysis and reliability analysis are later employed. Concurrently, prior to implementing further analysis on the entire manufacturing activities, computer simulation model is developed to identify the operations that would be affected. Therefore, the analyses and implementation could later be employed more efficiently and effectively.

Computer simulation modeling is considered to be one of the essentials on increasing the effectiveness during manufacturing capability analysis while implementing non-linear improvements. Therefore, the simulation software - Simul8 is utilized for simulating the manufacturing activities. Simul8 is chosen due to its high cost effectiveness and its high flexibility on modeling design; therefore, the simulation model can be custom-made for imitating all PCB manufacturing activities. During the development of the simulation model, a number of aspects have been considered; they include detailed PCB manufacturing operations, production capabilities, operation periods, etc. After the simulation model is developed, initial and potential bottlenecks are then positioned and benchmarked within the manufacturing operations.

After realizing the crucial bottleneck operations, reliability analysis and cost analysis are employed to accommodate the potential failure mode and effects after the implementation of the organizational reengineering project. The reliability analysis demonstrates that there would be relatively negligible effects on most of the manufacturing operations; though, there would be quality affects on the silkscreen printing process and baking process. With sufficient modification on the design of silkscreen fixture, the quality variance of the operation is minimized. Alternatively, there is quality improvement on the baking process due to its enhancement in ventilation effectiveness. Concurrently, the cost analysis is considered in measuring various cost recovery periods for multiple-operational changes. As a result, the productivity improvement for operations that have implemented changes varies from 25% to 103% while the cost recovery periods are all within approximately four years.

The results of the implemented changes are considered to be satisfactory. On the other hand, due to time limitation, not all non-linear changes of the organizational-level FBPR project is entirely finalized. With the impressive quantitative results observed from the implemented reengineering projects, the top management of the organization has gained confidence of the concept of FBPR. Thus, the un-finalized organizational-level FBPR project will continuously be implemented on the planned non-linear operational changes. Tin stripping process and fine grinding process are some of the processes and operations that are planned for further non-linear improvement.

This organizational-level FBPR project is only served as one of the many fields that FBPR can implement non-linear improvement. As for this non-linear improvement project, the goal aimed to derive a Value Delivery System (VDS) and enhance the production effectiveness. Therefore, it could increase the production flexibility, decrease TPT and WIP, and improve the organization's market competitiveness. Unlike a number of other previously implemented business process reengineering project, this FBPR project did not enable the use new Information Technology (IT) and/or process automation due to the nature of the defined process intent. Alternatively, FBPR would also suggest future non-linear improvement project to utilize the most updated IT and/or process automation, if their process intent aims to further improve their operating system after all their non-value adding activities are minimized and at the same time demand less variation or flexibility. Nevertheless, there are no unsuitable improvement tools for FBPR project, as long as the tools match the goals and the process intents of both the linear and non-linear improvement objective.

7.4 Summary of quantified results – The three levels of FBPR

The summary of quantified results obtained from the three levels of FBPR is illustrated in Table 8:

Table 8: Summary of quantified results of the FBPR work

Improvement Level	Dept	Business Activities	Productivity Enhancement	Status
Process	SM	Silkscreen printing process	29%-37%	Implemented Improvement
Operational	HASL	Post-HASL baking operation	operation eliminated	
Organizational	SM	UV exposure process	25%	
	DF	DF developing process	103%	
	HASL	HASL operation	57%	
	PT	Tin stripping process	90%	Planned Improvement
	SM	Fine grinding process	93%	
	SM	Solder mask printing process	32%	

7.5 FBPR constraints and limitations

To optimize the scope of FBPR, there are a number of constraints and limitations. The first constraint is that, it is essential for FBPR project to follow the course of the Value Delivery System (VDS), that is process intent identification; process model development; in-process control and evaluation; design of new learning system. The VDS determines the business area that would receive the greatest performance improvement when applying FBPR.

The second constraint is that, it is vital to initiate a FBPR project by applying the linear improvement scheme – an evolutionary change approach prior to applying non-linear improvement scheme – a revolutionary change approach, because evolutionary change approach can gain top management believe and support toward the FBPR management concept. As demonstrated in this FBPR research, evolutionary change concept is applied on the process-level FBPR project, the revolutionary change concept is then applied on the operational-level and organizational-level FBPR project.

If the course of FBPR is followed, there is no limitation on either the scope or supporting tools for any FBPR project. Since FBPR combines the advantages from both evolutionary change concept and revolutionary change concept, it forms a continuous self-learning and self-improvement working environment and promotes the fundamental perception of rethinking and restructuring.

CHAPTER EIGHT: FURTHER FBPR IMPROVEMENT

After the manufacturing productivity is enhance through the use of both linear and non-linear improvement scheme, it is suggested to shift the process intent and redesign the process model toward the quality concern, since quality is one of the ultimate trend and value adding on customer's perception at the present time. To be the suppler of choice, it is important to understand the concept of "*You can win a customer with low cost, but you retain their loyalty through quality and response.*" Alternatively, in cycle time or TPT management, it is often said that inventory is evil; that inventory is the graveyard of poor management. Similarly, in quality control, variation is evil, and large variation is the graveyard of poor quality management. Therefore, after the goals of the productivity improvement projects are achieved, the next process intent should aim at quality improvement.

Once the quality improvement perspective is shared throughout organization and the new process intent is defined, new process model can then be developed. The new process model should include *Three Levels of Quality Transformation*, they include mind level, delivery system level and continuous improvement level:

8.1 Mind level

During the mind level transformation, it is important to transform the conventional style of management and the traditional method of thinking. Therefore, in order to continuously improve the organization's competitiveness, organization must constantly position the causes of poor quality and the opportunities of superior quality, must be committed to surpass customer expectations, must develop and initiate various quality-improvement plan, must establish goals and performance measuring progress, provide quality-improvement training and knowledge and develop a rewarding scheme based on quality improvement such as zero defects programs.

8.2 Delivery system level

During the delivery system level transformation, it is important to realize the causes of defects, to identify the reasons of performing non-value adding activities and to reduce and preventive quality related defects. An effective delivery system is a combination of three inter-related system. They include quality targeting system, information feedback and feed-forward system and Total prevention system.

8.2.1 Quality targeting system

Within the quality targeting system, there contain four types of quality improvement program, they are:

1) Quality planning
2) Quality Function Deployment (QFD)
3) Design for manufacture with minimum variation
4) Design Of Experiments (DOE)

8.2.2 Information feedback and feed-forward system

A high ratio of quality defects is caused by the mal-information transfer and feedback.

The major cause of mal-information transfer and feedback was caused by excessive Work-In-Progress (WIP). Excessive WIP not only induced non-value adding costs but also delay of information feedback and quality of information. With the mentioned reason, it would take an unnecessary long time to correct any error. Therefore in order to solve such problem, it is necessary to develop an effective information feedback system by employing the concept of lean production to reduce the time to detect and improve the quality of feedback information. If the time and quality of the feedback information are enhanced, the time correct will subsequently improved. In addition, a standardize quality problem-solving process and technique must be developed to further improve the information feed-forward system.

8.2.3 Total prevention system

Finally, the last of the delivery system – Total prevention system should be designed to minimize the possibility of problem recurrence, installed and improve processes that prevent defects to occurs by employing quality tools such as "Six QC tools" and Process/Potential Failure Mode, Effect and Criticality Analysis (PFMECA).

8.3 Continuous improvement level

In order to remain and continuously enhance the organization's competitiveness, sufficient continuous improvement must be applied. To develop a sufficient continuous improvement program, FBPR teams must be organized around quality aspects, quality target and goal must be measured and set, Pareto analysis of defects must be performed to identify the most frequent types of defects, sources and causes of defects must constantly be determined and investigated, and redesign the process thus to permanently prevent and eliminate defects.

8.4 The 10 great quality principle

While the organization redesigns a new quality management system, it must identify the major principle for quality improvement. Factors such as the causes and effects of quality shifts are some of the aspects that should be considered during the stages of quality system redesign. Therefore, in order to enhance the effectiveness of the suggested quality focused FBPR project, it is vital to position the *10 Great Quality Principle*, they include:

(1) Quality can be improved and costs reduced at the same time, since bad quality introduces additional non-value adding activities.

(2) Improving quality increases competitive advantage. Therefore, the end goal should be ultimate quality performance.

(3) All variance results in loss to the system as a whole. Therefore, variance must be minimized.

(4) Quality is perceived in the mind of the customer. Discover what customers value now and what they may value in the future. To be the supplier of choice, exceed their expectation.

(5) Design products and services according to customers' values, and standardize the processes that produce them while also accommodating the specific needs of customers.

(6) Management controls the system; therefore quality improvement must begin with management.

(7) Detect defects, errors, and variances immediately, and provide high-quality feedback as soon as possible.

(8) Correct errors within the process immediately and prevent their recurrence.

(9) Anticipate and prevent the introduction of errors and defects.

(10) Use statistical tools to indicate the degree to which a process is "in control."

By summarizing all the Great Quality Principle, the Greatest Principle has been defined – "To be the top of its industry, the rate and quality of learning and improvement is designed into its management system."

Finally, it is important to realize that not only poor quality and inefficient productivity introduce additional cost to the organization; costs from people, services, material, tools, equipments, facilities, overheads, and sub-optimal design can also considered to be aspects that will reduce the competitiveness. Though, the stated costs are important to minimized, the greatest cost of all is well-beyond the mentioned, it is "*The Cost of Lost Opportunity.*" The cost of lost opportunity introduces by the reduction in competitiveness will bring about the loss of existing customers, lost market share, loss profit, etc. Therefore, it is important to constantly apply FBPR into different sections within the business by employing both linear solution and non-linear solution to maximize the organization's competitiveness.

CHAPTER NINE: CONCLUSION

The objectives of the FBPR methodology are achieved. The process intent is defined as to improve the manufacturing productivity and production effectiveness. The Value Delivery System (VDS) is developed based on the predefined process intent and process model. After the VDS is developed, the management concept of Positioning, continuous Improvement and business process Reengineering (PIR) of FBPR is employed into three independent FBPR projects. A number of supporting tools such as strategic planning, performance analysis, action description table, relational diagram, benchmarking, process decomposition, analysis development, preventive analysis, Design Of Experiment (DOE), benchmarking, prototype testing, computer simulation model and process analysis are employed to enhance the effectiveness of the FBPR projects.

Both the revolutionary tactics and evolutionary tactics are employed on the FBPR project. Linear improvement scheme is applied on the process-level FBPR project to enhance its production effectiveness, and non-linear improvement scheme is employed on the operational-level FBPR project and organizational-level FBPR project to accelerate their manufacturing flexibility and productivities. The quantitative and qualitative improvement results is identified and analyzed. With the satisfied results from FBPR projects, further improvement areas and process intent are named.

The analyzed reengineering results suggested that although FBPR can deliver radical designs, it did not necessarily promise a revolutionary approach to change. Moreover, revolutionary change processes might not always be feasible given the potential risks and costs of revolutionary tactics. Sustainable linear improvement and non-linear improvement might be what companies should sometimes expect as success from FBPR.

To become the top within its industry, it is essential to *transform one self's mind and then the business in order to maximize the rate and quality of learning and improvement.* In other words, improvement can be optimized by un-learning one's known and re-learning the essential by utilizing the concept of fundamental rethinking.

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