Introduction

Because of increasing world-wide competition, most companies are faced with the challenge to manufacture innovative high quality products at shorter product cycles and lower cost. Today, manufacturing process control technology has become increasingly important to many high technology industries to improve product yield and quality, e.g., semi-conductor, disk storage and others. Manufacturing needs effective flexible tools for engineers and operators to understand and to rapidly diagnose process problems.

A manufacturing plant process control system generally has hierarchical layers of control and involves many elements of technology, as shown in Fig. 1. This paper discusses some of the requirements and design issues for manufacturing process control (MPC).

Evolution of Approaches to Quality Products

The usage of statistical process control techniques to improve product yield and quality has evolved over the last few decades. In the 1940's, inspection after production was a common approach. Control charts were developed in the early 1920's by W. A. Shewart of Bell Telephone Laboratories and were in wide use at Western Electric. During World War II, statistical quality control gained widespread use and acceptance in manufacturing industries, since volume production experience made it apparent that statistical techniques were necessary to control product quality.

With the introduction of electronic computers in the 1960's, emphasis was made to incorporate statistical process control (SPC) during production. As manufacturing processes become more complex, the interactions between different process operations become more important. Process target changes in one process influence the operations of downstream processes. The use of Design of Experiment techniques to help product and process design before manufacturing production has become increasingly important in the 1980's. G. Taguchi from Japan has introduced new methods in the area of Experimental Design and his principle has been widely used in Japan to produce superior quality products [Taguchi87], [Kackar85].

It is important to note that on-line quality monitoring methods cannot compensate for engineering design errors and unstable processes. Out-of-control warning messages alone have limited usefulness if there is no clear feedback control strategy defined to react to the warning signals. In the future, we have to characterize process interactions and process capability, and to set statistical tolerance limits to optimize overall manufacturing quality/yield.

Manufacturing Process Control System

The term Statistical Process Control (SPC) may have different meanings to different groups of people. In Quality Control (QC) area, SPC generally refers to the use of control charts to detect out-of-control conditions and to issue warning messages. In this paper, we use the term Manufacturing Process Control (MPC) in a broader sense than what is commonly known as SPC. An MPC system has different levels or layers of process control, as shown in Fig. 1. At the lower level, we may have a tool controlling a set of process variables. Real time feed-back to compensate for process disturbance is important. Proper instrumentation and knowledge of the process physics are important for this level of process control.

When we move from the inner layer to the outer layer of control, there can be many hierarchies, e.g., multiple tools to form a cell, multiple cells to form a subprocess line, and so on. As we deal with manufacturing process control problems at the outer layer, the issue database design becomes increasingly more important. A product consists of many components and these components were built and tested by many sub-processes over a large span of time history. The data may be collected and stored in multiple computer systems. Finding the right history data for correlation analysis of various components is not an easy task [Hodges88]. This topic will be discussed in more detail when we address system and database issues.

A manufacturing plant process control system involves many technology elements, e.g., automatic data collection, network, process monitoring, modelling, design of experiment, statistics, optimization of set-points, expert systems, databases, user interfaces, etc. (illustrated in Fig. 1). It is important to note that most manufacturing engineers (ME)
only have limited detailed knowledge of the above technology elements. Also, their goal is to solve manufacturing problems which, in most cases, have schedules to meet. Process control tools need to be flexible and easy to use by operators and ME with minimal detail understanding of the underlying technologies.

Problems and System Design Issues in MPC

The "Data Jail" Problem

The most common problem in large MPC systems is that we have too much raw data and not enough "flexible" tools to access the "right" data in a timely manner to solve process control problems. We usually get product yield reports, but these reports provide engineers with the information "What is wrong". Engineers generally want information "Why is something wrong and how to fix it"? Thus, the lack of flexible tools to access the right data has created what is generally called the "data jail" problem. Some of the reasons for the "data jail" problems are:

- Lack of understanding and communication between application users and database system designers.
- Lack of skills by ME to understand database issues.
- Lack of useful interface to databases. SQL statements are not easy for manufacturing engineers to extract data when a complex relationship exists between component traceability and test measurement data.
- Poor data table design
- Non-efficient joining of poorly designed tables, resulting slow computer response for large query.

How much data should we keep?

For a complex product, its components are manufactured by many sub-processes. Component traceability and test measurement data may be collected by multiple computer systems over a large time span. To correlate process control problems, we store data with a time history longer than the product manufacturing cycle. In semiconductor and disk drive manufacturing, storing several months of data for correlation analysis is common.

A common question in designing a database for manufacturing process control is: "How much data and what type of data should be kept"? Unfortunately there is no simple answer to this question. Data in manufacturing are being used by different groups of people doing different types of analysis. Product failure analysis (FA) engineers are interested to find out the causes of product failure from many interrelated sub-processes. They generally need the raw data to correlate any abnormal conditions between multiple sub-processes. They may sort data by operators, machines, time (e.g., week days vs. week ends) incoming vendors, tool maintenance records, etc. Statistical data summarized over time is not sufficient for Failure Analysis engineers for many data sorting operations.

Statistical data summarized over time, is more useful to people who are interested in process control, quality assurance and process optimization. The issue of "How much data and what type of data should be kept" is not simple. During early manufacturing time, there are many problems that require study; hence storing collected data in raw form as well as in statistical summary is appropriate. As the process is being fine tuned, one may need to keep more statistical summarized data and less on-line raw data. However, the cost of storage is going down rapidly each year, the cost issue in storing a large amount of raw data may become less significant.

Component Traceability and Parametric Data

Manufacturing usually requires many processing, assembly and testing operations to build a complete product. In each operation, several types of information are being recorded and sent to a database, e.g., time stamp, operator identification, machine number parts added to assembly, etc. Process instructions from a database may be required at the manufacturing floor for an operator or machine to perform the right operation on incoming sub-assemblies. For example, certain cells in a wafer have been identified to be defective in an up-stream operation, hence no more processing steps are required to be performed on those cells in the current operation. Figure 2 illustrates the information flow of a generic operation.

To trace problems in a manufacturing process, we often have to correlate test measurement (parametric) data from different operations. The problem of component traceability and accessing the right parametric data becomes much more complex when there are reworks and repairs. In a sub-assembly, there may be multiple tests of the same type corresponding to different components. Likewise, a component can appear in different sub-assemblies if this component is taken out, repaired and mounted on another sub-assembly. Often a data collection system in manufacturing may not be designed with adequate "reworks" problems taken into consideration. We have to compute "time-stamps" to sort out which components correspond to which tests and at what time. Records of data may have missing time-stamps or not detailed enough time stamps; hence, only part of the collected data can be used for correlation analysis.

System and User Interface Integration

We have mentioned previously that Manufacturing Engineers are generally not experts in various elements of technologies required to support complex manufacturing process control. In the development of an integrated system for an MPC or for data analysis, it is desirable to shield users from the details of "How an analysis is being done". Users should interact with manuals and/or commands with a suitable syntax structure. Currently, we are developing ideas on a command syntax structure for process analysis. We are considering the following generic building blocks for supporting a MPC System for either outer level process control or Data Analysis System, as shown in Fig. 3. The generic building blocks are:

- A data source – a database where data is being collected
- Data selection program – to select from the database the
desired variables to be analyzed. This may amount to reading a particular column from a table for simple data retrieval or to performing a complex query with many table joins.

- Data analysis program — doing the actual computation, e.g., histogram, Cusum, Regression Analysis, etc.
- Control parameter tables — a set of control parameters to pass on to the data analysis program, e.g., number of quantization levels for histograms, how to set control warning limits for control charts, etc.
- Outputs from the data analysis
  - Charts — histograms, control charts
  - Reports — Yield reports
  - Statistical analysis — analysis of variances, estimation of model parameters, test of hypothesis, etc.
- Warning messages table
- A catalog or library of the output charts, reports, etc.

Users need to know how the statistical function is being organized and implemented; but they must have an easy interface to the data selection program, control parameter tables, and search/query of the outputs.

**Conclusion**

This paper discusses some of the issues in design a large manufacturing plant process control system. Much of the discussion focuses on process control technology, particularly related to system design. In the real world, the success of integrated manufacturing process control at a plant level also depends on other key factors, such as management understanding and commitment to process control (not just local yield control), people skills, education, communication and collaboration between groups in process design and in manufacturing, commitment to continuous process improvement over time, and so on. It is a great challenge to build and to implement successfully an integrated plant site manufacturing process control system.

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**References**


![Fig. 1: Elements of Manufacturing Process Control](image-url)
Generic model of an operation

Fig. 2: Generic input-output model of an operation

Fig. 3: Generic building blocks for a process analysis system