IEEE
CONFERENCE RECORD OF 1979 THIRTY-FIRST ANNUAL CONFERENCE OF ELECTRICAL ENGINEERING PROBLEMS IN THE RUBBER AND PLASTICS INDUSTRIES

79CH1455-5 IA

IEEE

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Papers presented at the Thirty First Annual Conference
Akron, Ohio
April 9-10, 1979

Sponsored by the

Rubber and Plastics Industries Committee
of the IEEE Applications Society
and the IEEE Akron Section

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GETTING OFF TO THE RIGHT START — GOOD SPECIFICATIONS AND DISTRIBUTED PROCESSING MAKE MATERIAL HANDLING SYSTEMS WORK

Martin W. Jones
Cutler-Hammer, Inc.
9475 Center Road
Fenton, MI 48430

Summary

Recent advances in electronics technology have, by virtue of increased processing power, led to more and more complex material handling systems. Advances in mini-computer, microprocessor, programmable controller, multiplexing system and related equipment design have provided the design engineer with more powerful tools with which to solve his material handling problems. This power has enabled the engineer to build systems with control and monitoring capability not previously practical or possible. At the same time, however, this versatility has greatly increased the complexity of such systems.

Perhaps the most important step in controlling the development of, and in understanding and overcoming the complexity of, a new material handling system is the preparation of detailed specifications. These specifications present what the system is, what it is to do, how it does it, the results required and what must be done to implement it. A major material handling system procurement typically results from one of three primary activities:

1. Building a new facility
2. Expanding an existing facility
3. Modernizing an existing facility

Implementation of such a system is typically performed by:

1. Internal Personnel (called the Purchaser)
2. Mechanical and/or Controls Contractors (called Vendors)
3. A joint effort between the Purchaser and the Vendors

Although each combination of project requirement and implementation has its own problems and idiosyncracies, all share a common requirement — the need for good system specifications.

The intent of this paper is to follow the stages of development of system specifications in terms of today's typical material handling system involving a distributed processing network. By properly preparing such specifications, both the Purchaser and the Vendors benefit. The more complex the system, the more important the specifications become. Discussed below are many considerations which must be addressed in order to produce a good specification.

Why Distributed Processing for Material Handling?

Material handling means moving — moving "things" such as boxes, or "stuff" such as coal. Modern material handling systems are responsible for not only moving, but also for other activities, such as sorting, storing, weighing, tracking, and inventorying the moved materials. Many material handling systems are so integrated with related discrete manufacturing processes that it is sometimes difficult to tell where the boundaries are drawn. A distributed processing network serves to tie the individual pieces of the material handling system together, to make them work in harmony.

Mechanical Equipment

Physically, automated material handling systems are composed of one or more of several types of mechanical apparatus including:

- Roller Conveyors
- Belt Conveyors
- Power & Free Conveyors
- Monorail Conveyors
- Storage/Retrieval Cranes
- Bridge/Gantry Type Cranes
- Service Cranes
- Driverless Vehicles
- Unique Custom Apparatus

Also, involved in some material handling applications are non-automated devices such as fork trucks and manually operated transfer mechanisms (hoists, grabs, etc.).

A well designed distributed processing network individually controls each item of automated equipment, and directs the use of non-automated equipment, such that material flow is efficient, economical, and well organized. The network may be so highly developed that it also includes control and/or direction of the various processes to which the material is transported.

Control Equipment

A simple definition of a distributed processing network is a control system in which each piece, or group of pieces, of mechanical equipment is individually controlled by a dedicated controller, with all controllers connected through a hierarchical communications chain to a central system master. The individual controllers are dedicated to a specific function, allowing simultaneous processing to occur, but at the same time providing overall direction of system activity from a single point.

Distributed processing networks can be composed of several types of equipment, including:

- Relays
- Hard-wired solid state logic
- Programmable Controllers
- Analog feedback process controllers
- Microprocessors
- Mini-computers
- Large scale data processing computers
- Support Peripherals

Figure 1 shows a shared network distributed processing system. Each sub-host mini-computer is dedicated to a specific portion of the overall system (such as incoming conveyors, high rise storage, packing area, final delivery). Programmable controllers (PC's) and microprocessors control individual pieces of equipment (such as conveyor sections and storage/retrieval machines). The system is tied together by communication to the Host mini-computer, with futher communication to a remote data processing computer. Every application requires a custom-designed network to meet the specific requirements of the application.

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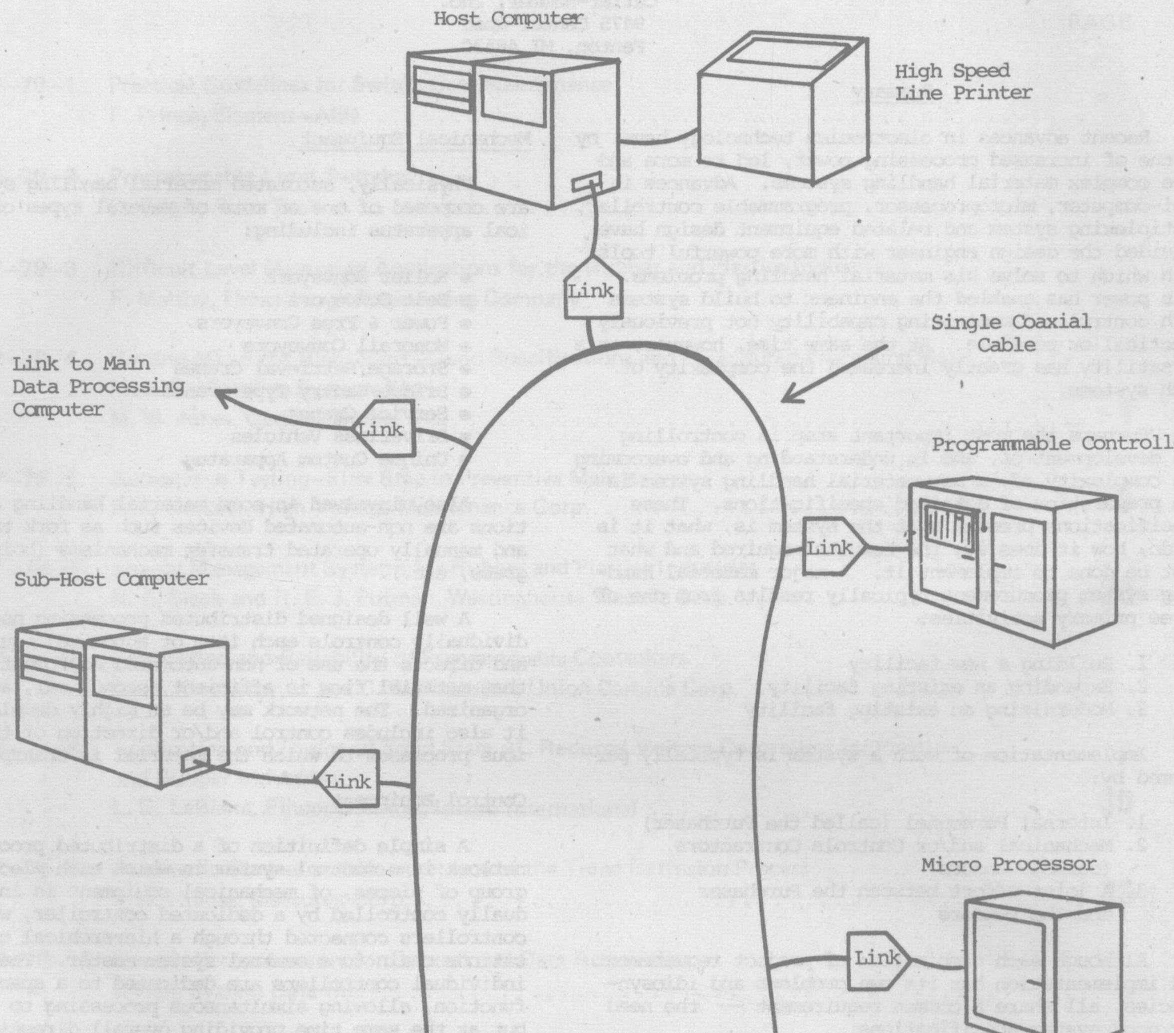

SHARED NETWORK DISTRIBUTED PROCESSING SYSTEM

Figure 1

Capabilities and Advantages

The introduction of computer technology into control devices has permitted many advanced functions to be performed in the control. Some of these functions include:

- Automatic Batching - "Stuff" type material is weighed and fed into a process automatically, with process batch records kept for historical purposes.

- Automatic Routing, Positioning, and Traffic Control - "Thing" type materials are tracked throughout the material flow in relation to source, product type and destination. These items, and in many cases the equipment which makes them move, are automatically routed to the correct locations.

- Scheduling and Man-Power Planning - A computer based system can aid the users in scheduling both the flow of material through the system and the staffing required to operate the system. This scheduling can be extended to maintenance dispatching.

- Production Monitoring - Automatically produced reports indicate inventory, productivity levels, and historic information regarding the function of the system processes.

- Equipment Monitoring - Automatic reports indicate the condition of both the equipment being controlled and the control equipment itself, thus aiding in the prompt identification and repair of problems.

Using the versatility available with today's technology, many other similar functions can be implemented. The dramatic decrease in the relative cost of processing technology allows more power to be applied for a lower investment, leading to the increased return on investment for a distributed processing network.

The principle advantages of a distributed processing system include:

- Reliability - The total network can be made more reliable for a low cost by supplying a back-up processor of each type which can be easily switched into the network to assume the functions of a faulty processor. A single processor failure is not catastrophic in terms of the total system.

- Responsiveness - Individual control of each major process means that response time to any particular event is kept to a minimum. This is particularly true of operator response in a multiple computer system.

- Flexibility and Expandibility - The modular nature of the distributed processing network concept permits the maximum in flexibility to meet future system requirements. Assuming the original system overhead functions are adequately designed to incorporate such expansions, the system can be modified to meet new applications as they arise.

Recognizing the Project Needs

The first step in implementing a distributed processing network for a material handling application is in recognizing the need for such a system. When a major project is conceived, some of the general application requirements are obvious, at least in concept. Based on a knowledge of what can be done using today's control technology, and a knowledge of what the real requirements of the project are, a well organized project team can further clarify the intent of the project and put together an efficient, cost effective system. The most important factor is determining what the real requirements are.

Once it has been determined that the project is of sufficient magnitude to warrant some type of distributed processing network, the next step is to carefully prepare a specification for the implementation of the project. The specification must clearly define the goals and requirements of the system. The specification is equally important for a project which is to be implemented completely with in-house personnel, or one which is totally contracted to a vendor; it gives a firm definition of the scope and intent of the project. Without this commitment to a solid specification, the project is destined for difficulty.

As implementation of any major project progresses, changes in original ideas, as dictated in the system specifications, are virtually inevitable. A solid specification makes these changes far more easy to identify, and thus easier to adapt.

The specification is created in a basic four step process:

1. Selecting the Project Team
2. Developing the Conceptual Design
3. Identifying the Functional Requirements
4. Detailing the System Specifications

These steps are discussed in detail below. In reality, it is often difficult to differentiate between steps, knowing when one ends and the next begins. Some steps may appear to take place concurrently. However, if a conscious effort is made to follow the guidelines discussed below, a more comprehensive, and thus more valuable specification will result.

Selecting the Project Team

The first step in preparing a system specification is to determine who is going to put the specification together. For simple systems, a specification can generally be written by a single individual. However, more complex systems, such as most distributed processing systems for material handling, require the efforts of a team of people.

Internal Personnel

Development of system specifications for a major project requires expertise in two principle areas.

1. Operation of the facility and requirements of the resulting project
2. Implementation of high technology control devices in system applications.

Internal (or Purchaser) personnel must be an integral part of the project team, since they are the people who are intimately familiar with the operations within their own plant, and consequently with what constitute the real requirements of the project.

While the size of the project team will be somewhat proportional to the size of the project, the purchaser's team should include, at a minimum, the following individuals:

1. Project Leader - This individual is the team leader, the one who must make sure that everything happens. His primary responsibilities are:

   - Organizing the project team
   - Scheduling activity
   - Reviewing results
   - Communicating with Purchaser's upper management
   - Communicating with Vendors
   - Understanding the total project

   The project leader is the key to success. He should be someone experienced in both the mechanical and electrical concepts employed in systems of the type required for the system.

2. Mechanical Specialist - This individual should be someone experienced with the installation of the type of equipment which is to be implemented and with the physical constraints of the building in which the system is to be implemented. His responsibilities include:

   - insuring that a proposed concept can be physically adapted to the area in question.

   - insuring that a proposed concept will mechanically perform the intended function.

3. Controls Specialist - This individual should be someone experienced with state-of-the-art control systems similar to those proposed for the project. It is desirable that this function be filled by someone with experience in both control electronics and computer technology. His responsibilities include:

   - insuring that a proposed concept can be functionally adapted.

   - insuring that the hierarchy proposed consitutes a practical, efficient, and reliable method for satisfying the project requirements within the framework of plant operations.

4. Operations Specialist - This individual ties the mechanical and control concepts together. His primary function is to refine the basic system design in terms of both its functional aspects and its ability to be operated and maintained by plant personnel. An important rule to remember is that no matter how "neat" a system looks in design, it will be a total failure if plant operations cannot handle it once it is installed.

As in any organization, it is often difficult to draw distinct boundry lines between the various responsibilities of the team members. It is the duty of the project leader to recognize the abilities and limitations of each team member, and to make sure each team member is given a clear and understandable assignment.

Vendor Personnel

It often becomes desirable to augment the project team by adding consulting members from various mechanical and/or controls vendors. These individuals can provide the following valuable services:

- Expertise on similar system installations - while only internal plant personnel know the intimate details of the results required, Vendor representatives are familiar with the capabilities of their own equipment, and often have expert knowledge of similar applications. This expertise can lead to a better (more efficient, more cost effective) system in light of fresh ideas. These individuals may also fill key spots on the project team where the Purchaser is weak due to unavailability of experienced personnel.

- Project Documentation - Typically Purchaser's personnel are involved in the day-to-day activities of keeping the plant going and cannot devote full time to development of the specification. A systems vendor (particularly a controls system supplier) can generally supply technical writing and documentation assistance, thus providing the Purchaser with the required and necessary documentation for directing project results.

Vendor personnel may or may not be full time members of the project team, depending on the extent of their involvement in the development of the specifications. Their role in the project, when they are called in, must be clearly defined by the project leader.

The project team should include, at least on a part time basis, mechanical consultants from leading firms associated with each particular type of equipment proposed, and control consultants experienced with control system and computer system design for similar applications.

Preliminary Activity

The first duty of the project team, perhaps even before the project team is completely assembled, is to produce a document which outlines the project objectives and required results. This document must include at least the following:

- Reason for the project - a general statement is required which defines why the project is being considered and what is expected as a result. Such discussions might include items such as man-power reduction, increased productivity, and increased reliability.

- Goals of the project - management criteria such as project time frame, throughput capacity or productivity, and information requirements must be stated.

- System boundaries - a definitive statement is required which states what the physical and functional boundaries of the project are. For instance, in modernization project, this portion of the document must state what, if any, existing equipment is to definitely be replaced or is to be left in place. Similar statements are required in terms of operational characteristics of the same.

It must be recognized by the project team that this preliminary document is a starting place, and will be subject to change based on the findings of the team as they progress through the system development. The purpose of this document is to orient the project team members in the proper direction, and insure a joint effort toward the same end.

Developing the Conceptual Design

Before a definitive system specification can be completed, the project team must agree on a basic conceptual design. This design, or in some cases alternative designs, is the product of the "think" stage of the project development. The most important output of this stage is a document which details what basic ideas were employed in the concept and why, and what ideas were discarded and why. In any material handling system, there are many different ways of doing the same thing; however, for a particular application some ways may be more beneficial than others. It is the responsibility of the whole project team to weigh the merits and limitations of each alternative, and to clearly indicate why selected paths were followed.

Think Big

Most projects are bounded by two very important criteria — time and money. In putting a material handling concept together, however, it is often advantageous to at least temporarily ignore these restraints. In so doing, the project team can open its eyes to "what would be the best possible system". Final implementation may well be a compromise from the grand dream, but such far reaching thinking will pick up advantageous and beneficial ideas which might otherwise be missed in a more narrow minded approach.

The project team must always keep in mind the goals of the project, and thus differentiate between the "needs" of the system and the "wants" for the system. By open-mindedly approaching the task of conceptual design, some of the more abstract ideas may prove in the long run to better satisfy the needs than a simpler approach, while also providing some of the wants. Throughout history, technology has advanced due to creative thinking of open-minded individuals. The same concepts can be applied to defining a material handling system.

Research

One of the most important lessons to learn in the implementation of a large scale material handling system is to profit from the experiences of others. While each application has its own special problems, the project team can, by investigating previous work in similar applications, ascertain what concepts are sound and should be repeated and what pitfalls to avoid.

The project team members should arrange to visit sites where similar applications have been implemented. The personnel responsible for such installations are typically willing to discuss their systems, pointing out its good and bad features, what they would change if they had it to do all over over again, what they would avoid and what benefits they derive from the system. Magazine articles and vendor contacts often provide good leads to such previous projects.

In observing other systems, the project team must keep in mind the requirements of their own system, looking for:

- Things that can be copied
- Things that work in concept, but must be tailored in detail for the application
- Things to avoid at all costs.

Assistance from Vendor members of the project team can prove valuable in determining what is and what is not practical in terms of implementation based on thier previous experiences.

Multiple Concepts

Particularly in terms of placement of mechanical equipment, it is often advantageous to develop several different arrangements, in at least preliminary detail. The project team should avoid the trap of following a one-track concept. In the long run, the team should agree on a maximum of two or three major plans to define in detail, but in the prelimimary stages the number of concepts is limited only by the imagination of the team members.

Typically, several iterations of a concept will be made before it reaches a stable point. The more the team members study a plan and discuss it, the more apparent certain requirements and benefits become. Changes are inevitable, and it is far better to change at the beginning of the project, in the specification stage, than later, in the implementation stage.

It is important to always consider the adaptability of the system to changes in future operation and expansion. It is generally impossible to predict what will happen in terms of system parameters, such as product mix, four or five years from the time of implementation; however, the system design should be flexible enough to accomodate such changes with reasonable efficiency. By comparing the advantages and the disadvantages of contrasting approaches, the adaptability of one approach over another will become apparent.

Simulation

Computer simulation of both the entire system and the individual pieces of the system provides a beneficial tool for perfecting the conceptual design. These similations can help determine several aspects of the system, such as:

- How much storage space is required
- What transfer/transport speeds are necessary to meet production requirement
- How much banking area is required
- How many vehicles/carriers are required
- What are worst/best case conditions (peak loads, etc.).

Simulation programs are often available through vendor consultants, if not available to the Purchaser through his own resources. Analysis of simulation results will help prove or disprove the validity of certain concepts, and also establish criteria for system boundaries (number of storage aisles, length of conveyor, etc.).

Identifying the Functional Requirements

Once the basic project conceptual design has been completed, and one or more basic concepts have been agreed upon, the next task is the preparation of a detailed functional specification. This specification outlines how each individual sub-system is to operate and what are the expected overall results. It is this document that becomes the basis of the system implementation. It will define the operational characteristics and responsibilities of each control unit, each computer system and each point of operator intervention.

Material Flow and Component Function

The best overview of the function of a complex material handling system is a step-by-step description of material flow. Starting at the initial input point, the material flow is followed throughout the system, with detailed descriptions of each motion and process stage along the way. Even if a particular process station's control is not a part of the overall system, a description of what occurs at that station is helpful in understanding the general scheme of the project.

The individual sub-system descriptions should include a discussion of what the general mechanical attributes and the corresponding control attributes of that sub-system are to be.

These descriptions should also include a discussion regarding:

- What information is to be collected in terms of production and maintenance monitoring
- What operator actions are required
- What information is passed to other portions of the system for control purposes
- What special functions are required for parts tracking, routing, inventory control, etc.

Consideration should also be given in this section to abonormal conditions which might affect the system. Abnormal conditions can either be the result of production related difficulties (no parts, equipment failure, etc.) or control related (I/O malfunction, computer malfunction, etc.). A failure analysis is required; decisions on what should be done in each case must be recorded.

Man-to-Machine Communications

Operator interface within a typical distributed processing network based system can usually be classified into one of two areas:

1. Daily Operation
2. Management Information

Daily Operation operator interaction involves those operator activities which must be performed on a continuing basis in order for the system to function. Such activities might include:

- Individual process station manual or semi-automatic operation (pushbutton console)
- Product identification (keyboard or special console operation)
- Scheduling information (product output requirements via keyboard)
- Material routing decisions (keyboard or special console operation)

The system functional description should detail as close as possible what actions the various operators are to take and with what reactions the system should respond. These details can go as far as including conversational routine formats for computer system data entry and inquiry, and sequences of operation for various process station items.

Management information operator interactions are typically requests for reports which enhance the ability to control the productivity of the system. The system functional description should detail what data is to be collected, how it is to be derived, and the format in which it is displayed. These reports are typically on-demand type reports which are requested only when a decision must be made, or automatic type reports which are kept for historical purposes. The specification should discuss how, when and by whom the various reports can be generated.

Man-to-Man Communications

Often one of the most important aspects of efficient material handling is communication among operators, between operators and supervisory personnel, among different shift supervisors, and between operators and maintenance personnel. A well-designed distributed processing network can be instrumental in aiding these types of communication. The system functional description should itemize what communication is required, and how it is to be implemented.

Project Phasing

Many major material handling projects are implemented in phases. The functional description must clearly identify what these phases are, what each phase encompasses and how each phase is to be implemented in terms of the control system.

A particular problem is realized in the modernization of an existing facility, wherein the modernization must be implemented without seriously interrupting on-going production. In this type of application, the material handling system, and consequently its control, must be implemented in small chunks and brought-on-line individually. Often such a method of implementation requires temporary measures to be implemented, and then replaced when the next phase of the system is brought on line. The system functional description must take into account the methods of operation and controls required at each stage of the operation, not just the final master plan.

Detailing the System Specifications

The final step in putting together a system specification involves adding details to augment the functional specifications. These details range from types of equipment through schedules and project responsibility. This phase of the specification is important, even if the project will be implemented totally with in-house personnel. A bid specification may have a slightly different format, but the basic content should be essentially the same.

Standard Specifications

Standard specifications are defined briefly as those specifications which are general to the plant (or corporation or division) or have been used for previous jobs of the same nature. Such specifications might include:

- Corporate Electrical and Mechanical Specifications
- Plant Electrical and Mechanical Specifications
- Noise level specifications
- Painting and construction specifications
- References to Industry Specifications (NEMA, OSHA, ANSI, etc.)
- Functional and (or equipment) specifications from previous jobs.

While the use of such standard specifications is encouraged, a word of caution is advised. The project team should carefully review these specifications, and determine if any items are contradictory or otherwise not applicable. Particularly in regard to use of previous job specification, the text should be examined for incorrect references such as quantities, types, etc. In so doing, a great deal of confusion during the project implementation can be avoided.

A common problem with general standard specifications is that they are sometimes not updated at the same rate at which technology advances; thus, in terms of equipment and practices, the general specifications might be obsolete. This is particularly true for specific model numbers or brand name components, which may have been superceded by more advanced versions. A careful review of these specifications will benefit the overall project.

Equipment Selection

It is difficult during conceptual design not to think of the capabilities of certain brand names of equipment, both mechanical and electrical, and automatically bias the control system toward those capabilities. While such a practice may at some times be required, it is in general discouraged. It is usually more effective to prepare the specification based on theory, than on the known use of a particular manufacturer's product.

There are circumstances where a specific product must be identified. Typically, these circumstances include:

- Previous jobs and consistency of training maintenance personnel
- Spare parts stocking
- In-House development and communications capability

When specific products are not identified, the detailed specification must describe the desired properties of the various types of equipment to be incorporated. Such specifications might include processing capability, input/output capacity, power consumption, or other similar attributes. If a particular function is required, it must be made known, along with a justification for its necessity.

Alternatives

Regardless of how well organized and intelligent the project team is, there will always be fresh ideas from outside sources on different ways certain portions of the system could be implemented. Such inputs are often valuable; the specification should, in fact, encourage the submission of alternative approaches.

However, for purposes of evaluation of competitive bids, it is essential that all bidders respond to the same requirements. The more carefully the specification is prepared, the more well organized and clear the specification is, thus making it easier for bidders to quote "apples-to-apples", and ultimately easier for the Purchaser to evaulate.

What Else is Required?

In the continued interest to make the system specification clear and understandable, it should identify the user's requirements in several areas beyond the functional and physical aspects of the system. Those requirements which should be identified include:

- Schedule - the time frame in which the project is to be implemented must be clearly identified. This is particularly true if the project requires phasing.

- Responsibility - the specification must make clear what portions of the work are to be supplied by the Vendors, which portions are to be supplied by the Purchaser and what each party's responsibilities are.

- Documentation - the specification must establish what types of documentation will be required, what form this documentation must take and who is responsible for its production.

- Training - the specification must establish what types of training will be required, and who is responsible for providing the training.

- Testing - testing requirements and performance standards must be clearly stated. This statement should include both preshipment testing at the Vendor's facility, and acceptance testing once the various system components are installed.

- Commerical Aspects - terms and conditions are an important part of any system which is issued for bids.

Again the more clear the specification, the easier it is for Vendors to respond and for the Purchaser to evaluate.

Conclusions

The importance of the specification phase in the undertaking of a major material handling system project cannot be underestimated. This document, regardless of the ultimate method of implementation, is a key to the success of the project. Without a good specification, a good basis for implementing the project, the project can fail due to misdirection.

A well-chosen project team, composed of both the Purchaser and Vendor representatives, can create an effective specification. Conceptual design, functional descriptions, and refining details which are carefully developed, reviewed, and documented lead to a specification which eases the task of both the Purchaser and the Vendor.

The use of shared network distributed control concepts makes this specification activity easier, allows for flexibility regarding change, reduces overall system costs and provides a longer useful life for the implemented system.

ACCEPTANCE TESTING
FIRST STEP IN PREVENTIVE MAINTENANCE

Patrick R. Herbert
High Voltage Maintenance Corporation
Mentor, Ohio

An increasing awareness by industrial and utility engineers of initial electrical equipment sophistication and replacement costs, the direct and hidden expenses involved with manufacturing downtime, and the development of efficient field electrical testing equipment and service organizations are all contributing to the growing practice of preventive, or planned, electrical maintenance, testing, and inspection programs for complete distribution systems.

A very important, but often overlooked, preventive maintenance function is the practice of performing an initial acceptance test. A major purpose of this test is to provide a quality reference or "benchmark" for subsequent preventive maintenance tests. Future comparisons of test data with the initial information can detect sudden or long time deterioration trends before equipment failure occurs with its costly or catastrophic outages.

The principle reason for the failure of most companies to include acceptance testing as the first step in their maintenance program is the lack of communication between the construction engineering responsibility and the electrical maintenance department. The engineering department is often unaware of the planned maintenance program and rarely consults with maintenance on new installations until after all contracts have been written.

"On site" electrical acceptance testing is not intended to replace the individual manufacturers' quality control programs, but to supplement and enhance the total project quality assurance. The proper installation, operation, and interaction of equipment from various suppliers, as well as multiple component packages (such as indoor transformer unit substations) from an individual manufacturer, will not be assured of proper operation unless an all inclusive, combination inspection and testing program is accomplished. All too often, the manufacturer's start-up or service engineer will inspect only his own specific equipment with little or no attention paid to its function or connection in the system. Sometimes the start-up service included in the equipment purchase price or sold as an alternate is used by the service representative to correct manufacturing errors or to repair or replace defective components. This cost should NOT be the responsibility of the purchaser.

A question is often raised as to why new equipment requires "on site" testing. The feeling is that the manufacturer's reputation is on the line; therefore, "additional" testing is not required. An explanation would include:

1. Although a manufacturer's image is tarnished by faulty construction or careless assembly, the recognition of manufacturing problems as common rather than the exception has allowed an acceptance of mediocrity as a standard. Acceptance testing will demand that the quality specified will be received.
2. The reference or benchmark type of data is usually not available from the manufacturer. Thus, this valuable first step information is lost.
3. Many manufacturer tests are for mechanical and electrical compliance with manufacturing standards, rather than operational requirements.
4. Equipment is subjected to transportation damage that may not cause a problem within the warranty period but can cause premature failure. This type of damage occurs after the equipment leaves the factory and can only be determined by field acceptance testing.
5. Equipment is often stored in unheated, damp, or otherwise hostile environments for long periods following shipping and prior to installation.
6. Although installation instructions may be very clear to the manufacturer issuing the installation bulletin, the tradesman or contractor installing the equipment may incorrectly interpret these instructions.
7. The manufacturer's statistical quality control methods may have allowed a defective unit to be shipped.
8. Shipping braces and blocking, necessary for proper support during transport, must be removed for operation. Unless a proper inspection is performed, additional items such as inspection tags and instruction manuals may be attached at a location that could cause damage if left undetected.
9. During installation, parts may have been cannibalized from equipment to accommodate shortages or damage on similar equipment.
10. Items such as power cable installations cannot be tested for other than material quality by the manufacturer. A cable system is actually a field-fabricated assembly of terminations and splices which cannot be tested until after installation. The installation skills of handling, pulling, terminating, and splicing, as well as the manufacturer's quality, will be evaluated during a field acceptance test.

A major development in the trend toward acceptance testing has been the organization of The National Electrical Testing Association in 1972.[1] This non-profit technical organization was chartered for the purpose of developing and promoting standards for use in evaluating electrical equipment. NETA's high membership standards and rigid adherence to technical excellence have developed NETA into the most effective organization of all independent electrical field testing laboratories. Federal and state electrical authorities, as well as leading electrical engineering consulting firms and corporate engineering staffs, are utilizing the "NETA Acceptance Testing Specifications for Power Distribution Equipment and Systems" handbook[2] as their standard for assuring quality installations. NETA's insistence on technician certification, wide experience requirements, test instrumentation accuracy with N.B.S. traceability, and overall engineering responsibility by a registered professional engineer has led to a steady growth of independent member companies throughout the United States and Puerto Rico.

The following acceptance testing procedures have been excerpted from the copyrighted NETA Acceptance Testing Specifications, Publication 2.001, which represents a complete single source for a distribution system acceptance testing analysis. Further reproduction of this material in part or in its entirety is permitted by NETA provided notice of NETA copyright is included.

Inspection & Test Procedures

7.1.

Switchgear and Switchboard Assemblies — General

Visual and Mechanical Inspection (A)

1. Inspect for physical damage.
2. Compare equipment nameplate information with latest single line diagram and report discrepancies.
3. Inspect for proper alignment, anchorage and grounding.
4. Check tightness of accessible bolted bus joints by calibrated torque wrench method. Refer to manufacturer's instruction for proper foot pound levels. In the absence of specific instructions use Table 7.1.1.
5. Key interlock systems shall be physically tested to insure proper function.
   a. Closure attempt shall be made on locked open devices. Opening attempt shall be made on locked closed devices.
   b. Key exchange shall be made with devices operated in off-normal positions.
6. All doors, panels and sections shall be inspected for paint, dents, scratches and fit.

Electrical Tests (B)

1. Insulation Resistance Test
   a. Measure insulation resistance of each bus section phase to phase and phase to ground for one (1) minute. Test voltage and minimum acceptable values in accordance with Section C.
2. Overpotential Test
   a. Perform overpotential test on each bus section phase to ground. Potential application shall be for one (1) minute. Test voltage shall be in accordance with Section C and/or manufacturer's recommendations.

Test Values (C)

1. Bolt torque levels shall be in accordance with Table 7.1.1 unless otherwise specified by manufacturer.
2. Insulation resistance test to be performed in accordance with Table 7.1.2.

TABLE 7.1.2.

INSULATION RESISTANCE TEST VOLTAGE

Voltage Rating	Test Voltage
150 - 600V	1000V
601 - 5000V	2500V
5001 -	5000V

Values of insulation resistance less than manufacturer's minimum or KV + 1 in megohms should be investigated. Overpotential tests should not proceed until I.R. levels are raised to said minimum.

3. Overpotential test voltages shall be applied in accordance with Table 7.1.3 – ANSI 37.20c.

TABLE 7.1.3.

OVERPOTENTIAL TEST VOLTAGES

Rated KV	Test Voltage KV A.C.	Test Voltage KV D.C.
5	14.3	20.2
15	27.0	37.5
25	45.0	Consult Manufacturer
35	60.0	Consult Manufacturer

Test results are evaluated on a go no-go basis by slowly raising the test voltage to the required value and applying the final test voltage for one (1) minute.

TABLE 7.1.1

U.S. Standard

BOLT TORQUES FOR BUS CONNECTIONS

Heat Treated Steel

GRADE	SAE 1 & 2	SAE 5	SAE 6	SAE 8
MINIMUM TENSILE (P.S.I.)	64K	105K	133K	150K
BOLT DIAMETER	TORQUE (FOOT POUNDS)			
1/4	5	7	10	10.5
5/16	9	14	19	22
3/8	15	25	34	37
7/16	24	40	55	60
1/2	37	60	85	92
9/16	53	88	120	132
5/8	74	120	167	180
3/4	120	200	280	296
7/8	190	302	440	473
1.	282	466	660	714

NOTE: REDUCE TORQUE BY 20% WHEN CADMIUM PLATED BOLTS ARE USED.

7.2 Transformers – Liquid Filled

Visual and Mechanical Inspection (A)

1. Inspect for physical damage. Inspect impact recorder prior to unloading transformer if applicable.
2. Compare equipment nameplate information with latest single line diagram and report discrepancies.
3. Verify proper auxiliary device operation such as fans, pumps, sudden pressure device, indicators, tap changer, and gas pressurization system.
4. Check tightness of external bolted electrical joints in accordance with Table 7.1.1.
5. Check all liquid in tank and bushings for proper level.
6. Perform specific inspection and mechanical tests as recommended by manufacturer.

Electrical Tests (B)

1. Insulation resistance tests shall be performed winding to winding and winding to ground. Appropriate guard circuit shall be utilized over all bushings. Test voltage and minimum acceptable values shall be in accordance with Section C1 and C2.
2. A dielectric absorption test shall be made winding to winding and winding to ground for ten (10) minutes. The polarization index shall be computed as the ratio of the ten (10) minute to the one (1) minute reading. Test voltage and minimum acceptable values shall be in accordance with Section C2.
3. A turns ratio test shall be performed between windings for all tap positions. The final tap setting is to be determined by the engineer and set by the testing laboratory. A ratio test shall be in accordance with Section C3.
4. Insulating oil shall be sampled in accordance with ASTM D-923. Sample shall be laboratory tested for:
   a. Dielectric strength
   b. Acid neutralization number
   c. Interfacial tension
   d. Color
   e. PPM water (only required on units above 69 KV)

   Acceptable values in accordance with Section C5.

TABLE 7.2.1

INSULATION RESISTANCE
CONVERSION FACTORS

FOR CONVERSION OF TEST
TEMPERATURE TO 20° C

TEMPERATURE		TRANSFORMER	
° C.	° F.	OIL	DRY
0	32	.25	.40
5	41	.36	.45
10	50	.50	.50
15	59	.75	.75
20	68	1.00	1.00
25	77	1.40	1.30
30	86	1.98	1.60
35	95	2.80	2.05
40	104	3.95	2.50
45	113	5.60	3.25
50	122	7.85	4.00
55	131	11.20	5.20
60	140	15.85	6.40
65	149	22.40	8.70
70	158	31.75	10.00
75	167	44.70	13.00
80	176	63.50	16.00

TABLE 7.2.2

OVERPOTENTIAL TEST VOLTAGE FOR
POWER AND DISTRIBUTION TRANSFORMERS

Nominal System Voltage* (kv)	Insulation Class	A-c Factory Test (kv) Oil — immersed**
1.2	1.2	10
2.4	2.5	15
4.8	5.0	19
8.32	8.7	26
14.4	15.0	34
18.0	18.0	40
25.0	25.0	50
34.5	34.5	70
46.0	46.0	95
69.0	69.0	140

*5. A.C. overpotential test shall be made on all high and low voltage winding to ground.

*6. Insulation power factor tests shall be made on all high and low voltage windings and bushings equipped with power factor taps.

7. *(Optional)* Individual exciting current tests shall be performed on each phase in accordance with established procedures.

8. *(Optional)* Winding resistance tests shall be made for each winding at nominal tap position. Acceptable values in accordance with Section C6.

9. Measure dew point and oxygen content of top gas when applicable.

10. Perform special tests and adjustments as suggested by manufacturer on tap changer, fan and pump control and alarm function.

Test Values (C)

1. Insulation resistance and absorption test. Test voltages to be in accordance with Table 7.1.2. Resistance values to be temperature corrected in accordance with Table 7.2.1.

2. The absorption test polarization index should be above 2.0 unless an extremely high value is obtained at the end of one (1) minute that when doubled will not yield a meaningful value with the available test equipment.

3. Turns ratio test results should not deviate more than one-half of one percent (0.5%) from calculated ratio.

4. Power factor test results corrected to 20° C should not exceed one percent (1%) for free breathing, conservator or sealed tank transformers unless satisfactory explanation is received from the manufacturer. Bushing power factor shall not deviate more than ten percent (10%) from manufacturer's rating.

5. Dielectric fluid should comply with the following:

   a. Dielectric breakdown (ASTM D-877) 35 KV minimum. Transformers rated 69 KV and above (ASTM D-1816), 30 KV minimum at 0.4" gap.

   b. Neutralization number (ASTM D-974) .025 mg-KOH/gm maximum.

   c. Interfacial tension (ASTM D-971) 40 dynes/cm minimum.

   d. Color (ASTM D-1500) 0.5 maximum.

   e. PPM water (refer to manufacturer's specifications).

6. Winding resistance test results should compare within one percent (1.0%) of adjacent windings.

7. A.C. high potential test voltage shall not exceed seventy-five percent (75%) of the factory test voltage for a one (1) minute duration. Evaluation shall be on go no-go basis. ANSI C57.90.

7.3 Transformers — Dry Type

Visual and Mechanical Inspection (A)

1. Inspect for physical damage.

2. Compare equipment nameplate information with latest single line diagram and report discrepancies.

3. Verify proper auxiliary device operation such as fans, indicators and tap changer.

4. Check tightness of accessible bolted electrical joints in accordance with Section 7.1.1.

5. Perform specific inspections and mechanical tests as recommended by manufacturer.

Electrical Tests (B)

1. Insulation resistance tests shall be performed winding to winding and winding to ground. Appropriate guard circuit shall be utilized under all bushings. Test voltage and minimum acceptable values in accordance with Section C1.

2. A dielectric absorption test shall be made winding to winding and winding to ground for ten (10) minutes. The polarization index shall be computed. Test voltage and minimum acceptable values in accordance with Section C2.

3. A turns ratio test shall be performed between windings for all tap positions. The final tap setting is to be determined by the engineer and set by the testing laboratory upon completion of the ratio testing acceptable values in accordance with Section C6.

*4. A.C. overpotential test shall be made on all high and low voltage winding to ground.

*5. Insulation power factor tests shall be made from each winding to each other winding and from each winding to ground.

6. Winding resistance tests shall be made for each winding at nominal tap position.

7. *(Optional)* Individual exciting current tests shall be performed on each phase in accordance with established procedure.

8. Perform special tests and adjustments as suggested by manufacturer for tap changer, fan and controls, and alarm functions.

Test Values (C)

1. Insulation resistance and absorption test voltage to be in accordance with Table 7.1.2. Results to be temperature corrected in accordance with Table 7.2.1.

2. The absorption test polarization index should be above 2.0 unless an extremely high value is obtained at the end of one (1) minute that when doubled will not yield a meaningful value with the available test equipment.

3. A.C. high potential test voltage shall not exceed seventy-five percent (75%) of factory test voltage or Table 7.3.1 for a one (1) minute duration. Evaluation shall be on go no-go basis. NEMA standard 20.

4. Power factor test values in excess of three percent (3%) should be investigated.

5. Winding resistance test results should compare within one percent (1%) of adjacent windings.

6. Turns ratio test results should not deviate more than one-half of one percent (0.5%) from calculated ratio.

TABLE 7.3.1.

APPLIED POTENTIAL TEST VOLTAGES

Nameplate Winding Voltage Rating, Volts	Test Potential, KV
0 - 250	2.5
251 - 1200	4
1201 - 2500	10
2501 - 5000	12
5001 - 8660	19
8661 - 15000	31