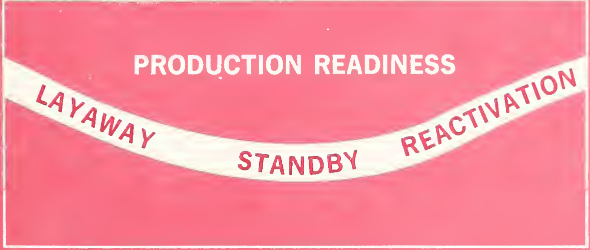
NBS SPECIAL PUBLICATION 522

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

CONTROL SYSTEMS READINESS FOR MUNITIONS PLANTS: A FIRST PASS



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The National Bureau of Standards was reorganized, effective April 9, 1978.

Special publication no. 522

Control Systems Readiness for Munitions Plants: A First Pass

Proceedings of the Workshop on Control Systems
Readiness for Munitions Plants held at
Purdue University, West Lafayette, Indiana,
September 19-20, 1977

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  Project Manager for Munitions Production Base
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  Armament Material Readiness Command
  Armament Research and Development Command

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Issued October 1978

Library of Congress Catalog Card Number: 78-600075
National Bureau of Standards Special Publication 522
Nat. Bur. Stand. (U.S.), Spec. Publ. 522, 192 pages (Oct. 1978)
CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1978

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Stock No. 003-003-01981-0 Price $3.75
(Add 25 percent additional for other than U.S. mailing).

FOREWORD

The U. S. Army now has single service responsibility for the production of conventional munitions. The majority of the facilities for munition production were acquired before and during the World War II mobilization. During the Southeast Asian conflict it became apparent that these facilities might not be capable of supporting another conflict. Subsequently, the Army initiated a $10 billion program that will run through the 1990's to modernize the munitions production base. Additional background on this program can be found in the Introduction of this report.

To effectively modernize the munitions production base requires, in many cases, the use of advanced, computerized process control systems. Process control system technology has recently undergone rapid change, in part because of increased uses of computers. To assist toward the goal of making proper and effective use of this technology the U.S. Army in cooperation with the National Bureau of Standards has undertaken the development of a Control Systems Handbook. The Handbook will have a tutorial function, in that it will provide a common knowledge base for both military and civilian personnel who are involved in the specification, design, procurement, and acceptance of control systems. It will also have a reference function in that it will include annotated listings of all relevant standards.

One of the topics in the Handbook is control systems readiness. Because of the nonuniform demand for munitions, the operation of these control systems will frequently go through a layaway phase, a standby phase, and a reactivation phase. The readiness problem is concerned with designing control systems to facilitate handling during these three phases.

Since experiences in this area are not adequately documented in the literature, the National Bureau of Standards contracted with the Purdue Laboratory for Applied Industrial Control to organize a workshop on control systems readiness. The Workshop brought together selected experts from Government, industry, and academic research groups. The objectives of the Workshop were to identify issues in the design and operation of control systems which would facilitate readiness, and recommend procedures to be used in the layaway, standby, and reactivation phases.

The proceedings of the Workshop consist of a description of the production readiness problem, a collection of twelve papers which serves to identify the issues in production readiness, and a set of eighteen consensus recommendations that reflect many of the issues and concerns expressed in the papers. We believe that these proceedings will be useful to Government, industry, and academic research groups in improving their abilities to specify, design, and construct process control systems for production readiness.

ABSTRACT

Experts in the field of Industrial Process Control were asked to assist the U. S. Army and address a most challenging and unique problem. Large capacity munitions manufacturing production facilities are required only in times of national emergency. These production facilities are complex manufacturing processes normally operated by sophisticated industrial process control systems.

Long periods of dormant storage may occur between facility construction and required operation. Guidance is required for the Army to properly plan for appropriate technical activity which will assure the readiness of these industrial processes at the time of national emergency. The Workshop which is reported upon in this document was held to help provide some of the needed background to this problem. It also generated a set of recommendations to be considered by the U.S. Army when setting up its procedures in this area. In addition to a set of background papers, discussions were held in the areas of transducers, magnetic media reliability, electronic and mechanical element needs, testing and proving of control system components, reliability enhancement techniques, simulation for personnel training purposes, and the effect of initial control system design on personnel skill requirements. The recommendations developed treat each of these. Further work is needed to refine and verify these recommendations.

Key Words: Readiness, Layaway, Standby, Reactivation, Automatic Control Systems, Dormant Storage, Reliability, Magnetic Tape, Simulation, Sensors

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EXECUTIVE SUMMARY

The Workshop on Control Systems Readiness for Munitions Plants, was held at Purdue University on Monday and Tuesday, September 19-20, 1977. The Workshop was commissioned by the Office of Developmental Automation and Control Technology of the Institute for Computer Sciences and Technology of the National Bureau of Standards under subcontract from the Munitions Production Base Modernization and Expansion Program, U. S. Army.

The purpose of the Workshop was to bring together a group of those government personnel who are concerned with the planning for and the designing of the control systems involved in the modernization and expansion of our nation's munitions plants, along with a group of technical experts in computer control system development and installation in the plants of civilian industry. The two groups then exchanged information concerning the U. S. Army's plans for the modernization and expansion program. The difficulties which the military foresaw in installing modern control systems in these plants and then deactivating them for a period of years before eventually requiring production were developed. The technical experts then responded to present their concepts of the design, installation, and storage precautions which should be taken, the procedures for maintenance and readiness testing to be used during the inactive period, and the requirements to be established for the reactivation itself.

A large part of the discussions of the Workshop were directed by the set of twelve papers which are included in this report. The first three papers described the Production Base Modernization and Expansion Program, the difficulties with previous munitions plants which prompted it, and the problems and difficulties which were foreseen by the military planners and designers.

The next set of five papers described the requirement for sensors in terms of the layaway problem, precautions and capabilities concerning magnetic tape files of computer programs and plant operating data, the environmental effects on electrical and electronic equipment under long storage, handling of valves and other mechanical elements, and methods for testing and proving out computer hardware and software elements.

The operation of a beet sugar mill bears some resemblance to a munitions plant in that it operates periodically. A munitions plant is different because the frequency and duration of the period is not known, and because it requires more advanced control systems. Nonetheless, this industry's experiences are relevant, and therefore a paper was presented describing the maintenance activities during the period between active campaigns, and the staffing practices and problems engendered by the periodic operation.

The last three papers described the applicability of modern high reliability techniques which should soon be available with the reduction in price of computer hardware, the use of simulation as a training aid for bringing new crews rapidly up to speed during the reactivation period, and the effect which modern plant and control system design techniques can have in reducing the need for highly skilled operating personnel. The reliability paper emphasized the trends in new computer control systems made possible with integrated circuit elements and the new reliability techniques. The simulation and training paper described operator training work that uses the techniques of computer simulation to present realistic plant type problems to these personnel while in training. The final paper presented some of the capabilities of modern systems engineering techniques to ease operator tasks, particularly in the interpretation of plant data in emergency situations, and thus lower the training requirements for these personnel.

The major results of the Workshop are presented in the "Recommendations" section. These results are a set of eighteen consensus recommendations that were reached by the participants during discussions that took place the second day of the Workshop. The recommendations concern issues and procedures for control system readiness. They reflect many of the specific concerns discussed in the individual papers. They are grouped into the following topic areas: General and Organizational, Computer Hardware, Computer Software, Other Systems Considerations (e.g. Instrumentation, Mechanical Elements), and Personnel.

Appendix I presents a list of all participants. Appendix II shows the agenda and program of the Workshop.

INTRODUCTION

BACKGROUND

The conventional munitions used by United States forces and supported allies are manufactured in a network of government-owned, government operated (GOGO) and government-owned, contractor operated (GOCO) ammunition plants supported by a vast network of contractor-owned, contractor operated (COCO) facilities. Typically the government owned facilities (GOGO, GOCO) are involved in the production of lethal propellants and explosives and the loading, assembly and pack-out of lethal munitions. This is done to retain a base that would not otherwise be available in industry. On the other hand, industry owned facilities supply a myriad of components and end items that include cartridge cases, fuzes and shell metal parts. Items manufactured by the base include a wide array of sizes and shapes of ammunition ranging from 5.56mm small arms cartridges costing six cents to 2,000 pound bombs costing $17,000 each. (A typical artillery round is shown in Figure 1). The plants included in the production base contain over 250 production lines.

These lines may be classified according to the production function they perform. Propellant and explosive (P&E) facilities include lines to produce all types of propellants, high explosives and pyrotechnic compositions as well as explosives ingredients such as nitrocellulose, nitroglycerin and acids. Metal parts (MPTS) lines manufacture shell and projectile bodies for mortar, tank and artillery rounds. They also manufacture bombs, cartridge cases, fuzes and small metal parts. The propellants and explosives, metal parts and components for munitions items are loaded, assembled and packed in what are known as LAP facilities. These facilities usually include equipment for the melting and pouring of high explosive into the munition along with finishing, assembly and packout operations. Small arms lines combine the generic functions of metal parts and LAP facilities into one complex due to their small size and extremely high production rates.

The munitions production base is distributied into 28 Army plants, and 131 commercial sites as depicted in Figures 2 and 3. This munitions production base is managed by the US Army Armament Materiel Readiness Command (ARRCOM), headquartered in Rock Island, IL. ARRCOM is responsible for procurement, production and logistics management of conventional ammunition for the Navy and Air Force as well as the Army. ARRCOM workloads the base during peacetime. When there is no work for a particular plant then that plant is shut down and laidaway for future use. ARRCOM then has the responsibility for maintaining the facilities and equipment in a state ready for rapid reactivation in case of a surge in requirements or general mobilization. The present goal is to be able to start production within 90 days of initiating reactivation. To help achieve this goal, ARRCOM, in conjunction with DARCOM's Industrial Base Engineering Activity and the Project Manager, MPBME, is looking at process control systems as a potential aid in reducing reactivation time.

As previously mentioned, the great majority of metal parts required for munitions manufacture are produced by the private sector. However, there is no industrial base for many of the largest munitions items, and/or in some cases insufficient capacity to satisfy overall needs. In these instances, government-owned, contractor-operated plants fill the void.

Small caliber ammunition for military rifles and carbines is very similar to rounds for sporting rifles and the production lines are almost identical. However, the capability of industry is limited so that the full requirements for military rounds cannot be accommodated. Accordingly, government-owned, contractor-operated production plants are required to satisfy mobilization requirements.

In peacetime, munitions requirements are extremely small as compared to full mobilization requirements. As a consequence of this non-uniform production requirement, nearly the entire initial ammunition consumption is satisfied from inventory stockpiles during mobilization. As the production base comes up to speed, more of the ammunition consumption will be satisfied directly from production thereby lowering the stockpile drain (see Figures 4 and 5). Clearly, decreasing the response time of the production base reduces the inventory stockpile requirement. Studies indicate a cost avoidance of approximately one billion dollars for each month that response time can be reduced. This figure does not include the cost of transportation, storage, maintenance or obsolescence of munitions in the stockpile.

The majority of the production base was acquired or constructed during the World War II mobilization. These obsolete and in some instances deteriorated facilities produced ammunition for three wars after long periods of inactivity. At the peak of the Southeast Asian conflict, it became apparent that the production base might not be ready for the next conflict. First, the equipment was worn out. It was very labor intensive, had extensive safety and health problems and was, in some cases, a very serious polluter. In addition, it could not manufacture a host of new generation munitions items that were being developed. This, along with a relatively slow mobilization response persuaded defense officials of the need to completely overhaul and modernize the ammunition plants. In 1970, the Army launched a comprehensive program of unprecedented scope to update the ammunition production base from a circa 1930 vintage into a system that would be responsive to the needs of the 1980's and 1990's.

PRODUCTION BASE MODERNIZATION PROGRAM

In recognition of the criticality of the efforts to provide the nation with a modernized ammunition production base of the proper size, the Secretary of the Army established a Project Manager (PM) for the management of the Munitions Production Base Modernization and Expansion

Program. The PM exercises centralized management authority over the planning, direction, control and execution of the production base modernization and expansion program at all U. S. Army ammunition plants and arsenals and for the government equipment located at contractor-owned and operated facilities included in the program. The PM office is located at the Armament Research and Development Command (ARRADCOM), Dover, N.J.

This diverse and complex program is now in its eighth year and will be completed in the 1990's. At a cost of $10 billion (excluding inflationary growth), it is one of the largest facilities programs ever undertaken in peacetime by either the government or private industry. As currently structured, the program is made up of about 600 individual projects for facilities and about 400 supporting manufacturing engineering projects.

The size, scope, diversity and complexity of the program are awesome. But with the establishment of a PM, the utilization of the collective expertise and experience of the participating organizations, and the development of new planning, programming and execution methodologies, the mission is proceeding in an orderly manner toward its goal of a fully responsive ammunition production base at an affordable cost.

Modernization is a broad term denoting the improvement of industrial facilities through replacement, modification, rearrangement, or addition of capability in order to achieve economic, quality, time or safety advantages. Under this program, a partially or completely new system-engineered production line or process, incorporating the latest proven manufacturing technology, replaces an obsolete or non-economic facility. In essence, this will improve readiness, abate pollution and correct OSHA deficiencies. Based upon DoD directives, the defense establishment has been charged to set the example for industry in the fields of pollution abatement and safe working conditions (OSHA). However modernization does not supplant restoration and replacement projects for current production support, although it might incidentally achieve such a goal. The addition of new or improved facilities is classified as an expansion effort when justified by expanding current procurement or increased mobilization requirements. An expansion of an ammunition production facility usually incorporates the latest proven manufacturing technology; therefore, modernization is also associated with expansion.

As previously noted, the munition production base prior to 1970 incorporated technologies of the 1930's. The key aspects of this program are to reduce the use of critical materials, energy and skills through the use of improved manufacturing technology.

In addition to the economic advantages of more efficient production facilities producing lower unit-cost items, a modernized production base will result in improved responsiveness of the base. The new production base will shorten the time required to reach a production rate equal to consumption rate; these factors decrease the quantities of ammunition which must be stockpiled to support mobilization requirements.

MANUFACTURING TECHNOLOGY PROGRAM

Along with every other consumer, the Army has been hit hard in the pocketbook by a steeply inflationary economy. The effects of inflation must be counteracted by increased productivity. Historically, increased productivity has been achieved by installing processes incorporating the latest and best technology. This briefly is the rationale which justifies the DoD manufacturing technology program. Some of the results achieved in this program have resulted in major improvements in manufacturing methods in the civilian sector in addition to their contribution in the production of defense items. Modernization of the Army's outmoded production facilities is well underway particularly at government-owned P&E and LAP facilities. The next area emphasized will be MPTS both in government owned and the industrial owned sectors. Some of the new technologies are ready for production adaptation now; others will be ready in the next several years.

In the P&E area, modernization projects have been undertaken to eliminate the air and water pollution associated with the older processes. New acid production facilities have been constructed incorporating the latest industrial technology. Future year effort has been allocated to the construction of single and multi-base propellant plants.

The MPTS modernization program began in the early 1970's with the updating of forging and heat treating facilities at one of the GOCO plants. Equipment being installed in the MPTS program will be capable of processing not only current ammunition designs in carbon steels but all the new generation munitions that will require alloy steels and high-fragmentation alloys. The small caliber ammunition modernization program, known as SCAMP, is currently completing its prove-out phase and will ultimately produce ammunition at rates previously deemed unattainable.

The LAP modernization program is divided into three broad categories; melt-pour facilities, projectile and component facilities, and support facilities. The major thrust is in the melt-pour area. The new process of continuous melt-pouring of TNT, Composition B, or other high explosives into artillery shells has been piloted at ARRADCOM.

Due to the diminishing horological industry in the United States since the 1930's, the DoD has relied heavily on imported precision fuze components to support its mobilization posture. Subsequent to the Korean War, an intensive effort has been made by the Army to modify fuze designs and exploit new fuzing concepts to minimize dependence on foreign sources of components. The modernization program, in addition to automating the fuze production base, incorporates new designs which eliminate the government's former predominant reliance on non-indigenous, precision-type watch producers.

The application of modern processes and manufacturing technology to the munitions production task requires, in many cases, the use of modern process control systems. Further, it is expected that some present and future control systems will provide capabilities which will greatly enhance the readiness posture of modern production facilities. The potential increased benefits available from modern control systems technologies are, however, accompanied by some new problems. Little, if any, experience base exists concerning the long term (5 to 10 years) dormant storage of classical and modern (analog/digital) industrial electronic, optic, fluidic, and pneumatic components and systems. The definition of procedures for layaway, standby and reactivation of control systems is required to assure that the best possible approach is chosen to accurately predict the readiness posture of the munitions production base using these systems. Further, the definition of control system design standards is expected to enhance design uniformity and familiarity with system documentation (design, operations, maintenance, etc.).

READINESS PROBLEM

The production facilities management problem can be grossly segregated into two main categories. The first area is the system or component degradation in the dormant (nonproduction) environment. The second area is the human element of the process and the learning curve which must be traversed at mobilization to effect full, reliable production. The Army is in need of technical guidelines to address both these areas. The ARRCOM participants specifically were searching for solutions to the problem of layaway, maintenance and reactivation of process control systems over long periods of time (10-15 years) including continual vendor support and equipment obsolescence. Before process control systems can be adopted as a solution to reducing reactivation time, an assessment must be made regarding the practicability of laying away and reactivating these same systems. Maintenance procedures must be developed which will assure rapid reactivation. Therefore the goal of this workshop was to address this practicability and subsequently to develop guidelines governing the layaway, maintenance and reactivation of process control systems. These general guidelines will be used to generate design and logistics guidelines (standards) and procedures to be used as a matter of policy for modernized munitions production systems.

Technical position papers were solicited from a large group of such experts. These papers were then distributed to all other participants prior to the meeting. All participants reviewed the papers and were prepared to discuss each paper in perspective with the other papers at the Workshop. The individual papers and discussions will be used by the government to formulate and implement a set of procedures to assist in reaching the goal of a suitable readiness program.

MUNITIONS PRODUCTION

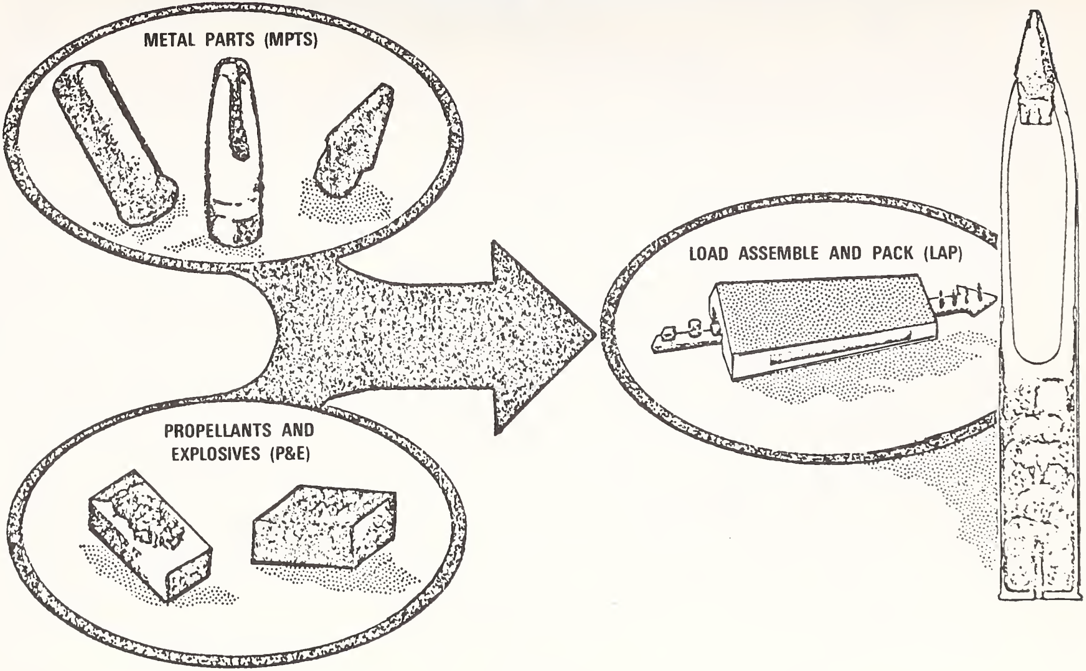

Figure 1

DOD CONVENTIONAL AMMUNITION PRODUCTION BASE
GOVERNMENT OWNED FACILITY LOCATIONS

Figure 2

LOCATION GOVERNMENT PEP LINES

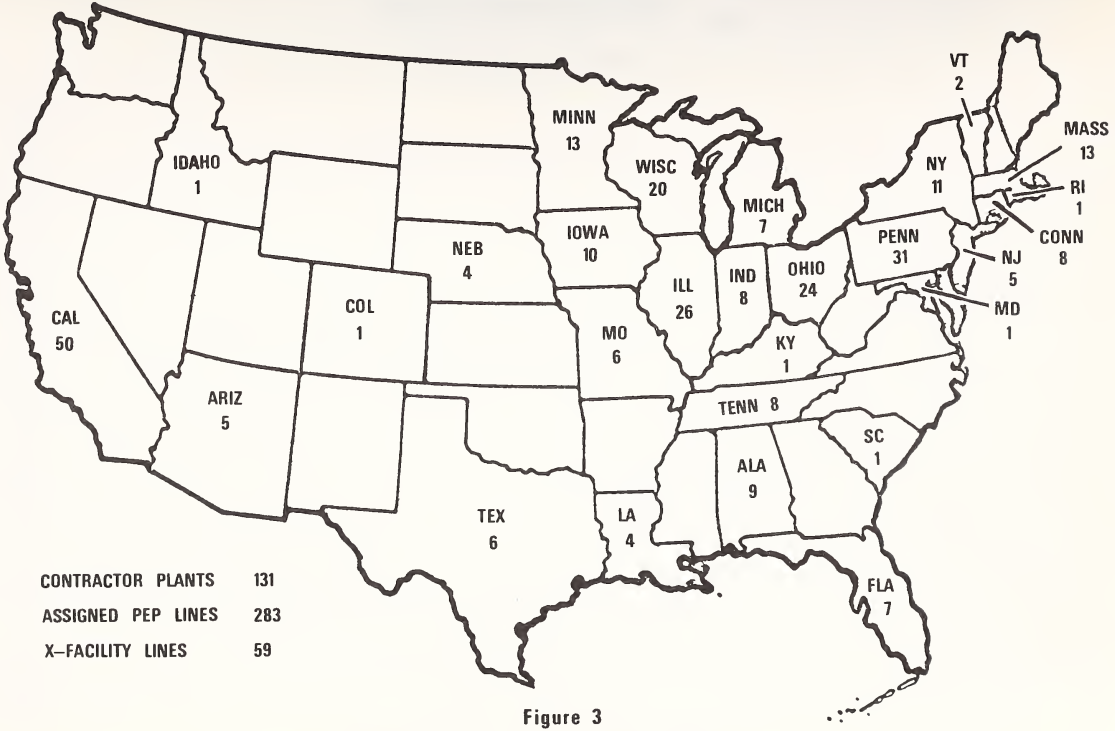

Figure 3

PRODUCTION RESPONSE TIME

(ORIGINAL PROCESS)

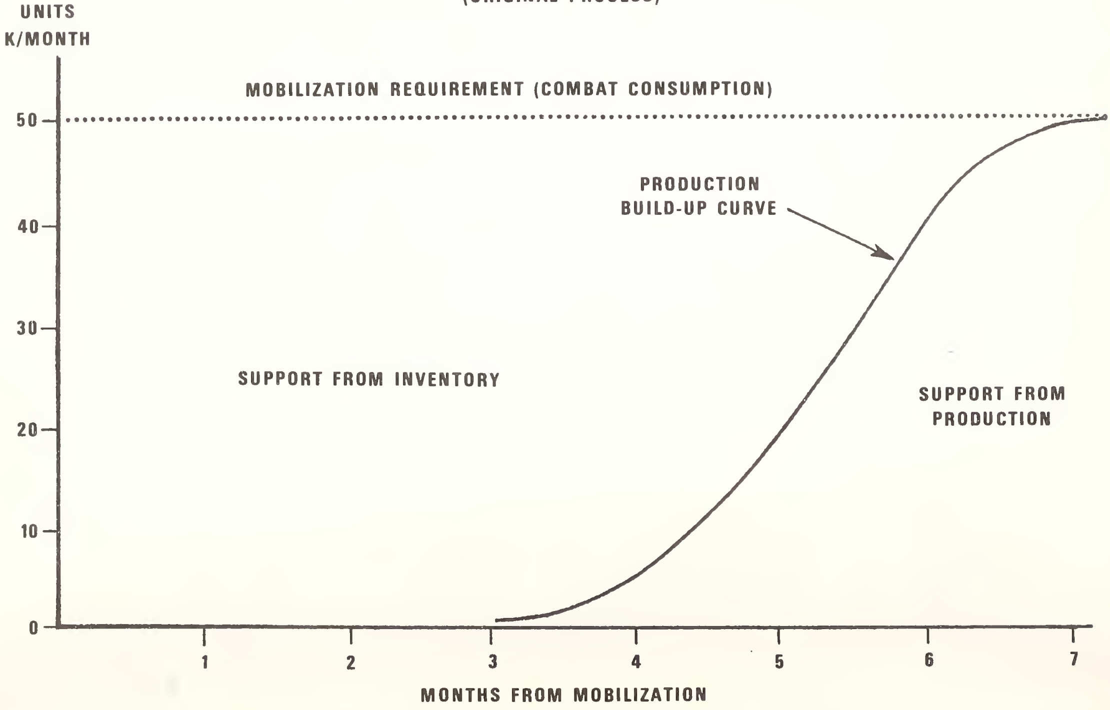

Figure 4

PRODUCTION RESPONSE TIME

(IMPROVED/ORIGINAL PROCESS)

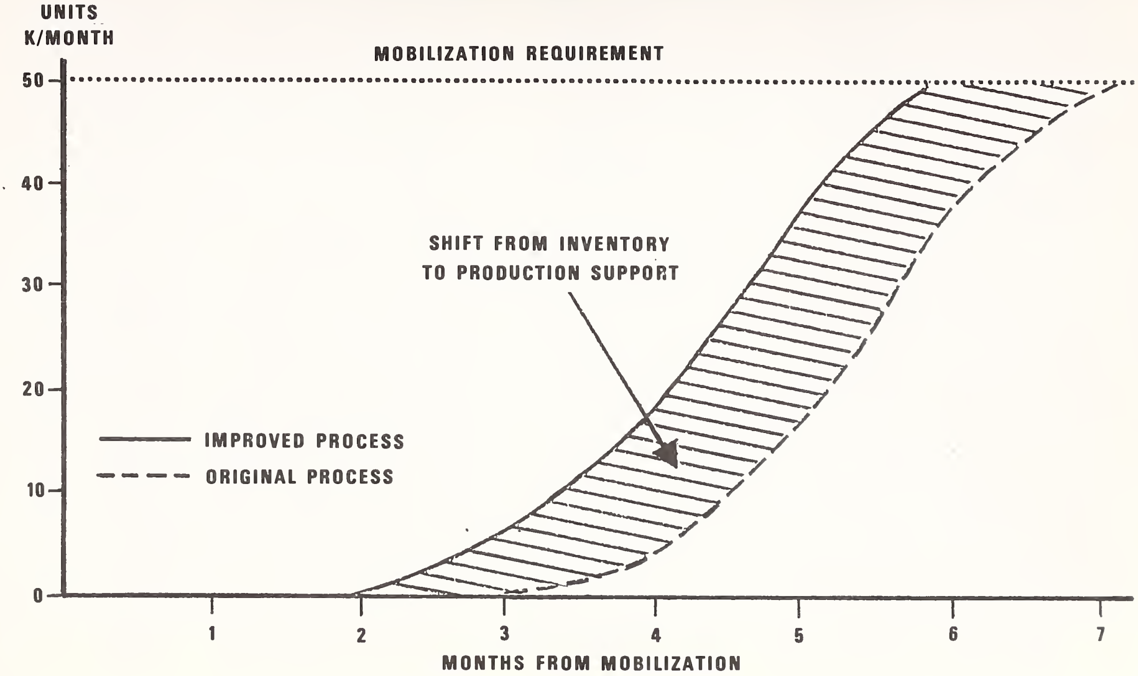

Figure 5

RECOMMENDATIONS

The first day and one half of the Workshop was spent presenting the contents of the technical papers. As each paper was presented, participants actively expressed their thoughts regarding the significance of its contents to the control systems readiness problem. These presentations and discussions formed a basis for the afternoon of the second day, which was spent formulating the following eighteen recommendations.

The list of Workshop participants contained in Appendix I shows that the assembled group represented a widespread knowledge base and set of experiences. Representatives from industry (both users and suppliers of control systems), Government, and academic research groups with experiences in both specialized aspects as well as system responsibilities were present. Such a diverse group provided a broad yet technically deep basis for the recommendations.

The recommendations are grouped into five topic areas. The first group is concerned with general techniques, procedures, and requirements which are applicable at a systems level. These recommendations are largely influenced by industry practices as related by the industrial participants. The second and third groups concern practices related to the use of computers to implement the control aspect of a system. There are recommendations for hardware and software. The fourth group includes recommendations related to sensors, mechanical elements, power supply, and communication elements of a system. The final group of recommendations speaks to personnel aspects of control systems readiness.

The recommendations themselves are based, of course, on the aggregate of the experiences of the participants. Many of them have proven both practical and beneficial in various industrial applications. It was agreed that the implementation of the complete set of recommendations is ambitious, but is required to meet the Army's readiness goals. The recommendations were formulated by all participants, and thus represent a consensus agreement. There was, however, a diversity of opinions expressed regarding such things as the relative importance of individual recommendations and mechanisms for implementing individual recommendations. The unanimous agreement on the ambitiousness of the task, and the diversity of the opinions expressed underscores the difficulty of implementation.

The underlined text constitutes the recommendations as formulated at the Workshop. The explanation which follows each recommendation gives relevant background discussion. To varying degrees these explanations answer the what, the why, and the how of each recommendation.

GENERAL AND ORGANIZATIONAL

1. Systems should be designed so that all hardware and software features are organized on a well-recognized modular basis.

Every industrial plant is different from its fellows in ways which nearly always prevent the direct transfer of complete control systems designs from one to the other. At the same time, all plants are constructed of different arrangements and combinations of very similar building blocks or modules. These modules are based on functional requirements for systems such as those identified by the International Purdue Workshop on Industrial Computer Systems (*Significant Accomplishments and Documentation of the International Purdue Workshop on Industrial Computer Systems*, Part IV, pp. 11-57). Designing modular hardware and software systems necessitates the use of standardized communications links, structural software engineering techniques, and modular operator interface components. Designing on a modular basis minimizes the engineering effort that goes into a new plant, facilitates the maintenance of existing plants, and simplifies the difficulties of responding to unexpected demands.

2. Each system should be implemented and handled during all phases by a user team which includes government and plant operating personnel. Those disciplines lacking at the plant location should be supplied by an in-house central control systems group. The central control systems group should have an approval function in order to preserve Army objectives and policies.

The Army must insure that it is involved in functional specification, design, implementation, prove out, and indeed in all intermediate aspects of the construction of a plant. The involvement must include personnel from a central control systems support group, as well as personnel who are concerned with the day to day operation of the plant. The involvement of the support group is necessary so that a high level of technical competence and the broad perspective of a central group can be maintained. Only a central support group can enforce a basic commonality among systems at different sites, which often are designed and constructed by different companies (a mechanism for this enforcement is described in Recommendation 3). The involvement of the plant operating personnel is necessary so that basic knowledge of the system, as well as identification with the system can be established by the people who will some day run the plant. This knowledge and identification will avoid a reversion to manual operation should system difficulties occur, and will facilitate maintenance and repair. A complete dependence on external personnel at such times can involve unacceptable delay and expense.

The two major user corporations represented at the Workshop have central support groups, and involve these groups and plant operating personnel in all phases of plant implementation. The corporations are large users of advanced control systems, and consider these policies absolutely essential to meet the corporate goals of effective use of advanced control systems.

3. The government should develop a set of system performance, application design, evaluation, documentation, and procurement standards which will be the basis for the carrying out of the recommendations stated herein.

A primary mechanism for implementing the Workshop recommendations is the development of the above standards. The central support group (described in Recommendation 2), would use the standards as a major tool to accomplish its task. The standards must be developed to satisfy the Army's control systems requirements for munitions plants. The standards should encompass all aspects of a project life cycle, including procedures for functional requirements specification, design, performance, documentation, and acceptance testing.

Participating representatives of corporations that are users of control systems reported that they use such internal standards and procedures. Thus, as is the case for Recommendation 2, accepted and proven practices in industry are the basis for this recommendation.

4. Systems to be procured should have an established application history and consideration must be given to the future programming and maintenance support availability of similar systems. A ten year minimum period is considered desirable.

Industry experience has shown the undesirability of the use of a new computer design in a plant control system application. This is because such systems tend to have many "bugs" or design and programming errors which have not yet been uncovered through continued testing and use. It has been shown that a plant installation period of about two years is necessary to assure that a new computer system design has received adequate testing and use to assure its future viability.

An established application history also helps to answer the question as to whether the computer system vendor intends to support this particular computer system with spare parts and programming aids for the life of the plant system which has just been installed. A minimum life of at least ten years is forecast for most industrial plant control systems today. Spare parts and programming aids must be available from the vendor for at least this period of time.

This recommendation can be implemented by incorporating it into procurement standards and procedures.

5. No control system enhancements should be made other than those necessary to maintain currently required performance capability while in the dormant phase. Equipment should be replaced only when obsolete and no longer supported by the vendor.

The rate of development in computer control systems is so rapid today that most systems are obsolete almost as soon as they are installed - they are still perfectly capable of performing their assigned tasks but are nevertheless no longer up to the state-of-the-art. The natural desire to have an up to date system is a strong incentive to make alterations or enhancements to existing and otherwise capable systems. These enhancements are not only expensive in manpower needs, costs, and plant downtime, but will often cause many other problems in the system if the interaction of the new functions with existing ones are not fully understood. Therefore such enhancements for the sake of modernization alone should be strenuously avoided. Likewise the replacement of an existing satisfactory system with a newer, less expensive, more capable, etc., system should also be strenuously avoided, unless the present system is no longer supported by the vendor for spare parts and programming aids.

This recommendation can be put into practice by establishing an enhancement and replacement policy.

6. Simulation is an excellent method of verifying the design of equipment and controls in critical situations. It should be used whenever such verification is desirable and feasible.

Simulation is the duplication of the behavior of a given system by another system or by a computer. The duplication of behavior is accomplished by developing a model of the given system based on mathematical, chemical, and engineering analyses. Increasingly, the computer is being used as an effective tool to implement the model.

The advantages of simulation center around being able to derive information about the given system prior to its actual construction. Simulation allows for a deep understanding of the processes which are part of the system; it makes it possible to perturb system parameters and thus evaluate alternative designs and devices. Still another advantage of simulation (described in Recommendation 18) is that it can be the basis of an ongoing training program.

A potential disadvantage of simulation is its dependence on models. The evaluations derived from the simulation are valid only to the extent that the model used actually represents the processes that are part of the system. A poor model will yield questionable evaluation. However, this should not be interpreted too negatively, since the state of the art of model building is good, and it is possible (based on considerations such as past experiences with similar processes) to verify models. Simulation requires manpower to carry out the necessary studies and equipment to perform the required computations. Inadequate planning can result in excessive cost for these resources.

Simulation has high potential benefit in the areas of process understanding, alternative design evaluation, and training. A realization of these benefits requires a commitment to the technique itself, as well as a commitment to building up an inhouse group of technical expertise that is part of the central support group described in Recommendation 2.

The recommendations contained in the following three sections, COMPUTER HARDWARE, COMPUTER SOFTWARE, and OTHER SYSTEM CONSIDERATIONS, can be implemented by incorporating them into developed procurement procedures and readiness policy.

COMPUTER HARDWARE

7. The recommended layaway procedure for a computer system is in the power-off state in a humidity and temperature controlled area with a periodic recycling to insure operability. Recycling is to be done by the vendor or user at the option of the user.

There has been considerable controversy in recent years as to the best method of handling electronic equipment while not in use. Should it be turned off or should power be kept on even when not in use. Recently it has been determined that the power-off state is probably acceptable for long dormant periods. At the same time, the necessity for a humidity, temperature, and environmentally controlled storage space has been reaffirmed because of the sensitivity of electronic equipment to variations in these conditions.

A periodic activation of the equipment, probably at yearly intervals, is necessary to assure that it will be operable should reactivation of the plant become necessary in a national emergency. This periodic activation and test is an excellent training device. Therefore user personnel should make such tests if they are available for the task.

8. At recycling time and at reactivation the system should be completely restored to a new machine operational condition. The original program and hardware system checkout should be repeated.

The only way to assure that a computer system reactivated after a long dormant period is completely operational is to subject it to the same tests which are used to prove out a new machine. Therefore these same tests should be used at each activation test (one year intervals) of the system and at plant reactivation itself.

9. Complete wiring diagrams, circuit board, and chip specifications and designs, etc., should be available for all computer and related electronic hardware.

A defense establishment such as a munitions plant must not allow itself to be dependent upon any one individual or any one company for its future maintenance and/or spare parts. Therefore it is necessary that a complete set of wiring diagrams, circuit board layouts, chip specifications and designs, etc., used in the computer or other electronic equipment be supplied with them. If the primary vendor should fail, this hardware documentation allows for the development of alternative sources of maintenance and spare parts.

COMPUTER SOFTWARE

10. Project generated program system source code should be written in a high-level, real-time language such as FORTRAN which is as close as possible to existing standards.

Recent work in the comparison of program development costs has shown the superiority of high level languages (over assembly languages) in reducing the overall costs of complex computer programs, such as for computer-based control systems. The use of standard versions of a language greatly enhances the transportability of software. This will encourage the software modular construction techniques contained in Recommendation 1.

There has been considerable work recently to develop standards for process control versions of the Fortran language. Since Fortran is the most commonly used and the most highly standardized of the high level languages for real time control, it should be the number one candidate. Work toward standardizing other more advanced procedural languages is beginning, and these efforts should be monitored by the central support group.

Some participants pointed out the advantages of fill-in-the-forms languages. With these languages a user specifies what he wants the computer to do by entering the appropriate information into a form or table. The advantages of these languages are the ease of programming and their self-documenting nature. Often an applications engineer, with only a minimal knowledge of the computer system, can fill in the forms. The documentation of the program is inherent in the forms. The disadvantages of fill-in-the-forms languages is their rigid structure (compared to FORTRAN), and the fact that each vendor has his own language. To a certain extent the use of functional criteria (see Recommendation 1) in control systems design alleviates the vendor-dependence disadvantage.

11. All vendor generated programs and operating systems must be provided in well-annotated source code.

Just as all plans, etc., for the electronic elements of the computer must be available for all defense related computing equipment to avoid dependence upon one individual or company in a national emergency (Recommendation 9), likewise a well-annotated source code for all computer programs must be available to permit any well qualified individual or company to perform any necessary maintenance or modification on the software of the system. The Army cannot afford to be completely dependent on a single vendor for this capability.

12. Vendor generated support programs, parameters, constants, etc., must be able to be dumped at layaway time and reloaded at reactivation time to achieve the same system configuration.

A complete and accurate record of the actual program existing in the computer system at any moment must be able to be retrieved and stored separately from the computer system itself. Then should any accident change the stored program of the computer, the original accurate program can be restored by reading in the copy retained separately. This is especially important during the dormant period when changes may take place in the memory of the system. The program existing at layaway can then be restored at reactivation, so that the computer is in the state which it held at deactivation.

13. Record copies of computer programs, such as discussed in Recommendation 12, should be preserved on magnetic tape as discussed in the paper entitled "Layaway, Standby, and Reactivation Procedures for Computer Magnetic Media" contained herein. A total of two separate copies in different locations should be utilized. The technique known as 1600 phase encoded recording should be used. Strict temperature and humidity control should be maintained and strict enforcement of proper handling techniques must be carried out.

For the foreseeable future, magnetic tape will remain the principal technological base for long term auxiliary storage in digital computer systems. Therefore proper procedures must be followed in the preparation, storage, and recall of magnetic tapes. The proper tapes must be procured and certified. When recording data the proper technique (1600 phase encoded recording) should be used, and care must be exercised in handling. During storage strict temperature and humidity control must be maintained. At reactivation tapes should be allowed to adjust to the temperature and humidity of the computer installation. Duplicate copies of all data should be maintained. Details of these procedural and policy matters are contained in the paper entitled "Layaway, Standby, and Reactivation Procedures for Computer Magnetic Media."

OTHER SYSTEM CONSIDERATIONS

14. All sensors, transducers and non-mechanical modulators should be calibrated when installed and recalibrated on a periodic basis including immediately before shutdown. They should be removed and stored separately on deactivation, calibrated annually while in storage and recalibrated on reinstallation.

The major requirement for an accurate process data handling and control system is for an adequate maintenance and calibration of the sensors used with the system. In particular, a calibration history of the device will show when nonlinear changes occur in the device due to stress or other occurrences. Because these devices can be particularly sensitive to environmental changes it is best to remove them from the field site and store them in a controlled area during the dormant period. Detailed background is provided in the paper entitled, "Environmental Devices and Equipment Under Long Storage Conditions" contained herein.

15. Current ARRCOM procedures for the handling of the mechanical elements of the plant control systems, such as valves, solenoids, etc., should be enforced. They appear adequate to handle most foreseen situations which may occur during layaway and the dormant period.

In the views of the Workshop participants the requirements of Army Regulations and ARRCOM Procedures as outlined during the Workshop discussion appeared entirely adequate for the layaway problem as envisioned by them. Following are the regulations and/or procedures that were outlined.

MIL STD 107E - Preparation and Handling of Industrial Plant Equipment for Shipment and Storage

TM 38-260 - Preparation at Industrial Plant Equipment for Storage and Shipment

MIL-P-116F - Methods of Preservations - Packaging

AR 700-90 - Army Industrial Preparedness Program

MIL-E-17555 - Packaging and Packing of Electronic and Electrical Equipment

It is recommended that these Regulations and Procedures be enforced.

16. Electrical power and signal cabling appears to have a virtually unlimited life if properly handled. The major problems are corrosion of contacts and connectors and attack on insulation by rodents. The former can be prevented by encasing all connectors in plastic bags along with a dessicant which is renewed periodically. Cables should be protected from rodents by conduit or by removal and storage in a safe area.

Potentially one of the more difficult topics of concern in the layaway of plant control systems and power systems is that of the cabling involved because of its extended nature. Fortunately procedures are well established for caring for the contacts and connectors involved as outlined above. Likewise the common use of conduit for safety purposes also protects the cabling from rodents, the most common causes of damage.

PERSONNEL

17. Because of the very short period planned for reactivation of dormant plants, it is imperative that training programs be developed for all critical operating and maintenance skills necessary in the plant.

Since reducing reactivation time directly reduces the munitions inventory cost, and the skill level of the operators is a significant determinant of reactivation time, it is absolutely essential that personnel be highly trained. A cadre of plant operating and maintenance personnel must possess all of the critical skills required to reactivate and operate the plant. These skills must be maintained during peacetime, when demand for munitions is relatively small. They must be maintained by existing personnel and acquired by new personnel, since normal attrition will necessitate their recruitment.

Therefore, it is imperative that a training program be developed for all critical operating and maintenance skills. Responsibility for planning and implementing such a program should reside at a high level of the organization. Considerations that should go into the plan include: 1) identification of critical skills, (it was assumed that non-critically skilled labor can be acquired at reactivation time), 2) required levels of peacetime personnel, 3) mechanisms for incorporating periodic recycling into the plan (see Recommendation 7), and 4) techniques for making effective use of computer-based systems such as Computer-Aided Instruction and Simulation (see the paper "Use of Simulation and Other Related Techniques for the Training of Startup Crews for Reactivation of Laid-Away Plants" contained herein, and Recommendation 18).

18. The technical and economic feasibility of incorporating simulation capabilities in on-line systems as an aid to reactivation operator training should be investigated.

Simulation was described following Recommendation 6 as the duplication of the behavior of a given system accomplished by developing a model of that system. This duplicated behavior can be used as the basis for operator training. During periods of training the operator interface is unchanged, but the actual process is replaced by a computer-implemented model of that process. Simulation is particularly well-suited for the Army's training program because it permits "hands on" experience without producing any products.

The discussion following Recommendation 6 pointed out that simulation can be an expensive technique. Thus, the economic feasibility of its use must be investigated. Nonetheless, the value of on-line simulation as a training technique for operators has been demonstrated by many industrial companies, and it appears well-suited for the Army's training requirements.

PAPER NUMBER 1

PAST EXPERIENCE IN THE REACTIVATION OF ARMY AMMUNITION PLANTS

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PAST EXPERIENCE IN THE REACTIVATION OF ARMY AMMUNITION PLANTS

INTRODUCTION

The information and data in the following pages will provide insight into problems experienced by the Government and its Government-Owned Contractor-Operated (GOCO) plants during reactivation for the Southeast Asia conflict.

This information is a compilation of inputs from the Army ammunition plants, recalling on the knowledge and experience of those who were present during reactivation, and also contains extractions from Profile on Munitions by R. J. Hammond.

The GOCO plants are grouped into four categories based on their production capability. The groups are Propellant & Explosive (P&E); Metal Parts (MPTS); Small Arms (SA); and Load, Assemble and Pack (LAP).

After World War II, the GOCO complex was maintained on a reduced scale so that at the time of the Southeast Asia (SEA) buildup in 1965, eleven plants were still active. Full reactivation of 26 plants required an average of seven months and a cost less than $300 million. Chart 1 reflects the buildup leadtimes by various categories of operation for Southeast Asia.

Prior to 1965, the level of production was mainly peacetime requirements for training, and manufacture of a few of the sophisticated items coming out of development for phasing into the inventory.

It was not until the introduction of American combat troops into Vietnam that a more intensive effort was given to reactivation and/or modernization of the ammunition complex.

Chart 2 reflects the history of reactivation of Army ammunition plants following our entry into SEA. As the war began to build in intensity, six additional plants were brought to active status in FY 66. Eight more plants were phased in during FY 68. By this time, the capability to produce the "bread & butter" type items that were necessary and critical to troop support in SEA was all being utilized. There was only one plant, Alabama Army Ammunition Plant, that remained in an inactive status. It has since been declared excess.

The GOCO complex, although smaller in terms of plants and personnel than its predecessors of World War II and Korea, was, on 31 Dec 68, still a vast enterprise which spread from New Jersey to California and from Texas to Nebraska with a peak contractor employment level in excess of 120,000. The capacity utilization of our GOCO plants during SEA is reflected in Chart 3. It should be noted that 100% of the LAP capability had been reactivated and 96% was being utilized, 100% of the metal parts capability had been reactivated and 94% was being utilized, 85% of the explosive capacity had been reactivated and 89% was being utilized (the 15% that remained inactive was the Alabama Army Ammunition Plant, which had partial TNT lines available). In propellants, 92% was active with 70% utilization. The 8% remaining inactive was also located at the Alabama Army Ammunition Plant which had single base lines partially constructed after Korea.

By 1969 it became readily apparent that it was not only essential to maintain current capability but also to modernize and expand the production base. It was realized that the production of qualitatively superior ammunition on a timely basis was significantly affected by the lack of availability of advanced manufacturing processes, techniques, and new equipment. The continued advancement of the state-of-the-art had to become an integral part of our efforts to retain and/or build an effective mobilization base that would be responsive to any future military contingencies.

It is noted that at the time of reactivation of Southeast Asia (1965-67), most of the Army ammunition plants did not have "automated process control systems" in layaway status. Therefore, the reactivation experiences are not totally comparable to that of the present day situations.

MAJOR AREAS OF EXPERIENCE AND PROBLEMS

The problems experienced during the reactivation of the production base in support of the Vietnam operation were many and varied; running the full range of labor, social economic, political, geographic, and technical. Selected problems and selected plants will be highlighted in this paper. The problems and plants to be discussed are believed to be typical, but may not necessarily be the most critical or most important when viewed from individual points of interest.

PLANNING FOR REACTIVATION

One of the major problems in planning for reactivation was the uncertainty of the changing position the United States was to take in the overall operation. This made it nearly impossible to get clear and concise guidance as to production requirements and the anticipated duration of the operation. It also made orderly planning extremely difficult. This resulted in piecemeal reactivation, delayed full production, and increased the overall cost of reactivation and initiation of production.

Another major problem in planning was the mobilization planning did not match the type of war the United States was called upon to support. Plans were often developed on short notice and on a crash basis to meet changing delivery requirements and asset posture. The resultant reactivation was often for production of items not previously included in the plant's mobilization plan. Experience tells us that the most meticulous planning most likely will not meet the actual situation when we are called upon to reactivate/expand the production base.

ORGANIZING AND STAFFING FOR REACTIVATION

Considerable management effort was required to develop and justify organizational structures since there were no pre-determined plans to expand the headquarters (HQ) or to recruit personnel to support the reactivation process and manage those problems arising from increased production. This effort detracted from the primary jobs of reactivating plants and delivering ammunition to the troops.

Recruitment problems were compounded by the lack of suitable housing at reasonable prices, unwillingness to accept positions at what appeared to be a temporary installation, and the grade structure of jobs which were not in line with standards required to qualify for jobs.

FUNDING

Funding was limited and often provided on an incremental basis due to the nature of the United States commitment. There were a few plants that did not experience any funding problems while others fitted into one or more of the following:

1. Adequate funds to cover the general scope of work for reactivation were furnished on a timely basis but subsequent funds for production were slow.

2. Funding required for reactivation was insufficient because programmed buildup was compressed into a shorter timeframe than estimated. Production support funds were inadequate for the same reason.

3. Funds required for training and debugging were short and overage expense was later charged to end items and resulted in higher production costs.

4. Confusion existed in the type of funds to utilize. It became necessary to reactivate, convert, and produce the end item with the available funds.

GUIDANCE

Guidance was a problem for HQ, the Government staff, and the operating contractor because of uncertainties, constantly changing requirements, and inexperienced people at all levels.

The most serious problem in guidance was that some of the plants were activated to produce items which were not on their mobilization schedule and some items had not been previously produced at the plants.

In many cases, initial guidance was lacking except for direction to get into production as quickly as possible. Needs were made known but the "how" to fulfill the needs, and "how" to reactivate were lacking. The prime objective was production without regard to cost.

Indecision regarding the exact configuration of items to be produced delayed production as did late, inadequate, and sometimes unavailable technical data packages.

STATE OF MAINTENANCE/DETERIORATION OF FACILITIES

The condition of the facilities, upon reactivation, was dependent upon the layaway status, the length of layaway, and the amount and type of maintenance. Standby maintenance funding constraints during layaway were a major contributing factor in the deterioration of facilities and the high cost to reactivate. Some facilities were in fair condition but required modernization, others were in very poor condition and extensive repairs were needed to restore to operative standards, while others were damaged beyond repair. Equipment condition codes on record could not be relied upon. Equipment in many instances was of World War II or Korean War vintage, was not easily adaptable to automation, and many revisions were required to meet safety standards. Equipment, motors, electrical systems, building interiors and exteriors, storage tanks, conveyor rollers, air receivers, control systems, railroads, roads, and distribution systems and other items were damaged and deteriorated and required repair or replacement.

ACQUISITION OF MATERIALS, SUPPLIES, & TOOLING TO SUPPORT REACTIVATION & PRODUCTION

The acquisition of materials, equipment and supplies to support reactivation was hard to manage because many people were looking for the same items at the same time. Lead times were constantly extended and promised delivery dates were constantly missed.

Much of the equipment needed to support reactivation had to be obtained from other plants, purchased, and/or built. Government furnished material (GFM) was in poor shape since most of it was excess or salvaged from other plants. Rebuilding and maintenance of GFM increased reactivation costs. Several production lines were cannibalized to support requirements elsewhere.

Some problems in the acquisition of materials were attributed to an extremely limited staff of personnel qualified to develop the general and specific material requirements, including descriptions and qualities. For example: At Kansas AAP most of the tooling required to produce the mobilization planned items was on hand and ready for use. However, Kansas did experience problems in acquiring tooling for the new items relative to incomplete technical data packages, shortage of qualified personnel to properly interpret requirements, and using tool shops of unproven ability. Incomplete/outdated technical data caused delays and shifts in schedules. Kansas had retained some long leadtime items during standby that were not required but proved necessary at reactivation; these were parts for air compressors, deluge systems, explosion proof disconnects, switches, tooling, presses and drills.

The acquisition of materials and tooling at Joliet AAP became very critical in meeting startup and production schedules due to unavailable current Bills of Material, outdated and unavailable technical data packages, inability of material vendors to meet requirements and unavailability of metal parts and components; i.e., cartridge cases, projectiles, fiber containers, primers, and propellants.

At Cornhusker AAP the supply of bomb casings controlled production. Most stocks of casings had been disposed of and bomb manufacturers no longer had tooling or the capability to make casings.

Twin Cities experienced considerable difficulty in the acquisition of plant procured raw materials, such as case cups, bullet jacket cups, etc. Blanking and cupping facilities were limited so it became necessary for the plant to procure brass stripping and accomplish blank and cupping operations. GFM shortages of clips, links, bandoliers, ammunition boxes, etc., impacted packing schedules. The most serious problem at Twin Cities was procurement of perishable tools which resulted from a combination of no technical data package or material specification, inaccurate tool design, limited (often incapable) procurement sources, limited sources of raw material (Tungsten carbide, high carbon alloys), tool revisions, lack of control of engineering changes, and inexperienced personnel.

Generally, the acquisition of tooling and materials at all plants was extremely difficult. Leadtimes were abnormally long, major suppliers were unable to fill orders, quality and workmanship were frequently below standard, and late deliveries encroached on time required for debugging and startup. Acquisition was further complicated by a limited list of vendors capable of supplying items of material associated with the production of ammunition.

RECRUITMENT AND TRAINING

Generally, recruitment of unskilled personnel presented no particular difficulty. A high percentage of female help was utilized and most of the local areas produced more than adequate numbers of applications for production workers, laborers, and clerical positions. However, recruitment problems were experienced in hiring skilled workers, graduate engineers, professionals, supervisory, and administrative personnel. Since most of the new hires were unfamiliar with ammunition production, extensive training was conducted both by classroom instruction and on-the-job training. Training was hampered by a lack of updated methods and procedures, experienced instructors, training equipment and materials, funds, space, and time.

PRIVATE SECTOR

The private sector was not reactivated in the classical sense but experienced many of the same problems that have been discussed; i.e., deteriorated equipment, lack of technical data, missing parts, unavailable material and inexperienced personnel.

SUMMARY

As can be seen from the previous discussion, the problems of reactivation are varied and complex and in most cases directly relate to the previous preparation that has been accomplished. Major problems are funding, availability of trained personnel, up-to-date mobilization plans, item and process documentation, availability of spare parts and raw materials, and physical plant and equipment deterioration due to inadequate layaway and maintenance. The introduction of new, modern, sophisticated, single purpose, automated production and process control equipment compounds the effect of each of these factors. The new systems and the effect of each factor must be given proper consideration in planning for mobilization.

REACTIVATION COST/TIME

	SEA	
ACTIVITY	COST $M	TIME AVG MONTHS
LOADING	162.5	7.6 months
PROP & EXP	110.4	9.0 months
METAL PARTS	11.1	3.0 months
TOTAL	284.0	7.0 months

CHART 1

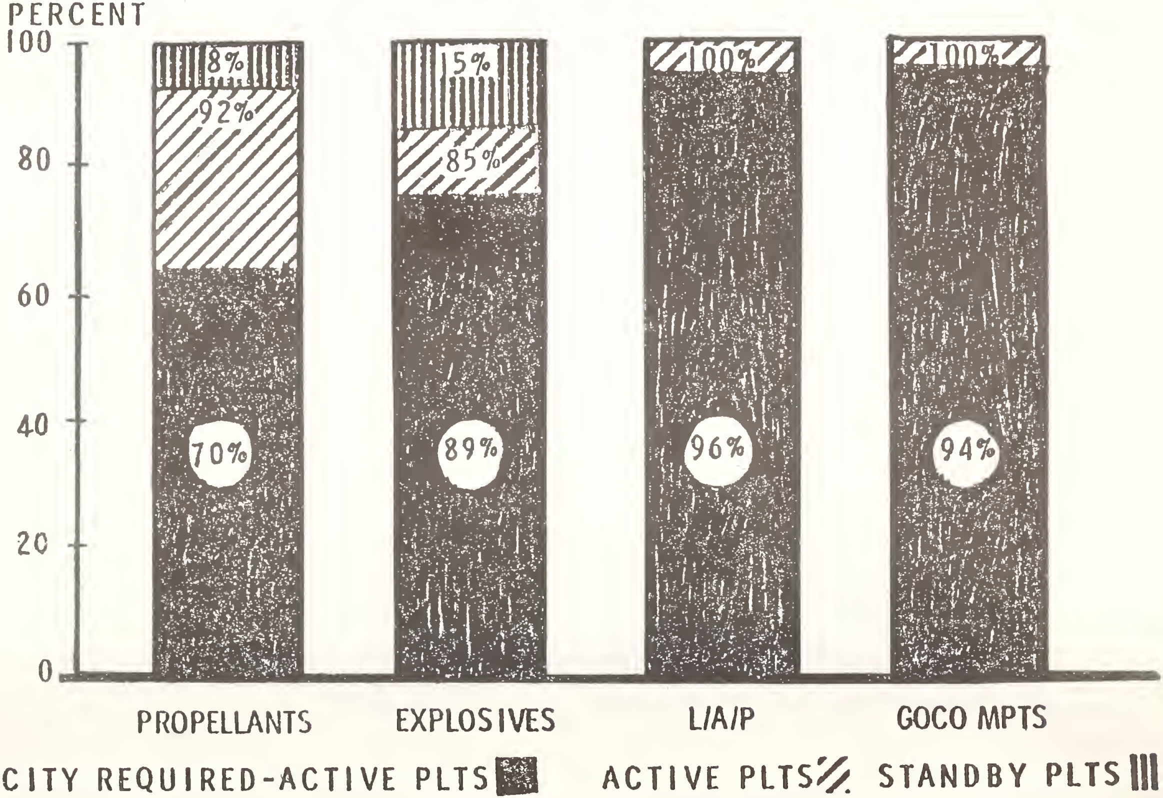
REACTIVATION HISTORY OF GOCO PLANTS

COMMODITY	*FY 65	FY 66	FY 67	FY 68
LOAD ASSEMBLE & PACK	INDIANA (BAG LOADING) IOWA LAKE CITY LONE STAR LOUISIANA MILAN LONGHORN (MISSILE MOTORS) NEWPORT (GB-VX)	CORNHUSKER TWIN CITIES (SMALL ARMS)	JOLIET (L/A/P) KANSAS COHASSET (GRAVEL MINE)	RAVENNA
PROPELLANTS	RADFORD	BADGER SUNFLOWER		INDIANA
EXPLOSIVES	HOLSTON	JOLIET VOLUNTEER		NEWPORT RADFORD
METAL PARTS	SCRANTON		BURLINGTON HAYS ST LOUIS TWIN CITIES (DONOVAN) GATEWAY	

*ALREADY ACTIVE BEFORE 1965

CHART 2

CAPACITY UTILIZATION - GOCO PLANTS



PAPER NUMBER 2

CURRENT PROCEDURES AND PROBLEMS IN THE LAYAWAY AND REACTIVATION OF PROCESS CONTROL SYSTEMS

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CURRENT PROCEDURES AND PROBLEMS IN THE LAYAWAY AND REACTIVATION OF PROCESS CONTROL SYSTEMS

INTRODUCTION

In the early 1970's, an extensive effort was initiated to modernize (MOD) the ammunition production base. One of the main objectives was to reduce production costs thru automating production processes. In the mid 1970's many MOD projects reached completion and it was found that the technique of laying away (LWY) control systems in a way that would permit rapid reactivation needed further improvement.

Resolution of this problem area is important since we want to protect our past investments; we want to assure mobilization readiness; and we want to modify as necessary, those modernization and expansion projects currently in the planning stage.

ARMY GUIDANCE

Existing guidance on the LWY and reactivation of control systems dates from the years when control systems were simpler. It does, however, recognize many important problems:*

Moisture - "... variable and adjustable resistors may be effected because of exposed metal surfaces; various kinds of capacitors may be damaged by moisture, dust, leaking electrolyte, etc.; inductors may absorb moisture in their windings; transformers have a tendency to rust; alternate heat and cold will cause insulation deterioration; connectors and sockets will rust and corrode from moisture; relays, timers, solenoids, and switches suffer from corrosion on contact points and fungus growth on coils; and wires and cables are damaged due to chemical attack on the insulation from contact with organic solvents."

Solvents - "...Extreme care must be exercised in the selection of a cleaning material to prevent damage to parts. Solvents (and their vapors) may cause dimensional or chemical changes to insulations, wiring, or other susceptible organic parts of critical electronic equipment."

Preservaties - "Petroleum (P-type) preservatives...may destroy the usefulness of an item due to the difficulty of their removal. A preservative may penetrate into unwanted areas and cause swelling or decomposition of the material, or reduce its electrical conductivity..."

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*Quotations from TM 38-260, Preparation of Industrial Plant Equipment for Storage or Shipment.

The recommended methods of cleaning, preservation and storage are:

Cleaning - "...Low pressure, dry, prepared compressed air, vacuum cleaning, or wiping with a clean lint free cloth may be used for cleaning ...Never, under any condition, use abrasive materials for cleaning electronic components..."

Preservation and storage - Since at least March 1965, it has been specified that contact preservatives which require removal before reactivation shall not be used on computers, controllers, and printed circuit boards. Specifications, however, prescribe removal of water vapor from the storage environment. In environmentally controlled storage, the relative humidity is maintained at 50% or below.

CYCLING

Cycling, or exercising used to be a popular method of LWY. Hydraulic presses were nearly always cycled. It was done to prevent peening of areas on bearings, shafts, etc.; to recirculate lubricants, hydraulic fluids, etc.; and to verify operability.

Subsequently, it was realized that cycling merely "rubbed off corrosion" (which then contaminated the lubricating oil); that it was expensive; and that it was no substitute for the proper cleaning and preservation (including blocking to relieve concentrated loads, using additives in hydraulic and lubricating fluids, etc.).

The issue of cycling has come up again in connection with the LWY of process controls. Some have proposed periodic cycling for several days at a time to verify operability. A Computer Sciences Corporation (CSC) study*, for example, has recommended that the TNT control system at Volunteer and Joliet Army Ammunition Plants be cycled as follows:

"Once every two years turn on electrical power to the control system for four or five days, and run diagnostic checks of all digital and analog equipment. Repair all failures and turn off power."

The major factor that determines cycling frequency is the number of interrelated failures. In computer maintenance, the computer is generally used as its own diagnostic tool. During normal operations, failures appear one at a time, and it is relatively easy to find one fault. During storage, however, two or more failures may develop which will become simultaneous failures upon reactivation. Simultaneous failures may interact and the amount of time to find and correct several interrelated faults increases at an exponential rate. Cycling should be scheduled

*Contract Number DAAA21-75-C-0244, "Recommended Approach to Laying Away PCP-88 Control System Electronics at CIL TNT Plants".

then before too many interrelated faults accumulate.

A minor factor that determines cycling frequency is the thermal stress caused by power on-off cycling. To determine the effect of cycling on control systems, Martin Marietta* has looked into the question of thermal stress. It concluded that "...it appears that a single power on-off cycle to thermal equilibrium and back to room ambient temperature is between...165 to 375 (depending on component mix)...times more stressful...than one hour of dormant time. Another way of saying this is that one would expect 33 power on-off cycles...to be equivalent to just over one year of dormancy in precipitating failures." In accordance with this conclusion, too much cycling would not only be more expensive, but would contribute to the deterioration of the control system. (It should be noted here that power on-off cycling was found to be much more stressful and it generates more failures than continuous operation in a fully energized state).

The theoretical rate of dormant failures can be determined for each control system. In one method, a physical count of each component must be made and multiplied by the dormant failure rates specified in MIL-HDBK-271B**. Since this data is only for controlled environment, it has to be modified when the humidity and temperature are uncontrolled.

OBSOLESCENCE

Several government publications indicate that the economic service life of electronic data processing equipment is shorter than metal working and general process equipment. The PCP 88 computer such as at Joliet and Volunteer AAP's, is no longer manufactured. Does this mean that the process controls we already have should be replaced, or that we should postpone the purchase of new control systems until after M-day? The CSC study indicates that even in active computers, physical wear is not a factor in obsolescence even though continuous use or periodic cycling would somewhat increase failure rates. In the 10 to 15 years since computers have been applied to process control, the usual cause for replacing the computer has been that the requirements have changed. Users wanted more calculations, more inputs and outputs, more background capability which could not be provided by the old machine. In terms of

*"Dormancy and Power On-Off Cycling Effects on Electronic Equipment and Part Reliability" prepared by Martin Marietta Aerospace, August 1973, AD 768-619.

**MIL-HDBK-217B, "Reliability Prediction of Electronic Equipment", 20 September 1974.

the requirements for which it was purchased, the computer was still a useful tool.

Obsolescence does imply though that it could be difficult to find an alternative user for the computer during periods of LWY. Universities, for example, might prefer their students to work with more modern computers. Other potential users could run into costly conversion problems, or may not want a computer that won't be available if the ammunition plant is reactivated. It is possible though that a qualified, long term user could be found for the general purpose digital computer. Field equipment, digital and analog input and output circuits, line panels and operator consoles would still have to be maintained with government funds.

Obsolescence also implies that the service organization's maintenance man would have to spend more and more time on the familiarization, diagnosis and repair of an obsolete computer. Keeping a knowledgeable cadre of engineers and control house operators during the LWY period would minimize reliance on the manufacturer or servicing organization, and would assure a higher state of readiness.

The availability of replacement parts for obsolete computers is also a problem. A proposed solution is the stockpiling of spare components based on their frequency in the system, their availability, and their failure rates as observed during operation, or determined based on MIL-HDBK-217B. Data from this HDBK indicates, for example, that certain transistors are 15 times more reliable than others, that certain capacitors are 50 times more reliable than others, etc. In addition to having a higher stockpile of relatively unreliable components, new designs could minimize the use of materials that are unreliable in use or quickly deteriorate in storage. Postponing computer purchase until M-day could solve these problems, but only at the expense of long leadtimes for design update, manufacturing, proveout and training.

Somewhat related to the topic of obsolescence is the problem of skills that the LWY of sophisticated control systems create. Even if these systems were proved out, and used for production, there are a small number of people who have hands on experience. This distinguishes it from the many other systems the Army has in storage which have been used by hundreds or thousands of troops on active duty. When a war emergency occurs, the Army has on active duty at least some number of officers or non-coms who have used and have been using equipment similar or identical to the equipment in storage. These officers and non-coms provide the nucleus of the reactivation and training teams for the reactivated equipment. CSC feels that there has to be a similar group of capable people to reactivate the control system and production facilities. During the LWY period, these people would perform the cycling of control equipment as well as assist in the maintenance and surveillance of the general process facilities. Highly skilled individuals could be shared between facilities with identical control equipment, as Joliet and Volunteer AAP's.

STORAGE ENVIRONMENT

When humidity control is desirable, conventional equipment is usually consolidated for storage in humidity controlled, pipe supported polyethylene hutments or in sealed buildings, where moisture is removed through dynamic dehumidification. This becomes impossible when the equipment is too large or when other structural peculiarities prevent hutment construction or the proper sealing of the building. In these situations, localized - as in control cabinets - humidity control must be considered. Humidity is controlled through heating by light bulbs/electrical heating strips or through direct removal of moisture by desiccants.

An alternative way to protect exposed electric contacts and wire terminals is to use brushable or sprayable compounds that need no removal before reactivation. Since these products have not been properly tested and approved for government use, a project is being funded to do that.

As far as the storage environment is concerned, the general concensus is to store electronic control systems in a controlled environment. Maintainability and reliability people at CSC and Foxboro, as well as documents on the shipping and storing of electronic assemblies, all recommend environmental, especially humidity control for assuring the operability of the equipment.

Basic failure rate analyses for electronic parts, such as in MIL-HDBK-127B, were made in a controlled environment. To compare different environments, Martin Marietta has analyzed failure rates in satellites, on the ground, and in submarines. The results were presented as Location Mode Factors (LMF's) to be applied to the basic failure rates. These factors are reproduced below:

NORMALIZED DORMANCY LOCATION MODE FACTORS FOR

PASSIVE AND ACTIVE HIGH RELIABILITY ELECTRONIC PARTS

	LOCATION MODE FACTOR	
DORMANT ENVIRONMENT	PASSIVE PARTS (RESISTORS AND CAPACITORS)	ACTIVE PARTS (SEMICONDUCTORS AND MICROELECTRONICS)
SATELLITE	0.2*	0.5
GROUND - INSIDE CONTAINER IN CONTROLLED ENVIRONMENT	1.0	1.0
GROUND - NO CONTAINER IN CONTROLLED ENVIRONMENT	1.9	5.0
SUBMARINE	7.4	13.1

*One failure was assumed to obtain this factor.

In calculating the failure rates of control systems in uncontrolled storage CSC assumed that the LMF's for submarines apply. It was concluded that digital circuit failures would greatly increase. Consequently, cycling frequency would have to be increased, so that failures could be diagnosed a few at a time, using the computer as its own diagnostic tool. From CSC calculations, it was evident that heating and air conditioning the control house would cost a fraction of the cycling/repair costs necessary without environmental control.

CONCLUSION

Based on the prior discussion, the following conclusions are suggested:

1. If existing control systems have to be deactivated, they should be stored in an environmentally controlled area.
2. Computers will continue to perform the job for which they were purchased, but as they age, they will be more difficult to maintain in terms of skills and replacement parts.

In view of the many unsolved issues remaining, it is hoped that this seminar will throw some light on maintaining our existing control systems, and designing new control systems for our processes currently under expansion, conversion, or modernization. Some of the questions that need to be discussed are:

1. What kind of failures develop in inactive computers, and could they be repaired to allow production within 90 days?
2. How realistic are dormant system failure calculations based on individual component failures?
3. In what circumstances is trickle current, or "leaving power on" sufficient?
4. In designing for LWY, which failure prone materials/components/ subassemblies should be avoided? How could the diagnosis of interrelated failures be simplified?

PAPER NUMBER 3

AN OVERVIEW OF THE PERFORMANCE CHARACTERISTICS OF SENSORY TRANSDUCERS

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AN OVERVIEW OF PERFORMANCE CONSIDERATIONS OF SENSORY TRANSDUCERS

INTRODUCTION

This paper provides an introduction into some of the considerations relating to the performance of sensory transducers. Specific issues of interest to the Workshop on the Layaway Problem are among those that have been little investigated in the transducer field. The discussion which follows draws necessarily upon expertise gained over the long-term on transducer application and calibration questions as well as upon experimental work.

"The application of modern processes and manufacturing technology to the munitions production task requires...the use of modern process control systems. Potential increased benefits...are accompanied by some new problems. Little, if any experience base exists concerning the long-term (5, 10 years) dormant storage of classical and modern (analog/digital) industrial electronic, optic, fluidic, and pneumatic components" (1). These excerpts from D. A. Morlocks' paper "Munitions Production Base Readiness" put this problem in a nutshell.

The sensory transducer is a vital link in the process control system because it measures those parameters of a process which must be accurately controlled in order for the product to meet the stipulated requirements.

The transducer is often the weakest link in a measuring system, either because of its inherently limited performance, particularly when exposed to severe environments, or because of limited knowledge concerning its performance. This situation results from two major factors. In the design of transducers, adequate information has not always been available to transducer manufacturers concerning special performance needs of users. At the same time, adequate information of the performance of transducers has not been available to guide users in the selection and application of transducers (2).

The measuring transducers (transmitters) used in industrial systems may be based on electronic, optic, fluidic, or pneumatic principles. The increasing use of computer control places correspondingly increasing emphasis on electronic measuring devices or at least on those with an electrical output. Such electro-mechanical transducers have been used extensively in aerospace and defense research, and are being used in industrial applications in ever-increasing numbers. Although the following discussion deals with specific devices, the problems encountered and needs for solutions should be viewed as being common to the application of other types of process control transducers.

OPERATING REGIMES

The primary requirement imposed on any sensory transducer is that it measure the parameter it was designed to measure with the desired accuracy.

The operational capabilities of a transducer are described by its performance characteristics, which are in general obtained from a series of calibrations and evaluation tests. The degree to which the operational capability can be predicted or verified depends on the completeness of the knowledge of the performance characteristics, which, in turn, depends on the ability of the calibrations and evaluation tests to establish all the needed performance parameters.

For the purposes of this paper, the operating environments in which sensory transducers are used may be categorized into regimes as follows: operation at laboratory conditions, operation in severe environments, operation over extended periods of time, non-operating storage, and operation in any of the first three regimes following storage. Practical experience with transducers suggests that the order in which these regimes are given represents the order of increasing possible degradation of performance and, most significantly, the order of decreasing knowledge of the actual type and magnitude of performance degradation.

OPERATION AT LABORATORY CONDITIONS

Operation at laboratory ambient conditions, for short periods, essentially in a well-controlled environment, eliminates the need for concern over the effects of severe environments or the effects of long periods of operation. The next concerns are then the two major modes of measurement which the transducer is called upon to perform: static (or quasi-static) measurements and dynamic measurements.

STATIC CHARACTERISTICS

The performance characteristics which determine the transducer's ability to measure static (or quasi-static: only very slowly changing) quantities are established by means of static calibrations. These characteristics include such parameters as sensitivity, zero output, linearity, hysteresis, repeatability, resolution, creep, dead band, etc., (3). Static calibration procedures for many transducers have been published and incorporated in standards documents (4), and although gaps exist in some areas, the general field of static calibration for transducers is covered reasonably well.

DYNAMIC CHARACTERISTICS

With rare exceptions, sensors are called upon to measure changing quantities. It is necessary not only to know the amplitude of the quantity at a given time but how it is changing at that time, since the latter may require rapid corrective action.

If the sensor is to be used to measure (or follow) such changes, the dynamic characteristics of the device correspondingly must be known. Calibrations to establish the dynamic characteristics (such as amplitude response, phase response, resonant frequency, etc., (5), are less well developed, in general, than static calibrations. Those dyamic calibrations that are available tend to cover relatively narrow amplitude- and frequency-ranges (6).

OTHER FACTORS

Even at laboratory ambient conditions, there are factors external to the sensor which can affect its performance. Power supply variations, electrical noise, mechanical vibration, lead resistance variations, etc., will tend to degrade the measuring ability of the sensor.

Thus, information is needed on a large number of performance characteristics before the quality of measurements performed by the sensor at laboratory ambient conditions (the most benign operating environment) can be estimated.

OPERATION IN SEVERE ENVIRONMENTS

The majority of sensory transducers do not operate in a benign environment. They are subjected to a variety of environmental conditions which can severely influence their performance.

Such severe environments can affect sensors in two major ways. Measurement performance can be adversely affected while the sensor is subjected to the specific environment. Such changes in performance are generally reversible, and disappear when the severe environment no longer acts on the sensor. In addition, the action of the environment on the sensor may result in some irreversible, and thus permanent, change in its performance.

To adequately assess sensor performance, it is essential to be aware of both types of effects. This subject will be considered in the next two major headings of this paper. Environmental parameters that have proven to be of practical interest are briefly discussed in the following paragraphs.

TEMPERATURE

Temperature above and below laboratory ambient is the most frequently encountered environmental condition influencing sensor performance. While sensor performance normally is affected by temperature, it is frequently possible to compensate for temperature effects, provided the operating temperature is known and constant. This is true whether the entire sensor is at the operating temperature or only a part of it, such as the diaphragm of a pressure transducer. In the latter case, a temperature gradient may exist between the sensor and the surrounding environment, but when the gradient is stable, compensation can be effective.

If the process or environmental temperature varies, temperature compensation cannot be effective. In fact, compensating networks within the sensor may actually degrade the output. Thermal transients can cause unexpectedly large measurement errors unless transducers are selected for their imperviousness to them or are protected against them (7).

SHOCK AND VIBRATION

As with temperature, measurements performed by a sensor can be severely affected by the presence of shock and vibration environments. which may generate spurious signals and otherwise interfere with transducer performance.

HUMIDITY

The presence of moisture may cause undesirable shunting of resistive and capacitive elements, as well as current leaks to ground. More importantly, however, exposure to humidity can result in corrosion of metal parts and components and can lead to component failures.

OTHER ENVIRONMENTAL PARAMETERS

There are a number of other environmental parameters which may affect the measurement performance of sensors, such as dust and sand, salt spray, high-level acoustic excitation, electromagnetic radiation, magnetic fields, and ionizing radiation.

OPERATION OVER EXTENDED PERIODS OF TIME

In aerospace and defense applications, transducers are generally expected to perform properly and reliably over short periods of time, from minutes to hours. In industrial applications, on the other hand, the periods of time over which these devices are expected to operate may range from days to several years.

When extended-time operation is considered, reliability is a particularly important factor. The reliability of devices has been computed from knowledge of component failure rates and has been applied to critical aerospace applications and expressed as mean time between failures. This concept of reliability, however, is usually concerned with the total failure of the sensor, not with the deterioration of sensor performance. The latter has received relatively little attention.

LIFE CYCLING AND DURABILITY

A limited investigation was conducted on the effects of a million pressure cycles on the performance characteristics of several types of strain-gage pressure transducers. In these tests, the transducers were subjected under laboratory ambient conditions at a rate of about once per second to pressure pulses with amplitudes of 80% to 90% of the range of the transducer until a total of 10^6 cycles had been completed. The main conclusions from this investigation were: (A) both output at zero pressure and sensitivity changed more during the first 10^5 cycles than subsequently; (B) after about 10^6 cycles, the output zero pressure had shifted about 1% of the full-scale range and the sensitivity differed by as much as 0.5% from its initial value; and (C) linearity and hysteresis changes due to cycling are minor compared to the changes in zero output and sensitivity (8).

A more extensive investigation was conducted on a group of bonded-wire strain gage pressure transducers. These experienced pressure cycles at a rate of five times per second under laboratory ambient conditions until 40×10^6 cycles had been completed. Some of the transducers were cycled at 66°C (150°F). Among the conclusions drawn from these tests were: (A) the sensitivities of the transducers tested at ambient conditions decreased with cycling as well as time; the sensitivities increased at the elevated temperatures; at zero pressure outputs decreased with cycling and time for both temperature regimes; (B) changes in hysteresis and linearity were very small; and (C) somewhat larger changes in characteristics occurred during the first 10^5 cycles (the first three or four days of testing) than subsequently (9). In both investigations cycling at pressures higher than full scale produced total failures or radical changes in characteristics within the first 10^5 cycles.

It should be noted that the conclusions obtained from both investigations are based on a small number of specimens of a few types of pressure sensors subjected to a particular durability testing concept. Nevertheless, the test results point to the type of behavior which other sensors might be expected to exhibit. It is clearly desirable to investigate such behavior further, to obtain an indication of possible problem areas.

NON-OPERATING STORAGE

Shelf life is probably the area of greatest concern for the Workshop, but there appears to exist little information on sensor behavior following specificed storage conditions, nor has any experimental work been done at NBS to address this special area.

A limited investigation was conducted on the effects of storage at elevated temperatures on the performance of strain-gage pressure transducers. Seven transducers were subjected to temperatures of 107°C and three others to 91°C for a period of five weeks, followed by a three-week period at laboratory ambient conditions. Excitation voltage was applied during the entire test period. Test results indicated permanent changes at the end of the test program of about 0.5% in sensitivity and up to 4.5% of full scale in output at zero pressure. It should be noted the storage temperature in all cases was below the maximum specified operating temperature for the transducers tested. The largest portion of the changes appears to occur during the first five days of the test (10). These conclusions are valid only for the actual transducers tested and may not apply to other pressure transducers types.

While information should be available from sensor manufacturers on the shelf life of transducers, proprietary considerations make it difficult to obtain this information.

Again, as in the other areas discussed earlier, considerable work remains to be done to explore the shelf-life aspects of measurement transducers.

ELECTRONIC SIGNAL CONDITIONERS

In the vast majority of applications, the electrical output from the transducer or sensor is fed to some kind of electronic signal conditioner. Such a device may be used (for example) as an amplifier to raise the signal level, as an impedance converter to match other circuits, as an analog-to-digital converter to provide computer-compatible signals, or as a comparison amplifier for subsequent control purposes.

The electronic siganl conditioner is most likely to be a solid-state device, either hybrid or LSI (large-scale integrated circuit). Furthermore, the signal conditioner may be an intergral part of the transducer, or it may be remote from it.

Electronic signal conditioners may also be affected by evnironmental and storage conditions, particularly in the case of long term storage. The specific type of electronic components, and their particular technology, will largely determine what changes might occur with time. Certain general considerations apply, however.

Environmental humidity may well be the major factor of concern. The action of moisture on many metals can lead to corrosion, which in turn can cause poor contacts at junctions. On the other hand, moisture can also set up additional conductive paths across insulators to create leakage currents and short circuits. Extensive work on hermeticity and sealing problems of semiconductor devices has been carried out in the Electronic Technology Division of the National Bureau of Standards. Plastic semiconductor packages may be more prone to moisture leakage tham metal cased ones. The effects of the normal climatic variations in temperature on semiconductor electronics is probably minimal, but thermal expansion and contraction can cause atmospheric moisture to be drawn into imperfectly sealed electronic packages. Temperature-time effects on some insulating materials can lead to their deterioration (11).

OPERATION FOLLOWING STORAGE

Operation of devices following storage depends on the history of the transducer during storage, and that prior to storage. Very little information appears to be available on non-operating storage. It is likely, however, that organic compounds used in transducers such as rubber o-rings or seals and insulation will deteriorate with time, particularly in the presence of ozone or UV light. The limited experimental investigation described in the section on Non-Operating Storage was conducted basically at benign laboratory conditions except for the temperature variable. That is, the pressure medium was breathing quality air, the transducers were new when the test started, and the duration of the test was relatively short. Nevertheless significant changes were observed. Similarly, shelf storage at the transducer manufacturer's facility would probably be at relatively benign environmental conditions for new transducers, possibly in closed boxes. This would serve to reduce the influence of atmospheric contaminants.

On the other hand, storage of transducers in situ after they have been used for process measurements is likely to be quite different. Unless the entire measurement system is carefully purged of all traces of the measured process medium, chemical processes could occur with harmful effects on the sensor. Midly corrosive remnants of this medium acting over the postulated storage life could cause substantial change in some sensor components such as diaphragms and seals. Otherwise harmless traces could be hygroscopic, attracting and holding enough atmospheric moisture to accelerate corrosion greatly.

REACTIVATION CONSIDERATIONS

It may be desirable that when an industrial process is reactivated after a prolonged period of layaway the following steps should be considered: First, one might determine if the measuring system is clean and if not, correct the condition. Corrosion or debris may block passages, and may even have damaged sensor components. Second, it is suggested to check the functional integrity of the entire measurement system to identify faulty components for replacement. Third, it is desirable to carry out a complete system calibration from the sensing end of the transducer through the entire measurement system to establish the performance characteristics following layaway storage. Fourth, one might follow this calibration by a short period of exercise: by applying the full-scale value and zero value of the process variable (or suitable test input) alternately to the transducer at a moderate rate for a short period of time (of the order of minutes). Fifth, one might carry out a second complete system calibration. If the results of these two system calibrations agree with each other, the short-term stability of the system is likely to be satisfactory. If these calibrations also agree with a system calibration obtained before layaway, then it is likely that the long-term stability of the system is also adequate and there is assurance that this measurement system will perform as intended during the subsequent process reactivation provided the operational considerations below are incorporated also.

OPERATIONAL CONSIDERATIONS

It is not sufficient, however, to verify only once the performance of any measurement system that is to be used for any extended period of time. Continuing operation of any measurement system tends to lead to degradation of performance. Also, following reactivation residual effects resulting from storage may gradually degrade sensor performance.

Consequently, it is necessary to recheck system operation and transducer calibration at selected intervals. At present there seems little agreement as to the proper time intervals for such recalibrations. Economic considerations play a large role in the decision, particularly when calibration requires interruption of the process operation.

CONCLUSIONS

It can be seen that there are a large number of factors which have a bearing on the performance characteristics of transducers. The factors can be grouped into (A) those inherent to the transducer principle, design and fabrication, (B) those due to the environment in which the transducer operates, (C) those due to the continued, long term operation, and (D) those due to long term, non-operating, storage. Relatively little has been done to investigate these factors or to develop test methods or theoretical concepts to attempt to predict the influence of these factors.

RECOMMENDATIONS

A two-fold approach is needed to assure continuing proper measurement performance on the part of transducers and measurement systems, in particular following layaway.

1. The development of performance concepts and test methods to verify sensor performance under the variety of operational and environmental conditions constitutes the major need.

2. The design and installation of measurement systems with the capability of in-place calibration is highly desirable for any kind of industrial process application, and is particularly critical for a process meeting national defense needs.

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PAPER NUMBER 4

PRODUCTION BASE RESPONSE REQUIRED TO MEET MOBILIZATION REQUIREMENTS

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PRODUCTION BASE RESPONSE REQUIRED TO MEET MOBILIZATION REQUIREMENTS

INTRODUCTION

A fundamental policy of the Department of Defense is to maintain an ammunition production base capable of responding to emergency production requirements in the event of a full scale or limited mobilization. In general, this base is expected to produce end item ammunition at a rate equal to consumption within a specified time period. To provide this responsive base requires a considerable amount of planning with industry, and an intensive management of the Government resources required to supplement private industrial capacity.

MOBILIZATION REQUIREMENTS

First, the mobilization requirements themselves must be developed. Due to the tremendous number of items required for mobilization, a selection process is necessary to limit planning to essential items. Items are selected for planning only if one or more of the following criteria are met:

1. Require a long leadtime (at least 6 months)
2. Require development of Government-owned facilities or additional capacity to meet requirements.
3. Require continuous surveillance to insure preservation of an adequate base.
4. Require critical skills or specialized production equipment.

For those items selected, base retention mobilization rates are generated based on anticipated combat consumption rates at D+6 (6 months after commencement of military operations). It is sometimes not readily understood, however, that there are different mobilization rates expressed for different purposes. For example, there are base retention mobilization rates that differ from modernization or investment level rates. Investment level rates are used to determine the investment in facilities required to support peacetime procurement to satisfy inventory deficits. Modernization level rates are lower in priority and are used to determine the extent of approved modernization projects for existing facilities. These rates are usually lower rates that are constrained by budget levels and available funding. Industrial Preparedness Planning is accomplished against the base retention level rates.

M-DAY ASSUMPTIONS

Included within the various plans are assumptions that are made with regard to the anticipated environment and circumstances that will exist on the day that mobilization is to begin (M-Day). Critical M-Day assumptions include the availability of all required funding as well as the availability of required personnel. These two basic assumptions underlie the plant's estimated mobilization response capability and are critical to the initial production leadtime. Other assumptions which might apply to a specific plant, e.g., that equipment on loan from standby lines will be returned, or a project to expand facilities will be completed, may also be critical to the acceleration or build-up from initial production to peak production rates in the particular situation.

INITIAL PRODUCTION LEADTIMES

Various factors must be given consideration in determining initial production leadtime. Generally, component production is scheduled for M+3 with LAP one month later. Since few producers will be in production of the assigned item on M-Day, the most common problem is to set up the production line. Many pieces of industrial equipment must be retrieved from storage. Some will be located in Government storage and must be transported to the production site, installed and tested prior to initial production. Commercial facilities must generally runout the current product, procure materials and hire and/or train additional personnel. Clearly this reactivation process must be well planned in order to avoid problems that will delay production beyond the required time frame.

SUSTAINED PEAK PRODUCTION

The build-up to maximum must be capable of being sustained indefinitely. In order to develop a credible sustained peak schedule, it is current practice to schedule a production line to produce at not more than its rated capacity at 500 hours per month at 70% efficiency. For example, a line would not normally be scheduled to operate at a sustained rate on a 3-8-6 or 3-8-7 shift basis.

PRIVATE SECTOR INVOLVEMENT

In accordance with Department of Defense policy, the U.S. Army relies upon private industry, where feasible, to meet these wartime mobilization requirements.

In order to encourage producers in private industry to be prepared to participate in the Mobilization Production Program, the Government has established Plant Equipment Packages (PEP's) where it has been determined that ownership by private industry of the equipment required in the production of munitions is not economical.

A PEP is a complement of active and/or inactive plant equipment which has been formally approved for retention as part of the munitions production base by the Assistant Secretary of Defense (Installation and Logistics) and assigned a number. These PEP packages comprise a significant portion of the industrial base and complement the Government-Owned Contractor-Operated (GOCO) and Government-Owned Government-Operated (GOGO) Facilities.

ORGANIZATION AND POLICIES/PROCEDURES

The U.S. Army Armament Materiel Readiness Command (ARRCOM) has the responsibility for integrated commodity management of conventional weapons and ammunition. Within ARRCOM there are four major directorates concerned with the management of the Industrial Base. These are the Installations and Services Directorate, which is primarily responsible for facility management and maintenance other than Industrial Plant Equipment (IPE); the Industrial Management Directorate, which is responsible for the IPE management, layaway and reactivation of the Industrial Base; the Procurement Directorate which is responsible for contractural effort, and the Production Directorate which is responsible for scheduling of current requirements.

Within the Industrial Management Directorate, the Industrial Preparedness Division developes mobilization requirements and executes planning agreements with industry. The Industrial Resources Branch of the Industrial Preparedness Division, is specifically responsible for equipment allocation and management, layaway, and reactivation of facilities.

There are other elements in addition to ARRCOM that interface with industry. Among these are:

A. Industrial Base Engineering Activity (IBEA), which is an agency of DARCOM Headquarters and coordinates responsibility for the Equipment Management Program.

B. The Defense Industrial Plant Equipment Center (DIPEC) has the responsibility for management of all Defense Industrial Plant Equipment.

C. Defense Contract Administration Service (DCAS) which is the onsite liaison organization between the Procuring Contracting Officer (PCO) and the private contractor. DCAS and DIPEC are both part of the Defense Supply Agency (DSA).

D. The Project Manager of the Munitions Production Base Modernization and Expansion (MPBME) located at Dover, who among other missions has the responsibility for the PEP Modernization Program.

The ARRCOM Industrial Base consists of:

A. Contractor-Owned and Contractor-Operated (COCO) facilities.

B. Government-Owned and Government-Operated (GOGO) Plants, Production Test Facilities and Depot Level Maintenance Facilities.

C. Government-Owned and Contractor-Operated (GOCO) Plants.

D. Plant Equipment Packages (PEP's) capable of augmenting the above capabilities.

ARRCOM is concerned with the layaway and reactivation of GOCO, GOGO, and COCO plants and with the management of equipment located in the approximately 172 PEP's throughout the nation in GOGO, GOCO, and COCO plants. Twenty-one ARRCOM PEP's are for weapons and 151 PEP's are for munitions production. Of the 151 munitions PEP's, 24 are located with GOCO producers, 6 with GOGO's, 80 located with private industry and 41 are designated as Former Facilities (X-Facilities).

The PEP's contain the Industrial Plant Equipment (IPE) and are controlled by procedures established in AR 700-90. Documentation is prepared by ARRCOM and must be coordinated with the Assistant Secretary of Defense.

The PEP includes a means through which a contractor can obtain additional IPE. When a contractor requires an item of Government-Owned Production Equipment to support current production due to expansion of current production, replacement of inoperable equipment or to improve efficiency of production; procedures are available which allow obtaining replacement equipment from the DIPEC inventory. If no replacement equipment is available thru DIPEC new equipment may be obtained on loan or purchase if justified.

The decision to lay away a particular line or PEP is brought about by a reduction in requirements. The information on this reduction transmitted to the contractor through the PCO results in production stoppage and a line becoming idle. The PCO then requests the Industrial Preparedness Planning Branch to provide a decision as to whether the PEP should be retained or disbanded. The decision is based on the capability of the line and the current mobilization requirements.

When no need exists for further retention of the PEP, action to disband the PEP is taken. Equipment contained in the PEP is allocated to other PEP's as required or released to DIPEC for redistribution or disposal as appropriate.

When the decision has been made to retain a PEP, the project engineer responsible for the formulation of the layaway project determines costs and storage location and processes a layaway project to obtain funds for execution of the project. Determination of where to locate Plant Equipment Packages is based on dispersion, the time required for reactivation, losses which could result from moving the equipment, and a comparison of costs of on-site and other types of storage. The final decision is consistent with attainment of maximum economy, essential state of mobilization readiness, and the best interest of the Government. Preference is given in the following order:

1. Maintain the equipment in the facility where it was last operated.

2. Hold the equipment on-site or adjacent to the point of last use.

3. Hold the equipment in government-owned storage sites.

The project Scope of Work, which defines the layaway parameters in accordance with applicable regulations, related specifications and standards, provides the criteria for the preparation and handling of Industrial Plant Equipment for shipment and storage. Production equipment must be thoroughly cleaned and preserved to assure capability when required. Upon project and program approval, funds are provided the PCO for negotiation with the contractor concerned for execution of the work. This contract may be with the mobilization planned producer or independent contractor on an individual basis. Projects are monitored for compliance with specifications, quality of work, and costs, by the responsible ARRCOM elements and assigned DCAS personnel.

In conjunction with the aforementioned layaway procedures, the latest edition of Army Regulation 700-90, effective 15 September 75, requires inspection and testing. If the inspection and testing indicates unsatisfactory performance, one of three actions will be taken:

1. The equipment will be replaced with equipment from unassigned reserves or excess inventories.

2. The equipment will be repaired or rebuilt to the extent necessary to assure satisfactory operation.

3. The equipment may be laid away with deficiencies, but in such cases, the deficiencies will be identified and recorded. Follow-up plans will be taken to replace or rehabilitate the unserviceable equipment.

Appendix B of the Armed Service Procurement Regulation (ASPR) establishes the requirement that contractors provided Government-Owned property, develop a plan for its proper care and maintenance. This plan is subject to review and approval by the Government. Standards for equipment maintenance are normally contained in either the supply or facility contract. Program authority for maintenance of equipment in active use is normally provided in the cost of the end item of the supply contract and is the user's responsibility. Some contracts define abnormal maintenance as a joint responsibility of the contractor and the Government. In these instances, the Facility Contract is the vehicle to reimburse the contractor for the Government share of the cost. Program authority for maintenance of inactive PEP's is provided in the Government Facilities Contract. Contracts for maintenance of inactive equipment are for a period of one year with option for renewal for four additional years.

SUMMARY AND CONCLUSIONS

The preceding has briefly summarized requirements generation policies and procedures relating to layaway, equipment management and maintenance. Although the policies are normally adequate they cannot always be followed precisely due to limitations in time, manpower or funding. In addition, funding for maintenance of buildings and equipment after layaway has often been limited. Lack of maintenance accelerates deterioration and decreases readiness. Recent policies and plans are directed towards more reliability and shorter reactivation lead times. Although more sophisticated equipment is being included in modernized lines, information for layaway and reactivation of this equipment is inadequate to date. In addition, a more advanced degree of sophistication is often not compatible with the goal of rapid reactivation.

It is not always possible to attain the required response capability. Constant review and analysis of contractor capacity and readiness is necessary to assess and determine measures to improve the responsiveness of the production base. In many cases additional equipment, critical components or materials must be furnished before facilities can meet assigned mobilization schedules. Projects must be initiated to provide the needed capacity for new munitions. In times of severely limited funding, such as the present, the problem is compounded by the need to prioritize and spread the limited government resources where the need is most urgent.

PAPER NUMBER 5

LAYAWAY, STANDBY AND REACTIVATION PROCEDURES FOR COMPUTER MAGNETIC MEDIA

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LAYAWAY, STANDBY AND REACTIVATION PROCEDURES FOR COMPUTER MAGNETIC MEDIA

INTRODUCTION

This paper outlines the practical procedures which should be followed in order to assure successful preparation, storage, and recall of magnetic computer tapes and the stored data which are used in a deactivated computer controlled manufacturing plant which is to be reactivated at some later time. It discusses preconditioning and selection procedures for the layaway phase, the static and dynamic factors of the standby phase, and finally some reactivation procedures which are available for use with a magnetic computer tape storage medium.

At the present time and for the foreseeable future, it appears that magnetic recording will remain the principal technological base for long-term auxiliary storage in digital computer systems. There is no other practical approach to machine readable archival data storage which is economically superior to computer magnetic tape recording. For example, comparing the figure of merit, CxDxS (which is the information capacity times the information density times the data speed), of computer magnetic tapes to that of punched paper cards and paper tapes, it is found that computer magnetic tapes are superior by five to six orders of magnitude. A single 731m (2400 ft) long reel of 12.7mm (0.5 in) wide magnetic computer tape can store as much information as 40,000 to 200,000 - 80 column punched paper cards. In addition, there is no unique environmental advantage to be gained by using paper based storage media rather than the prevalent polyester (mylar) based computer magnetic tapes since both of these media are sensitive to temperature and humidity conditions in storage. Therefore, although punched paper tapes and punched cards have been used in the past for auxiliary data storage, only the layaway, standby, and reactivation procedures for use with computer magnetic tapes will be discussed in this paper.

Magnetic recording is essentially a tape surface area technique. During the layaway phase, a recording head magnetizes the magnetic material in the region next to the head gap as a function of the input data. During the reactivation phase, these magnetized surface areas are made to induce voltages into a reading head which reproduces the stored digital data that was originally encoded magnetically by the write head. The principal objectives of the layaway, standby, and reactivation phases are to maximize the probability of data recovery by reducing the potential for physical damage or distortion of these magnetized tape surface areas and by recording the data on these areas with techniques which are most resistant to information loss.

Experimental evidence has shown that failures to extract the information from magnetic media are almost always attributable to the physical deterioration of the media rather than to the deterioration of the data. In fact, the theoretical lifetime of the magnetically encoded data is virtually endless under ideal environmental and handling conditions.

LAYAWAY PHASE

There are three areas to be considered in the layaway process. They are: the quality of the tapes that are chosen; the physical preparation of the tapes; and the preparation of the tape contents.

THE QUALITY OF THE TAPES THAT ARE CHOSEN

The candidate tapes should be chosen to be in compliance with specifications which are described in documents such as the U.S. Interim Federal Specification WT0051C (GSA-FSS), March 1, 1975 for 12.7mm (0.5in) computer magnetic tapes. Compliance with these specifications assures the interchangeability of the computer tapes when used both internal to or external to the originating computer control system. Each tape will not be restricted to operate only with specific transports and electronic setups.

THE PHYSICAL PREPARATION OF THE TAPES

The chosen tapes should be "certified," within six months before being stored, at the information density (bits per inch) at which they will finally be recorded. The certification process measures the signal amplitudes of pulse trains written on each of the computer tape tracks and compares these amplitudes against a pre-established reference level. It then rejects those tapes whose levels drop below a reference amplitude if the cause for the signal decrease cannot be eliminated using mechanical or chemical means. The reference levels can be traced back to the National Bureau of Standards Secondary Standard Magnetic Tape (Computer Amplitude Reference) SRM 3200. It is recommended that a maximum of five write skips should be allowed for any chosen computer tape and the tape should also have been run on a transport for less than fifty but more than four passes over its entire length. Computer magnetic tapes which were produced in the mid-1960's or earlier should not be chosen even if they have never been used previously since it has been found that they have a greater tendency to develop permanent defects as a function of time in storage than tapes which were developed and produced in the 1970's. These defects develop in all tapes due to the "cold flow" (viscoelastic) characteristics of the plastic constituents of the tape such as the polyester (mylar) base material. This cold flow causes physical deformation of the tape and is accelerated by nonuniform and excess stress buildup in the tape reel when it is subject to changes in temperature and humidity. It has also been found that the buildup and accumulation of tape errors in storage increases approximately as an exponential function of time and that errors develop even in good storage environments.

THE PREPARATION OF THE TAPE CONTENTS

Once the computer tapes have been chosen, then the information is recorded on them in the system format, i.e., using a specific bit and track density and modulation method. The recording system and transports should be carefully adjusted to minimize head misalignment and skew effects. Various investigators have reported that computer tapes which had been recorded at 800 bits per inch (BPI) using the non-return-to-zero (NRZI) mode of recording tended to develop more errors in storage than tapes which were recorded using phase encoded (PE) methods.* It has been recommended that either a 1600 bpi PE method or an NRZI method at a lower information density such as 200 bpi be used for archival storage purposes. Although relatively new, it appears that the state-of-the-art high density, 6250 bpi computer tapes will probably have good archival qualities because of the extensive error detection and correction codes into which the recorded information is embedded. Another experimental finding of interest by NASA-GSFC is that there are regions along the length of many computer tapes that appear to be more susceptible than other regions to developing data losses while in storage. On a typical 731m (2400 ft) length computer tape, these undesirable regions are from the beginning of the tape to the 100m (328 ft) point, from 300m (984 ft) to 400m (1312 ft) and from 600m (1968 ft) to the end of the tape.

It was noted that if a recording strategy could be devised which avoided these regions then there could be a significant increase in the useful storage life of the data on the tape medium. In this study, a tape was rejected if more than one permanent error was detected over any 300m (984 ft) of the tape. It was also felt that an effective strategy might be developed which was based upon the statistically derived observation that there was an optimal block length which minimizes tape errors while realizing efficient packing of the data. The block lengths however are usually constrained by the system requirements and a practical application of this concept may be difficult to achieve.

After the tapes have been finally recorded, the write enable ring is removed in order to protect the data against erasure. Then, a "read only" pass is performed on each tape to verify that it is completely error free before being put into standby. The tapes should then be rewound at the normal operating speeds using a constant tension or programmed wind of six to eight ounces in order to avoid large variations in pressure from building up in the stored reel. The winding of the tapes before storing is a very important part of the layaway procedure since considerable mechanical damage can be caused by nonuniform and excessive stress build-up in the windings, particularly if the ambient storage temperature and humidity undergo large variations. Excessive tape winding pressures and temperature swings can produce permanent distortions of the tape while very low winding pressures can produce layer-to-layer slipping and creasing or "cinching" in the tape pack which can lead to serious data losses.

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*This is due to the deformation previously described.

It has been noted that tapes which are recorded and read over only a small portion of their total lengths display a greater tendency towards cinching. In addition to winding the tapes so that they experience the proper tension, it is important to maintain the tape transports in good mechanical condition so that they will produce smooth tape winding quality That is, the edge of the tape pack should show no protrusion of individual tape layers after being wound on the reel because this causes tape edge damage and data losses. The hub or center of the tape reel is the strongest and most stable member of the reel, therefore, the reels should be both handled by and stored while supported by the hub whenever possible Operating personnel should be instructed not to handle the tapes by their flanges since this can cause tape edge damage as well as flange damage. The operating environment should be kept clean and in the case of long-term storage the tapes should be stored in clean transparent plastic canisters which may in turn be sealed in clean plastic bags. Transparent plastic canisters are desirable because the tape labels can be read without opening the units.

It may often be necessary to transport the tapes to various vault or repository locations for the standby or storage phase. Containers should be used which are designed to resist temperature variations, moisture, dirt, and shock. The magnetic tape should be two to three inches from the outside surfaces of the container. This will protect the recorded tapes against external magnetic fields which could erase or damage the tape signal. Ferromagnetic containers would afford considerabl protection but tests have shown that this is an overkill except for the most valuable tapes. Considerable efforts should be made to control the logistics of the medium transfer to a vault or other location. Storage en route in extreme cold or high temperature environments which are sometimes encountered in uncontrolled warehouses should be absolutely avoided unless these ambients can be passed through rapidly. It is recommended that the media vaults and the testing facilities be in proximity to the plants. If a sufficient number of these deactivated plants exist, it may be feasible to construct centrally located vault systems and testing facilities to service the entire U.S. complex.

STANDBY PHASE

Standby is the program phase which deals with the archival properties of the media and system. The Chief Archivist of the United States has established that "archival" is defined as "permanent-forever." Howeve since most practical stored materials neither require nor possess such extreme capabilities, several other varied classifications have arisen. These are: medium term--up to approximately 10 years; long term--approximately 100 years; and expendable--used and discarded within a short time. Since it has been estimated that present day computer magnetic tapes have a shelf life of approximately 15 to 20 years, it appears that the standby phase should be considered as a medium term archival program. It will be seen that the dynamic portion of the standby program can extend the archival time well beyond the medium term.

The standby program consists of a static phase and a dynamic phase. The static phase deals with the control of the ambient storage environment and the physical housing of the magnetic media. The dynamic or active portion of the standby program consists of measures which can be undertaken, often on a scheduled basis, to prevent, to seek out, and to circumvent the loss of stored data due to the physical distortion of the medium.

STATIC PHASE

The static measures consist of maintaining a proper temperature, humidity, and security environment for the stored tapes. A good storage environment is one which approaches the characteristics of a tape test laboratory. Although the very high class clean room conditions which are produced for example with laminar air flow systems through electrostatic filters are not needed, positive internal air pressure systems in the vaults are highly recommended. This will prevent the intrusion of external dust into the storage area. The vault temperature should be maintained at approximately 15.6°C (60°F) to 26.7°C (80°F) at a relative humidity range of from 40% to 60%. Whenever possible, the temperature and humidity of the media vault should be close to that of the operating computer environment in order to avoid subjecting the tapes to large ambient changes when they are transferred from the vault to the computer installation. The tapes should always be stored in an upright position and supported by their hubs in the enclosed canister.

There are commercial organizations* available that provide secure storage vault services for computer magnetic tapes, microfilms, and paper. They are often located underground in order to protect the stored materials against explosion. They are held at a constant temperature and humidity and employ electronically filtered air systems. The use of these commercial repositories would be very valuable if a redundant storage approach is taken, i.e., duplicate tapes are made for all or part of the tape library and stored in various locations as a precautionary measure.

It has been found that a magnetic field supplies the only kind of energy that can cause undetected data destruction without any accompanying physical distortion or damage to the magnetic storage media. It has been determined experimentally that normally there is no need to shield the stored data against x-rays, high voltage fields, nuclear radiation, high frequency fields, or light energy. Most important, a spacing of only a few inches is sufficient to protect the recorded media against magnetic fields which are far more intense than are ever found in the normal environment or that can be produced by a concealable permanent magnet.

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*For example, see Information and Records Management, page 38, January 1977.

Finally, security measures should be undertaken to protect the tape vault against unwarranted intrusion or catastrophic damage. This is done with monitoring devices such as magnetometers and properly insulated vault construction which can protect the tapes against fire hazards. Fire has been found to be the greatest threat to the magnetic tape repository.

DYNAMIC PHASE

The dynamic portion of the standby program consists of ongoing measures which can be instituted to improve the chance of survival of stored magnetic computer tapes and their contents. These measures include tape rewinding, physical inspection, recopying of key tapes, and scheduled reading of sample tapes from all of the tape files.

It has been found that if the tapes are "exercised" by winding and rewinding them several times on an annual or semiannual basis before tape errors have formed that many errors can be circumvented. The rewinding process which is performed at normal operating tape speeds tends to remove some of the stresses which have built up in the tape reel during the storage interval and can remove incipient errors.

There are two types of tape errors: temporary and permanent. Temporary errors can usually be removed by cleaning and rewinding the tape, while permanent errors, which are caused by defects such as missing oxides, deep scratches and creases, are not removable. It has been found that even temporary tape errors tend to become permanent if they exist for a long time in storage. Usually a small sample (approximately 5%) drawn from a large tape file is representative of the tapes in that same file. It is recommended that a random sample of tapes from each file should be read on an annual basis and checked for permanent errors. If these errors exist, it may be necessary to read through the entire file and recopy or replace all of the defective tapes. Computer installation managers will sometimes recopy their important tapes on an annual basis as a normal routine. If there are no permanent errors on a stored computer tape, then it is possible to recopy the data onto a new tape and to rehabilitate the original tape for future use. Rehabilitation of good used tapes consists of erasing, cleaning (wet or dry), recertifying, rewinding, and relaxing the tapes before returning them to service. There are commercial organizations which specialize in tape rehabilitation. Some Government organizations such as NASA have an in-house tape rehabilitation facility.

Tapes should also be inspected visually for any physical defects such as cinched, i.e., creased and folded over layers of tape, warped tape edges, discoloration, etc. Tapes which display these defects should be checked immediately for data losses, recopied, and replaced if necessary.

REACTIVATION PHASE

The success of the reactivation phase is strongly influenced by the measures that are taken in the layaway and standby operations.

When the computer tapes are brought out to the computer installation from the vault, they should be permitted to adjust themselves to the ambient temperature and humidity of that environment for approximately 24 hours before being placed into operation. The tape operating environment at the computer installation should also be maintained as a clean area by using positive internal air pressures at flows of several thousand CFM.

Avoid bringing products such as paper stock and cardboard or other lint producing items into the high pressure section of the installation where the tape transports should be located. No cigarette smoking or eating of food should be permitted in the computer room. The operators should be trained to handle the reels by their hubs and not by their flanges and should return the tapes to their canisters when not being used. The tape operators should use clean lint-free smocks (for example, 100% dacron polyester) and gloves while on duty.

The recovery of the original data from the stored tapes is the indicator of success for the entire operation. During the reactivation phase, the data base which has been stored on the computer tape is transferred into the computer to load the system or it is transferred to peripheral devices such as rapid access magnetic disks for on-line operations. In the event that data loss problems are found to have developed during this transfer phase, there are some corrective measures which can be undertaken. For example, it was noted previously that tapes which are recorded at 800 bpi in the NRZI mode tend to lose data easily. The cold flow distortion and skewing of the tape is believed to be the principal cause for the data loss at this density. Sometimes the tape can be sufficiently straightened by rewinding it at normal speeds several times, and then relaxing the tape for one or two days and then finally winding and rewinding it a number of times on the transport which will be used to finally read the tape. This same procedure can be initiated before reading a tape if it is noted that the tape windings appear to be irregular with some tape edges protruding from the pack.

There is a wide range of electronic and mechanical transport adjustments which can often be performed by technical personnel which will recover marginal tape information. Quite often a tape which is difficult to read on one transport will be read easily on another. It has been noted that some tape drives which have the capability of reading backwards can often read a balky computer tape which resisted being read in the forward direction.

SUMMARY

Measures have been described which can be applied during the layaway and standby phases of the computer magnetic tape program; these measures greatly enhance the probability of successful reactivation and final data recovery. It should be noted that this paper has outlined only a portion of the possible actions which can be taken to preserve the media and its data and that there is a considerable amount of research which must still be done in the area of the archival properties of magnetic media. The guidelines which have been presented in this paper are generally applicable to all flexible magnetic storage media with some additions required for different media housings. It is not anticipated that large data base archival systems will use computer magnetic disk pack systems in lieu of the lower cost magnetic tape systems.

The following is a summary of the practical procedures which have been described in the paper. They assure the successful reactivation of magnetic computer tapes and the recorded data.

LAYAWAY PROCEDURES

1. Purchase computer magnetic tapes which are based upon specifications such as U.S. Interim Federal Specification WT-0051C (GSA-FSS), March 1, 1975.

2. The magnetic tapes should be certified within six months prior to being stored.

3. Permit a maximum of five write skips on any chosen magnetic tape. The tapes should have been run less than 50 but more than 4 full passes before testing or storing.

4. Purchase tapes which have been produced within the last five years.

5. Avoid the 800 NRZI data recording format.

6. Perform a "read-only" tape pass prior to storage.

7. Rewind the tapes at normal speeds using constant tension or programmed winding techniques.

8. Package the magnetic tapes in clear, transparent canisters.

9. Shipping containers should resist temperature variations, moisture, dirt, and shock.

10. Prolonged temperature and humidity extremes should be avoided when the tapes are transported.

STANDBY PROCEDURES (STATIC)

1. Maintain vault temperatures ranges of approximately 15.6°C (60°F) to 26.7°C (80°F).
2. Maintain a vault humidity range of from 40% to 60%.
3. Employ positive internal air pressure systems to reduce dust in the vault.
4. Use commercial vault systems for redundant tape storage if feasible.
5. Store tapes in an upright (vertical) position.
6. Maintain vault security against entry by unauthorized personnel.
7. Use magnetometer detection for concealed permanent magnets.
8. Maintain insulated vaults against fire hazards. Insulate the vaults for fire resistance up to at least 66°C (150°F). Allow a minimum of combustible materials within the vault area.
9. Carbon dioxide (CO_2) and water are permissible for fire extinguishing.

STANDBY PROCEDURES (DYNAMIC)

1. Exercise each stored tape on an annual or semiannual scheduled basis.
2. Read at least one tape from each small tape file annually and a 5% random sample from each large tape file. Recopy and replace defective tapes which have shown data losses.
3. As an option, recopy very important tapes on an annual basis.
4. Inspect tapes for creases, warped edges, discoloration, or other physical anomolies. Recopy and replace if necessary.
5. Maintain all of the operating magnetic tape transports in a clean and properly adjusted condition. Check for points of wear in the tape head and guidance system which can cause tape damage.

REACTIVATION PROCEDURES

1. Relax the tapes in the computer environment for 24 hours before they are run.

2. The computer installation should be maintained as a clean area by using positive internal air pressures. Avoid introducing dust or lint producing products into the computer area.

3. Operators should be trained relative to the proper handling of the magnetic computer tapes.

4. Exercise tapes which display skew losses or which are not evenly wound.

5. Technical personnel can recover marginal data through electronic and mechanical adjustments.

6. Balky computer tapes can sometimes be read in reverse more effectively then in the forward direction.

The information and recommendations in this paper have been assembled from various sources including personal investigations and private communications, particularly with members of the National Archives and Records Services staff to whom the author is indebted.

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PAPER NUMBER 6

ENVIRONMENTAL EFFECTS ON ELECTRICAL AND ELECTRONIC DEVICES AND EQUIPMENT UNDER LONG STORAGE CONDITIONS

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ENVIRONMENTAL EFFECTS ON ELECTRICAL AND ELECTRONIC DEVICES AND EQUIPMENT UNDER LONG STORAGE CONDITIONS

An important aspect of the Base Modernization Program (under the direction of the Project Manager's Office for Munition Production, Base Modernization and Expansion) is to take advantage of historical information and modern expertise, and to insure that facilities which produce munition type items can be mobilized quickly and effectively. Automatic processing has required sophisticated computer control systems to perform a variety of functions with reliability and speed, hence reducing human error while increasing safety and production rates. It has been shown in a broad range of systems and industries that computer control production lines can be extremely effective, both cost and reliability wise. Although the same advantages apply to Munition production, a distinct difference exists: the base modernization program requires shutting down for long periods of time, referred to basically as layaway. After periods of dormancy there will be some effect on the ability to restart the system properly, impeding needed mobilization rates, effectiveness and safety. The degree of these problems is quite dependent on the attention we pay to shut down, layaway and restart procedures and problem identification to address dormancy effects.

This paper will address the control system and the interface electronics. It is well recognized that other problems are associated with layaway which are not to be minimized. However since our interests, experience and expertise lie basically in understanding failure mechanisms and failure modes of microelectronic devices, this is our present area of concern.

This discussion will be divided into two phases. First is a dedicated effort in the area of failure analysis. Second is a standby monitoring of subsystems to observe important parameter values for determining how degradation proceeds to adequately signal when out of spec or catostrophic failures occur.

A discussion of these two phases follows but first a basic premise should be considered. A most obvious question, "Does time alone degrade microelectronic devices?" That is, if a reliable system is operating in a prescribed fashion, and left in a dormant state (even with the temperature and humidity control) will the system degrade as a function of time?

Although information in this area is limited, it appears the answer to this question is a definite yes. This is based on observation in the technical community and in particular the munitions industry. Stockpile testing show that after a system, either complex or simple, has been left in a dormant environment and then put through the same testing program as similar units had passed earlier, a marked change in reliability mechanism and its trend before catostrophic failures occur. This is one single situation indicative of the role and value of the failure analysis facility for establishing an effective layaway program.

An even better way to address the above problem can be accomplished by placing components in a laboratory storage test and evaluation program simultaneous with their life cycle in the plant. Therefore, let's look at a unique complementary way to track and prevent failures from occurring in our systems and more accurately and timely determine how the dormant environment affects microelectronic devices of concern.

To accomplish this we are proposing test and evaluation of selected components to be done on a coninuing basis using the Long Term Dormant Storage Data Acquisition Facility. We are suggesting to withdraw specific spare parts normally obtained from stock kept at the site. These may include a variety of items including sensors. A selection of these components/sub-systems will be made and used as prime candidates to be maintained in a simulated storage environment in the laboratory at the ARRADCOM facility and specific electronic monitoring of these items will be performed. Test sets and systems software would be developed to automatically measure important parameters on a routine basis for permanent computer storage. The accumulated data will also be analyzed routinely. Small changes in the operating parameters of the components on the board will be observed and as realizable the trends of degradation which occur in these microelectronic devices will be gleaned and the mechanisms which are causing these trends to occur will be evaluated. Determination of how these trends will effect efficient, reliable and safe operation will be established and recommendation to ARRCOM will establish what type of action is needed to either curtail the trends or to engineer your way around them. Feedback to the periodic maintenance procedures is the most likely way to keep the control system operational. This is also the most effective way to prevent catostrophic failures from occurring which may occur at a time when system operation is required. The ARRADCOM has an ongoing facility to measure fuze components in the dormant environment specifically designed to determine how device degradation occurs in relation to years of this type of storage. It is a straightforward matter to incorporate a large number of the components and subsystems from the base modernization program into our dedicated Dormancy Evaluation Facility. Once trends have been established and failure mechanisms determined a greater degree of assurance (of how devices will perform in a dormant environment) can be made. Needed changes could be prescribed for our new systems.

This paper above describes two extremely important areas which need to be addressed. It makes poor engineering sense in our estimation, to do maintenance on a system without benefit of detailed failure analysis to determine the cause of failure. In any case this information is extremely important in future layaway systems and will help improve maintenance of present systems and perhaps allow the maintenance interval to be expanded which would reduce the cost of maintenance. In and functioning is noticed. Similar observations were noted by Martin Marietta, in two separate studies which have shown that degradation of microelectronic components does take place as a result of storage alone. This work was reported almost a decade ago. Revisions to their report have been made in the last few years. The work clearly indicates that microelectronic devices and electronic devices in general do degrade as a function of time. Although this degradation may be slow compared to the microelectronic degradation rates which are published for active devices, the degree of degradation can be important to a particular storage situation. It appears certain that time alone does change microelectronic component behavior. Since microelectronic components are used extensively throughout the base modernization program a layaway program must address this aspect if a position of readiness is to be realistic.

It is assumed that the plant control system facilities will be put into some sort of dormant or layaway status. For the purpose of this discussion assume that the control system and housing will be left in a temperature/humidity controlled environment, (temperature would be maintained at approximately 75° F ± 5° in the humidity will be controlled to some value less than 50%). At some period of time (this period is open to discussion and should be a major point of this conference, however, will not be addressed in this paper) the entire system will be reactivated following prescribed start up procedures. As maintenance personnel perform this task, specific adjustment and calibrations will be made and the checkout procedures should identify by system, subsystem, assembly or component, any out of spec operation. Each such item should be removed and replaced. These defective items should be identified to the ARRADCOM failure analysis point of contact and returned as per their instructions. Given these assumptions we will indicate how the failure analysis group should be dedicated to determining the failure modes and trends that exist in dormancy and interface with the layaway program.

Upon receipt at the central failure analysis facility, a complete diagnostic analysis will be performed. The item will be cataloged for identification with details such as its lot, date code. The specific failure mode will be analyzed and the failure mechanism determined. The realtionship of the failure to the system performance and safety will be determined; e.g., is the failure mechanism generic or random in nature.

Control systems of the type we are concerned with generally have a number of repetitive device-types since the design engineer or company applies similar logic elements as many places as possible for design purposes as well as to reduce inventory and parts control. This also breeds greater familiarity with that component among the design engineers and commonality of device selection can propagate further. This can give a distinct disadvantage to the user if a defect does exist in a device type of a particular lot date code as it may exist in all of those components with the same lot date code. Even worse, it could exist in all of the devices made by that same technology. It is therefore important to determine the failure mode and identify whether it was a random or other type of failure mechanism. Failures can be caused to occur due to improper stimulization in either the shut down or start up procedure hence root-cause also needs to be classified as well.

An additional advantage of a central failure analysis facility, controlling the detailed failure analysis and categorization, is the ability to maintain an exact record of how specific components and technologies relate to performance and safety in the layaway environment. Also determinations can be appropriately feedback to the design engineers.

A simple illustration may be given: consider a hypothetical case of a plant which has been successfully checked out and the control system has functioned properly. The system is shut down following prescribed guidelines and a period of dormancy ensues, say for approximately one year. The maintenance organization performs system start-up following prescribed procedures. A number of adjustments were required in the voltage stabilization portion of the logic section however tolerances could be met successfully. The unit was returned to layaway for another year and periodic maintenance was again performed. This time it was impossible to complete the calibration of the voltage regulation circuit. Appropriate microcircuit cards were withdrawn and new ones were plugged in allowing calibration to be completed. Removed cards were returned to the failure analysis facility. The failure mode was analyzed and is determined to be a shift of the Zener parameter causing an out of spec behavior. The trend indicates adjustments at the plant will soon not be able to be made to attain the proper output. Circuit evaluation, analysis of test data (available and generated) is combined with special examination of the solid state components to isolate the xener as the culprit. The Zener is then scrutinized with further special tools such as the scanning electron microscope, microprobe, and optical microscopy.

The analysts established that the failure was due to oxide breakdown due to a type defect common in that particular lot date code. Regulators from other control boards from that system are examined. It is determined a trend in parametric behavior is present which shows degradation is taking place. Effected boards can be withdrawn from the stockpile and retrofitted with a newly selected diode which are not subject to the same type of failure mechanism.

Now assume failure analysis was not done in the suggested fashion and maintenance again tries to adjust the system as prescribed. Again they would find that they have to adjust the voltage regulation circuit and perhaps one or two cards are replaced. The system continues until the inevitable time the Zener diode fails catastrophically causing the board to burn out or causing serious voltage stressing of other components in the system. This is not a far fetched hypothesis and in fact has been observed to exist in similar situations. It is clear from this hypothetical case that you would much prefer to determine the failure addition, we have an opportunity to examine selected devices in a controlled environment and determine the effects of dormancy on a routine basis. Hence we can understand the behavior of the devices with time, and this trend information can be applied to our present systems as well as those being developed.

PAPER NUMBER 7

A LAYAWAY PROGRAM FOR CONTROL VALVES

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A LAYAWAY PROGRAM FOR CONTROL VALVES

INTRODUCTION

It is the intent of this presentation to bring together in outline form many of the factors that should be considered for a layaway program for control valves with a view to stimulating discussion and further analysis. There will be many ramifications and special situations, but I think we can say there are three basic steps involved in the preparation of a program.

First, guidelines and objectives must be specified.

Next, instructions and layaway data should be prepared.

Finally, there must be a recordkeeping system for this data plus equipment records.

GUIDELINES AND OBJECTIVES

Ground rules for the plant as a whole presumably will be available where needed. Some of the items to include in the ground rules are the following:

Expected duration of a startup

Cost of delays during startup

The degree and nature of monitoring during shutdown

Minimum and maximum duration of the shutdown

Materials and methods for recordkeeping

Recommended practices for handling time-related deterioration

INSTRUCTIONS AND LAYAWAY DATA

Collecting, screening, and documenting data for layaway instructions requires engineering consideration and time, hence it is costly. Some generalized data may be obtained from equipment suppliers, but the main burden will fall on in-house personnel. A prime and valuable source of data is the on-site operating and engineering staff who will have first-hand experience with the various, and often noxious, process fluids encountered.

The principal problem for valve layaway programs is corrosion. If a carbon steel valve can be flushed after shutdown and left in a warm, dry place with no pockets of fluid inside, it should stand up indefinitely. On the other hand, moisture pockets in various areas, such as the lower portion of a stuffing box, will cause corrosion in carbon steel. Just the moisture condensation from atmospheric conditions in summer will cause rusting in a carbon steel valve. But valves are not unique in this regard, and they can be treated in the same manner as other carbon steel equipment. It is also important to flush and clean out corrosive solutions from an alloy steel valve. Keeping a roof over idle equipment, and preventing sudden changes in temperature will help prevent corrosion. For noncritical areas, a small amount of rust on equipment can usually be tolerated. When rusting becomes a problem, you should consider replacing carbon steel with stainless steel.

Dissimilar metals in contact with one another, as you know, are subject to galvanic corrosion. Typically we have found that #416 stainless steel in contact with nickel will pit within six months. Any of the #400 series stainless steels in contact with a #300 stainless steel can be a source of galvanic corrosion. Particular items to watch are valve plugs and plug seals in contact with valve guides. Another item is valve stems in contact with stem bushings. Stellite 6 and other cobalt alloys are almost entirely free from galvanic corrosion and are good materials for these applications. Teflon coatings or parts are equally corrosion free. It is easy to conclude from these observations that specification of the proper materials in the early design stages can reduce cleaning and storing problems at layaway time.

When two surfaces are in contact with each other and subject to vibration, fretting may occur. Normally two surfaces stored in contact will be in a static condition, particularly when an operation is shut down. However, fans or compressors in operation nearby can create enough vibration at times to be a hazard to stored equipment.

Elastomers have a limited shelf life. Elastomer rings for slipper seals, seat ring seals, actuator diaphragms, and static "O" ring seals are a few of the items in this category. When items are made of elastomer materials, their shelf life is a factor governing a layaway program.

As you know, teflon has a tendency to flow under pressure. It is essential to reckon with this factor when planning the stock for replacements of teflon items such as soft seats for valves.

Any plants located near salt water will have a special problem with chlorides. All steels, even #316 stainless steel, are subject to stress corrosion when in contact with chloride solutions. Potential damage from this factor should be assessed and all reasonable actions taken to limit the corrosive effects. When the chlorides are present in the process, one would expect to find extensive use of alloys such as Monel, Hastelloy C, and Hastelloy B.

Sometimes it is necessary to take certain valves apart at shutdown to clean them or dry out pockets of fluid. When this is done, the valve should be serviced and stored ready for startup. Usually carbon steel valves can be stored in the pipeline. It is desirable to monitor the valve condition periodically on representative units and record findings.

Valve positioners and signal converters should be recognized as instruments and treated accordingly. Even though they may be assembled as an integral part of the actuator, the whole assembly should be treated as an instrument. This may required indoctrination of personnel.

The considerations discussed are representative of many operating conditions found in plants and processes. The list is almost endless, and I invite you to add to it from your experience.

DOCUMENTATION

Records are essential so that guidance and basic information may be available to those who follow. The subject can be divided into five main topics:

Control valve records

Specification and procurement instructions

Shutdown procedures (reference data)

Layaway procedures (reference data)

Startup procedures (reference data)

Most of these topics are interrelated and can seldom be analyzed independently of one another.

Generally the valve layaway records should form a part of the equipment and maintenance records. Control valve records could look like this:

Control Valve Records

a. Identity - tag and location in process line

b. Procurement data

    Supplier

    Manufacturer

    Order No.

Date Purchased

Serial number

Size

Body material

Class

End connections

Actuator pressures

Bench Open Closed

Process Open Closed

c. Process data:

Fluid

Upstream press Max. Min.

Downstream press Max. Min.

ΔP Max. Min.

Temperature Max. Min.

Flow Max. Min.

C_v Max. Min.

Viscosity Max. Min.

Specific gravity Max. Min.

d. Signal data:

Instrument output signal

Converter - input signal

output signal

location

power required

Positioner-input signal

output signal

power required

e. Layaway and startup data:

Procurement reference - see below

Shutdown reference - see below

Layaway reference - see below

Startup reference - see below

Location during layaway

Spare parts for startup list, part numbers, quantity, location

Special tools and location

Startup priority (a process decision)

f. Spares and replacements:

This should include a complete list of parts required for normal operation and for layaway program.

SPECIFICATION AND PROCUREMENT INSTRUCTIONS

These instructions can be very simple or quite detailed depending on the information available. Care should be taken to dovetail special requirements for a layaway plant with general specifications for plants that remain in service.

General Instructions on the Following:

Selection of body material

Elastomers, i.e., composition for actuator diaphragms

Plastics

Packing, i.e., inhibitor with grafoil

Actuators

Standardization

Specific Data for Each Process Solution, Temperature, and Pressure

Body and bonnet material

Trim material

Stem material

Packing

Gaskets

Soft seats

Seals

Combinations to avoid galvanic corrosion, e.g., 440C and nickel are incompatible

  Plug and guide materials

  Stem and guide bushing materials

  Seal ring and guide

  Cobalt alloys are high resistant to galvanic corrosion

Other

SHUTDOWN PROCEDURES

Prepare standard shutdown procedures covering the following:

Flushing instructions

Draining and drying instructions

Storage instructions

LAYAWAY PROCEDURES

Prepare a series of standard layaway procedures for each different set of conditions, covering the following:

Is the valve to be removed or left in the line?

To what extent will the valve be taken apart?

Cleaning instructions. Solutions required, areas to watch, e.g., remove pockets of liquid in stuffing box.

Protective coatings compatability with process fluids, removal instructions, etc.

Parts to be stocked for reassembly, e.g., gaskets, packing, soft seats, actuator diaphragms.

Instructions for maintaining stock of parts with limited shelf life.

Reassembly instructions (if stored unassembled).

Type of location during layaway. Special instructions, e.g., temperature, moisture, vibration.

Personnel involved, training, magnitude of task.

Type of tools required. Data on special tools.

STARTUP PROCEDURES

Prepare a series of standard startup instructions. The following items should be covered:

Priority

Elapsed time for preparation

Rehabilitation data

  Tools required

  Personnel required

  Size of task

  Removal of protective coatings, etc.

  List of replacement parts

  Assembly instructions, i.e., bench initial, hydrostatic test, seat leakage, hysteresis

Installation instructions

  Tools required

  Personnel required

Procedures, precautions

Data on line leakage test

System test procedure

This summarizes my immediate thoughts on the matter of layaway programs for control valves. I trust this outline will help those who have no formal programs and stimulate additional thinking on existing programs.

PAPER NUMBER 8

THE INDEPENDENT TESTING AND PROVING OF HARDWARE AND SOFTWARE ELEMENTS OF PLANT COMPUTER CONTROL SYSTEMS ON REACTIVATION OF MUNITIONS PLANTS

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THE INDEPENDENT TESTING AND PROVING OF HARDWARE AND SOFTWARE ELEMENTS OF PLANT COMPUTER CONTROL SYSTEMS ON REACTIVATION OF MUNITIONS PLANTS

INTRODUCTION

There has traditionally been a separation between hardware and software in computer control systems. Typically, different people--often in entirely separate organizations--are responsible for the hardware than for the software. These two groups usually, by default, test each other's work. What is needed, however, is independent testing of both the hardware and the software to insure proper operation under all possible conditions. The overall system must be structured in a manner to make this possible, and in an optimal way.

I recommend integrating a judicious philosophy of independent testing with a five-part approach to optimize the reactivation of computer-controlled munitions plants.

Modularize the system.

Design for start-up.

Use applicable standards.

Design in reliability.

Separate design and implementation.

SYSTEM MODULARITY

Modularity is very important in any sizeable system. The overall task must be broken down into manageable sections. Both hardware and software need to be modularized. Each module can then be tested independently before it is integrated into the total system. It should be possible to perform the same or similar tests - again independently - for continued maintenance after the system has been installed.

Properly structured modularity will permit optimizing the hardware-software tradeoffs in system design (1). That is, the total system should be structured and modularized, then the decisions made as to which sections are to be implemented in hardware and which are to be in software.

I find it inconceivable that any major production facility will be designed and built once and not have changes made to it. As new technology makes better performance possible, it is essential that appropriate improvements be made to the original design. Again, a properly modularized system will allow such changes to be made with minimum cost and minimum effect to the remainder of the plant. This includes future substitution of software for hardware, or vice versa.

There are many ways to slice a pie. Likewise, modularity may be obtained in a number of different ways. Functional modularity offers many significant advantages over other methods (2), particularly in regard to testing and maintenance of the system. Take, for example, the instrumentation for a temperature signal, such as from a thermocouple (t/c). Such instrumentation could be modularized in the following manner:

Cold junction reference

Multiplexing with other analog signals

Analog-to-digital conversion

Digital multiplexing into the computer

Signal linearization of the t/c signal (software)

However, this method generates a variety of relatively arbitrary intermodule signals of which the specification and testing can quickly get out of hand. A better approach is to use total-function instrumentation where a single instrument module processes the thermocouple input into a digital temperature reading for the computer. Now, any problem with readings from a given t/c can be readily handled with single parts substitution (3).

Software can also be modularized in many ways. The classical method of structuring process inputs and outputs is as follows (4):

Analog Inputs

Analog Outputs

Digital Inputs

Digital Outputs

However, these are hardware-related divisions, when we really need software divisions (5,6). The software portion of the system does not care - nor should it need to know - how the hardware is implemented. The modularity of the system should always provide adequate information hiding.

For example, a liquid flow transducer may transmit a proportional analog d.c. signal (e.g., 4 to 20 mA), a pulse-width modulated contact closure (e.g., 3 to 12 seconds per 15-second cycle), a variable frequency pulse train, a parallel BCD encoded data word, or a string of ASCII characters. Analog input? Digital input? To the software, it is just "input a proportional variable".

A better division for software modularity is by software function. For example:

Input an integer valuc

Output an integer value

Input a logical value (single bit on/off)

Output a logical value

This structure allows the software to be tested independent of the hardware implementations.

DESIGN FOR START-UP

The designers of manufacturing facilities often think of a one-time start-up and give the majority of their attention to the continuous operation of the plant.

> When he was young, J. C. Penny was taught the most important shirts to sell are the last two in the box - that's where the profit is. However, if you don't sell the first ten shirts, you won't have any "last two".
>
> Similarly, the profit in a commercial production facility occurs during its operation. But if you can't get the plant started, you won't have any production at all.

In time of national crisis, the time when a munitions plant on layaway suddenly becomes needed, the highest priority is to get started. (After it is going you can turn your attention to keeping it going). Design first for start-up.

Even plants that are already in operation have occasion to stop, whether by desire or otherwise. The time to restart a plant impacts the overall reliability and usefulness of the facility.

The telephone industry, with its modern computer-controlled electronic switching systems (ESS), has a design objective of no more than two (2) hours total cummulative downtime in the 40-year life of an installation. The early ESS offices experienced downtime rates of 12 hours per projected 40-year life - not good enough. Bell Laboratories found they could reduce the downtime by 50% - just by making software changes.

No, software does not fail, at least it does not wear out or break down as hardware equipment does. Once software is working correctly it keeps on doing that. However, software (and hardware) can fail to meet design objectives, as in the case of the telephone ESS offices. By redesigning the software start-up sequences significant reduction in the mean time to repair (MTTR) was achieved for the telephone operation, entirely independent of the system hardware.

One computer company sold a large system to a customer who had specified unique keying for each different type of circuit card in the system. When it came time for acceptance tests, the customer walked in, removed every card from the system and stacked them in a huge pile in the middle of the room. Then they proceeded to pick up cards at random and try until they found a slot in which the card would fit. After all cards had been inserted - somewhere - they asked the builder to turn the power on. (The manufacturer asked for a two-day delay while they checked the card locations for proper keying). Design for start-up, not just continued operation.

Test for start-up. Test software initilization sequences. Test hardware warm-up times. Test the start-up time after making repairs, i.e., after installing spare circuit cards or spare sensors.

USE APPLICABLE STANDARDS

A key to successful modularity is the use of standard definitions for the interfaces, or boundaries, between modules (7). An industry standard that is applicable in the hardware area is CAMAC*(8,9,10). CAMAC is a modular instrumentation system intended for centralized digital control of plug-in instrumentation units. A number of plug-in units share common power supplies and controller (typically a microprocessor or computer) in a common assembly (crate). The CAMAC standards include both packaging and digital interface specifications sufficient to insure modules will fit together regardless of manufacture.

The basic CAMAC standard (IEEE 583) is further augmented by IEEE 595 (serial highway) and IEEE 596 (parallel highway) which readily allow the centralized control to be extended to handle multiple crate assemblies.

CAMAC is in widespread use throughout the world in nuclear research, astronomy, and other laboratory applications, as well as in industrial production control systems. NASA has studied the use of CAMAC for the Space Shuttle program. As a result, the CAMAC standards are currently

* CAMAC - Computer Automated Measurement and Control

being used to develop equipment for payload instrumentation.

In the software area a noteable standard that may be applied is the programming language FORTRAN**(11). In each case the standards provide valuable design interfaces between system modules. This permits different project teams to proceed independently of each other, each working towards common reference points.

In addition to providing program-to-program independence (Fortran) and instrument-to-instrument independence (CAMAC), the combination of the two provide even more powerful independence, as was illustrated at Purdue University a few years ago.

The International Purdue Workshop on Industrial Computer Systems had already been working on standards for process control computers for a number of years when it was decided the attendees would benefit from a live demonstration of the actual Workshop results. One month prior to the Workshop meeting, the idea was conceived to demonstrate software transportability, using ANSI X3.9-1966 Standard Fortran, with ISA-S61.1 external procedures for process control input and output, and to point out the need for and potential of standards in other areas. Two complete computer systems, including peripherals and process control instrumentation equipment, were borrowed from a dozen sources throughout the United States. The last major component was uncrated at Purdue on a Monday afternoon. Two complete systems, with interchangeable process I/O equipment, and using the same source program deck, were running Wednesday morning (1,5,6).

All process-signal instrumentation used the CAMAC digital interface standard. This enabled the same process instrumentation hardware to be used with each computer system, as well as to make programs using Fortra and the ISA-S61.1 procedures truly transportable.

> The ISA S61.1 procedures had been developed around the Fortran standards so as to be computer independent. However, because of the I/O hardware-dependence of the S61.1 procedures, it wasn't until they were combined with the computer-independent hardware standards (CAMAC) that the applications software actually became computer independent.

The CAMAC system, by the way, provides a standardized "Read Module Identification" function. CAMAC modules may be inserted into any position in a crate, the only difference between positions is the address. The module identification feature permits the start-up software to check for proper module/location match, similar to the keying of circuit cards in older equipment.

One important consequence of using standards must not be overlooke Every module, every design team, must toe the mark. A weakness in one

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** FORTRAN - Formula Translation

module cannot be compensated in the module on the other side of the standard interface. This makes independent testing not only possible, but essential.

This is the reason a set of Tests of Standard Fortran were developed and published by Alcoa (12). They are distributed by Dr. T. J. Williams of Purdue University and have been used by nearly 100 organizations as independent tests of Fortran compilers. In just a few years after the introduction of these tests, there was a noticeable improvement in Fortran compilers available on the market. A similar set of independent tests for the ISA61.1 procedures is also available through Purdue University (13).

Independent module testers have been developed to test CAMAC modules for adherence to the standard interface specifications (14). Independent test units are also available for standard process signals, e.g., from thermocouples, and such testers should be used.

DESIGN FOR RELIABILITY

During a recent visit to the Norden Division of United Technology Corporation, I observed a large sign that read, "You cannot inspect reliability into a product, it has to be built in". I would add, you can't build reliability unless its in the design.

Circuits should be conservatively loaded. There should be no race conditions in the circuit timing. All software sequences should be deterministic. Independent testing is essential.

A common method for increasing reliability is the use of backup systems. How do you insure the backup system will work properly when you need it. (When was the last time you checked the spare tire in your car?).. An operating system has many inherent monitors. A standby system needs comparable monitoring. Even on-line redundancy has limitations for achieving reliability. If duplicate circuits produce different results, which results do you use? Two-out-of-three redundancy requires a voting circuit. What checks it?

Another form of redundancy, and of independent testing, is the provision of software checks for validity of the data acquired from process sensors. Similarly, hardware should include rate-limiting circuits for software generated signals.

> There is a classical computer problem in which an input of value one is to be changed to a value of two, and vice versa. But what if the input is neither one nor two as it should be? Independent testing is needed (15).

Reliability can be improved by including automatic compensating circuits, or programs, such as automatic zeroing to track load cell drift. Independent testing must be provided to test for out-of-range conditions in the compensation circuit itself, i.e, where it could no longer correct for the signal drift (16).

SEPARATE DESIGN FROM IMPLEMENTATION

Independent testing is the backbone of Quality Assurance programs. QA departments are properly separated from production departments. It also helps to separate design and implementation teams. That is, the implementation group should be largely made up of people not involved with the original design. This provides a good check and balance - and early enough to make any necessary adjustments to the design.

How many times has a project engineer wanted to personally check every aspect of the system. This is good to have his interest but, assuming he was involved in the original design, it would be better to have someone unfamiliar with the circuit, or program, do the detailed implementation and debug.

At the same time, continuity is of great importance. All too often initial project planners move on to newer and bigger projects, leaving someone else holding the bag of poor specifications that are impossible, or at least impractical, to implement. As designers of closed-loop systems we must not forget to close the loop on ourselves. Everyone needs feedback in order to correct and improve future output.

CONCLUSION

Independent testing is a primary ingredient for achieving successful start-up or reactivation of any major system. Modularity in system structure is important in making this possible. The use of standards makes all this practical. Testing cannot create reliability but it can help expose that reliability.

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PAPER NUMBER 9

THE LAYAWAY AND REACTIVATION PROBLEMS OF BEET SUGAR MILLS FOR THEIR ANNUAL CAMPAIGNS INCLUDING MANAGEMENT, MANPOWER AND TRAINING ASPECTS

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THE LAYAWAY AND REACTIVATION PROBLEMS OF BEET SUGAR MILLS FOR THEIR ANNUAL CAMPAIGNS INCLUDING MANAGEMENT, MANPOWER AND TRAINING ASPECTS

INTRODUCTION

A large part (25%) of the sugar used in the United States comes from sugar beets raised principally in four regions of this country, the mid west, principally northern Ohio; the eastern Colorado-western Nebraska area; Idaho; and central California. The wide-spread distribution of thi growing area has required the sugar manufacturing companies to develop a large number of small but complete sugar manufacturing plants for this purpose. Since sugar beets have a relatively short storage life these plants must complete the processing of their supply of beets within a three to four month "campaign" starting about October 1 each year when the beets first mature and are harvested by the farmers.

Thus the sugar beet mills must go through a deactivation, a layaway period, a reactivation and an operational period each year. In that respect they resemble the munitions plants being discussed in this Production Readiness Workshop. A description of their methods of handling the several phases of their operation and the reasons for these is therefore considered valuable for the munitions plant discussion.

Figure 1 is a sketch of the flow paths through a typical beet sugar mill indicating the equipment involved. A short description of the processes involved is given below (3). They can be followed on the diagram of Figure 1.

The mills begin operation in early October, the farmer harvesting his crop with machines that uproot the beets. Field workers follow the machines, remove the dirt and leaves from the beets, and load them for shipment to the factory. The beets, containing from 13 to 17 per cent sucrose and 0.8 per cent ash, enter the factory by way of flumes, small canals filled with warm water, which not only transport them but wash them as well.

The beets are rewashed, weighed, and sliced into long narrow strips called <u>cossettes</u>.

The <u>cossettes</u> are dropped into large tanks or cells, 12 or 14 of which are connected in series to form a diffusion battery. The sugar is extracted counter-currently with water at 160 to 175°F., the water being in contact with each cell for 6 to 8 minutes. The resulting sirup contains 10 to 12 percent sucrose, a small amount of invert sugar, and 2 to 3 per cent ash. The pulp remaining contains 0.1 to 0.3 per cent sugar (based on the beets). This pulp is dried and sold as cattle feed.

The sirup is given a rough screening to remove foreign materials.

Milk of lime is added until the concentration is equivalent to about 2 to 3 per cent. The lime aids in the precipitation of undesirable impurities. Any calcium saccharate formed is decomposed in carbonators by passing carbon dioxide through the sirup for 10 to 15 minutes. The foaming that occurs at this stage is reduced by adding a small quantity of soybean oil.

The sludge produced by the lime is equal to 4 or 5 per cent of the weight of the beets charged. This is removed by filtering the mixture on Oliver filters.

Lime is added again until the concentration is equivalent to 0.5 per cent and the mixture again carbonated, this time hot.

It is then filtered on a plate-and-frame press.

The resulting filtrate contains a large concentration of calcium ions, which are removed by bubbling sulfur dioxide through the sirup in sulfitors. At the same time the sulfur dioxide serves to bleach the solution of its pale yellow color.

The precipitate of calcium sulfite is removed on plate-and-frame presses.

The purified sugar is concentrated from 10 to 12 per cent sugar to about 55 per cent sugar in multiple-effect evaporators. This increases the concentration of calcium ions again and necessitates retreatment with sulfur dioxide and another filtration.

The resulting sirup is grained in vacuum pans, centrifuged, washed, dried in a granulator, screeded and packed for commercial shipment.

The sirup from the first vacuum pan is given further treatment to recover more sugar crystals, but they are not pure enough for market and are sent back to the process for further purification.

The sirup remaining after the several crystallizations is called <u>molasses</u> and may be sold to the various industries. Processes for the <u>recovery</u> of the remaining sugar have been worked out and are used commercially. Initial recovery is obtained by the Steffen process.

In the Steffen process the molasses from the centrifugals is cooled to 10°C., and finely ground quicklime added. A precipitate of tricalcium saccharate is formed and filtered off. This "saccharate cake" is washed and returned to the process, where it is mixed with the juice from the diffusion battery, thereby clarifying it in the same manner as the lime which this tricalcium saccharate partly replaced. The molasses remaining, so-called <u>discard molasses</u>, contains about 60 to 63 per cent sugar, 2 to

5 per cent raffinose, and 14 to 16 per cent ash, based on the dry material. It is sold as livestock feed or processed for the recovery of monosodium glutamate and other amino compounds.

OPERATION OF THE SUGAR BEET MILL

As mentioned above the sugar beet mill operates on a 3-4 month "campaign" each year to extract sucrose from sugar beets and convert it into commercial and table sugar. The remaining 8-9 months of the year, the "intercampaign" in sugar company parlance, the plant is idle. It must therefore, each year, go through a deactivation or shutdown, a layaway, and a reactivation or start-up, just as the munitions plant being considered in this Workshop. The major difference, of course, is that it is known ahead of time that the sugar beet mill must be restarted each fall. Thus planning covers this occurrence. In addition, the relatively short "layaway" or inactive period is used for any maintenance or remodelling work needed on the mill prior to its being restarted. No planning need be done for an indefinitely long, totally inactive period which might occur with the munitions plant.

Table I outlines the deactivation or shut down procedures followed in the beet sugar mill. Table II outlines work during the inactive period and Table III covers restart or reactivation operations. The degree of repair work undertaken and the amount of renovation planned during the inactive period is, of course, a matter of available company budgets.

PERSONNEL POLICIES

During the campaign a typical beet sugar mill operates on a staff of about 150 persons. All management and supervisory personnel, skilled tradesmen such as maintenance men, and year-round tasks, such as watchmen, constitute a permanent staff which are full-time employees. All others are part-time employees hired only for the campaign period. The permanent staff amounts to about 45-56 persons distributed as shown in Table IV. The permanent staff carries out as much of the plant repair, renovation, and product warehousing work as possible during the intercampaign. Additional personnel are hired to carry out as much of this work as necessary to assure its completion before the next campaign.

Maintaining all supervisory, maintenance, and key operational personnel on permanent employment does cut down considerably on any training programs necessary for part-time employees hired only for the campaign period. The major training problem facing plant management is the training of laboratory assistants needed to test intermediate and final products, to monitor plant operation and assure product quality. Regular training sessions must be held for this purpose since they are mainly local house-wives hired only for this purpose and turn-over is high.

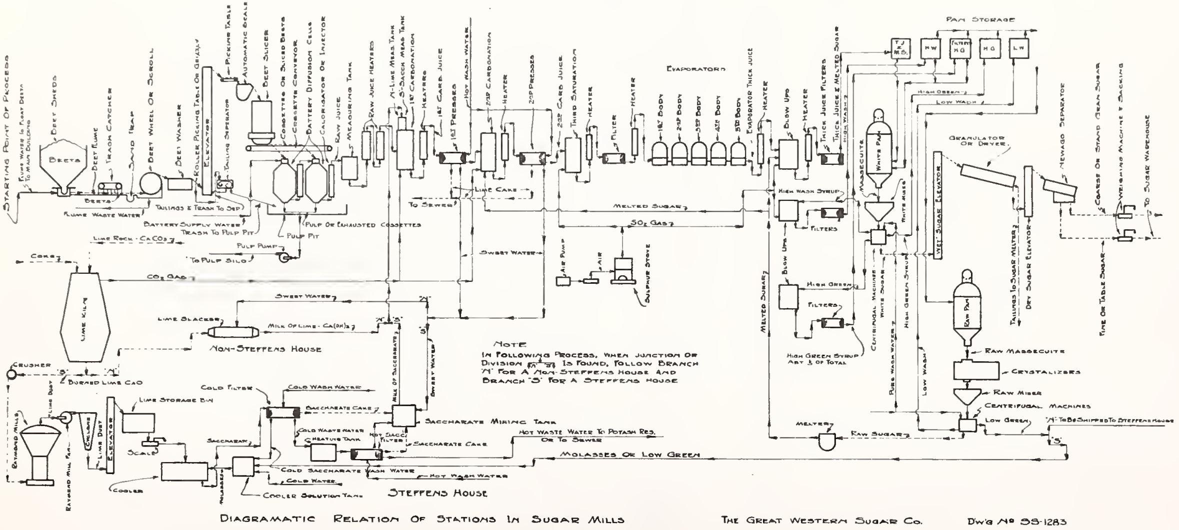
Starting Point Of Process
Flume Water to Float Beets To Main Building
Beets
Beet Sheds
Beet Flume
Trash Catcher
Sand Trap
Beet Wheel Or Scroll
Beet Washer
Roller Picking Table Or Grizzly
Elevator
Tailing Seperator
Picking Table
Automatic Scale
Beet Slicer
Cossettes Or Sliced Beets
Cossette Conveyor
Battery Diffusion Cells
Calorisator Or Injector
Raw Juice
Measuring Tank
Raw Juice Heaters
'N'-Lime Meas. Tank
'S'-Sacch Meas Tank
1st Carbonation
Heaters
1st Carb. Juice
1st Presses
Hot Wash Water
2nd Carbonation
Heater
2nd Presses
2nd Carb Juice
Third Saturation
Heater
Filter
Heater
Evaporators
1st Body
2nd Body
3rd Body
4th Body
5th Body
Evaporator Thick Juice
Heater
Blow Ups
Heater
Thick Juice Filters
Thick Juice & Melted Sugar
High Wash
Beets
Flume Waste Water
Tailings & Trash To Sep.
Battery Supply Water
Trash To Pulp Pit
Pulp Or Exhausted Cossettes
Pulp Pit
Pulp Pump
To Pulp Silo
Lime Rock - CaCO3
Coke
CO2 Gas
Lime Kiln
To Sewer
Lime Cake
Melted Sugar
SO2 Gas
Sweet Water
Air Pump
Air
Sulphur Stove
Sweet Water
'N'
'S'
Lime Slacker
Milk Of Lime - Ca(OH)2
Non-Steffens House
Crusher
Burned Lime CaO
Lime Dust
Raymond Mills
Raymond Mill Fan
Cyclone
Lime Dust
Elevator
Lime Storage Bin
Scale
Cooler
Molasses
Saccharate
Cold Filter
Cold Wash Water
Saccharate Cake
Milk Of Saccharate
Sweet Water
Saccharate Mixing Tank
Cold Waste Water
Heating Tank
Hot Sacc. Filter
Saccharate Cake
Hot Waste Water To Potash Res. Or To Sewer
Molasses Or Low Green
Cold Saccharate Wash Water
Cold Water
Hot Wash Water
Cooler Solution Tank
Steffens House
Note
In Following Process, When Junction Or Division 'N' 'S' Is Found, Follow Branch 'N' For A Non-Steffens House And Branch 'S' For A Steffens House
Pan Storage
T.J. & M.S.
H.W.
Filtered H.G.
H.G.
L.W.
High Green
Low Wash
High Wash Syrup
Filters
Blow Ups
High Green
Filters
High Green Syrup Abt. ⅓ Of Total
Melted Sugar
Massecuite
White Pan
White Mixer
Centrifugal Machines
White Sugar
Pure Wash Water
High Green Syrup
Low Wash
'Wet' Sugar Elevator
Granulator Or Dryer
Tailings To Sugar Melter
Dry Sugar Elevator
Hewago Separator
Coarse Or Stand Gran Sugar
Weighing Machine & Sacking
To Sugar Warehouse
Fine Or Table Sugar
Raw Pan
Raw Massecuite
Crystalizers
Raw Mixer
Centrifugal Machines
Low Green
'N'-To Be Shipped To Steffens House
'S'
Melter
Raw Sugar
Diagramatic Relation Of Stations In Sugar Mills
The Great Western Sugar Co.
Dw'g No 55-1283

FIGURE 1

TABLE I

ACTIONS ON DEACTIVATION OF A BEET SUGAR MILL AT THE END OF A CAMPAIGN

1. All process units: tanks, lines, pumps, etc. are disassembled and cleaned with water. Those units which have accumulated lime scale are cleaned first with acid and then with water.

2. All pump impellers are checked for wear, any which are excessively worn are marked for repair during the inactive period. All bearings are checked for wear and repaired and repacked if necessary.

3. All exposed or smooth surfaces of pumps, valves, etc. are coated with grease or oil to prevent rust.

4. All transducers, valves, etc. are disassembled, checked and repaired as necessary. Parts are stored in a dry place to prevent any corrosion during the inactive period.

5. After cleaning, all instrument boards, power panels, etc. are covered with polyethylene sheets to keep out dirt and excess moisture.

6. Tanks are coated with sugar water or soybean oil to reduce any incipient corrosion.

TABLE II

OPERATIONS DURING THE INACTIVE PERIOD FOR BEET SUGAR MILLS

1. Repairs are made on all units which require replacement or repair prior to the next campaign.
2. Units requiring repainting are taken care of during this period.
3. Any alternations planned for the plant are accomplished.
4. In high humidity areas, those pieces of equipment subject to damage from corrosion are stored in air conditioned areas.
5. Bearings of all large equipment are turned weekly to avoid flat-spotting.

TABLE III

OPERATIONS DURING THE REACTIVATION PERIOD FOR BEET SUGAR MILLS

1. Units are cleaned of protective coatings applied during the deactivation period.
2. All disassembled units, transducer, valves, pumps, motors, etc. are reassembled. All valve stems, impellers, bearings, etc. are repacked as necessary. Packings are saturated with oil and graphite.
3. Once the plant has been reassembled, it is operated with plain water to assure that all joints are tight, that all lines are clear, and that all instruments, pumps and other components are operating correctly.

TABLE IV

PERSONNEL COUNTS FOR A TYPICAL BEET SUGAR MILL DURING THE INTERCAMPAIGN

(I.E., PERMANENT STAFF)

1. Management Personnel
    - 1 Factory Manager
    - 1 Master Mechanic
    - 1 Factory Manager's Clerk-Stenographer
    - 3
2. Maintenance Staff
    - 4 Ass't. Master Mechanics
    - 8 Mechanics
    - 8 Repairmen
    - 20
3. Operational Personnel
    - 3 Supervisors
    - 9 Foremen
    - 8 Operators
    - 1 Clerk
    - 21
4. Watchmen, etc.
    - 2 Watchmen
5. Total - 46

Likewise operators assistants must be briefed by the operators during the reactivation period and the water test phase of initial operations.

IMPLICATIONS FOR MUNITIONS PLANTS

The scheduled reactivation of the beet sugar mill does appreciably change the deactivation and inactive period operations in comparison to the munitions plant. However, it is felt that the experiences of the beet sugar plant are valuable, particularly their steps to inspect, repair and preserve all plant components at the end of a campaign. Thus the munitions plant should be treated in a similar manner - the only difference being more thorough preservative measures because of the indefinite length of the inactive period. It is felt that all items should be in a perfect state of repair before storage to assure the best possible state in the beginning of reactivation.

ACKNOWLEDGMENTS

The author is grateful to the Great Western Sugar Company, Denver, Colorado, and its subsidiary company, Northern Ohio Sugar for access to the information necessary for this paper and for an inspcetion of the Findlay, Ohio, Plant of Northern Ohio Sugar. Special thanks are due Mr. Kenneth Hoff, District Manager of Northern Ohio Sugar and Mr. Daniel D. Lesser, Factory Manager at Findlay, Ohio, for their great help in developing the material for this paper.

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PAPER NUMBER 10

HIGH RELIABILITY DESIGN TECHNIQUES FOR DISTRIBUTED DIGITAL SYSTEMS

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INTRODUCTION

The reduction in prices of minicomputer systems and the availability of a variety of microprocessors and related digital hardware have made distributed digital systems both feasible and affordable in industrial applications. These systems have a number of failure modes and performance characteristics which are different from previous generations of control hardware, and therefore require new reliability design techniques. However, these programmable systems also have capabilities for self-diagnosis and fault tolerance which could not even be considered in earlier hardwired systems. In this paper, the characteristics of distributed digital systems which are relevant to system reliability are described. Also, a number of reliability design techniques which can be used in the development and implementation of the system architectures are described. While this paper was prepared specifically to discuss the problems which exist in the deactivation and activation of munitions plants, the techniques surveyed also can be used in other applications of distributed digital systems.

A DISTRIBUTED SYSTEM FOR MUNITIONS MANUFACTURING

One of the ways in which munitions manufacturing facilities can be improved is through the use of the "latest proven manufacturing technology", as described in Attachment I to the Workshop directives. The latest technology to appear on the manufacturing scene is digital medium-scale and large-scale integrated circuitry, which has been used in programmable controllers, computer information and monitoring systems, and digital controllers for individual units of production machinery. Currently, a number of electronic equipment manufacturers are using this technology to develop distributed digital systems for control and monitoring of chemical processes, electrical power generation and distribution systems, and discrete manufacturing processes.

One possible configuration of such a distributed system in a munitions manufacturing plant is illustrated in Figure 1. In this plant, there are a number of relatively independent production lines, each of which receives parts or subassemblies from (or provides them to) other lines. In general, there is a sufficient amount of storage space for inventory between the lines so that the shutdown of one line for a short time would not shut the whole plant down. In this case, it makes sense from a system reliability point of view to provide a separate page of hardware to control each production line individually. In Figure 1, this hardware is called a "Line Control Unit" or LCU. Each LCU can perform any or all of the following functions:

1) Closed-loop modulating control (e.g., control of continuous melt-pour of TNT)

2) Closed-loop sequence control (e.g., sequential machine tool control)

3) Monitoring of data for record-keeping or safety assurance purposes.

4) Provision of a local interface to an operator for manual control or supervision of the production line.

5) Transmission of data to a central control room.

6) Acceptance of control commands (such as set point inputs, production rate commands, etc.) from a central plant operator interface or computer system.

In addition, each LCU has the following features:

1) Any failure in an LCU does not affect the operation of any other LCU.

2) Each LCU is responsible for only one production line or unit (or a portion of a production line, if the line's complexity is high).

3) Each LCU has its own "intelligence" in the form of one or more minicomputers or microprocessors, in addition to conventional hardwired equipment (e.g., sensors, actuators, controllers, hardwired logic).

As indicated in Figure 1, a Plant Operator Interface System may be provided to allow an operator in a central control room area to monitor the performance of the total plant and to take control actions as appropriate. This system may include both conventional panelboard instrumentation as well as CRT (cathode ray tube) displays, and would be driven by its own computer system or processors. Also, a Plant Computer System may be supplied to execute various plant performance calculations, diagnostic routines, or production optimization functions. The various elements of this distributed system then are connected by a digital Plant Communication System, which allows control commands and other data to be transmitted among the individual "intelligent" system elements.

The operation of munitions plants which are subject to layaway can be divided into three phases: dormant phase, startup phase, and operational phase. In the dormant phase, the system has been deactivated and is in layaway. Periodic tests of system operational readiness may be required to identify dormancy failures and initiate module repairs or replacements. The startup phase occurs after mobilization and may involve a sequenced initialization of the individual LCUs, the computer system and display system. Detailed diagnostic tests at all levels of the hierarchy may be required to verify the operational readiness of each system element before the next step in the initiation sequence is taken. Finally, when the operational phase is reached, the munitions plant is run in the same way as are other continuous manufacturing

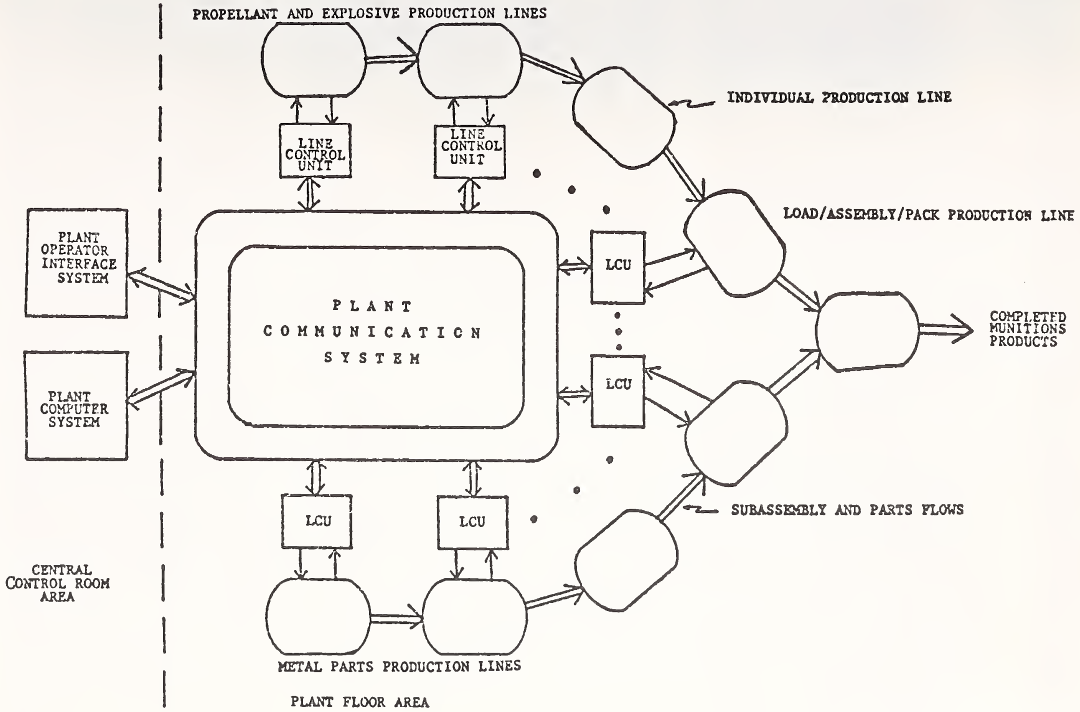

FIGURE 1

DISTRIBUTED CONTROL SYSTEM IN A MUNITIONS PLANT processes. The types of techniques used to ensure the reliability and safety of this system will be different at each phase of the plant's operation. In the next Section some of these techniques are discussed, in the context of the distributed system architecture shown in Figure 1. These techniques are described in more detail in the following Section.

RELIABILITY FEATURES OF DISTRIBUTED DIGITAL SYSTEMS

The structure and performance characteristics of distributed digital systems present both problems and opportunities to the manufacturing system designer. The failure modes and rates of mechanical, pneumatic, and discrete electronic devices have been established through long years of experience; therefore, they can be taken into account in the design process to provide high-reliability systems with acceptable failure modes. As described by Boyd (44) and Bryant (32), the state of reliability design knowledge in the case of processor-based systems is not nearly as well advanced. Thus, the designer must be more careful to follow proven reliability design principles and be perhaps more conservative in estimating the failure rates of system elements.

The two main advantages that distributed digital systems provide the designer in the area of reliability are: 1) the ability to detect actual or impending failures more easily through the use of diagnostic programs, and 2) the ability to minimize the effects of failures on the total system by partitioning the distributed system properly. Neither of these features would be possible without the existence of inexpensive computing power provided by the minicomputer and microprocessor. Diagnostics and self-checking programs can be added to these devices with almost negligible increase in cost. Also, the low cost of the processors allows each to be assigned only a small portion of the total functions of a system, thus minimizing the impact of a single processor failure. In a centralized or integrated control system (such as a direct digital control system in a central computer), there is a danger that the total system will fail if a single element in the system fails. In a distributed system architecture such as that shown in Figure 1, a failure in a single LCU affects only that LCU if the system design has been done properly. (See Reference 5 for a comparison of centralized and distributed system reliability). Similarly, a failure in the central computer or operator interface system (which are at the top of the system hierarchy) does not affect the operation of the LCUs (which are at the bottom of the hierarchy). To ensure that this is the case, a detailed <u>Failure Modes and Effects Analysis</u> (FMEA) must be performed during the system design phase to determine the effect of all likely failures of individual system elements. Another useful design technique which minimizes the likelihood of catastrophic failures is the <u>Common Mode Failure Analysis</u> (CMA), in which system elements having similar mechanical, electrical or other properties are grouped together and analyzed for common failure sources. A related technique which is used to identify potential critical failure modes in a hazardous environment (certainly characteristic of a munitions plant) is the Fault Tree Analysis (FTA) approach. In this method, all possible undesired events (such as explosions) are identified. Then, the combinations of "gated" events which could lead to the undesired event are identified and analyzed for probability of occurrence. (Note: The underlined techniques mentioned above are described in more detail in the next section).

When the munitions plant is in its dormant phase, periodic tests of system elements may be useful in minimizing plant startup time by identifying failures before mobilization occurs. A technique known as Test Interval Analysis (TIA) may be useful in identifying the maximum time interval between which tests should be made to guarantee a given level of system reliability. This approach allows the designer to perform an economic tradeoff between the frequency of tests and the resultant reliability of the system.

The partitioning of the distributed system shown in Figure 1 also allows the selective introduction of redundant hardware at the subsystem level if required to perform critical functions. This results in a more cost-effective system with equivalent or better reliability than a system having redundancy at the total system level. Redundancy can be introduced at the following levels:

1) hardware within each Line Control Unit

2) total Line Control Unit redundancy

3) Plant Communication System

4) Plant Operator Interface System

5) Plant Computer System

Of course, one of the key issues in Redundancy Design is the approach used to combine or switch the outputs of several redundant channels to perform a single function. Some of these approaches are described in the next section.

The reliability design techniques mentioned above are standard ones which have been used in the past in hard-wired system design as well as being appropriate to stored-program digital systems. Other techniques have been developed more recently and are more suitable to the latter class of systems. Fault Tolerant Design Techniques are used to ensure that a system can continue to operate despite momentary or permanent equipment failures. In the distributed system shown in Figure 1, these techniques would be applied to the design of the Line Control Units and Plant Communication System. As indicated previously, the availability of stored program logic allows the use of more sophisticated Failure Detection Techniques or fault diagnostics than were possible previously. These techniques can be applied to the design of both the Line Control

Units at the low end of the hierarchy as well as to the Plant Computer System at the high end. The many advantages of stored program devices are partially offset by the new problem of ensuring that the software which defines the operation of these devices is accurate. While software design can be controlled, reviewed, and documented in the same way as is hardware, its relatively nebulous nature increases the temptation to short-cut sound design procedures. As a result, a number of Software Reliability Design Techniques have been developed to improve the quality of software being generated for distributed digital systems.

RELIABILITY DESIGN TECHNIQUES

The techniques mentioned briefly above are described in more detail in this section. More information on these techniques is contained in the references list in the Bibliography at the end of the paper.

REDUNDANCY TECHNIQUES

Redundancy is a system design method used to improve reliability by providing back-up equipment to replace the function of failed equipment. Redundancy offers the greatest improvement in reliability when the system can be repaired without shutdown. Care must be taken when specifying a type or level of redundancy because in some cases it can actually degrade system reliability. Redundancy is also a costly design method because it requires a duplication of hardware, and, in some instances, additional software. The cost effective design uses no more redundancy than required to achieve the required reliability objectives. There are numerous redundancy techniques. The type employed depends on the specific application. The following are some of the more generally used methods:

1) Simple Parallel Redundancy - The duplication of functionally similar components/modules (channels) with no switching or isolation between channels. This method is employed when the failure mode of a failed channel is such that it does not alter the operation of the remaining good channels. This method could be used to provide multiple paths between LCUs in the Plant Communication System shown in Figure 1.

2) Simple Series - Parallel Redundancy - The duplication of functionally similar components/modules with a series isolation element. This method is employed whenever the failure mode of a failed channel is such that it does alter the operation of the remaining good channels, but the failed channels can be detected and isolated by a simple series element. This method is used in power systems in which power supplies are provided in parallel and isolation is obtained through an auctioneer panel.

3) Stand-by Parallel Redundancy - The duplication of functionally similar components/modules with one or more channels in an off-line mode. This method requires a series switching element. It is employed when the failure mode of a channel could alter the operation of the remaining good channels and when the failure of a channel can be tolerated for the period of time required to switch out the failed channel and switch in the stand-by channel. This method is used in computer systems in which (for example) multiple peripherals of the same type are provided, and the switching device is the control section of the computer.

4) Voting Redundancy - The duplication of functionally similar components/modules with a compare circuit which monitors the output of all channels and which accepts the majority as the correct output. This method requires at least three channels. It is employed when the failure mode of a channel could be any one of several states and the failed states are possible normal states. This method is used in the safety systems for nuclear power plants and in a number of safety-related military applications.

5) Analytical Redundancy - The duplication of functionally similar components/modules with a compare circuit which monitors the output of all channels, and determines when a failure has occurred. It also requires an algorithm which determines the failed channel and bypasses it. This method is employed when the failure mode of a channel could be any one of many states and the failed states are possible normal states. It could be used to provide redundancy in the sensors used in the munitions plant distributed control system. This method typically requires less hardware than the voting method; the difficulty is obtaining an algorithm that can detect and isolate a faulty channel.

A related method which is useful in the study of redundancy is the Reliability Block Diagram (RBD). This is an analysis technique which presents pictorially the success path of the system. Its purpose is to identify all possible success paths leading to satisfactory operation of the system. The RBD does not consider human interactions with the system. Rather, it is used to identify areas within the system that require redundancy.

The RBD is constructed as follows:

1. Define system failure and success.

2. Prepare a list of all system components/modules.

3. Prepare a list of all possible success paths.

4. List for each success path all of the components/modules required for the path.

5. Present pictorially in logical form all of the success paths. Use symbols to represent each component/module.

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

The FMEA is an analysis technique used to identify credible modesl of failure and to evaluate their consequence. Any system employing redundancy or fault location techniques must have knowledge of the possible failure modes of each component/module and their effect on the system. Redundancy would be detrimental if the only possible channel failure mode compromises all channels. Fault location is possible only when one knows all of the failure effects and which components/modules could cause them. The FMEA method outlined below was extracted from IEEE-STD-352-1975.

The FMEA is performed as follows:

1. Prepare a list of all System Components/Modules.

2. For each Component/Module, list the following:

    a) Possible credible failure mode; for each failure mode, list the following:

        i. Possible failure mechanisms

        ii. Symptoms and local effects (including dependent failures)

        iii. Method of detection

        iv. Inherent compensating provision

        v. Effect on system

        vi. Remarks and other effects

COMMON MODE FAILURE ANALYSIS (CMA)

The CMA is an analysis technique used to detect multiple failures attributable to a common cause. Systems stored for long periods in the dormant state may contain some devices approaching or exceeding their design life. Some examples are: shelf life of aluminum capacitors, degradation of printed circuit boards due to humidity or dirt and grease accumulations, and corrosion of open contacts. In addition, operating transients and maintenance errors may result in multiple failures of similar components. In systems employing redundancy, multiple similar failures can result in unsafe system operation; especially in those instances where the failed state is a possible normal state. The CMA method outlined below was extracted from IEEE-STD-352-1975.

The CMA is performed as follows:

1. Prepare a list of all System Components/Modules. (List A)
2. Prepare a list of units each of which is composed of all components/modules identical or similar in design or construction.
3. Prepare a list of units composed of all components/modules that have identical function and are not completely diverse.
4. Perform FMEA on units identified above.
5. Examine, as a minimum, the following considerations for all failure modes which cause primary system failure or fails secondary systems:
    a) Random failure (List A only)
    b) Determine the credible sources of failure due to:

        manufacturing process

        environmental factors

        maintenance or installation errors

        operator interactions

        operating transients and credible accidents

FAULT TREE ANALYSIS (FTA)

The FTA is an analysis technique that organizes deductively and presents pictorially all actions that can contribute to an undesired event. Its purpose is to identify all credible sources of an undesired event. The technique is an extension of both the FMEA and the Reliability Block Diagram (RBD) in that it considers all actions, not just equipment malfunctions. It is different from the RBD in that it is a failure diagram instead of a success diagram. Startup and operation of most systems require some man-machine interactions. Undesired events, such as explosions, are to be avoided at all costs. The FTA allows one to ascertain all of the possible human and machine actions that can lead to the event. The FTA pinpoints areas requiring redundancy. The FTA method outlined below was extracted from IEEE-STD-352-1975.

The FTA is performed as follows for each undesired event:

1. Define undesired event.
2. Define the main branches that can lead to the undesired event.
3. For each main branch deduce the chain of subevents back to the fundamental event (source).
4. Document the analysis via logic symbols.

TEST INTERVAL ANALYSIS (TIA)

The TIA is a method used to determine the test interval necessary to meet a specified system reliability. Any system operating in a dormant state and/or employing redundancy requires testing to achieve a high level of reliability. Equipment standing-by in a dormant state still possesses a finite failure rate. Even when redundancy is employed, testing is still required to achieve a high level of availability. Periodic testing can impact the system to the extent that some redundancy may not be required or a lower level may be sufficient to meet a specified reliability. In most large systems there will be an infinite combination of test intervals on the various system elements which will satisfy the reliability requirement. An analysis is required to determine a satisfactory combination.

The TIA is performed as follows:

1) Prepare a list of all System Components/Modules
2) Determine an estimate of the failure rate of each component/module for both the operational and dormant modes.
3) Perform an FMEA
4) Either construct an RBD, or:
5) Construct an equation which mathematically represents the reliability of the system. The equation is a function of failure rate, repair rate, test interval and operate time. It is a mathematical representation of the RBD. It is developed using probability techniques such as Bayesian, Markov, or Monte Carlo.
6) Solve the equation, at the specified reliability level, for the test interval. Engineering judgement and a judicious

choice of initial parameters will result in a satisfactory solution.

FAILURE DETECTION TECHNIQUES

There is a need to detect faults or failures in a distributed digital system for a number of reasons:

1) to shut down a portion of the process so that the field control equipment will not cause an unsafe condition

2) to inhibit startup of a portion of the process until the failed control equipment has been repaired or replaced

3) to initiate a transfer to a redundant piece of control equipment

4) to revert to a manual mode of process operation which bypasses the failed control equipment.

Equipment in a digital system generally falls into three catagories: processors, memories, and other hardwired equipment modules. The failure detection approaches used depend on the category considered. Some processor failure detection techniques are:

1) Test programs - Programs with known inputs and outputs are run by the processor on a regular basis; if the results do not agree, the processor declares itself "sick" and shuts itself down. Obviously, this technique works if there is a failure in only a portion of the processor's circuitry. This technique also provides a partial check on the operation of the memory.

2) "Watchdog" timer - A hardware timer external to the processor must be reset periodically by the processor at regular intervals in its execution cycle. If it does not, the timer times out and transmits a signal announcing that the processor has failed. This approach does not depend on the processor to check itself.

Techniques for detecting failures in other equipment rely on the proper operation of a processor (either the central computer or a processor in the LCU). In addition to the test program diagnostic described above, other memory failure detection techniques are:

1) Parity checks - a single bit is appended to every data word in memory to allow checking for an odd number of errors in storage or fetching operations. If an odd parity check is

used, the parity bit is set in such a way that the total number of ones in the data word plus parity is odd (in an even parity check, the sum is even). Then, when the processor fetches a word from memory, it compares the parity bit with the total number of ones in the word to see if an error exists. If it does, the processor flags that portion of memory as having failed (perhaps after one or more retries to fetch the word).

2) Sum checks - The words within a specified block of memory are added together at system generation time and the sum is stored at the end of that block. Periodically, the processor recomputes the total and compares it to the sum previously stored to identify any failures in that memory block. This technique is useful only for read-only memories (ROMs) or for random access memory (RAM) containing a fixed set of data or instructions. It is an effective technique for dedicated-function microprocessor systems using ROMs.

Failure detection techniques for other equipment modules fall into two categories:

1) Processor-directed diagnostics - These are programs run by the processor to detect module failures by exercising the modules and comparing the actual results with expected results. For example, one way to test input/output modules in an LCU is to provide a "wrap-around" hard-wired connection from an output module to an input module. The processor then writes a known signal value to the output module, reads the corresponding channel on the input module, and compares the two. If they do not agree (to within the accuracy specifications of the modules), there is a failure in the I/O module string.

2) Module-level diagnostics - Each module can provide a binary output signal which indicates its state of health and which is made available to the processor for use in shutdown initiation, switchover to a redundant module, or other purposes. The status signal is derived from internal checks on module power status, operational activity (the watchdog timer approach also can be used here), and other indicators of module "health". The specific checks made will depend on the type of module (e.g., input, output, controller, communications interface) and its level of "intelligence" (some modules may contain their own dedicated processors).

The various failure detection techniques described above can be implemented in the plant central computer as well as in the LCUs during all phases of plant operation. Since the most likely maintenance approach in this system is simple failed module replacement, the detection techniques used should not attempt to isolate failures below the module level.

FAULT TOLERANT DESIGN TECHNIQUES

Fault-tolerant design features allow a system to continue operation despite momentary or permanent hardware failures, electrical noise transients, or other system faults. The performance of the system (e.g., time responsiveness, data throughput capability) may be degraded to some extent, but the basic functions to be performed are still accomplished. Some of the fault-tolerant design techniques used in distributed digital systems are as follows:

1) Fault-tolerant system partitioning - To the maximum extent possible, the individual modules and subassemblies in the system are designed in such a way that their failure does not affect the rest of the system. This fault independence is then verified by means of a failure modes and effects analysis. The chief limitation of this approach is usually the cost involved in providing separate services (such as electrical power, cooling, etc.) to the individual elements in the system.

2) "Load-sharing" system design - In this approach, the system functions are assigned to the available facilities in such a way that the performance load is shared equally by the facilities, with no facility being dedicated to a particular function. This is the approach used in banks which have multiple tellers to service a single queue. The loss of any one teller results in a degradation in queue servicing rate, but not in a loss of any banking function. The digital system equivalent is a multiprocessor system in which several processors share a common memory and perform tasks assigned to them in real time rather than at system generation time. If properly designed, these systems provide "graceful degradation" in case of failure, since the loss of a single processor affects throughput but is not catastrophic. However, these systems often require operating system software which is quite complex and which contains a large amount of overhead in assigning tasks, managing memory, and performing fault diagnostics. This type of system is also quite susceptible to single-point hardware failures or software errors which could cause the entire system to fail.

3) Fail-safe output hardware - When hazardous processes (such as munitions plants) are being controlled by automatic digital or analog equipment, great care must be taken to ensure that an equipment failure does not cause an unsafe process condition. For this reason, outputs from the control equipment are

usually interfaced to the process through fail-safe hardware. This hardware is designed so that a failure in it or in upstream equipment causes the control outputs to revert to either a) a "safe" state, if such a state can be identified or b) the last valid output state. In the case of processor-based control systems, two approaches are commonly used:

a) Outputs from the processor are contact outputs which increment or decrement an external memory; a processor failure causes the outputs to remain in their previous state. They can then be manipulated through manual inputs from an operator station.

b) The output hardware requires that the processor actively switch a contact or reset a watchdog timer before the processor's control outputs are transmitted. Otherwise, a standard "safe" set of outputs are used.

Additional discussions of these techniques are given in References 32 and 37.

4) Use of parity and error correction codes - In a distributed digital system, data transfers occur across internal parallel buses (such as between a processor and its memory) as well as across serial communication links (such as between LCUs over a Plant Communication System). Various codes are used to check the accuracy of these data transfers and either a) indicate that an error has been made, in which case the transfer must be repeated; or b) use the capabilities of the code to correct the error, thus making the transfer tolerant of faults in the transmission mechanism. The former case was covered in the discussion on error detection techniques in Section -"Failure Detection Techniques". In the latter case of error correction, hardware in the data transmitter appends an additional check field of bits to the basic data word or message. The check field contains the results of several different parity calculations based on various bit combinations in the data field. When the expanded data message is received, the receiving processor uses the contents of the check field plus an additional set of parity computations to determine the location (not just the existence) of errors in the data field. It can then correct these errors by reversing the bit status at these locations and continue operation without repeating the data transfer. In essence, the check field provides redundant information in the data transfer to allow reconstruction of the data field under a limited set of error conditions. This approach is rarely used in industrial systems due to the inefficiency (and resulting cost) of including the redundant information in each data transfer.

SOFTWARE "RELIABILITY" DESIGN TECHNIQUES

As mentioned above, one of the problems in designing processor-based systems is that of guaranteeing that the software or programs which define the processor's functions is correct. The methods which have been developed to help ensure that the software is correct are loosely grouped under the name of "software reliability" design techniques. This phrase is somewhat of a misnomer, because software in itself cannot fail, any more than a wiring diagram or circuit diagram can fail. Rather, it is either correct when implemented or it is incorrect. A true failure can occur only in the hardware with which the software is implemented. If no hardware failure occurs, a piece of software may only appear to fail when the particular conditions which expose its incorrectness occur, either through following a program branch containing an error for the first time or through encountering a set of input conditions which expose the "failure".

A number of techniques have been developed to improve the quality or "reliability" of software, including the following:

1) Structured Programming - The flexibility of program structure allowed the programmer is restricted so that the resultant code is more amenable to automatic checks for errors.

2) Use of special high-level languages - The syntax of high-level languages can be designed to reduce the likelihood of software errors and to simplify their detection through automatic means.

3) Off-line software checks - These are static analysis procedures which check program structures for blockages, loops, or other execution flow problems, and make consistency checks on the use of machine resources and peripherals.

4) On-line software checks - These are dynamic analysis tools (sometimes called "software audits") which verify the accuracy and consistency of the contents of volatile memory and the integrity of register linkages associated with facilities, among other things. These tests are executed periodically on a "snapshot" of the system state at one time, and are designed to consume only a small fraction of the system resources.

5) "Proofs of correctness" - The structure of the program itself is analyzed off-line to determine whether or not it meets a set of validation conditions. The analysis procedure is similar to that used in proving mathematical theorems, and is amenable to automation. The validation conditions also can be checked on-line to verify proper program operation.

These techniques are covered in more detail in References 38 to 42. They are not strictly reliability techniques in the classical sense, but they may be useful in improving the accuracy of the software in distributed digital systems.

ADDITIONAL INFORMATION

The subject of high-reliability system design is an extremely broad one, as can be seen from the range of techniques discussed above. Only the key concepts which are most applicable to the munitions plant layaway problem have been described here. Additional pertinent information can be obtained through the references listed in the Bibliography as well as from the literature on related research and development areas which use high-reliability design techniques. Some of these related areas are as follows:

1) Studies of equipment failures during dormancy conditions conducted by the Air Force at the Rome Air Development Center (see Reference 49, for example).

2) Studies of the storage reliability of components used in the U.S. Army missile program (see Reference 47, for example).

3) Development of safety systems for nuclear power plants.

4) Design of redundant computer systems for air traffic control and railroad dispatching applications (see Reference 44, for example).

5) Use of fault-tolerant digital systems in other military and space applications (e.g., ICBM program, unmanned NASA deep space probes, space shuttle, and fly-by-wire aircraft control systems).

Each of these areas has its own particular reliability and safety requirements, and each should be examined to identify the specific design techniques which can be adapted for use in distributed digital systems for munitions plants.

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PAPER NUMBER 11

USE OF SIMULATION AND OTHER RELATED TECHNIQUES FOR THE TRAINING OF STARTUP CREWS FOR REACTIVATION OF LAID-AWAY PLANTS

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USE OF SIMULATION AND OTHER RELATED TECHNIQUES FOR THE TRAINING OF STARTUP CREWS FOR REACTIVATION OF LAID-AWAY PLANTS

INTRODUCTION

Arthur C. Clark in his motion picture and book, "2001 : A Space Odyssey", projected that a team of skilled astronauts would be maintained in suspended animation aboard traveling space vehicles until the time arrived for future operations to begin. At a pre-determined time/space threshold they would be gradually revived and made ready to conduct the intricate phases of the mission. This is an interesting and unique solution for meeting a rather extended need. While there is a simularity of need associated with the future operation of earth-bound, reactivated production facilities, a wholly different set of conditions apply and so some other kind of solution must be provided. For PROJECT LAYAWAY it is a package of technical know-how that is to be preserved - and in such a form that it can be acquired readily by a future team assembled for operations whenever the need arises. Later, we may want to debate whether the challenges of establishing a life support system or of preparing a training mechanism is the easier to satisfy.

A startup crew has to be oriented to the system it is expected to operate and given a means of developing the particular skills which will assure successful operation of the plant. A proper approach involves appreciating the characteristics, features, and environment of the production system, the attributes of the human operator, and the techniques available to us now and in the near future. An integrated design which combines automation technology, simulation techniques, and human factors considerations can permit an incorporation of the necessary intangible elements compatibly with the tangible parts of the production system. I propose to review methods and components which can be exploited to serve these purposes.

SYSTEM FEATURES AND ENVIRONMENT

I submit that the most capable type of system design for this project is one that employs an electronic, modularized, computer-based, consolidated instrumentation console for operations control. This choice (over conventional, panel-mounted, parallel instruments) is appropriate because it affords an extensive medium for on-line training activities that can be given directly in the context of the processes involved. While it may be premature, I am assuming for this discussion that such a configuration would be selected.

Typical of the process monitoring and control consoles which recently have been brought to market is the Taylor MOD III System depicted in Figure 1. The distributed modularization allows opportunities for incorporating additional items which can hold and present training information and responses coordinately with the primary dynamic process traffic. Looking more closely at the console in Figure 2, three aspects of the system can be seen. A colorgraphic display of a unit operation, a continuously updated status display of the processing equipment and conditions, and a display of selected variables showing trends as they transpire over the immediate past. The fourth bay contains cassette recorders for accumulating dynamic behavior which can be brought into display at will with considerable flexibility. Annotated detail of these bays are shown in Figures 3, 4, and 5.

A wide range of training functions can be accommodated by extending such a system in three ways. First, a mass memory added to the system bus can retain tutorial program material and lesson responses accessible through the third bay during periods when the process is on target or is not in operation. Second, an audio facility can be added for carrying coded tone alerts and textual commentary. Third, specially designed circuit modules can be appended to the control rack so that upon addressing programmable transfer switches, selected portions of the process (including the total process) will be simulated by dedicated hybrid computer channels.

So as not to encumber the principal control consoles unnecessarily, an auxiliary console should be located nearby for system diagnostics, repair, and calibration tasks. When not so needed this separate console, fitted with a video tape recorder (VTR), can serve as the base for initial orientation sessions and allow free access to preliminary simulation exercises.

The learning and working environment, then, is established such that the operator is seated before an array of console displays suitably human engineered for compatible lighting, comfortably reachable buttons, and modulated sound for effective attention (An optional high-quality headset should be available with local speaker muting to enhance concentrated following of lessons and process behavior.) Adjustable thresholds assigned to selected process signals are invoked automatically whenever training activity is initiated so that an immediate interruption can override in the interest of critical conditions.

THE TRAINING TASK

Over the years the training of operators in the process industries has undergone numerous developments and trials. Operators receive general instruction in scheduled classes at the plant site and are then exposed to the particulars of a given manufacturing complex on-the-job. Of course, considerable time is required to learn in this manner and the performance results are rarely uniform among individuals. Also, when an operator is transferred to another assignment, his training does not remain with the unit and some other person must undergo skill development.

In order to improve this situation and anticipate functional needs of new or modified processes, electronic computer models have been used to simulate process dynamics and characteristics for training purposes. Usually operators must be sent to the simulation laboratory for exposure sessions where the association with the subject process, unfortunately, is missing. One of the best techniques used for training involved connecting an analog computer model of a process to the actual instrument control panel at the plant site using mutiplexed, telephonic telemetry (by means of PFM, pulsed frequency modulation). The operators became conditioned to their system through the same interface they would continue to serve. While successful, this method is cumbersome and expensive so it is not employed often. A commercial firm (1) can supply the same technique in a separate, free-standing cabinet which can be transported from plant to plant. Of course, it also incurs quite an investment. As of today the training situation at most plants is still in need of vast improvement.

At the recent Summer Computer Simulation Conference,Killian reported (2) that current fuel and operating costs for commercial aircraft have led the U.S. airlines to set a goal for training flight crews totally through simulation. As the trends shown in Figure 6 for his company show, they are near reaching that goal. Their facilities are very extensive and continually being improved. The nature and style of modern cockpits lend themselves to reflected simulation much more completely than do process control rooms. Only with the latest console designs has our area of operation offered a reasonable chance to undertake a broadly applied improvement in operator training.

A computer-based system provides a medium to use self-tutoring, programmed instruction integrated with simulation exercises. Going at his own pace the operator is trained to deal with each section of the process in turn as he works across a series of instructional modules. Each section begins with a visual and aural description of the process purpose, design, functional features, and operational technique -- all accompanied with automatic placement of distinctive cursors, color shifts, and response trends. Normal operation is illustrated along with system tolerances and constraints. Upsets are imposed to show how overrides carry the process automatically to intermediate plateaus. Finally the operator is trained how to compensate for unscheduled faults and abrupt shifts in conditions.

Computer assisted instruction (CAI) has been promoted and used in the educational community for some years with mixed reaction and results. A number of factors and concerns have appeared with its use. First, the student finds the computer and interface terminal cold and unrelenting --

not always well aligned with the nature of the subject matter. The materials require intense preparation by extremely well qualified personnel. Simulation aspects must be implemented adequately so as to be convincing and not misleading. The student must be motivated and sustained to pursue a course and see it through to a conclusion.

With well-prepared materials process operators are likely to find CAI very acceptable because it is available to them in the context of their job where sufficient incentives can be maintained. To aid his progress the operator should be able to bring into a view a functional summary of any lesson he has previously covered. Also, each operator could be given a personal update cassette which accumulates his skill scores and lesson summaries (not to be monitored by their supervisors during the learning period). Motivation can be heightened by placing interesting gametronic programs in memory accessible to the individual a limited number of times when certain score or skill levels have been achieved.

To ease the intensity of lesson preparation Osin (3) has developed a software system he calls SMITH (Self-directed Mixed Initiative Tutorial Helper). SMITH relieves the course author of the burden of computer programming, thus greatly reducing course preparation time. The author writes his normal instructional text, divides it into frames (suitable for screen presentation), and describes each frame in terms of the topics it covers. He may also establish precedence and some other relations between frames. From then on SMITH structures the material and displays it to each student in a tutorial mixed-initiative mode, tailoring the presentation according to the student's performance and requests. SMITH is, in fact, an instructional information-retrieval system employing special-purpose algorithms in order to make intelligent use of minimal content. In this way it is possible to provide CAI in an efficient and adaptive manner without demanding an unrealistic time investment from the author.

SIMULATION TECHNIQUES

Creating and implementing the process models for training exercises and skill development is the most challenging part of this proposed system. Before touching on the details, let's review the description of the simulation procedure as published by Pobanz (4). Simulation consists of the several functional activities illustrated in Figure 7. The first block is simply a definiton of the physical system to be modelled. Once a system has been specified, the next function is to analyze the system in the particular areas of interest. For example, in the case of a compressor, this might include whether there is adequate anti-surge control and whether there is any undesirable system response resulting from the surge control method. With these objectives stated, the next functional block is to describe by a set of mathematical equations the physical variables which determine its transient behavior as related to the stated objectives. In the example of a compressor, this would involve variables such as suction pressure, discharge pressure, vapor flow, etc.

Developing good mathematical models is not black magic, but rather a sound application of existing principles and, when obtainable, empirical data. The next functional block involves the solution of these sets of equations. The proper computer is best determined by each application. The solution block produces results which can then be evaluated. The evaluation may lead to several courses of action. Three of these shown in the figure are:

Vary parameters

Re-analyze the math model

Re-design the physical system

In the case of varying parameters one can see that the functional blocks of "solve" and "evaluate" will determine how rapidly this action can be accomplished. Since evaluation time is controlled by the person using computer simulation, it suffices to say that a computational technique capable of producing many solutions in a short amount of time would be desirable. The hybrid computer (coupled analog and digital components) meets this criterion, especially when connected to real-time systems.

The second course of action results if the evaluation process determines that the simulation model does not adequately represent the physical system. In this case we are dealing directly with the validity of computer models. The third course of action, dictated by the evaluation process, results in a complete re-definition of the physical system.

To show how the technique is practiced an actual dual-train, multi-stage compressor system is shown in Figure 8. The describing equations are given in Figure 9 along with key components (indicated in parentheses) found in the programming diagram of Figure 10.

More than fifteen years ago a systems engineer said the following (5): "Process simulation has many diferences from more widely publicized military simulation projects. One of the most important is the fact that usually little is known about the mathematical behavior of a particular process. Most equipment is non-linear as well. As a result one often finds himself making an approximate simulation of an approximated non-linear equation which approximately describes the process". And just last year Lee and Weekman in reviewing control practice in the chemical industry had this to say (6): "The single most difficult problem to be overcome is understanding the process itself. Chemical processes are generally characterized by large dimensionality, strong interaction among process variables, and nonlinearity".

While this situation is likely to persist for propellant manufacturing processes as well, there are two considerations which are in favor of our being able to meet the training objectives. One is that high accuracy of model conformance is not essential to adequately represent the process for training exercises. It would be a different matter if the model were to serve design efforts. And second, since the process will be operational prior to taking it into the layaway state, the opportunity to tune the models against actual performance empirically will be afforded. As much as possible I would suggest using 2nd-order-plus-deadtime channels to match process dynamic responses and adjustable gain circuits for coupling parameters. Logic modules could be used to impose constraints and reflect configuration changes. The use of the control channels for both the operations and simulation modes will simplify the modeling and minimize the added investment in instrumentation.

CONCLUSIONS

Even though there has been an avalanche of new electronic products in recent years and outstanding development in audio/visual teaching methods, it must be emphasized that this reactivation project is an ambitious undertaking. While there is now no technical breakthrough needed to meet the goals, much will have to be done to reduce to practice the potential technology that is available. Only by embedding the system knowledge within when the total structure is engineered can a successful outcome be expected.

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MOD III SYSTEM

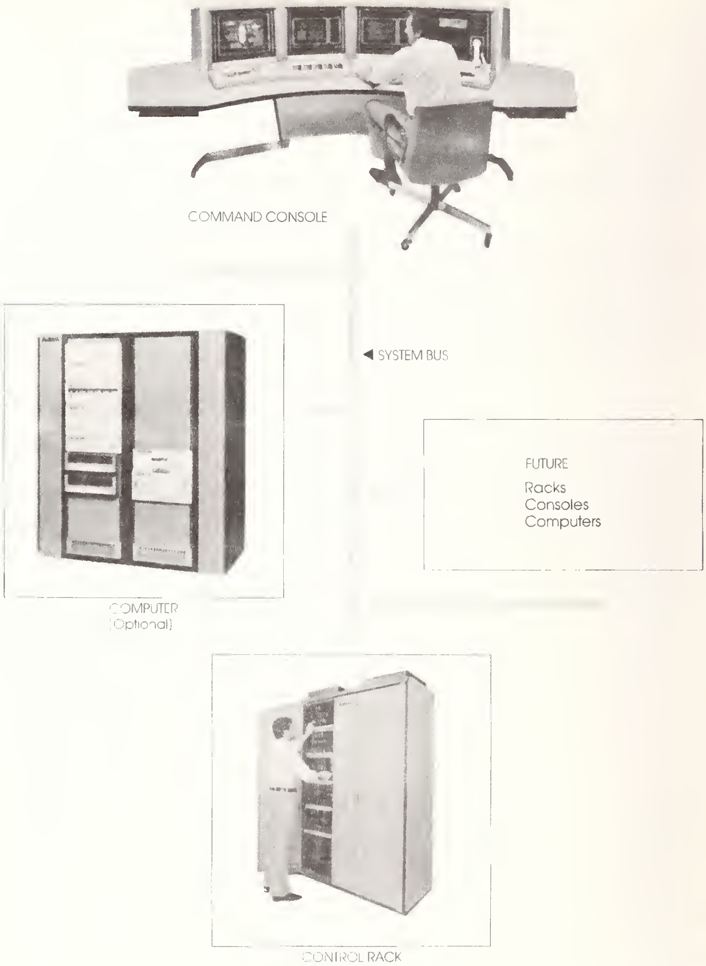
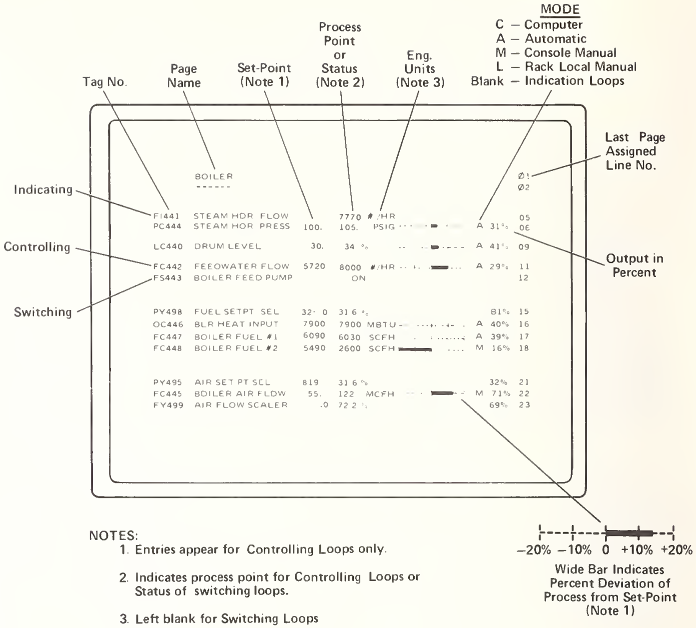


Figure 1.

Figure 2. The Operator's Console



```
                BOILER                                          Ø!
                ------                                          Ø2

F1441  STEAM HDR  FLOW           7770 # /HR                     05
PC444  STEAM HDR  PRESS  100.    105.   PSIG          A  31%    0E

LC440  DRUM LEVEL         30.     34 %                A  41%    09

FC442  FEEOWATER FLOW    5720    8000  #/HR           A  29%    11
FS443  BOILER FEED PUMP            ON                           12

PY498  FUEL SETPT  SEL   32· 0   31 6 %                  81%    15
OC446  BLR HEAT INPUT    7900    7900 MBTU            A  40%    16
FC447  BOILER FUEL #1    6090    6030  SCFH           A  39%    17
FC448  BOILER FUEL #2    5490    2600  SCFH           M  16%    18

PY495  AIR SET PT SEL    819     31 6 %                  32%    21
FC445  BOILER AIR FLOW    55.    122   MCFH           M  71%    22
FY499  AIR FLOW SCALER     .0    72 2 %                  69%    23
```

NOTES:

1. Entries appear for Controlling Loops only.
2. Indicates process point for Controlling Loops or Status of switching loops.
3. Left blank for Switching Loops

Figure 3. Status Display

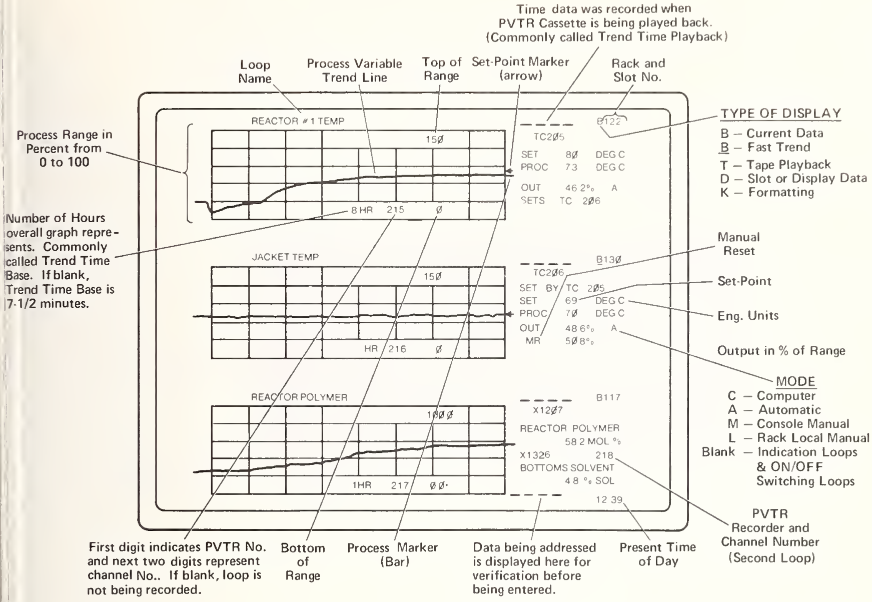


Figure 4. Variable Trend Display

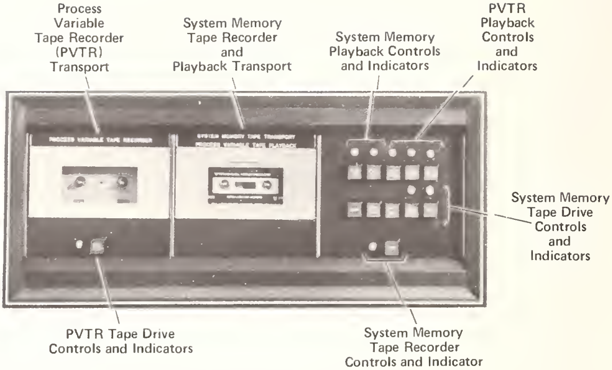
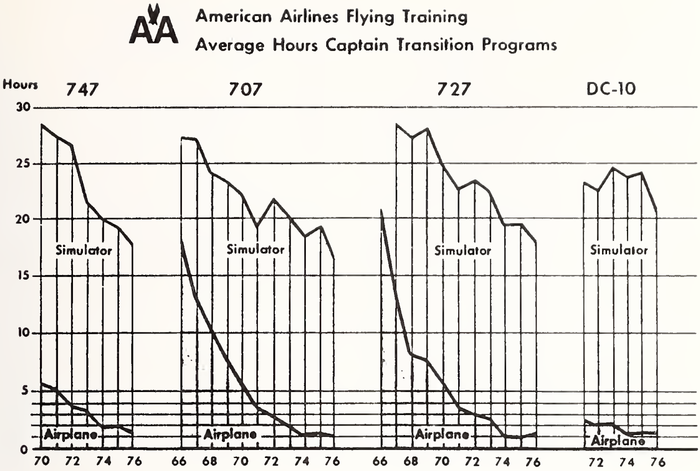


Figure 5. Cassette Recorder Station



American Airlines Flying Training
Average Hours Captain Transition Programs

Figure 6.

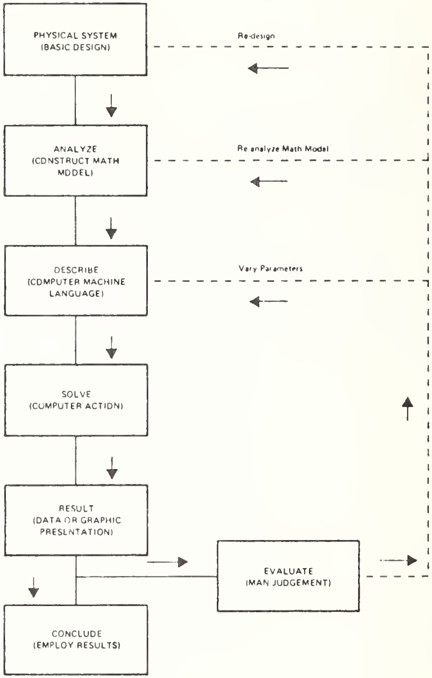


Figure 7. Simulation Process

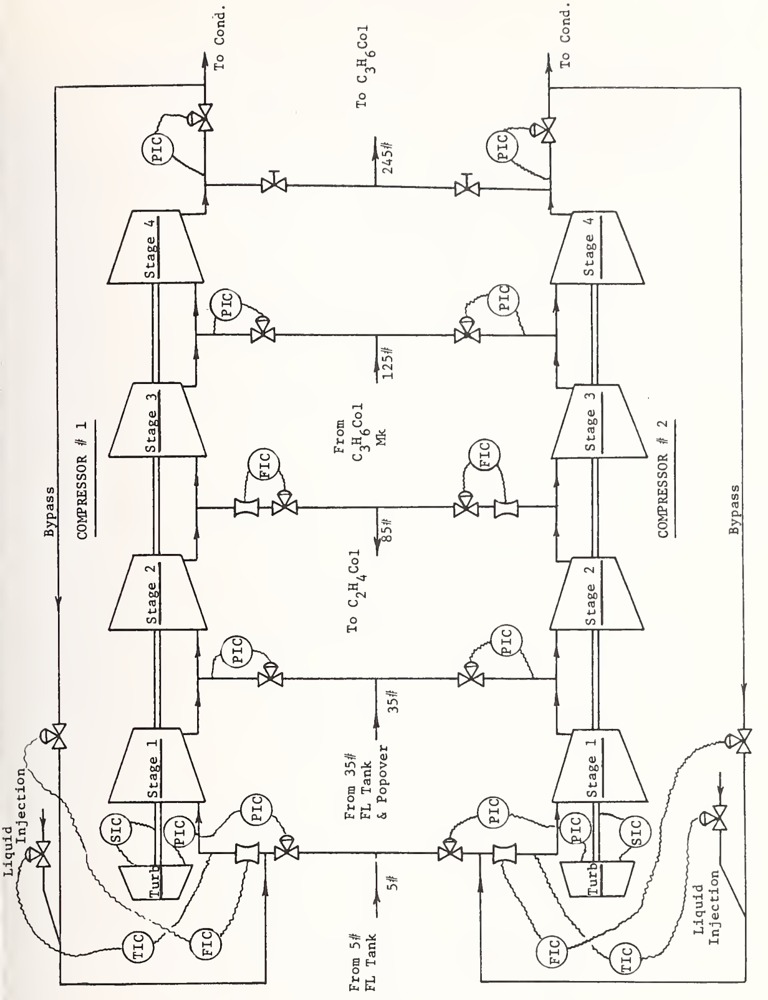

To Cond.
To C_3H_6Col
To Cond.
245#
Stage 4
Stage 4
PIC
PIC
PIC
PIC
125#
Stage 3
Stage 3
From C_3H_6Col Mk
COMPRESSOR # 1
COMPRESSOR # 2
Bypass
Bypass
FIC
FIC
85#
To C_2H_4Col
Stage 2
Stage 2
PIC
PIC
35#
From 35# FL Tank & Popover
Stage 1
Stage 1
Liquid Injection
Liquid Injection
SIC
SIC
PIC
PIC
PIC
PIC
Turb
Turb
5#
From 5# FL Tank
TIC
TIC
FIC
FIC

FIGURE 8

NOMENCLATURE

Q	Volume Flow Rate	T	Absolute Temperature
$\dot{m}$	Mass Flow Rate	P	Absolute Pressure
D	Impeller Diameter	K	Specific Heat Ratio
N	Shaft Rotation Rate	$\varnothing$	Flow Coefficient
H	Head or Work	ψ	Head Coefficient
R	Ideal Gas Constant	λ	Polytropic Efficiency
Z	Compressibility Factor	M, S, D	Subscripts for <u>mean</u>, <u>suction</u>, <u>discharge</u> conditions

EQUATIONS

$$PQ = Z\,\dot{m}\,RT$$

$$Q = \frac{Z\,\dot{m}\,RT}{P}$$

$$\text{(Amp. 1)}\qquad Q_S = \frac{\dot{m}\,T_S}{P_S}\cdot C_1$$

$$\text{where } C_1 = Z_S R \qquad \text{(Pot 4)}$$

$$\varnothing = \frac{Q}{ND^3}$$

$$\text{(Amp. 3)}\qquad \varnothing = \frac{Q_S}{N}\cdot\frac{1}{C_2}$$

$$\text{where } C_2 = D^3 \qquad \text{(Pot 5)}$$

$$H = Z_M R\left(\frac{K\lambda}{K-1}\right)(T_D - T_S)$$

$$\psi = \frac{H}{N^2D^2} = \frac{Z_M R\left(\frac{K}{K-1}\right)\lambda\,\Delta T}{N^2D^2}$$

$$\Delta T = \frac{\psi\,N^2D^2}{Z_M R\left(\frac{K}{K-1}\right)\lambda}$$

$$\text{(Amp. 5)}\qquad \Delta T = \frac{\psi N^2}{\lambda}\cdot C_3$$

$$\text{where } C_3 = \frac{D^2}{Z_M R\left(\frac{K}{K-1}\right)} \qquad \text{(Pot 6)}$$

$$\Delta T = (T_D - T_S)$$

$$\text{(Amp. 6)}\qquad T_D = T_S + \Delta T$$

$$\left(\frac{T_D}{T_S}\right) = \left(\frac{P_D}{P_S}\right)^{\frac{K-1}{K\lambda}}$$

$$P_D = \left(\frac{T_D}{T_S}\right)^{\frac{K\lambda}{K-1}}\cdot P_S$$

$$\text{(Amp. 9)}\qquad P_D = \left(\frac{T_D}{T_S}\right)^{\lambda\cdot C_4}\cdot P_S$$

$$\text{where } C_4 = \frac{K}{K-1} \qquad \text{(Pot 7)}$$

Figure 9.

PROCESS ANALYSIS SECTION

UNION CARBIDE CORPORATION
CHEMICALS & PLASTICS
SO. CHARLESTON, W. VA.

ANALOG COMPUTER
LABORATORY
BLDG. 2000-320
EXT. 4474

BY WBF/JAS
DATE 2-10-71

SUBJECT SIMULATION OF SINGLE CENTRIFUGAL STAGE

SHEET NO. 1 OF 1
PROJ. NO. 1503

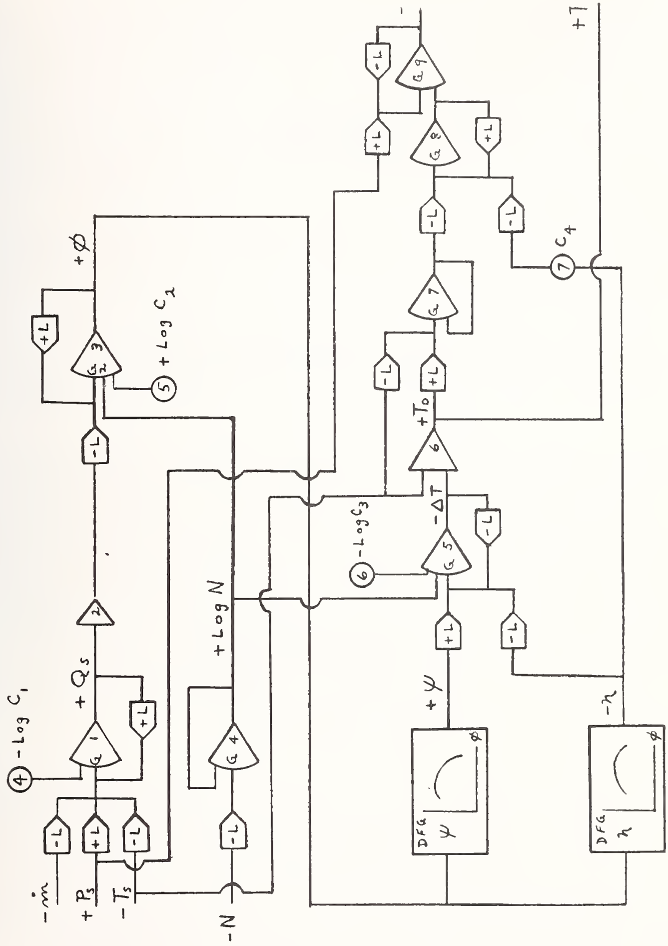


Figure 10.

PAPER NUMBER 12

OPERATING TODAY'S PLANT DESIGN TOMORROW

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OPERATING TODAY'S PLANT DESIGN TOMORROW

INTRODUCTION

Plant start-ups are difficult times even when they occur immediately after construction has ended and the design is still fresh in the minds of those involved. The situation is helped somewhat because at this stage the plant operating objectives can still be recalled; the basis for decisions can still be remembered; and those directly involved in the entire project are still available for consultation. The problem posed by the Army in its Munitions Production Base Modernization and Expansion Program complicates the start-up problem by introducting a time delay between the initial construction and the full plant operation.

During the intervening years when the munition facilities are in the "Layaway" state, the people involved will certainly change. The plant operators are not the only ones to be considered, but others such as the designers, managers, supervisors, contractors and vendors, must also be thought of as each provides a certain critical skill that is required for successful plant operation. The general problem posed by the Army involves how a layaway plant can be started up as quickly as possible to a desired production level. The measure of a plant's ability to reach the production target is its "readiness."

The particular aspect of the layaway and readiness problems addressed by this paper encompasses the use of design techniques that minimize reliance on critical skills of individuals after the layaway period. The objective of providing a plant design so self-documenting that its operation in theory and practice is obvious to the most casual observer is both impractical and unrealizable. However, this paper is intended to be both evocative and provocative so that at least the impact of the readiness requirement on design practice can be explored and some general directions indicated. Toward accomplishing this goal, a review of present industry attitudes and practices toward control design is as important as proposed solutions for the future.

INDUSTRY COMMONALITY

The Readiness problem (more so than the layaway problem) has intrigued the process industry in general for many years. Taken as a broad definition, it refers to a plant's ability to move, with little advance warning, from its present state to a desired state as quickly and efficently as possible. Examples include: seasonal products for the chemical industry (e.g., agricultural chemicals, antifreeze additives); raw material changes for refineries (e.g., crude switching control (18)); and changes in plant operations caused by labor strikes or walkouts. The Readiness problem is aggravated by projections of higher operator and staff turnover rates and a general reduction in the experience and training level of operating personnel. As seen by these examples, Readiness is intimately involved in the way a plant is operated. It is, therefore, useful to review some of the operating characteristics of plants that form a set of axioms which will always underlie the Readiness issue.

PLANT CHARACTERISTICS

Figure 1 lists a series of characteristics of operating plants which are worth considering. With many control loops and thousands of pieces of mechanical equipment, a large plant is usually always working with some automatic control loop in manual or some pump or valve down and out for repair. As Bristol (6) points out, the operation of a large process can be compared to the operation of an old car operated by a car buff. At any point in time, something is wrong. But the operation is carried on in spite of all, in a way which accommodates the current problems. If the car burns oil, oil is added every 50 miles. If the back doors are stuck, everyone piles in over the front seats. Likewise, the day-to-day operation of a plant is also subject to all kinds of irregular conditions or constraints: varaiation in raw material price or product value, change in inventory, or vacations of first run operating personnel.

In coping with such situations, it should be noted that in most plants no one person has direct responsibility to maintain an "on control" condition. The instrument department fixes "broken" instruments; the process engineer is responsible for the process itself; and the central engineer is too far away from the plant for day-to-day contact and probabl wouldn't be allowed to touch the control system anyway. Yet the plant run and a semblance of Readiness appears.

Acceptance of advanced control technology has been very slow in the process industries, mainly for reasons other than technology (2). A recent Process Industry review in Science (11) pointed out that "most observers in industry agree that the acceptance of advanced technology is far less than the state of the art would permit." Hence technology to improve plant Readiness exists and more will be developed, but acceptance problems inherent in the design methodology will have to be overcome.

Finally, it should be recognized that control equipment maintenance and operator training will always be perceived as being critical even if a completely automated, reliable plant control system were available. Such a system is just not considered to exist.

The previous discussion has focused on the plant operation from a control standpoint because the control system design actually defines the plant operation and its Readiness potential.

CONTROL SYSTEM CHARACTERISTICS

When you stop and think about it, almost all the operating procedures in a plant are based on some aspect of the control system design. The steps an operator goes through to make a change depends on the layout and design of the control panel. The control loop configurations dictate allowable control variables while valve sizing, measurement selection, and sensor placement can lead to processing and stability problems. As a result, the person who ends up specifying the control system design almost singlehandedly specifices the operating procedures and thereby influences the Readiness posture of the plant.

One would expect, therefore, that such an important Readiness function as control system design would be of prime importance in any plant design - but it isn't. Traditionally and across industry lines, a cost-effective plant design is frozen as much as possible once detailed engineering is ready for field construction. Unfortunately, control system decisions are normally carried out at this time as shown in Figure 2, and consequently, the impact of the decisions have little chance to feed back to the process design, plant operations, and Readiness issues with which they usually interact. All the average control engineer can do at this point is design conventional control schemes, usually based on the individual plant unit operations. These are then hurriedly combined into some form of process control system to meet plant construction and start-up schedules. In most cases, these time schedules do not allow any tailoring or innovation to better meet Readiness needs.

Historically, this worked out reasonably well because only conventional analog hardware systems were available and most higher level control functions were carried out by the operating personnel. Hardware set the structure and complexity of the control system. Such functions as anticipating disturbances, interacting control, and changes in operating conditions were done by plant operators.

This aspect of control design projects along with some other important characteristics are given in Figure 3. In addition to the lateness of the system design and its effect on plant operations, control decisions tend to be very emotional issues. This may be as a result of a subconscious awareness of their importance. Decisions for a small control computer have reportedly reached the president's office in some companies while more expensive process equipment purchases (even when prior experience was not available) have been handled on a design team level.

The result is that one must recognize that control systems tend to take a particularly conservative approach and are not subject to any standard, rigorous design procedures as is found for sizing equipment such as heat exchangers and distillation columns. In addition, delegation of control system design is often left to the instrument man, vendor or contractor to define.

To a great extent, however, it must be acknowledged that the processes to be controlled are analytically very complex so that even a sophisticated model would only approximate reality (6). Control systems are indeed legitimately designed as a compromise between what has been offered by vendors, what worked in the past, what others are doing and what side issues are present at any particular time. There is no better way. Dynamics are important because no one has come up with significant improvements over linear (or nearly linear) feedback control. Even feedback is necessary because chemical engineers basically don't know enough about their process to avoid it.

All of these points have to be considered when discussing Readiness because they impact on possible solutions and are not about to go away. The outlook isn't bleak, however. As mentioned previously, this system of control design has worked, "rules of thumb" have been established, and plants continue to operate and meet objectives. The problem, as it effects Readiness, is that the successful operation of such control systems requires a level of technical personnel with critical skills - the Technocrat.

THE TECHNOCRAT

The loss of a Technocrat at a critical moment can be devastating to Readiness because of the loss of his critical skill.

The person's identity is not always obvious. It may be the process engineer who picked up and learned the little procedures that really make the plant run. Or the FORTRAN programmer who wrote with twists of logic known only to him. It may be the instrument man who by trial and error found the correct grounding wire configuration that gave stable performance to the interface system. The Technocrat may even be far away from the plant, tucked in a research and development, vendor, or contractor's office where his design notes might go unnoticed, combined with many other projects.

Hidden knowledge is the weapon of the Technocrat while rapid technological change in computers and control equipment, customized installations, and the desirability of obtaining a high level of total plant control provides his ammunition. Most Technocrats don't realize what they are or recognize their potential importance to the installation. They are well intentioned control users or support staff who go unnoticed until they are needed.

Technocrats can not be eliminated. A completely supplied system - customized to a particular application - which doesn't require maintenance or change is a myth. Such system responsibility can not be put aside in the hope it will not be needed. There is no security in a black box! Even back-up hardware does not reduce the effect of the Technocrat. The back-up system itself requires design, maintenance and operating know-how to make it an effective system.

The Readiness level for a munitions plant will depend on how well the effect of the Technocrat is minimized and how well the other characteristics of plant operation and control design are taken into account. With that as a background let's see what can be done.

DESIGN TECHNIQUES

Analysis, communication, definition and enforcement are the key words that describe the techniques that can be used to neutralize the effects of the Technocrat and the present control system design methodology, thereby relieving the future critical skill requirements and increasing Readiness.

The techniques to be discussed do not come without a price and trade-offs will, of course, be necessary. The obvious trade-off will be economic since discounted cash flow puts high present value cost on a plant to be used in the future. Less obvious is the trade-off between simplicity of design and energy conservation. The former suggests a modular design technique (discussed later), while the latter would recommend a tightly coordinated plant with little internal hold-up and integrated energy streams.

DEFINITIONS

The technique of establishing a consistent set of definitions is especially critical for the Munitions Production Base program because of the many different organizations involved within the government and private industry as well. Definitions concerning the levels of automation are very critical since an advanced control system to one party may seem trivial to another.

Attempts have been made to define consistent terminology for the elements of control systems. Most notable is the International Electrotechnical Commission standard currently being reviewed. But this is not enough. An extension to the definitions of individual control elements is needed to adequately discuss control system design and possible hierarchies. It has been proposed that an adequate description of advanced control systems requires at least two distinct dimensions (2) as shown in Figure 4.

One axis represents increasing levels of control automation (involving the physical operation and control of the plant or process), and the other represents increasing levels of process management (where process management is defined as the gathering and application of both process and business information for decision making). As higher levels of control automation are implemented, increasing numbers of measurements must be brought into the control system. Furthermore, such a system must also encompass larger segments of the plant because of the need for multiunit coordination. The same measurements needed for advanced automation are also useful in decision making, and as one automates the control of the plant, it also makes sense to incorporate more information gathering and application functions in the overall control system. Therefore, most advanced control systems will usually progress along a trajectory as shown in Figure 4, where control automation and process management functions increase simultaneously.

There is insufficient time to go into the detailed description of each level in this paper, but the major characteristics are summarized in Tables 1 and 2.

Understanding the use of these definitions is important. They are meant to convey a "sense" of where a plant fits in the definitional structure. The scale is continuous but one would find it a fruitless experience to methodically count the number of different types of control he has in a particular plant and relate that to control level. Instead a user should read the complete definitions, consider them, and then think of the operation as a whole and pick the level of control or management that seems appropriate.

These definitions are reported to be a good base and a valuable tool to developing consistency in discussions concerning the level of process management and control (2). Such consistency is essential to good communications between government agencies, vendor and industrial communities, especially in these times of rapidly changing control technology.

Equally as important as the control definitions are the definitions and responsibilities of those groups taking part in the design, construction and operations of the munition based plants. A sample set of participants and responsibilities is listed in Figure 5. The list is a suggested one but the main point is that the list must be formulated and the responsibilities detailed.

Consistent definitions (probably made up by the government and operating sectors), if adhered to, will simplify decision making and cause it to be based on a visual set of objectives.

ITERATIVE DESIGN PROCEDURE

Many factors affect the design of a modern process control system. The process itself is the dominant influence since it defines what actions must be taken for proper operation. Parameters of the control system which carry out these actions are determined by hardware, software, measurement, control, and communication technologies as well as human factors (Figure 6). All of these aspects involve the critical skills of many people. However, we noted previously that there is presently little interaction between the design and control engineers. Consequently a change must take place and a new technique must be employed.

A recommended plant design technique is shown in Figure 7 which allows for an integration of process, plant operation, and control goals early in the plant design when a free exchange of concepts can be accomplished. Within this structure, questions concerning process requirements, plant operation, and process economic sensitivity as well as the technical areas of measurement, control, communications, and degree of control distribution can be considered. These and other factors to be considered during this design period are listed in Figure 8. Thus the process goals and plant operating goals are considered together by the design and control engineers in an iterative fashion.

One of the biggest problems in examining a plant design by the technique described above is the lack of formal methods of process system decomposition. Such decomposition leads to smaller sub-systems which are easier to analyze. Bernard (5) suggests a method which involves a horizontal break-down based on the concept of "operating units" instead of the standard unit operations. The result is a structure with many modes of minimum interaction. Carefully defined purposes, goals, and broad functional requirements are basic to the structure. The key to a good analysis is the willingness to write down purposes for different parts of the system and functions that seem obvious and simple. A good measure of the quality of the structuring is how little the whole system must be changed to accommodate changes in any of its parts.

From a Readiness viewpoint, these design techniques bring many critical skills together at one time, broadens the base of people who were involved with the design discussions, and at least presents a better opportunity to document the discussions for later use.

ADVANCED COMPUTING SYSTEMS

The use of advanced computing systems for the analysis of process flow sheets is an extremely valuable technique for development of some phases of the munitions program. The computing systems make extensive use of the most understood process characteristics - the conservation laws: material balance, component balance, and energy balance. They also provide a solid base for design documentation which can be easily and systematically reviewed at a later date.

Many of the systems available today were developed since the late 1960's and are considered a "second generation" (10). Examples are Monsants's FLOWTRAN, Exxon's COPE, Union Carbide's IPES, and DuPont's CPES. In general, these programs carry out steady state process simulations involving streams of vapors and liquids including heat and material balances. For large plants most engineers would not consider manually calculating design equations for distillation columns, heat exchangers, etc. The main problem with these programs is that they are not universally available and require specific skills to use.

MIT has recently been awarded a three million dollar grant by ERDA to develop a 3rd generation computer-aided design language (12). The project, named ASPEN, will concentrate on extending existing programs to include fossil energy conversion processes. In addition, it is hoped that ASPEN will be accepted as a universal system used by all process engineers and taught to students at universities. High priority is being given to make ASPEN readily accessible, fully documented, easy to use, and able to be extended to include dynamic simulations.

A 3rd generation flow sheeting system such as ASPEN would provide a nonpersonal link that could be used in the research, development, pilot plant, engineering and plant performance evaluation states of a project. A word of warning, though: assumptions inherent in any simulation should be clearly documented and be available when the program is used again after a layaway period.

MAN-MACHINE INTERFACE TECHNIQUES

Techniques for designing time-independent man-machine interfaces are only beginning to be thought about and are certainly not fully developed. A general methodology is required, however, as increasing levels of automation are resulting in a number of the human operator's mental processes being taken over or augmented by information processing systems.

Looking back one sees that the operator/process system was tightly coupled. The operator was "in touch" with his environment; he determined the operating procedure; and his "experience" was a key to the successful operation of the plant. As size and complexity of processes increased, more efficient methods for monitoring and control were required resulting in the central control room with its large panel of instruments.

The panel design and display format are traditionally developed based on the designer's "experience" in understanding the role of the operator and his needs. Infrequently some human factor may be added when the selection of colors or positioning of pushbuttons is involved. In general, the operator display - even more so than the control system - is almost included as an afterthought to the design of the plant. Consequently, this usually means a study of human operator behavior and a definition of his task was never included in the early planning of the installation. From a Readiness standpoint, this means that critical operator skills may not be recognized until after the plant start-up is initiated.

Techniques to counteract this problem are beginning to develop. Basically they involve analyzing the task required of the human supervisor as he watches the control system as shown in Figure 9. The tasks can be summarized as follows:

Learning, understanding, and interpreting goals required of him.

Monitoring the system outputs so that from the control actions he can identify the dynamics of the system.

Planning and determining which control actions should be performed.

Inputting the appropriate data to the control system for both initialization and on-line adjustments.

Intervening in order to switch from manual to supervisory control.

The guidelines for Man-Machine Interface Design established by the International Purdue Workshop (14) provide an excellent base for defining the operator tasks and relating them to display design. It would be impossible to design such a flexible display that would meet unknown requirements 10 years from now. A better technique is to specify details about the operator, his task, and environment as shown in Figure 10 and then design the interface accordingly.

For example: The education level and prior plant experience of the operator should be specified as well as whether training will be carried out away from the plant or covered on-the-job by the display system. The job requirements also have to be detailed including the type of decisions the operator will be expected to make, the degree of supervision that will be provided, and the use the operator is expected to make of the instruments (simple monitoring, comparison of set points, etc.). Even details such as the location of the control room (near or far from the equipment) or its size (will the operator be standing or seated) will effect the display design.

Basically the operator performs two functions: (1) getting information from the system; and (2) taking action on the control elements. The operator's need for information may be continuous, periodic, on-demand or automatic; and his choices of action varies widely in number and type, depending upon process conditions and the control elements with which he is dealing.

A present answer for this situation is an operating procedure matching available actions to a particular task and the current conditions, with a variable function keyboard, which changes its function under program control (15). A future answer may be indicated by a study underway at Delft University, the Netherlands, to model the human operator in order to analyze his ability to react to situations of excessive data, emergency conditions and analysis of information (4).

ANALYSIS TECHNIQUES

Fault tree analysis is a descipline which attempts to model and analyze failure processes of engineering systems. Construction of the fault tree, a basic step in fault tree analysis, requires an intimate knowledge of the manner in which a system is designed and operated.

Lambert (16) showed how the technique could be used to optimally locate sensors within the chemical processing systems.

A basic problem with fault tree analysis is the time required. A complete flow sheet of the process is needed and all the hazardous events that might occur must be documented. Each potentially hazardous event may then be evaluated to determine the possible paths that led to that event. These sets must contain "all" the important events in the proper logical relationships. A paper by Powers and Lapp (17) discusses a computer-aided fault tree synthesis procedure. They estimate that each fault tree will often require two to three man-days to carry out the generation, documentation, and computation on the analysis. They also point to a 25 man-year effort in a U.S. Atomic Energy Commission report that was required to generate fault trees for one boiling water reaction and one pressurized water reactor.

Fault tree analysis does provide a means to utilize the critical skills of the designers at one point in time and logically document the results for use later.

CONTROL TECHNIQUES

We can probably well assume that the time and manpower requirements, in addition to a lack of process knowledge, place a practical limit on the use of fault tree analysis. Therefore, a different kind of technique is needed, a technique which is based on operation rules. The tuning of controllers, the diagnosis of alarm conditions and the analysis of process data are carried out by operations oriented personnel who understand and use the process criteria. Unfortunately, this means reliance on the critical skills of these individuals.

Adaptive control techniques is one means of overcoming these problems. The problem in designing adaptive control systems has been to come up with a scheme which includes a minimum amount of computation, requires little special understanding, and which will adapt most processes under as many disturbance situations as possible. Such a system, based on a simple pattern recognition technique has been proposed (7, 8). The technique matches the way an operator tunes - to pattern or shapes rather than particular response values.

Adapation will be an essential future characteristic of the fully automated plant. With it human interference will not normally be necessary in any loop except for an initial pattern specification. In addition, a pattern based adaptation can prevent instability from ever occurring in any loop.

Pattern recognition can also be also be put to good use as a part of a system to help diagnose plant problems after an alarm condition and to help predict when an alarm condition is about to occur (9). Usually flashing alarms present only the "symptoms" of the malfunctioning process and responsibility for finding the cause and determining corrective action is left to the operator. The establishment of a symptom pattern is simpler than the fault tree described earlier as only the basic paths are followed for the most important faults. From that point the system stores new patterns each time an alarm is sounded. The operator may also enter new patterns. The procedure is then one of matching the actual alarm history to the dictionary. Matching of actual symptom pattern will allow diagnosis of the fault. Other "teachable" alarm and disturbance analysis system have also been suggested (13).

Newer systems produced under the name of "model reference" control systems are aimed to help the operator assimilate data from infrequent laboratory samples which may have random errors. The technique uses a model to take control action but updates the model parameters from an analysis of the laboratory samples using a Kalman filter approach (6). The system can operate through temporary measurement failures without suddenly degrading control performance.

Of course, designing the plant to be inherently stable in the first place eliminates many of the control problems and is not as impossible as one might imagine. Tanks with overflows for normal operation require no level controller. A very large heat exchanger and a vast constant temperature bath could be used to keep temperature control in a stable region - capital cost would be enormous, however. While some self-regulating control techniques can be used, the majority of the control will involve some measure of complexity and interdependence.

In the past, if the operator was uncertain about a loop, he put it in manual operation. With any degree of complex loops, putting a loop on manual might destabilize the process or otherwise affect the working or safety of other loops. Hence, use of advanced control techniques should include an interlock between the auto/manual functions and also provide a range of operational states between the conventional manual operation and the full automatic.

OTHER TECHNIQUES

Some other techniques are worth commenting on as they can affect the critical skill requirement problem when Readiness is required.

A training simulator developed along with the plant design and verified during the initial plant tests can be used to train operators in the future or maintain personnel with critical skills during the layaway period. Such a simulator can easily grow out of proportion and in excess of its value. Only the critical sections of the plant need be simulated and the simulation level should reflect the operating characteristics rather than be an exact mathematical representation of the process. A movie or video tape would provide good documentation of the way the plant should be controlled.

Good documentation is essential for technology transfer at some future time. Techniques employed here include: (1) listing assumptions used during the design phase; (2) visibility given to validity tests of the design programs during plant start-up to instill confidence; (3) use of structured languages for computer programming to facilitate reading; and (4) the use of hybrid flow chart type languages for showing both the parallel activity or simultaneous logical tests inherent in sequential operations.

SUMMARY

Four conclusions stand out as necessary to increase the possibility of obtaining a time invariant process design which possesses excellent Readiness characteristics because of a minimal dependence on future critical skills:

(1) Maintain a simplicity in design through modular design techniques making use of a systems approach and incorporating control early in the planning stage.

(2) Place emphasis of making sure the lowest level of control (single loop temperature, pressure, flow, etc.) is working properly because all other techniques will assume that this has been accomplished.

(3) Allow for the simultaneous evolution of information and design which will inevitably take place since at any point in the design process knowledge will always be lacking.

(4) Decide who will enforce the control and documentation procedures agreed upon.

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- PLANTS RUN FROM MINI DISASTER TO MINI DISASTER
- OLD CAR SYNDROME
- NO RESPONSIBILITY FOR "ON CONTROL" CONDITION
- LITTLE CHANGE IN OPERATION CAUSED BY TECHNOLOGY
- CONTROL MAINTENANCE PROBLEMS
- OPERATOR TRAINING

FIGURE 1

PLANT OPERATING CHARACTERISTICS

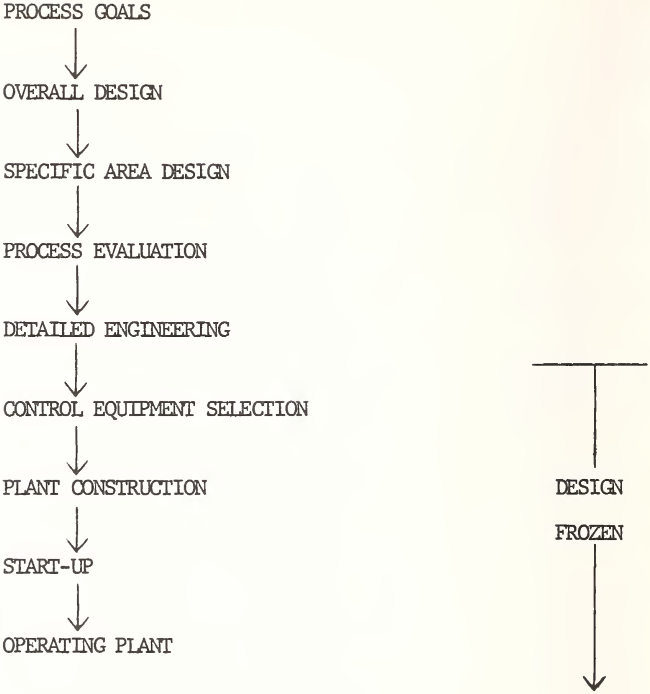

FIGURE 2

DESIGN APPROACH - TYPICAL

- FINAL STEP IN PLANT ENGINEERING
- EMOTIONAL ISSUE
- EFFECTS PLANT OPERATION
- USUALLY CONSERVATIVE APPROACH
- OFTEN LEFT TO VENDOR TO DEFINE
- NO STANDARDIZED APPROACH

FIGURE 3

CONTROL PROJECT CHARACTERISTICS

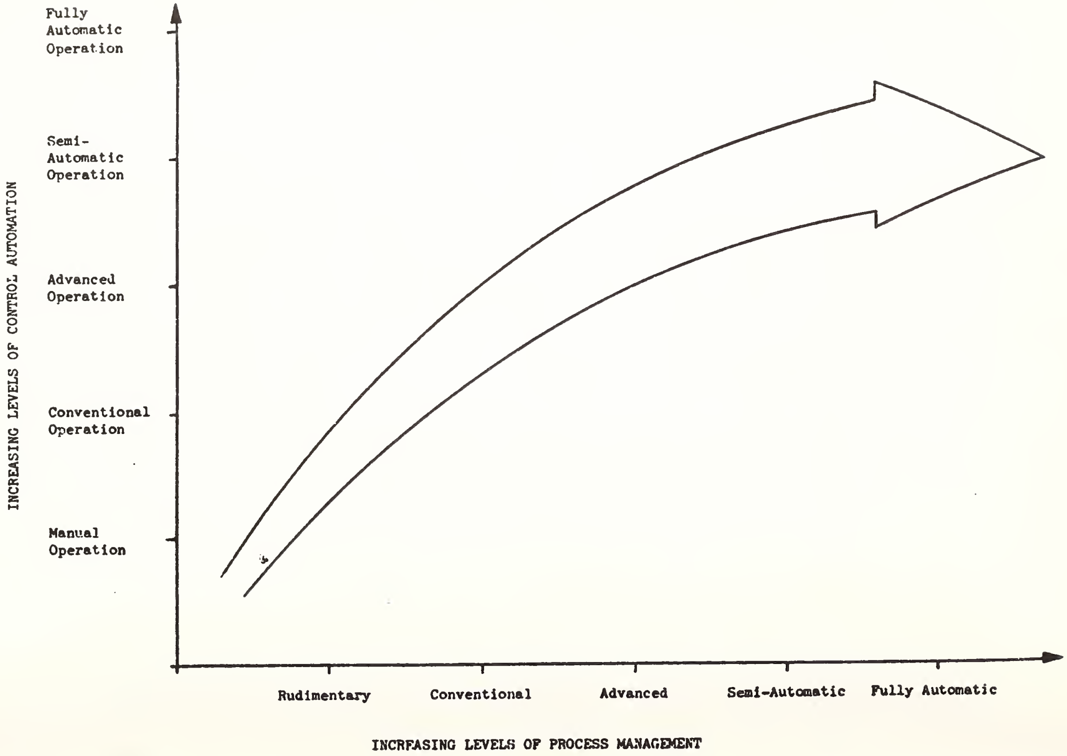

FIGURE 4

PROGRESSION OF ADVANCED CONTROL SYSTEMS

TABLE I

CHARACTERISTICS OF INCREASING LEVELS OF CONTROL AUTOMATION

CHARACTERISTICS / LEVELS OF CONTROL AUTOMATION	Manipulation Of Process Actuators			Control Law Used During Normal Operation Of Plant	Method Of Controller Tuning	Human Monitoring And Intervention	Alarm Condition Analysis	Measurements Used And Variables Computed	Plant Scope
	Under Normal Operation	During Startup, Shutdown Level Chgs.	During Emergency Conditions						
Manual Operation	Human	Human	Human	Written Decision Rule	NA	NA	Human	As Necessary	Independent Unit
Conventional Operation	Automatic	↓	Key Actuators Automatic	On-Off, 3-Mode, Cascade	Human	Automatic→ Manual, Emergency Trip	↓	↓	↓
Advanced Operation	↓	↓	↓	Above + Feedforward, Noninteracting	Some Key Loops Tuned Automatically	↓	Some Alarm Analysis Displayed	↓	Integration Of Single Units
Semi-Automatic Operation	↓	Semi-Automatic	All Actuators Automatic	Above + Coordinated	All Key Loops Automatic	↓	Some Automatic Action	↓	Integration Of Multiple Units
Fully Automatic Operation	↓	Fully Automatic	↓	↓	Fully Automatic	Emergency Trip	Fully Automatic	↓	Plant Treated As Single Entity

TABLE IA

FUNCTIONAL CHARACTERISTICS OF CONTROL TECHNOLOGIES REQUIRED

INCREASING LEVELS OF CONTROL AUTOMATION DESIRED FUNCTIONAL CHARACTERISTICS OF CONTROL TECHNOLOGIES REQUIRED	MANUAL OPERATION	CONVEN-TIONAL OPERATION	ADVANCED OPERATION	SEMI-AUTO. OPERATION	FULLY AUTO. OPERATION
MEASUREMENTS					
Basic Measurements (T, P, L, F)	X	X	X	X	X
Advanced (Composition, Vibration)			X	X	X
Complex (Product Quality)				X	X
CONTROL DECISIONS					
On-Off Controller		X	X	X	X
3-Mode Controller		X	X	X	X
Model Based Controller			X	X	X
Alarm Diagnostic Routines			X	X	X
Automatic Controller Tuning Routine			X	X	X
DISPLAY AND REPORTING					
Display and Recording of Variables	X	X	X	X	NA For Normal Operation
Annunciate Alarms		X	X	X	
Alarm Diagnostic Messages			X	X	
CONTROL MODELS					
Simple Heat & Mat. Balance Models			X	X	X
Dynamic Process Models				X	X
Detailed Safety Models				X	X
VARIABLE MANIPULATION					
Actuators (Basic)	X	X	X	X	X
Actuators (Increased Accuracy)				X	X
Actuators (Increased Reliability)					X

TABLE II

CHARACTERISTICS OF INCREASING LEVELS OF PROCESS MANAGEMENT

CHARACTERISTICS / LEVELS OF PROCESS MGT. NEEDED OR DESIRED	DATA GATHERING AND RETENTION			USE OF MANAGEMENT AND PROCESS INFORMATION			
	Data Gathering And Conversion To Machine Readable Form	Data Type Entered Into Process Management System	Data Retention	Display Of Performance Variables	Basis For Decisions	Degree Of Learning	Plant Scope
Rudimentary Process Mgt.	Manual Gathering	None	Logs, Records	None	Human Intuition	Human	Independent Single Unit
Conventional Process Mgt.	Manual Gathering & Conversion	Some Process	Some System Retention	Some Necessary	Human Judgement	↓	↓
Advanced Process Mgt.	Some Automatic Gathering & Conversion	Most Process Some Business	Most System	Most Necessary	Some Automatic Decisions	Some Models Updated Routinely	Some Integration Of Single Units
Semi-Automatic Process Mgt.	Most Automatic	All Process Most Business	↓	All Necessary	Most Automatic	Semi-Automatic Updating	Integration Of Multiple Units
Fully Automatic Process Mgt.	Fully Automatic	All Data	All System	No Variables Displayed	Fully Automatic	Fully Automatic	Plant Treated As Single Entity

TABLE IIA

FUNCTIONAL CHARACTERISTICS OF PROCESS MANAGEMENT TECHNOLOGIES REQUIRED

INCREASING LEVELS OF PROCESS MANAGEMENT DESIRED FUNCTIONAL CHARACTERISTICS OF PROCESS MGT. TECHNOLOGIES REQUIRED	RUDIMENTARY	CONVENTIONAL	ADVANCED	SEMI-AUTOMATIC	FULLY AUTOMATIC
INFORMATION GATHERING AND CONVERSION					
Process Data Gathering	X	X	X	X	X
Process Data Entry		X	X	X	X
Business Data Gathering And Entry			X	X	X
DECISION ANALYSIS TECHNIQUES					
Material And Energy Balance		X	X	X	X
Computation Of Performance Variables		X	X	X	X
Exception Identification		X	X	X	X
Inventory Analysis			X	X	X
Scheduling			X	X	X
Optimization Algorithms			X	X	X
Forecast Systems				X	X
Process Diagnostics				X	X
DISPLAY AND REPORTING					
Data Logging	X	X	X	X	
Trend Displays		X	X	X	NA For Normal Operation
Exception Reporting		X	X	X	
Receipts, Orders, Shipments Display			X	X	
Pattern Displays			X	X	
User-Directed Hierarchical Display			X	X	
DECISION MODELS					
Saftey and Environmental Model		X	X	X	X
Material Balance Model		X	X	X	X
Energy Balance Model		X	X	X	X
Inventory Model (e.g. EOQ)			X	X	X
Scheduling Model			X	X	X
Optimization Model (e.g. LP, NLP)			X	X	X
Distribution & Transportation Model			X	X	X
Forecast Model (e.g. Econometric)				X	X
Diagnostic Model				X	X
PROCESS MANAGEMENT DIRECTIVES					
Operating Guides		X	X	X	X
Plant Operating Conditions			X	X	X
Raw Material Selection			X	X	X
Shipping & Distribut'n Instructions			X	X	X
Utilities Management			X	X	X
Maintenance Schedules			X	X	X
Raw Material Ordering				X	X

U. S. ARMY	-	BASIC PRODUCT REQUIREMENTS PRIORITIES FUNDING
OPERATING COMPANIES	-	OPERATIONAL (FUNCTIONAL) REQUIREMENTS PROCESS TECHNOLOGY SCHEDULE PROJECT MANAGEMENT REALIZABLE SYSTEM SPECIFICATIONS
CONTRACTORS	-	CONSTRUCTION INSTALLATION
VENDORS	-	UNDERSTAND USER NEEDS PROVIDE VIABLE TECHNOLOGY OPTIONS DESIGN CONTROL SYSTEM TO MEET FUNCTIONAL REQUIREMENTS INSTALLATION AND COMMISSIONING SUPERVISION MEET CONTROL SPECIFICATIONS

FIGURE 5

PARTICIPANTS AND RESPONSIBILITIES

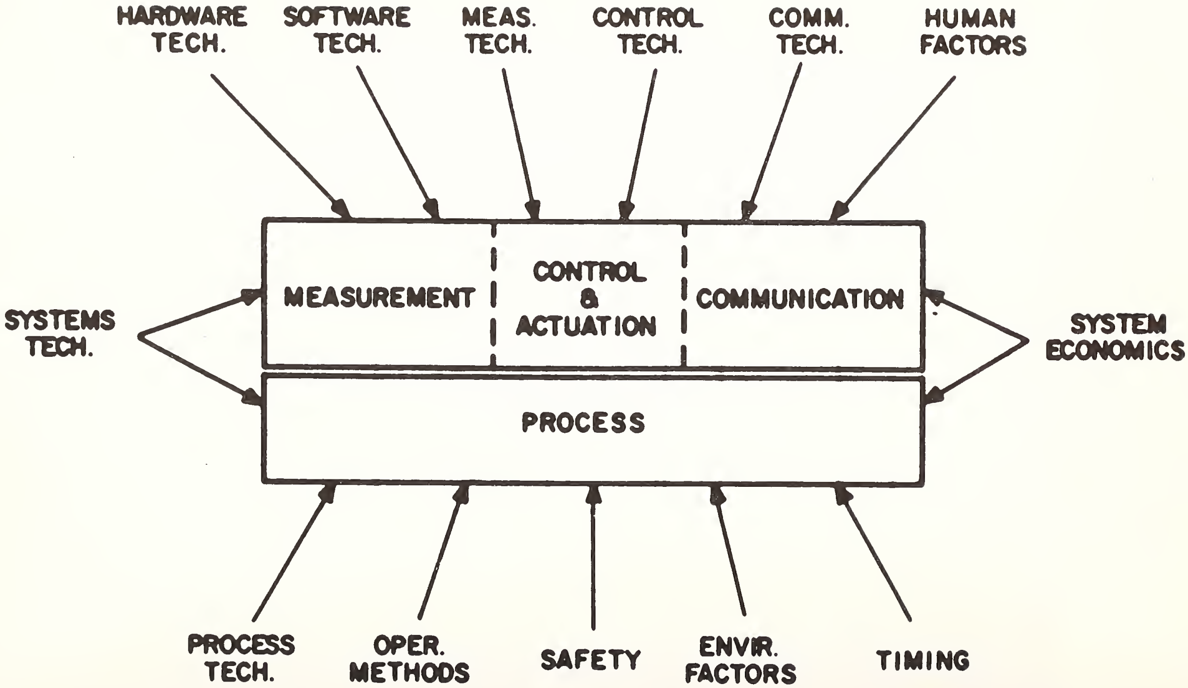

FIGURE 6

FACTORS AFFECTING CONTROL SYSTEM DESIGN

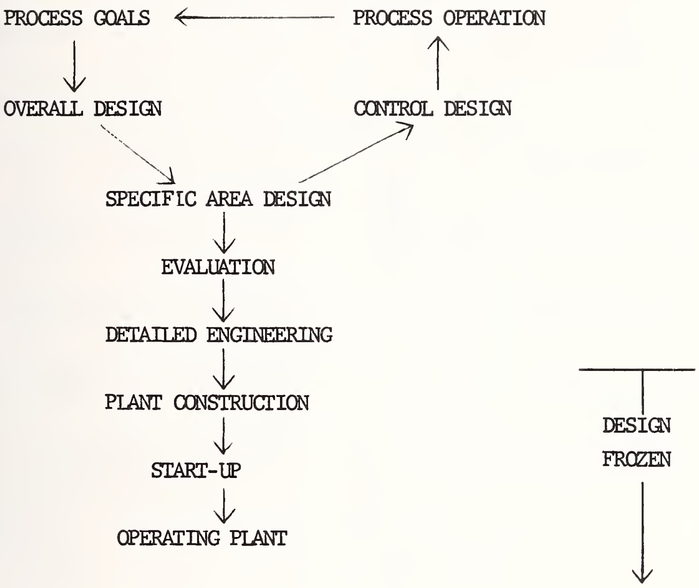

FIGURE 7

DESIGN APPROACH - RECOMMENDED

PLANT GOALS

PLANT OPERATIONAL/MANAGEMENT PHILOSOPHY

STAFFING REQUIREMENTS

MAN/MACHINE FUNCTION DESCRIPTION

CONTROL ROOM PROCEDURES

COMMUNICATIONS NEEDS

AREAS FOR CONTROL ENFORCEMENT

SAFETY CONSIDERATIONS

STANDARD OPERATING PROCEDURES

PROCESS ECONOMIC SENSITIVITY

CONTROL STRATEGY

LEVEL OF CONTROL DISTRIBUTION

PROCESS EQUIPMENT REVIEW

MEASUREMENT NEEDS/MEANS

CONTROL SYSTEM DESIGN RESPONSIBILITIES

FIGURE 8

FACTORS CONSIDERED DURING SYSTEM DESIGN

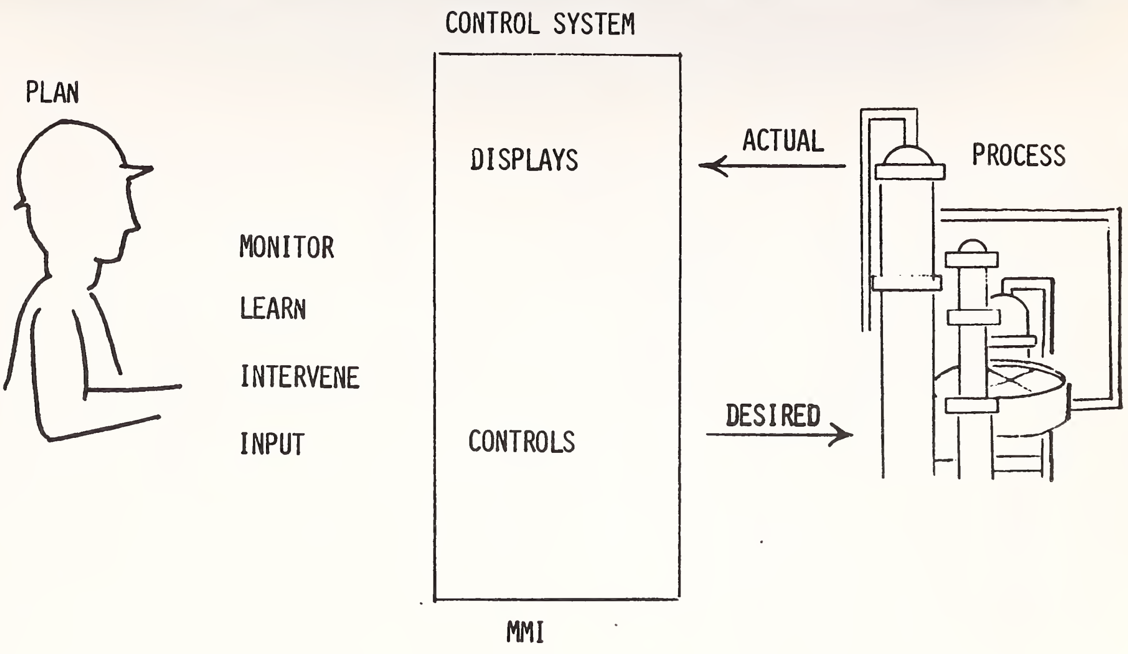

FIGURE 9

THE TASKS OF THE HUMAN OPERATOR

THE OPERATOR:

- EDUCATION
- OPERATION EXPERIENCE
- TRAINING LEVEL
- MENTAL LOAD LIMIT

THE TASK:

- JOB REQUIREMENTS
- DECISION LEVEL
- DEGREE OF SUPERVISION
- INSTRUMENT USE

THE ENVIRONMENT:

- LOCATION
- SIZE
- PHYSICAL REQUIREMENTS

FIGURE 10

WHAT THEY SPECIFY

APPENDIX I

LIST OF PARTICIPANTS

WORKSHOP ON CONTROL SYSTEMS READINESS FOR MUNITIONS PLANTS

LIST OF PARTICIPANTS

WORKSHOP ON CONTROL SYSTEMS READINESS FOR MUNITIONS PLANTS

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APPENDIX II

AGENDA AND TECHNICAL PROGRAM

WORKSHOP ON CONTROL SYSTEMS READINESS FOR MUNITIONS PLANTS

AGENDA AND TECHNICAL PROGRAM

WORKSHOP ON CONTROL SYSTEMS READINESS FOR MUNITIONS PLANTS: A FIRST PASS

Room 322
Stewart Center
Purdue University
West Lafayette, Indiana 47907

September 19-20, 1977

Monday, September 19, 1977

SESSION NUMBER 1

Chairman: Mr. Douglas A. Morlock
U.S. Army - DRCPM-PBM-T
Project Manager for Munitions
Production Base Modernization
Dover, New Jersey 07801

AM
09:00 - 09:30 Introduction Remarks

Mr. Douglas A. Morlock

Lt. Col. Denis C. Dice
U.S. Army - DRCPM-PBM-T
Production Base Modernization
Dover, New Jersey 07801

and

Dr. John M. Evans, Jr.
Manager, Automation & Control Program
National Bureau of Standards
Washington, D.C. 20234

09:30 - 10:00 Past Experience in the Reactivation of Army Ammunition Plants

Mr. Augie J. Zahatko
Chief of Production Base Concepts Office ARRCOM
Headquarters, U.S. Army Armament Material
Readiness Command DSAR-INC
Rock Island, Illinois 61201

10:00 - 10:15 Coffee Break

10:15 - 10:30 Current Procedures and Problems in the Layaway and Reactivation of Process Control Systems

Mr. Ferenc T. Beiwel
Mechanical Engineer
U.S. Army Industrial Base Engineering Activity
Rock Island, Illinois 61201

10:30 - 10:45 Policies & Procedures for Layaway Equipment Management & Maintenance

Mr. John Nemanich
Industrial Specialist
Headquarters, U.S. Army Armament
Readiness Command
Rock Island, Illinois 61201

10:45 - 11:15 An Overview of the Performance Characteristics of Sensory Transducers

Mr. Paul S. Lederer
Chief, Components and Application Section
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

11:15 - 12:15 Discussion of Material of Morning Reports

PM
12:00 - 01:30 Lunch

SESSION NUMBER 2

Chairman: Dr. Gordon J. VanderBrug
Project Manager, Automation & Control Program
National Bureau of Standards
Washington, D. C. 20234

01:30 - 01:40 Remarks

01:40 - 02:30 Layaway, Standby and Reactivation Procedures for Computer Magnetic Media

Mr. Sidney B. Geller
Manager, Magnetic Media Group
Institute for Computer Science & Technology
National Bureau of Standards
Washington, D. C. 20234

02:30 - 02:40 Coffee Break

02:40 - 03:10 Environmental Effects on Electrical and Electronic Devices and Equipment Under Long Storage Conditions

Mr. Albert J. Graf
Reliability Engineer, Large Caliber
Weapons Systems Laboratory
U.S. Army Armament Research & Development
Command DRDAR-LCA
Applied Sciences Division
Dover, New Jersey 07801

03:10 - 03:45 Layaway Program for Control Valves

Mr. Joseph Van Damme
Principal Development Engineer
The Foxboro Company
Foxboro, Mass. 02035

03:45 - 04:10 The Independent Testing and Proving of Hardware and Software Elements of Plant Computer Control Systems on Reactivation of Munitions Plants

Mr. Dale Zobrist
ELDEC Corporation
P. O. Box 100
Lynnwood, Washington 98036

04:10 - 04:25 The Layaway and Reactivation Problem of Beet Sugar Mills for Their Annual Campaigns Including Management, Manpower and Training Aspects

Professor Theodore J. Williams
Purdue Laboratory for Applied Industrial Control
Schools of Engineering
Purdue University
West Lafayette, Indiana 47907

with the help of

Mr. Daniel D. Lesser
Factory Manager
Northern Ohio Sugar Company
Findlay, Ohio 45840

04:25 - 06:00 Discussion of the Topics of the Afternoon Reports

BANQUET AND EVENING SESSION

Private Banquet Room
Morris Bryant Restaurant

07:00 - 08:00 Dinner

08:00 - 10:00 Discussion of the Program of the U.S. Army for Munitions Production Base Modernization and Expansion

Dr. Gordon J. VanderBrug
National Bureau of Standards

Mr. Carl Beaulieu

and

Mr. Douglas A. Morlock
U. S. Army

Tuesday, September 20, 1977

SESSION NUMBER 3

Chairman: Mr. Douglas A. Morlock

AM
09:00 - 09:50 High Reliability Design Techniques for Distributed Digital Systems

Dr. M. P. Lukas
Manager of the Systems Analysis Dept.

and

Mr. J. J. Steinkirchner
Group Leader for Reliability
Electronic Engineering Dept.

Bailey Meter Company
29801 Euclid Avenue
Wickliffe, Ohio 44092

09:50 - 10:00 Coffee Break

10:50 - 11:20 Potentials of Initial Systems Design Techniques to Help Relieve Critical Operating Skill Requirements in Reactivated Munitions Plants

Dr. Malcolm C. Beaverstock
Senior Research Engineer
Corporate Research Department
Foxboro Company
Foxboro, Massachusetts 02035

11:20 - 11:30 Discussion of Morning Reports

SESSION NUMBER 4

Chairman: Professor Theodore J. Williams
Purdue Laboratory for Applied Industrial Control
Schools of Engineering
Purdue University
West Lafayette, Indiana 47907

11:30 - 12:00 Discussion of a Set of Directed Questions to Obtain the Conclusions of the Workshop

PM
12:00 - 01:30 Lunch

01:30 - 02:30 Further Discussion of the Set of Directed Questions

02:30 - 04:00 Formulation of the Conclusions of the Workshop

04:00 Adjournment

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS SP 522	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Workshop on Control Systems Readiness for Munitions Plants: A First Pass

5. Publication Date

October 1978

6. Performing Organization Code

7. AUTHOR(S)

Theodore J. Williams, Editor

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

National Bureau of Standards; U.S. Army: Project Manager for Munitions Production Base Modernization and ARRADCOM, Picatinny Arsenal, Dover, NJ 07801; ARRCOM, Rock Island Arsenal, Rock Island, IL 61201; Purdue University, W. Lafayette, IN 47907

13. Type of Report & Period Covered

Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

Proceedings of a Workshop held at Purdue University, West Lafayette, Indiana, September 19-20, 1977.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Experts in the field of Industrial Process Control were asked to assist the U.S. Army and address a most challenging and unique problem. Large capacity munitions manufacturing production facilities are required only in times of national emergency. These production facilities are complex manufacturing processes normally operated by sophisticated industrial process control systems.

Long periods of dormant storage may occur between facility construction and required operation. Guidance is required for the Army to properly plan for appropriate technical activity which will assure the readiness of these industrial processes at the time of national emergency. The Workshop which is reported upon in this document was held to help provide some of the needed background to this problem. It also generated a set of recommendations to be considered by the U.S. Army when setting up its procedures in this area. In addition to a set of background papers, discussions were held in the areas of transducers, magnetic media reliability, electronic and mechanical element needs, testing and proving of control system components, reliability enhancement techniques, simulation for personnel training purposes, and the effect of initial control system design of personnel skill requirements. The recommendations developed treat each of these. Further work is needed to refine and verify these recommendations.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Automatic control systems; dormant storage; magnetic tape; layaway; reactivation; readiness; reliability; sensors; simulation; standby

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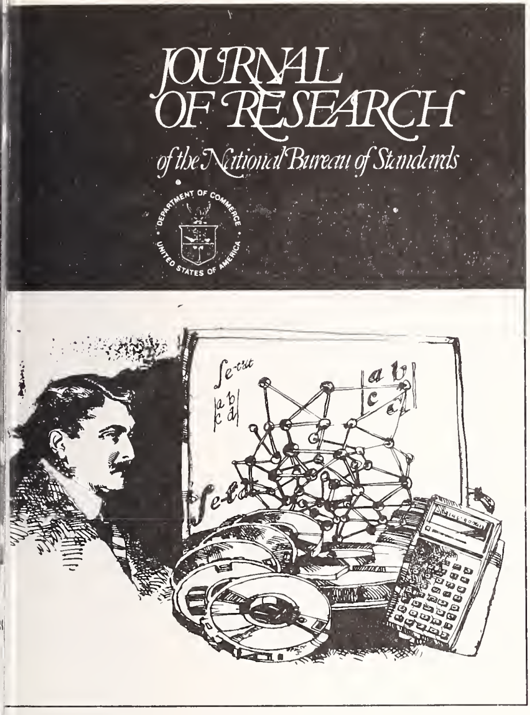

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