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TECHNOLOGY MODERNIZATION ASSESSMENT
FLEXIBLE AUTOMATION

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EXECUTIVE SUMMARY

This report was prepared by Pacific Northwest Laboratory (PNL) as part of its support to the READY 2000 Project.

The objectives of this report are:

- to present technology assessment guidelines to be considered in conjunction with DESCOM regulations before an automation project is developed
- to give examples showing how assessment guidelines may be applied to a current project
- to present several potential areas where automation might be applied successfully in the depot system.

When considering implementation of automation at the depots, perhaps the greatest potential misconception is that commercial manufacturing technology can be directly applied to all DESCOM operations.

In fact, DESCOM performs primarily repair and remanufacturing operations, with limited small batch manufacturing runs. While certain activities (such as Management Information Systems and warehousing) are directly applicable to either environment, the majority of applications will require combining existing and emerging technologies in different ways, with the special needs of DESCOM remanufacturing environment factored in.

Industry speaks of "flexible automation," and generally enjoys the ability to make revisions to its product lines seasonally, followed by batch runs of thousands or more. In a large number of cases, DESCOM batch runs are in the tens, at best the hundreds, of parts with a potential for large variation in product mix; reconfiguration may be required on a week-to-week basis. It is this need for a higher degree of flexibility that suggests a higher level of operator interaction, and, in turn, control systems that go beyond the state of the art for less flexible automation and industry in general.

Each DESCOM implementation requires integration of current and emerging technologies. Since the DESCOM environment generally differs from industry,

there is necessarily additional risk incurred in the context of forecastable technical performance and also relative to production of the desired system within the estimated cost and schedule. DESCOM staff must understand and fully evaluate these risks before "turnkey" contracting is attempted.

This report investigates the benefits and barriers to automation for DESCOM and concludes that, while significant benefits do exist for automation, DESCOM must be prepared to carefully investigate the technical feasibility of each opportunity and the direct and indirect life-cycle costs associated with implementation. Management and administrative feasibility must be investigated for each opportunity as well, since implementation of automation often requires training and reassignment of workers along with management restructuring.

Finally, phased implementation of automation technology is suggested in two ways:

- develop an implementation plan for automation technologies at DESCOM based on results of small demonstration automation projects to be initiated as part of the READY 2000 Project
- use phased implementation for both these and later stage automation projects to allow major technical and administrative risk issues to be addressed early in the process; require peer reviews on each phase of implementation.

DEFINITIONS

Automation	Automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that replace human observation, effort, and decision.
Computer-Aided Design (CAD)	The use of an interactive-terminal workstation, usually with graphics capability, to automate the design of products. CAD includes functions like drafting and parts-fitup.
Computer-Aided Manufacturing (CAM)	Working from a product design likely to exist in a CAD database, CAM encompasses the computer-based technologies that physically produce the product, including part-program preparation, process planning, tool design, process analysis, and part processing by numerically controlled machines.
Computer-Integrated Manufacturing (CIM)	The philosophy dictating that all functions within a manufacturing operation be database-driven and that information from within any single database be shared by other functional groups. CIM includes major functions of operations management (purchasing, inventory management, order entry), design and manufacturing engineering (CAD, NC programming, CAM), manufacturing (scheduling, fabrication, robotics, assembly, inspection, materials handling), and storage and retrieval (inventories, incoming inspection, shipping, vendor parts).
Core Functions	Sustainment function that must be performed organically to ensure the success of the Army's combat forces.
Excess/Surge Capacity	The ability of an automated system to handle relatively short periods of high demand.
Flexible Manufacturing Systems (FMS)	An arrangement of machine tools that is capable of standing alone, interconnected by a workpiece transport system, and controlled by a central computer. The transport sub-system, possibly including one or more robots, carries work to the machines on pallets or other interface units so that accurate registration is rapid and automatic. FMS may have a variety of parts being processed at one time.

Group Technology	A technique for grouping parts to gain design and operational advantages. For example, in robotics group technology is used to ensure that different parts are of the same part family when planning part processing for a work cell, or to design widely usable fixtures for part families. Part grouping may be based on geometric shapes, operations processes, or both.
Information Systems	Systems that assist in the transfer, storage, and retrieval of information or data.
Life Cycle Costs	Life-cycle costs represent the complete cost of a technology application including costs for implementing, operating, and decommissioning a system. Because these costs occur over a period of time, a "present value" calculation must be used in comparing alternatives on a life-cycle cost basis. The present value approach accounts for the time value of money and provides a method to select the alternative that provides the most economically efficient service.
Mobilization	Large scale implementation/production due to a national emergency or wartime effort. Implementation is generally considered to be needed for a period of several years.
Programmatic Technology	Functions typically provided by the depots which, for the purposes of this report, are divided into areas that are programmatic in nature.
Robotics	The science of designing, building, and applying a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

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1.0 INTRODUCTION

Achieving technical parity with industry is one of the Depot System Command's (DESCOM) priority goals in carrying out its modernization program, READY 2000 (REvitalization of Armey Depots for the Year 2000). An important part of achieving this goal is to know where industry is expected to be in the future. Pacific Northwest Laboratory (PNL)^(a), as part of ongoing technical assistance it provides to the READY 2000 program, has been investigating current industrial practices and trends.

Because DESCOM's manufacturing requirements are not strictly analogous to those of industry, further investigation was necessary to allow a focus on technologies that lend themselves well to DESCOM's unique requirements. This document presents the results of that work.

This document presents information on robotics and flexible automation technology options that could provide the capabilities DESCOM requires for the future. Technologies were evaluated only for activities that comprise the bulk of the depots' continuing and future workload and that will, therefore, have the greatest impact on improving depot operations in the future. In addition, this report provides guidelines for assessing the application of these technologies to DESCOM operations.

The information in the remainder of this report is presented in three chapters and an appendix. Chapter 2 presents general guidelines for assessing candidate automation projects at DESCOM. It includes a discussion of the unique requirements that the DESCOM mission brings to the implementation of automation technology. Both the reasons for and the barriers to automation are discussed, and an approach for assessing candidate automation projects is outlined. Chapter 3 presents the results of an example assessment. Chapter 4 gives specific examples of automation needs related to each of selected DESCOM core functions. The appendix provides additional information pertaining to the technologies discussed in this report.

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2.0 GUIDELINES FOR ASSESSING AUTOMATION TECHNOLOGIES AND APPLICATIONS

In a series of publications (TB18-100, -101, -102, -103, -104, -109, -111, and AR25-1), the Army has defined standards for the life-cycle management of its automated systems. The automation life cycle is defined and broad guidelines for assessing automation projects (starting with the initial concepts and continuing through various milestones) are provided. TB18-100 defines major automation life-cycle milestones. Each milestone requires a choice among alternatives, one of which is possible discontinuance of the project. In order to complete a system decision paper in support of the selected alternative, the proposed technology must be adequately assessed. The following information supplements the published Army standards by discussing in detail the potential impact of automation on the DESCOM mission, the assessment of actual needs for automation within the Army depots, and the assessment of applicable automation technologies.

2.1 THE DESCOM MISSION

The DESCOM mission is to enhance the readiness of the Army through the overhaul, repair, modification, conversion, storage, and distribution of assigned commodities for the Army Materiel Command (AMC), the Defense Logistics Agency, the General Services Administration, and others. DESCOM carries out this mission at 13 depots, 6 depot activities, and 15 other installations. Each depot, activity, and installation has specific mission responsibilities.

Each proposed concept for automation of a depot function must be justified in terms of enhancing DESCOM's ability to meet mission objectives. TB18-100 requires the preparation of a mission element need statement (MENS) specifically defining a deficiency within a mission area. This document forms a basis for deciding if a complete concept development should be performed and does not, in itself, recommend solutions.

To meet DESCOM's mission objectives in maintenance, rework, storage, and distribution, diverse capabilities were developed within the depots. Although these functions have parallels in the classic industrial manufacturing environment, they differ in several respects.

For example, maintenance activity at the Army depot is quite different from that of the industrial manufacturing setting. In particular, the high volumes seen in industrial manufacturing are rare in the depots. Many automation technologies were developed in the industrial manufacturing environment and may have limitations when applied to maintenance performed in a depot.

The following examples illustrate a few difficulties that were encountered in applying existing commercial equipment to needs found in the depots.

- Circuit Board Assembly - Commercial pick-and-place equipment is available for loading components into circuit boards during assembly. For accurate placement, this equipment requires fine-tuning, which is not cost-effective for the low board quantities the depots typically encounter during circuit board repair.
- Spray Painting - Robotic systems developed in the automotive industry for applying paint to automobiles must be modified for use with many of the coatings used by the Army, such as two-part chemical agent resistive coating (CARC).
- Paint Removal - Commercial equipment is available for removing paint by sand-blasting or with solvents. Some of the Army's modern materials, such as composites, may be damaged by these techniques.

Technology that performs well in a manufacturing environment will not always serve the needs of a depot. Table 2.1 illustrates some of the unique aspects of depot activity that can impact the assessment of a candidate automation technology.

TABLE 2.1. Comparison of Commercial Manufacturing and Depot Maintenance Activities

Commercial Manufacturing	Depot Maintenance
Must respond to gradual changes in market demand	Must be able to respond to sudden mobilization demand
High volumes	Typically low volumes
Lengthy product runs	Very short runs
Well-defined, repeatable processes	Processes may vary according to need
New materials and components	Items needing repair may exhibit varying degrees of wear and fatigue
Primary processes (painting, wave-soldering, etc.)	Secondary processes such as paint or corrosion removal must be performed before primary processes
Processes can typically be scheduled	Processes occur as needed
Workforce size can be adjusted to meet load	More constraints on adjusting workforce size

2.2 REASONS TO AUTOMATE

Automation will not fit every need of the Army depot. Some processes are best performed by a human operator whose breadth of knowledge and mechanical dexterity are difficult to emulate in a machine. There are, however, significant reasons for considering automation for some depot activities. A sampling of these reasons is discussed below.

1. Manpower

Perhaps the most obvious application for automation technology is the automation of manually intensive, repetitive, or hazardous operations. Staff can be better used in performing tasks that require the special capabilities of a human operator. In some cases, additional training may be required.

2. Throughput

Many processes can be performed more quickly by machines, resulting in improved throughput. Systems can be designed to permit sudden increases to peak production levels thus permitting the depot to increase throughput on short notice. Without this capability, long "ramp-up" times would be required as new staff are hired and trained. Thus, automated equipment can help a depot achieve surge or mobilization readiness.

Improved throughput can have important incidental benefits. For example, an automated cartridge case inspection system inspects 1200 cartridge cases every minute. A 100% product inspection can now be performed; whereas, only a limited sample could be inspected before automation. Since the cartridge cases can be inspected as rapidly as they are produced, a repeating defect can be detected early. Waste is minimized because production can be shut down as soon as the defect is discovered.

3. Safety

Some processes require the handling of hazardous materials or are, in themselves, hazardous. Automation of hazardous processes can improve safety by reducing such processes to safe, repeatable tasks and by removing the operator to a safe location.

4. Quality Improvement

Product quality can sometimes be substantially improved by automation. The reduction of a process to a simple set of repeatable tasks performed by a machine ensures that product quality is not affected by worker fatigue or error. The integration of inspection equipment can verify that the finished product meets desired specifications and is free from defects.

5. Reduced Costs

Automation can significantly lower unit costs. This is particularly true when large volumes are involved. When sudden increases of production are required, a properly designed system can be adjusted to a higher production level without large increases in staffing.

2.3 ASSESSMENT GUIDELINES

Throughout the life of an automation project, technical and economic assessments will be required at various decision points (defined in TB18-100 as milestones in the automation life cycle). This section does not define a step-by-step approach to performing these assessments. Rather, it provides a

set of guidelines that may be used in part or in whole, depending on the current phase of the project to which the evaluations are being applied. For example, need identification will be most important during project initiation. However, it may be revisited during a later phase of the project if the original needs have changed.

As new or existing technology is fitted to the broad range of automation applications found at a depot, many different projects are likely to be suggested. It is also likely that for a decision point within a particular project, various alternatives will be formulated. Selection among alternatives is difficult when the development or application of new technology is required because of the typically high uncertainty in projecting development costs.

Nevertheless, a rational approach needs to be developed for assessing the viability of a proposed project and for comparison of alternatives. General considerations for technical, economic, and administrative assessments that should influence the evaluation process are presented below and in Table 2.2.

2.3.1 Technical Assessment

The technical assessment comprises the first six items on the Automation Checklist shown in Table 2.2.

Need Identification

Automation must be based on the need to enhance DESCOM's ability to carry out its mission objectives. Specific mission deficiencies must be identified to justify the need.

To identify specific needs, a survey can prove useful. In response to a recent READY 2000 survey, depot staff identified automation needs throughout the depot system across a wide variety of functions ranging from track shoe repair to testing of electronic circuits. Chapter 3 of this report draws on the results of this survey and illustrates how assessments can be made.

The best source for specific needs will come from those most directly involved in depot activities, from line managers through technicians.

TABLE 2.2. A Checklist for Automation Assessment

1. Need Identification
 - What mission deficiency currently exists?
 - What are the reasons for automation?
 - What are the economic performance requirements for an automated system?
2. Depot Process Flow Analysis
 - Does automation of the candidate process provide maximum benefit to the depot as a whole?
 - How well will the automated system integrate with other depot functions?
3. Current Process Assessment
 - How is the process currently performed?
 - What can be learned from the current method that might benefit the development of an automated system?
 - Does the current method adequately satisfy the need?
 - Do the perceived benefits to the mission justify an investment in an automated system?
4. Selection of Candidate Technologies
 - Which technology offers the best "fit" for the application?
5. System Requirements Specification
 - Has a preliminary design been carried to the point that cost estimates can be performed.
 - If so, should the design be finalized and implemented?
6. System Process Flow Analysis
 - What processes will the automated system actually perform?
 - What requirements are placed on the operator and other support personnel?
 - How do these processes interact with other processes in the depot?
 - What throughput improvement can be expected?

TABLE 2.2. (contd)

7. Project Costs

Has an Automation Economic Analysis been prepared for each milestone in the automation life cycle?

Have the following been included in the costing?

- development
- installation
- training
- operation and maintenance
- decommissioning

8. Risk Assessment

Have the risks been identified and weighed against perceived benefits?

9. Administrative Impact

What impact will the proposed automation project have on staffing, training, organizational structure and accounting?

Depot Process Flow Analysis

Evaluating a need in isolation is, at best, risky. An analysis of the depot process flow as a whole will help illuminate the real benefits (or disadvantages) of automating a particular process. If the process under consideration involves the handling of materials, then the flow of these materials throughout the depot needs to be characterized and analyzed. Pinch points in the flow can be identified, revealing whether or not automation of the process under consideration will have the maximum benefit. Unless some benefit other than improved throughput can be perceived, processes that are not frequently used should not be automated.

An understanding of how the candidate process relates to other depot processes will be especially beneficial during the development phases of the project. How well the automated system integrates with the rest of the depot must be a significant decision criterion.

Current Process Assessments

Many needs will be accommodated by existing processes that provide an adequate, if not optimal, solution. These processes may be completely manual

or they may involve varying degrees of man/machine interaction. Though the need for automation may appear completely obvious, these current processes should be assessed to see how they meet the specific need, how they interface with the operator and the rest of the depot environment, and how they are managed from an administrative and accounting viewpoint. One measure of the technical and economic viability of a proposed automated system is how well it performs when compared with existing processes. Under most circumstances it is difficult to justify a large investment in an uncertain technology when the job is done reasonably well by existing means.

Selection of Candidate Technologies

As needs are identified and justified, it is likely that some idea of the appropriate technology will have been developed in parallel. Chapter 4 of this report shows how automation technologies are applied to satisfy specific needs. A helpful sampling of current and near-future technologies is presented in the appendix. The application of certain technologies is cost-effective only when there is a good fit. For example, applying artificial intelligence (AI) to a process that taxes the breadth of a human's knowledge is not likely to be successful. Expert systems can only be developed from the experience and knowledge of human experts.

If multiple options are presented, an economic analysis of each, examining benefits, risks and life-cycle costs, may be necessary.

System Requirements Specification

If project alternatives are too numerous, it may not be feasible to perform a detailed analysis of each. Good judgment will probably eliminate unreasonable alternatives. When a detailed analysis is required, a conceptual system design should be performed, beginning with a system specification and continuing through to engineering flow diagrams.

By the time milestone 1 of the automation life cycle is reached, the design level should be sufficient to define the functional capability and throughput of the system and should contain enough detail to support cost estimations. Projects with high technical risk must be phased, so that these risks can be addressed early and reconciled before substantial resources are

put at risk. Further into the project, the design will be finalized and implemented if justified by appropriate analysis.

System Process Flow Analysis

A proposed system should be evaluated from a process flow viewpoint. How the system interacts with the operator and depot environment should be analyzed. Labor requirements and level of operator training should be assessed. One result of this analysis should be an understanding of the improvement in throughput to be expected from the system. For some systems, changes in the consumption of raw materials (paint, solder, etc.) and the generation of wastes (toxic or otherwise) should be analyzed and factored into the economic analysis.

It is strongly recommended that a systematic design and analysis approach be used. This can be achieved by using one of the computer-aided software engineering (CASE) packages now commercially available.

2.3.2 Economic Assessments

Although there may be overriding factors, such as safety, that dictate funding decisions, in general a reasonable payback needs to be predicted before a project is approved. When several alternatives are under consideration, benefits, costs, and risks must be carefully assessed before a selection is made.

Project Costs

An Automation Economic Analysis using the present value method of cost estimation is prepared at each automation life-cycle milestone in accordance with TB18-109.

The estimate must cover the entire economic life of the project from initial development to final disposal, taking into account all inward and outward cash flows and discounting future cash flows at an appropriate rate. Typically, a discount rate of 10% has been used. This high discount rate creates a bias against capital-intensive projects and requires development projects to show an early payback.

Typical costs include:

- development
- installation
- training
- operations
- maintenance
- decommissioning.

A number of calculations will be necessary to determine the economic feasibility of the proposed automation. The first activity should be an assessment of depot throughput for the activity under consideration and of the costs associated with the activity using the present methods. Such an assessment establishes a baseline against which to calculate the payback period. Because little is known about the automated system at this time, several scenarios will necessarily be assumed and their economic performance evaluated. These evaluations should include consideration of several operating cost situations, e.g., varying levels of support staff, operating expenses, and equipment acquisition. Application of present value methodology to these scenarios will produce an envelope of economic performance that will show acceptable economic return on investment.

Risk Assessment

Army regulations do not specify methods for factoring risk assessment into a comparative economic study. Nevertheless, it is not likely that an investment decision will be made without weighing the risks against the perceived benefits. In the area of automation technology, a few risk areas that should be considered relate to the length of the project, and the maturity and appropriateness of the technology. If a project is too long, depot needs may change, reducing or eliminating the benefit of the technology. Long-term projects are also more difficult to justify economically. Development costs can be difficult to predict when the development of a new technology is involved, or when depot staff are suggesting technologies outside their expertise. If a new system implements procedures that are too unfamiliar or if it does not fit into the current "way of doing things," the staff is not likely to use it readily.

Administrative Impact

Administrative concerns include staffing, training, organizational impact, and accounting. Increases or reductions in staff may result from

implementation of an automated system. Trained staff will be required to operate the automated system. New staff may have to be hired or existing staff retrained to operate and maintain a new automated system. On the other hand, automation that displaces current staff is not without potential repercussions. From an organizational standpoint, some adjustments may be required in management structure to oversee a major new system.

2.4 RECOMMENDATIONS

Several recommendations flow from the discussion above:

- Carefully assess the need. An analysis of actual depot needs should be performed. "Front-line" staff should be involved in the survey process.
- Evaluate current processes. A study of how the needs of the depot are currently being met should be performed. This may suggest the best automation solutions for a particular problem. Significant errors in matching a potential system to its environment in the depot can be avoided if this study is carefully performed.

Unless some benefit other than improved throughput can be perceived, processes that are not frequently used should not be automated.

- Evaluate available technologies. Potential technologies for a particular application should be carefully chosen and evaluated. Expert knowledge should be sought in determining that a particular technology is practical for the given application. This expertise may reside within the depot or may be sought from other sources. Under most circumstances, it is difficult to justify a large investment in an uncertain technology when the job is done reasonably well by existing means.
- Phase the implementation. Given the risks that exist in developing a state-of-the-art automated system, it is prudent to implement the project in phases. The phases might include:
 - concept development (Milestone 1)
 - definition/design (Milestone 2)
 - prototyping of high-risk subsystems
 - general system development (Milestone 3)
 - deployment (Milestone 4).

To ensure a conservative approach, a prototyping phase has been added to the basic phases defined in the automation life cycle. Each phase would end with a technical and economic review resulting in a "go/no-go" decision.

In addition, the following elements are important for success:

- project champion - it is strongly recommended that the Program Manager/Project Officer (PM/PO) be selected according to the following guideline from TC18-100:

The PM/PO should be a multi-disciplined, experienced manager with sufficient tenure and interest in the program to provide continuity and to accrue personal accountability for his actions.

The PM/PO should become the project champion, giving personal attention to solving problems and helping advance the project. If an outside contractor is involved, good communication between the Assigned Responsible Agency and the contractor is essential. If possible, an individual who can remain with the project throughout its duration should be selected.

- cooperation of staff and management in determining system requirements - both the staff involved in current processes and the staff who will run the proposed system should be involved in drafting the system specifications to ensure that important details of operation are not overlooked. Additionally, if staff are involved early in the project, their acceptance of the new system should be greater when it is installed. Involving all levels of management will help ensure that the proposed system will fit into the overall operation of the depot.
- assessment of staff capabilities - understanding the capabilities of the staff who will be running the system will affect decisions concerning the degree of automation to be employed and the type of operator interface required. A new system will be better used if it matches the capabilities of the responsible staff.
- technical self-sufficiency - all the capability needed to operate and perform routine minor maintenance on the system should reside within the depot. Maintainability of the system is an important design criterion even when maintenance is done by a contractor rather than by in-house resources.

2.5 SUMMARY

The successful implementation of automation technology in the depot environment depends on carefully identifying needs; matching technology to those needs; and rationally assessing potential projects for technical, economic, and administrative viability.

The above guidelines are by no means exhaustive. Each type of project will have special concerns that must be considered. A potential project must be assessed for all its perceived benefits, risks, and costs.

Once a project has been selected, its level of success will be enhanced by implementing a phased approach, selecting a project champion, involving staff at all levels, and assuring technical self-sufficiency.

3.0 EXAMPLE TECHNOLOGY ASSESSMENT: AUTOMATED REPAIR OF PRINTED CIRCUIT BOARDS

The following example summarizes the results of the application of the guidelines (presented in Chapter 2) to an actual depot need: removal and replacement of defective components on printed circuit boards (PCBs). This particular example is based on a portion of an actual project initiated by the Sacramento Army Depot (SAAD). The work is presented here to underscore the "lessons learned" in transferring industry manufacturing technology to the DESCOM environment. This information is presented only as an example assessment and should not be interpreted as an endorsement of a particular project.

3.1 RESULTS OF THE TECHNICAL ASSESSMENT

The depot team was responsible for completing a Need Identification. Other activities were performed by the developers as elements of a conceptual design task. The conceptual design provided definitive functions and requirements. It also provided a conceptual design definition for a mechanized/automated system that meets these functions and requirements and fits within an economic performance envelope that was defined as part of initial planning.

3.1.1 Need Identification

Depot Force Modernization Staff had already documented the need for automated repairs to Army and joint services electronic weapon and communication systems and, in particular, to the repair of PCBs.

Repair functions are currently performed manually; an automated system would reduce costs related to staff labor, since two or three trained operators running the automated system could realistically perform the current component replacement task.

Quality would be enhanced, particularly in preventing electrostatic discharge and, subsequently, in reducing damaged components. Since product quality typically improves as a result of automation, rework is anticipated to decrease from current levels; thereby effecting further cost savings.

An automated system would improve readiness through its availability on a multi-shift basis. Normal throughput would be achieved with one-shift operation.

Turnover of trained staff is a concern. The depot produces trained electronic repair technicians in an on-the-job certification program. Other industry in the vicinity offers premium wages for certified technicians, creating high turnover of staff.

While safety associated with the existing process is not a primary concern, the automated system would reduce the quantity of hazardous materials used in repairs and would reduce the amount of hazardous waste produced.

Scoping studies that bound the range of cost/return-on-investment feasibility were performed at an early date. Required economic performance (in terms of payback time) was established, and a preliminary characterization of the product throughput and the repair costs were required input for the studies. Given this information, the maximum allowable cost of an automated system was determined. Since many alternative combinations of capital and operating costs are possible, several scenarios were defined and evaluated to understand the economic sensitivity to each of these parameters. The results of these initial studies were extremely helpful in evaluating potential approaches to automation of the PCB component replacement activity.

3.1.2 Depot Process Flow Analysis

The process flow for receiving, diagnosing, repairing, and testing PCBs was assessed. Inventory of repair parts and their delivery to the repair area was characterized.

Previous modernization programs have upgraded the depot's capability to diagnose component failures. Automated test equipment and test protocols have been developed, greatly reducing costs and time associated with the diagnosis portion of the repair process. A depot-wide automated part delivery system provides efficient delivery of replacement parts from inventory.

The primary portion of the PCB repair process that has not been updated with current technology is the removal and replacement of failed components from the circuit boards. Figure 3.1 shows the process flow for PCB repair.

FIGURE 3.1. Process Flow for Printed Circuit Board Repair

3.1.3 Current Process Assessments

Each step in the process for replacing components on PCBs was identified. Time and motion studies were performed to characterize the time required and the number of staff involved.

The throughput of PCBs by board type and the throughput of repair components was assessed. The number of board types processed in a campaign was also considered to determine the variability of the product stream.

Interfaces between the component replacement activity and related activities were defined. These interfaces included such elements as the warehouse for replacement components and the automated test activity. Time in transit for boards and components was established.

The amount of rework was determined. Although not a significant feature of the existing PCB repair activity, faulty repair or diagnosis can cause significant loss of productivity.

The amount of lost time, i.e., the time workers are not productively engaged in replacing components, was assessed. The PCB arrival rates vary markedly; thus, time is lost. Variability of the work load makes periods of lost time unavoidable. With a labor-intensive manual repair system, lost time under variable work-load conditions is extremely significant. Automation can de-sensitize lost time due to a variable throughput process by reducing the number of workers per unit repaired.

In-process storage of both PCBs and components was determined. While not a significant factor in the component replacement activity, it can, in some processes, take up significant space.

3.1.4 Selection of Candidate Technologies

Several candidate technologies were identified for each discrete process in the PCB component replacement activity. These technologies, including the existing technology used in the manual repair line, were evaluated for applicability to automation in terms of technical feasibility, technical risk, cost to implement, and compatibility with depot operations. A screening process was devised as an aid to the selection process.

In some cases, automated processes required technologies that were very high in technical risk. Early bench testing and demonstration of feasibility was required in these areas before a final selection could be made. This approach permitted process definition to proceed while maintaining reasonable technical risk. From a technical risk perspective, the most attractive technologies are those that have been previously used in a similar application. Contacts with vendors of commercially available equipment and with systems integrators provided valuable insight.

3.1.5 System Requirements Specification

Specific functions and requirements for the automated system were defined. The functions identified the necessary tasks that the system must perform and the interfaces that must be addressed. The requirements provide quantitative values for system parameters such as throughput rates, allowable rework, operating and maintenance cycles, maximum number of operators, safety requirements, and Army standards that are applicable. While the functions and requirements do not in themselves specify processes or technologies, they provide guidelines for selecting these items. Early agreement on functions and requirements led to good coordination between the depot and the system developers.

3.1.6 System Process Flow Analysis

The candidate processes were evaluated as units that make up the automated system. Assumptions about throughput rates were made for each unit operation. Queuing theory was used to establish system throughput rates and to identify pinch points and areas where in-process storage is required to maintain the operation's stability. When the candidate process would not significantly improve a unit's productivity, maintaining the manual process was considered. Mixing manual activities with automated systems requires special accommodation for smooth production, safety of personnel in the vicinity of autonomously operating equipment, and timely transfer of real-time data to support the process. The maintenance and repair environment of the depot system likely contributes to many situations of this sort.

In this instance, evaluations indicated that the optimized system would combine manually implemented processes with automated equipment.

3.1.7 Project Costs

A quantitative capital cost estimate was produced that included design, development, installation, documentation, and startup testing. This cost estimate was based on the conceptual design information produced earlier. Operating and maintenance costs were also estimated so that life cycle costs associated with the automated system could be compared with the costs of continuing to operate manually. This comparison was made using present value methods, and the savings to investment ratio was calculated.

3.1.8 Technical Risk Assessment

A risk study was performed at the unit operations level. The technical risk associated with automating each repair, material handling, and inspection process was identified. The risk assessment provided a rationale for prioritizing development work to reduce risk as early as possible in the project. Low technical risk was assigned to unit operations that were largely available from commercial sources and had been proved in similar applications. Higher levels of risk were associated with those technologies that required significant technological extrapolations beyond common practice. These latter items were addressed as first development priority.

The risk assessment also provided a basis for assignment of contingency as part of the cost estimating process. This permitted project contingency to be developed at the individual unit operations level.

3.1.9 Administrative Impact

Although it has not yet occurred, a human resource/organizational analysis will be conducted to define any necessary revisions to management practices. Also included in the analysis will be methods for preparing the depot staff to receive the automated component replacement system. Such human resource impacts as changes in job tasks, training needs, selection, recruiting, job classification and compensation, job progressions/career planning, and performance appraisal will be evaluated. The analysis effort will involve interviews with depot repair personnel and their management.

These interviews would solicit opinions, perceptions, suggestions, and other relevant feedback.

Depot staff are wary of automated systems that displace workers. Successful operation of any complex system requires that workers and management enthusiastically endorse use of the equipment. A program to educate workers and supervisory staff is necessary before any automation system is initiated. Depot plans for their future in terms of new opportunities resulting from automation, retraining, transfers, and, if required, reduction of force should be clearly explained. The information program should be implemented well before delivery of the planned equipment. Effects of displeased workers should not be taken lightly. Documented cases abound in other industries where automation applications failed because of worker/supervisory reticence.

3.2 SUMMARY

Figure 3.2 shows the flow chart for activities performed for the component replacement project. Note the iterative approach that was employed to obtain a system configuration that was optimized with respect to economic performance. As mentioned in Chapter 2 of this document, judgment based on the specifics of the candidate project should be exercised in the approach taken for each of these assessment elements. Therefore, this flowsheet should not be interpreted as a guide for all projects, but only as an approach that was appropriate for the given set of circumstances.

3.2.1 Lessons Learned

In summary, several lessons were learned that have general applicability to the DESCOM repair mission:

- A conventional manufacturing layout is often inappropriate. The high product mix, level of operator interaction, and general flexibility required meant that a conventional workcell with stand-alone unit operations would be much too difficult to reconfigure, would require job skills (automation specialists) outside the depot's normal pool, would occupy too much floor space, and would not increase throughput compared to a semi-automated system.

FIGURE 3.2. Project Task Flow Chart for the PCB Repair Project

- The single biggest challenge was responding to the product mix and flexibility questions. The DESCOM environment varies so significantly from an industrial manufacturing environment that in-depth rethinking of the system concept was required before a successful design could be completed.
- The human operator is a superior machine in unstructured environments such as inserting parts in the PCBs that were not originally manufactured with automated equipment. Because of the sophistication of the machines needed to perform an equivalent task, these subsystems were disproportionally expensive, and produced the least payback. The final conceptual design incorporated a mix of manual and automatic operations.
- It is essential that all parties to an automation effort be involved from the start and that depot management understand and support the effort.

3.2.2 Benefits

The following are some of the perceived benefits of this project: increased throughput, enhanced mobilization readiness, improved electrostatic damage control, and easier implementation of improved (paperless) accounting.

To fully realize the benefit of this work, the equipment should be used to perform repair operations across DESCOM, not just at a single depot.

Another major benefit of the system will be mobilization readiness. Although the system will be running at nearly full capacity for a single shift, it will be possible to increase to three shifts per day without a large increase in staffing.

4.0 POTENTIAL OPPORTUNITIES FOR AUTOMATION TECHNOLOGIES

The following discussion addresses specific automation technologies that could be applicable to each of the primary depot core functions. Examples of automation projects were drawn from depot responses to a recent READY 2000 request for automation needs through the year 2020. In this section, depot activities are separated into various programmatic areas; within these areas depot needs are identified and grouped.

4.1 OVERVIEW

The depot mission encompasses three basic functions: maintenance, supply, and ammunition. Within these categories lie certain groups of processes that are currently being conducted at the depots, that are common to several if not all of the depots, and that have potential for automation. The technology groups are separated into these programmatic areas:

- Maintenance
 - machining/forming
 - electronics/electro-optics/sensors
 - coatings/painting
 - mechanical repairs/upgrades/replacements
- Supply
 - supply warehousing and facilities
- Ammunition
 - storage
 - ammunition peculiar equipment
 - demilitarization.

A rough measure of benefit may be obtained by gauging activities performed in the depots against several issues that are thought to be representative and consistent with concerns important to DESCOM and to depot activities:

- mobilization potential
- excess/surge capacity potential
- safety
- staff training and retention.
- waste minimization potential
- product service/quality potential
- workplace quality/environment

Mobilization refers to a large-scale implementation or production increase due to a national emergency or wartime effort. Implementation is generally considered to be needed for a period of several years. If a component is needed in large numbers and the suggested automated system is expected to perform more efficiently, mobilization potential should increase.

Excess and surge capacity refers to the ability of a system to handle relatively short periods of high demand. The magnitude of excess and surge capacity will depend on the planned capacity of the system. Generally, if an automated system can handle more items in less time, surge capacity is enhanced.

Safety refers to the ability to perform a required task with little or no risk to the operator, other personnel, or the environment. Safety enhancement may be very significant in the implementation of an automatic system.

Staff requirements, training and retention refer to the demand, cost to train, and education level of the staff. These terms also refer to the number of staff, the type of work they are required to perform, and their cost.

Waste minimization refers to any improvement in the amount of waste generated, the type of waste generated, its characteristics, and safety.

Product quality and service refers to an improvement that allows the product to perform its task better or more efficiently.

Quality of workplace environment refers to the atmosphere, kind of work, and attitude found in the workplace. The work and its environment is thought to improve as labor-intensive and repetitious routines are eliminated.

The benefit obtained from each of the above issues will vary with each implementation. The role that these issues play relative to automation opportunities is shown in the examples in the following section. The issues will be rated to reveal the expected benefit to the specific operation. This

process does not pretend to substitute for a full assessment, but gives a quick glimpse of the benefit that may be expected should an operation become automated.

4.2 REVIEW OF AUTOMATION OPPORTUNITIES WITHIN DESCOM

The following sections list automation technologies that may be of benefit to each of the aforementioned programmatic areas. In each case, example applications are described so that a linkage can be established to the technology descriptions in the appendix.

4.2.1 Machining/Forming

This programmatic area is of primary importance to the depot maintenance mission. Operations that fall into this category include milling, drilling, turning, stamping, welding, and others.

WELDING

Example: restoring road wheels to tolerance specifications.

Statement of Need

The ability to repair and restore road wheels with an automated system would allow the re-use of out-of-tolerance road wheels. The cost savings would be substantial.

Current Solution

Road wheels are being repaired by manual methods. The reuse of some track components may be limited due to various kinds of wear or flaws.

Automated Solution

Technologies that might be used include:

- position and queuing stations - Robotic systems will be required to remove the road wheel from the conveyor system, to position the part for inspection or welding, and to load it back on the conveyor.
- sensors - Sensors will be used for such operations as determining if the road wheel is positioned correctly and that enough material has been replaced by welding.

- part preparation - The part might need to be cleaned, treated with a solution, or otherwise prepared for the welding operation.
- ventilation - Ventilation concerns should be addressed.
- inspection systems - The wheel might be inspected initially to determine its configuration and the extent of repair required. Later inspection would determine the soundness of repair. Some methods may include the use of machine vision and expert systems.
- material procedures - Considerations concerning the material properties need to be resolved. Questions to be addressed might include concerns about limiting temperatures and relieving stress.
- welding technologies - Various welding technologies may be required for different procedures and materials. Arc, acetylene, TIG, and MIG are a few to be considered.

Initial Benefit Estimation

Mobilization potential would be expected to increase. First, the time and money spent to repair the road wheel is expected to be less than that needed to construct one from new materials. Second, materials for such items generally become valuable during a wartime effort. Therefore, such a system would be expected to enhance mobilization.

Excess and surge capacity might be improved slightly, as the time to repair a road wheel should be less than that to manufacture one. The ability for an automated system to run continuously would allow improved performance and capacity when it is required to run all shifts.

Safety would be enhanced with the use of an automated system.

Staff would have to be specifically trained to run the system. The amount of staffing is expected to be less than that required to manufacture new wheels.

Waste would be minimized in rebuilding road wheels. Many of the wheels that would have been previously discarded have the potential for use.

Product quality and service would not be expected to improve. It is hoped that the ability of the repaired road wheel to accomplish its task would be comparable to a new wheel, but it should not be expected to exceed it in performance.

MACHINING

Example: automated machining and inspection of piston bores and main bearings.

Statement of Need

The ability to machine and inspect diesel engine bores and main bearings would allow more efficient overhaul procedures and would enhance the ability to comply with periods of high demand.

Current Solution

The above listed procedures are being performed manually.

Automated Solution

An automated solution might incorporate the following technologies.

- conveyor systems - A transportation system will be needed for engine block delivery. This system might consist of a power-and-free conveyor system, an automated guided vehicle (AGV) or a tow line vehicle.
- position and queuing stations - Robotic systems will be required to fixture, position, and align the block for the machining operation.
- sensors - Sensors will be used to determine that the engine block has been positioned correctly, that enough material has been removed, and that the correct finish has been applied to the surface.
- part preparation - The engine block part will probably require cleaning both before and after the machining operation. The operation can be automated using a conveyor and cleaning and rinse tanks.
- inspection systems - Some methods may include the use of machine vision and expert systems.
- machining technologies - Automatic (CNC) machine tools can be used to bore and hone engine blocks as required.
- artificial intelligence technologies - An expert system using sensors and machine vision could determine the extent of the machining operation needed as well as what dimensions the operation should use.

Initial Benefit Estimation

Mobilization potential would be expected to increase. The automatic operation would take considerably less time, which would increase throughput and, in turn, help mobilize the product.

Excess and surge capacities would be greatly enhanced because the system would be able to handle many more units in the same amount of time, with the same amount of staffing.

Safety would be expected to increase, because an automated system would limit operator contact with machine tools and other hazards.

Staff would require training for the automated system. The system would be expected to require fewer staff members for the same throughput.

Waste minimization might be expected to improve slightly as the failure rate is reduced through more precise and accurate operations.

Product quality is not expected to increase as the current product from manual operations is considered satisfactory. If tolerances were held closer, the quality might increase slightly.

The quality of the workplace environment would be expected to improve slightly as the work becomes less strenuous, but the environment would be similar to the shop where the operation is done manually.

MOLDING

Example: molding of track shoe pads and bushings.

Statement of Need

The current methods of applying rubber to track components could be accomplished more efficiently with an automated molding system.

Current Solution

Currently, rubber is applied to track components manually.

Automated Solution

Automated molding technology is not new, and it will continue to develop and invoke new technology in the coming years. Future systems will incorporate flexible manufacturing techniques and group technologies. Systems will become more integrated into other operations that make use of the molded product. A typical molding system might include the following technologies:

- conveyor system - After the products are molded, they must be moved out from the molding area.
- robotic material handling system - A robotic handling system might be used to remove the track components from the molds. If the products are to be packaged, a material-handling system could be used also.
- molding system - A molding system capable of successful application of rubber to track shoes and pads would be required.
- robotic flash trimming and finishing - While not essential for a working system, it would be beneficial to have a flash removal component to remove the excess material that remains from the molding process.
- an intelligent controller - An intelligent system might be used to orchestrate the operation, determining what parts are being molded and adjusting the systems to handle them.

Initial Benefit Estimation

Mobilization potential would be expected to improve as an automated system would allow much more efficient molding and production.

Excess and surge capacity would be expected to improve because an automated system should be able to perform the molding operation on a much larger scale with the same amount of labor.

Safety would be enhanced with the use of an automated system.

Staff would have to be specifically trained to run the system. The amount of staffing is expected to be less than that required to mold material to the track components manually.

Waste minimization would not improve significantly as the operation is already being performed manually, and the same amount of material is being molded.

Product quality and service would be expected to improve. More consistent molding practices would be available with an automated system. As a result, a superior product would be expected.

PACKAGING

Example: computer-controlled container manufacturing facility.

Statement of Need

An automated container manufacturing system that will take dimensional input, then output the required container, with little or no human intervention, would greatly increase shipping and delivery efficiency. The system could produce wood, fiberboard, and plastic injection molded containers.

Current Solution

The containers are either obtained from private industry or are constructed on site.

Automated Solution

The implementation for such a site would tend to be large because of the many different operations required. One way of dealing with this is to break the differing operations into substations. Following is a description of such a configuration.

- automatic measuring substation - This station would take the measurements and weight of the item to be boxed. Technology to be used could include laser measuring methods. If other qualities of the product are important to the way it is packaged, they would be noted here.
- intelligent systems - These systems would contain all of the information gathered on the item to be packaged. From this, the required container type and size would be automatically determined. If the type of container needed and size of the product are not available, this information could be entered manually.

- storage and retrieval systems - Such systems might be used to retrieve materials, and an electronic inventory system could be used to signal when supplies are low.
- material delivery and conveying systems - Such systems will be required to move various materials to and from the substations.
- packaging substation - At the packaging substation, the product would be placed in the newly constructed container. Containers would also be sealed at this substation.
- robotic devices (used throughout) - Some possible applications are the material-handling requirements in the substations and the construction systems that build the packages.

Initial Benefit Estimation

Mobilization potential is expected to increase directly as the ability to package, send, and deploy products becomes more efficient.

Excess and surge capacity would be expected to increase greatly as selecting, building, and using a container would be a much more rapid process.

Safety would not be expected to improve significantly.

Staff members would need to be hired and trained to use the new equipment.

Waste minimization potential would be expected to improve as products use containers that do not contain a large amount of excess material; this would limit the amount of waste once the product is received.

Product quality and service would improve only slightly, as conventional packaging methods are considered sufficient. Packages might suffer less in delivery depending on how conservatively the intelligent system is programmed. For example, a heavy duty package might be made up for a slightly heavier item.

The quality of the workplace environment would not be expected to improve. Construction of packaging units might very well be a noisy process.

4.2.2 Electronics/Electro-Optics/Sensors

This programmatic area is again included in the depot maintenance mission. Some of the operations done in these areas include PCB repair and electronics testing.

ELECTRONIC TESTING

Example: artificial intelligence for electronic testing.

Statement of Need

A system using artificial intelligence to debug and diagnose problems in large-scale electronics could minimize electronics repair time. This time savings would reduce the down time of the electronics device and would enhance mobilization.

Current Solution

Most electronic debugging operations are done manually by qualified personnel. A limited amount of Automatic Test Equipment (ATE) is used. The development of ATE routines is difficult, requiring a significant amount of time from highly trained personnel.

Automatic Solution

The development of an automated electronics testing system would involve the development of artificial intelligence software; the need for other automation technologies is not anticipated. Conceptually, such a system might operate as follows:

- Using a good PCB, a model will be built consisting of input/output data from all of the components on the board. This model might be built using a neural network system (essentially a self-teaching expert system). Using neural networks will save in the development of the diagnostic routines and programming times.
- Data from good models will be used for comparison with the various PCBs under test in order to isolate faults down to the component level.
- Storing models for each type of PCB will require significant amounts of memory. A high-density storage medium (e.g., optical laser disk) would be required.

Initial Benefit Estimation

Mobilization potential may very well increase. Excess and surge capacity of the system should increase as well. Because the circuit analysis should be completed much quicker, more PCBs could be debugged in the same amount of time.

Safety considerations are not expected to change.

Staff will have to be technically trained for use of this equipment; however, the qualified personnel now doing the testing are also specialized technically.

Waste minimization is not valid in this case; because the circuit is only to be checked, no waste will be produced.

The quality of the service should improve as the possibility of confusion and error is diminished with an automatic system.

The quality of the workplace environment would not be affected.

SURFACEMOUNT REPLACEMENT

Example: manufacture and repair of surfacemount.

Statement of Need

As surfacemount technology gains popularity, tools and equipment will have to be developed to repair, test, and replace the components.

Current Solution

The depots are not currently performing large-scale repair work on surfacemount PCBs.

Automated Solution

Surfacemount technologies are the next step in miniaturization. With electronic components already very small, surfacemount technology offers a challenge in developing miniaturized component handling systems. A system to repair surfacemount PCBs would be similar to that envisioned for through hole components, but would require greater precision, smaller movements, and new technologies for component removal and reattachment.

Components of such a system would include:

- automated parts handling equipment such as industrial robots
- precision "fine" manipulation subsystems for accurate placement of fine pitch (0.011) devices
- refinement of current state-of-the-art laser soldering system to accommodate the special demands of the operator interactive rework environment
- refinement of mechanical and/or laser milling techniques for the removal of defective components
- automated storage and retrieval systems to store the components and keep track of the inventory.

Initial Benefit Estimation

Mobilization potential should increase since it would be quicker and easier to replace the printed circuit board components.

Excess and surge capacity would not increase because fewer boards could be repaired than replaced in the same amount of time. The exception would occur if the boards required an extended lead time.

Safety would not be expected to increase although an automated repair station could be built to run quite safely.

Staff would need special training to operate the repair station.

Waste minimization is the strong point of such a repair system. Many of the components on a bad board might be in perfect operating condition. Repair of the board would save these components.

Product quality and service would be comparable to that of a replaced board.

The quality of the workplace is not affected in this case because this operation is not currently being performed manually. The workplace would be similar in many ways to a manufacturing environment.

4.2.3 Coatings/Painting

This programmatic area is included in the depot maintenance mission. Typical operations that fall under this category are the application and removal of coatings and the application of adhesive.

COATING APPLICATION

Example: automated coating application.

Statement of Need

An automated coating applicator would ensure compliance with OSHA regulations concerning volatile organic compounds (VOCs). Such a system would also promote quicker response times and better quality finishes, reducing returned parts as well as failure from corrosion.

Current Solution

The current coating procedure depends on manual application using spray, brushes, rollers, and other equipment.

Automated Solution

- conveying systems - A transportation system will be required to deliver and remove items to be coated. An important factor to consider with the conveying system is how the items are to be held so the robotic sprayer can coat all required surfaces. This system might consist of an overhead power-and-free conveyor system, an AGV or a tow line vehicle
- cleaning and preparation systems - A system may need to be developed for final surface preparation or cleaning.
- robotic spray equipment - Robotic painting systems are currently available technology. With appropriate modification, they can be used to apply coatings.
- air filtration - Proper air ventilation and filtering will be required on any finishing application.
- sensors - Sensors might be incorporated to determine that each spray head is operating correctly before an item is coated. Also, the sensors could be used with an expert system to perform various operations depending on the item configuration.

- curing considerations - An area reserved for the curing of the coating must be considered.
- artificial intelligence - Expert systems may be incorporated to determine the specific operations required for given configurations.

Other Considerations

- throughput - The depot should have enough throughput to justify the expense of automating. Also, a run of as many units as possible will increase the efficiency of certain sprayed coatings.
- coating material - Some coatings that may require additional consideration involve volatile organic compounds and CARC.

Initial Benefit Estimation

Mobilization potential should see some improvement in that the coating operations may be more efficient. The time to deploy the item should be reduced.

Excess and surge capacity would improve as the time to complete a coating operation would be less than if done manually.

Safety will be greatly enhanced. The operator would no longer have to be exposed to potentially dangerous coatings.

Staff will require technical knowledge on how to run the system and on the characteristics of the coating material.

Waste minimization will be enhanced as the automated coating equipment works more efficiently with fewer mistakes.

Product quality and service should improve, resulting in a surface that is more consistently covered with a better finish.

The quality of the workplace environment would be greatly improved as the work becomes less operator-intensive. The overall environment would be improved.

ADHESIVE APPLICATION

Example: automated application of adhesive to road wheels and track blocks.

Statement of Need

An automatic system used to apply adhesive to road wheels and track blocks would enhance safety, improve quality, and produce less waste than the current procedure.

Current Solution

Adhesive is applied manually with conventional spray painting equipment. Safety considerations require that the operator use special protective clothing and equipment.

Automated Solution

- conveying systems - A transportation system will be required to deliver and remove items to be coated. An important factor to consider with the conveying system is how the items are to be held so the robotic sprayer can coat all required surfaces. This system might consist of an overhead power-and-free conveyor system, an AGV, or a tow line vehicle.
- cleaning and preparation systems - A system may need to be developed for final surface preparation or cleaning. Such a system might rely heavily on robotics.
- robotic spray equipment - Robotic spray equipment is currently available technology. Also, other technologies might be investigated for other types of applications.
- masking systems - A robotic system might be required to mask the spray of critical areas to protect them from adhesive.
- air filtration systems - Proper air ventilation and filtering will be required on any adhesive application.
- sensors - Sensors might be incorporated to determine that each adhesive station is operating correctly before the application is performed. Also, the sensors could be used with an expert system to perform various operations, depending on the item configuration.
- artificial intelligence - Expert systems may be incorporated to determine the specific operations required for given configurations.
- curing considerations - With some types of adhesives, a time of careful handling must be incorporated while the adhesive sets up. Additionally, the respective parts must be joined before the adhesive cures.

Other Considerations

- throughput - The depot should have enough throughput to justify the expense. Also, when spraying certain adhesives, a run of as many units as possible will increase the efficiency.
- adhesive material - Some adhesives may require additional considerations because of their material properties.

Initial Benefit Estimation

Mobilization potential would probably not improve unless the application of adhesives was a "bottleneck" in a particular sequence. The application of adhesive tends to be just one process of a complete system. If the automation of this process does not improve the overall efficiency, then mobilization would not be expected to increase.

Excess and surge capacity might be expected to improve if the staff replaced by the automatic equipment could apply themselves in other areas to bring up the production rate.

Safety would be greatly enhanced as personnel would not be in direct contact with the potentially hazardous adhesive. Staff would no longer have to wear protective clothing.

Staff would have to be trained to use and maintain the system. The size and complexity of this system is anticipated to be small enough that staff could be trained quickly.

Waste minimization would be enhanced as experience has shown considerable savings in material waste.

Product quality and service would be enhanced as a more uniform application would be possible.

The quality of the workplace environment would be expected to improve. The application of adhesive would not be so repetitious or labor-intensive.

COATING REMOVAL

Example: removal of paint from composites with complex geometries.

Statement of Need

Current methods for the removal of paint on composite materials of complex shape are not acceptable. Blasting tends to pit or otherwise destroy the material.

Current Solution

Coating is removed with lasers, a process that works well on large smooth areas of the composite material.

Automated Solution

This potential project not only deals with the automation of a process, but the need to develop the techniques of a process. Technology for composites will develop with the increase in popularity of composite materials. New and more efficient methods of removing surface coating will be developed. A removal system might be configured as follows.

- laser system - If a laser system works well on large flat areas, perhaps a robotic system working in conjunction with the laser, could be made to work with components of complex shape. The robotic system would be developed to project the laser in many different directions. If configured properly, the system could be programmed to follow complex paths.
- blasting system - If blasting is to be minimized, most of the work could be done with a laser system. Areas where coating still remains could then be finished with very localized blasting. Other potential solutions might include blasting with other media such as carbon dioxide pellets. Other developments will undoubtedly occur in this area as composites become more popular.
- machine vision and depth perception - These capabilities coupled with an intelligent controller could be used to produce the path of a removal system. The same system might incorporate the ability to recognize areas that need further treatment.

Initial Benefit Estimation

Mobilization would be enhanced only if the components being processed used a method that was implemented more efficiently with an automatic system than with a manual system.

Excess and surge capacity would be enhanced as automatic removal of coatings would be faster than manual.

Safety would increase with an automated system because the operator would not have to handle blasting systems manually.

Staff would require specialized training to operate the system. The personnel operating the system should also have knowledge of the purpose of the component being stripped, and what constitutes a failure in the product.

Waste minimization might be expected to improve, depending on the method used.

Any improvement in product quality and service would depend on the method selected. Generally, an automated system is much more precise than a human operator.

The quality of the workplace environment would improve if the operator were removed from labor-intensive or repetitious tasks.

4.2.4 Mechanical Repairs/Upgrades/Replacements

This programmatic area falls under the depot maintenance mission. Work performed in this category is generally repair operations to maintain a variety of essential mechanical components.

MATERIAL REMOVAL

Example: a method for removing rubber from track shoes and road wheels.

Statement of Need

To repair/rebuild road wheels and track shoes, a system must be implemented to remove the molded rubber. A universal system that could do this would be very valuable. The road wheels and track shoes have metals in them that should not be heated beyond about 370°C.

Current Solution

Specialized equipment is used that is specific to the type of component being treated.

Automated Solution

The use of a fluidized bed removal system would require the following technologies:

- furnace - A furnace would be required to maintain the temperature of the fluidized bed at an elevated temperature.
- off-gas system - Gas given off by the process would require treatment.
- conveying system - Systems would be needed to transport the items into the bed, out of the bed, and through the washing systems.
- retrieval system - Some type of retrieval system to remove the pyrolyzed material would be required.
- water rinse system - A system will be required to wash the processed items.

Initial Benefit Estimation

Mobilization readiness would be expected to increase if the system proved to be more efficient than the previous methods. More investigation is needed on this type of process to determine how efficient it could be made.

Excess and surge capacity should increase as the universal fluid bed system is not limited to the capacity of the specific equipment. In other words, the fluidized bed removal system would have greater capacity than any specific equipment because it is meant to handle all types of components. The fluidized bed removal would not be overloaded by a large run of the same type of component.

Safety would be expected to increase as this process would be a universal implementation. The number of specific hazards due to specialized equipment could be expected to drop, thus enhancing safety.

Staffing would be expected to drop as fewer personnel are required to run the system. The staff, however, would have to be specially trained.

Waste minimization might not improve. Although the waste is all of the same type, there might be concerns about how it is to be treated. This area would be investigated further in a project assessment.

Product quality and service would be expected to increase when the process is perfected and performing reliably.

The quality of the workplace environment would probably remain very similar to that of the preceding shop. However, repetitious and labor-intensive tasks would decrease significantly.

INSPECTION METHODS

Example: inspection of engine components for cracks and other flaws.

Statement of Need

A nondestructive testing system using real-time radiography would result in a faster, more precise, and more efficient testing sequence for engine components.

Current Solution

The current method of nondestructive testing/inspection involves magnetic particle testing. This process is considered antiquated and labor-intensive.

Automated Solution

The risk involved in the system suggested is bound to be fairly high. Obtaining clear and accurate results with this technology while working with complex components is thought to be difficult. Other possible methods might include use of ultrasonics and dye penetrant techniques. A radiography system might include the following technologies:

- conveying system - A conveying system would be required to transport components into the analysis area.
- robotic positioner - A robotic device might be used to position the component in the required geometry for analysis.
- expert systems - Components could be tagged with a bar code, or similar identification device, during disassembly or after cleaning. Subsequent operations, including inspection, could use the identification device to reference the specific component and retrieve component-specific data and information.
- radiography system - The key element of the inspection implementation might be radiographic technology to inspect for flaws in engine components.

Initial Benefit Estimation

Mobilization potential would be expected to increase if there were a high demand for this type of inspection.

Excess and surge capacity would improve as the time to complete inspection would be greatly reduced.

Safety requirements would have to be developed for use of a radiography system. The safety requirements for radiography systems are very different from those for the magnetic particle inspection system.

Staff would need to be trained to use the system safely.

Waste minimization is not expected to see any improvement. Although the magnetic particle method is slow and labor-intensive, it works well.

Product (inspection) quality and service would not be expected to increase as the magnetic particle method works well.

The quality of the workplace environment would be expected to increase as magnetic particle testing is slow and labor-intensive.

COMPONENT REPLACEMENT/REPAIR

Example: the removal, relining/repair of brake shoes

Statement of Need

An automated system developed to remove worn, faulty brake shoes and to replace the lining would remove the operator from a potentially hazardous environment, as well as eliminate a degree of labor-intensive work.

Current Solution

Traditional methods are used to remove and rebuild the brake lining and shoes.

Automated Solution

An automated process might use the following technologies:

- positioning system - A robotic system might be used to pick the shoe from a delivery system, and position it for a variety of operations.

- water jet cutting - A water jet might be used to cut the rivets from the lining. Other methods of removal, such as automated drilling and machining, are also possible.
- lining stripper - A system consisting of a robotic parts handler could direct the component through a given path so that old linings could be ground or machined off.
- automated adhesive application - (See previous discussion in Section 4.2.3. An automated system could be used for the accurate application of adhesive to the brake shoes.)
- robotic riveter - Such a device may be required for certain types of shoes when applying adhesive is not sufficient.

Initial Benefit Estimation

Mobilization potential is not anticipated to be increased by the automation of this process unless it is a "bottleneck" keeping needed vehicles from deployment.

Excess and surge capacity should improve as the system is expected to outperform a manual operation.

Safety will be enhanced as operators are removed from the moving hazards generated by machine tools.

Staff will have to be trained to use the automated system.

Waste minimization is expected to remain about constant.

Product quality and service should be at least as good as those produced manually.

The quality of the workplace environment would be expected to improve. The labor-intensive features of the work would be greatly diminished.

4.2.5 Supply Warehousing and Facilities

This programmatic area deals primarily with the depot's supply mission. Operations that are performed in this category include storage and retrieval activities, warehousing, shipping, inventory control, and others.

STORAGE AND RETRIEVAL

Example: facility for the receipt, storage, and shipping of rubber products.

Statement of Need

Rubber products need to be stored in a controlled environment to prevent deterioration. Automation would enhance storage, receipt and shipping efficiency.

Current Solution

All handling of rubber products including receiving, storage, retrieval and shipping is performed manually. No special storage environment is provided.

Automation Solution

The following technologies can be applied to the storage and handling of rubber products:

- environmental control technology - Existing technology will provide the needed environmental control.
- commercial automated storage and retrieval systems (AS/RS) - These systems will meet the requirements for handling the rubber products.

Other Considerations

- The perceived benefits of a controlled storage environment should be weighed against additional investments in facilities.
- It may be difficult to justify a separate AS/RS for rubber products if the benefit of a separate environment is marginal.

Initial Benefit Estimation

Mobilization potential is expected to increase as rubber products are managed faster and more efficiently.

Excess and surge capacity will be enhanced only if peak loads are planned for.

Safety will not be expected to improve as a safety problem currently does not exist.

Staff will require training to operate the automated storage and retrieval system.

Waste minimization would be enhanced as fewer problems occur because the deterioration of rubber products will be reduced.

Product quality and service would improve as the deterioration of stock would be reduced. The automation of the inventory system would allow closer monitoring of the amount of stock available.

No change in the quality of the workplace environment due to storage of rubber products in a controlled environment is expected.

4.2.6 Ammunition Supply, Refurbishment and Demilitarization

This programmatic area deals mainly with the ammunition mission of the depots. Activities that fall under this category include ammunition management, storage, and demilitarization.

STORAGE AND RETRIEVAL

Example: automated ammunition management.

Statement of Need

Automation would improve the efficiency of ammunition handling and would enhance a depot's inventory tracking capability.

Current Solution

Munitions are stored and retrieved manually. Some systems are in place for the refurbishment of ammunition but they are specific to certain types and sizes.

Automated Solution

Ammunition handling includes a variety of processes that would benefit from the following technologies:

- automated storage and retrieval systems (AS/RS) - May be used to warehouse ammunition efficiently; however, the systems will be much different than commercial AS/RS. AGVs will be used extensively due to the way ammunition is stored.
- robotics, conveyor systems and automated machine control - These systems will benefit the refurbishment of ammunition.

- computer-integrated manufacturing techniques (CIM) - CIM can be applied to improve the handling of ammunition throughout the depot and to enhance accounting procedures.

Other Considerations

- Flexible refurbishment systems can be designed to minimize the reconfiguration needed when changing from one type of ammunition to another.
- The information available from a completely automated ammunition-handling system can be routed through a depot network so that management at all levels can access the data. In the event of mobilization, exact and timely knowledge of inventory levels will become critical.

Initial Benefit Estimation

Mobilization potential would be improved as an efficient, organized system would be in place to account for the management of these materials.

Excess and surge capacity would be enhanced if the system was designed to handle peak loads. The system would probably be more efficient than one that is operated manually.

Safety enhancement would be expected as robots handle the munitions instead of staff.

Staff would require training to use the system. It is also important that the system is accepted by the staff.

Waste minimization is expected to improve as the system is more efficient.

Product quality would remain about the same. The service would be expected to improve as delivery times and ammunition management is made more efficient.

The quality of the workplace environment is expected to remain about the same.

MUNITIONS WORKING AND DISPOSAL

Example: water jet cutting of munitions.

Statement of Need

The use of an automatic water jet cutter in ammunition demilitarization operations will increase safety and efficiency while reducing maintenance costs. The work will also become less labor-intensive.

Current Solution

Current methods include use of band saws and shearing. These processes are very hazardous to the operator.

Automated Solution

Elements of a system to perform automated and machine-assisted water jet cutting would include the following:

- automated storage, handling and retrieval systems
- robotics to position the water jet and guide it through a precise path around the munition to be disposed
- a vision system or contact probe to accurately locate the munition within the work cell
- a sophisticated database to recall previous cutting operations as a function of munition load, size, and material
- a sophisticated operator interface to allow rapid response to new jobs in a basically unstructured or semi-structured environment.

Initial Benefit Estimation

Mobilization of demilitarization activities is not generally a concern during a war-time effort.

Excess and surge capacity should improve as the cutting operations are quicker and more efficient than the same operations done manually.

Safety enhancement is one of the strongest arguments for the development of an automated system of this kind. Personnel would not have to handle the materials involved in the process.

Staff will probably need considerable training in the proper methods to use the equipment.

Waste minimization is not expected to improve unless improved procedures are developed to treat the waste products.

Product quality and service would probably improve as the work may be done more accurately with more precision.

The quality of the workplace environment would be expected to improve as the personnel do not have to handle the products.

4.3 SUMMARY

The above examples give an idea of the multitude of automation projects that may be implemented during depot modernization. They are by no means to be considered as priority projects, as many considerations should be taken into account and a complete assessment made before any automation project is implemented. Modernization efforts of the depot system must be flexible and must focus on areas that would be most beneficial.

APPENDIX

AUTOMATION TECHNOLOGIES

APPENDIX

AUTOMATION TECHNOLOGIES

This appendix provides supplementary information about technologies mentioned in Chapter 4.

A.1 INDUSTRIAL ROBOTS

Robotics has potential material-handling applications in the areas of supply, maintenance, and ammunition. Supply applications consist of selecting material to and from automated storage and retrieval systems. Applications of robotics in support of the maintenance functions may include such things as automated machine loading/unloading, welding, and painting.

Industrial robots represent a form of programmable automation that is applicable to the low-volume/high variability product mix of the depot environment. The annual growth rate in the number of industrial robot units installed in the United States is about 25%. Four factors or trends are expected to increase this growth rate to 40% annually in the near term (i.e., 2 to 5 years). These factors are:

- increasing awareness of industrial robot applications
- technology improvements that improve software and hardware interfaces
- reductions in the unit price of robots
- industrial robot market expanding from large corporations to medium-sized and smaller companies.

The majority of the industrial robot units installed in the private sector will be used for material-handling applications (White and Apple 1985). Industrial robots represent an investment-intensive form of material-handling equipment (Warnecke and Shuler 1985). Thus, future use of robots at Army depots will be limited to hazardous work area applications (e.g., ammunition handling) and applications offering high equipment utilization rates. High

equipment utilization rates (i.e., high ratio of active to idle time) for industrial robots have traditionally been obtained by moving work-in-process to and from the operation area of the robot station, or by circular arrangement of equipment stations around the operation area. Improved robot mobility is now being developed in the private sector to enhance the number of stations each robot can serve, thus increasing robot utilization rates.

Approximately one-third of the cost of a robot work cell is the fixturing that holds or feeds each part in a consistent manner (NRC 1986). Fixturing, gripping, and sensors for robotic systems are now being improved as a single robot unit will be able to handle a wider variety of parts with less end effector or fixture changes. For example, it is expected that within the next ten years, 60% of robots, especially those used for inspection, assembly, and welding, will use vision, tactile, and other sensors (NRC 1986). These improvements in robotic equipment will enhance the depots' capability to pursue flexible manufacturing techniques.

Using existing and near-term (5 to 10 years) industrial robot technology, private competitive firms will be using the following robot material-handling applications:

1. machine loading/unloading
2. parts feeding
3. material delivery
4. palletizing
5. depalletizing
6. case packing
7. bin packing
8. kitting
9. storage/retrieval
10. conveyor sortation.

Industrial robot technology is sufficient today to automate many aspects of Army depot machine loading/unloading, parts feeding, and material delivery. Because these tasks can be designed to accommodate a sufficiently narrow range of product variability, there is less dependence on vision systems or other sensory devices which are just now emerging. Examples of current private industry use of industrial robots include machine loading/unloading, parts feeding, and material delivery to support FMSs. Palletizing and depalletizing applications using industrial robots are also increasing in the private sector.

Case and bin packing, kitting, storage/retrieval, and conveyor sortation by industrial robots are areas of tremendous opportunity for the depot system. However, as component identification systems and complex end effectors are essential for these applications, this area of robot technology is only now emerging, and will be implemented in the private sector during the next 10 years. Because of increased stock-handling activity, current flexible manufacturing and just-in-time manufacturing thrusts are creating a greater need for capabilities such as automated packing and kitting. As in-process stock levels are reduced, inventories will need to be restocked more often. Currently, most part inventories have a 4:1 to 10:1 ratio of issues to restocks (Wenzel 1984). A 4:1 ratio of issues to restocks would be equivalent to removing parts from inventory on four different occasions before inventory is restocked. With flexible manufacturing and just-in-time inventory techniques, the ratio of issues to restocks can be expected to range from 1:1 to 3:1.

Currently, there is a void in automated equipment for handling individual items for packing, kitting, and storage/retrieval systems (NRC 1986). However, such systems will probably emerge during the next ten years and be available for depot modernization.

A.2 AUTOMATED GUIDED VEHICLES

Automated guided vehicles (AGVs) and tow line systems have dual functions. They can be used to transport material in support of the depots'

supply and maintenance functions, or they can be used as mobile disassembly/assembly stations. Both of these capabilities can be used to a greater extent in future depot operations.

Tow line vehicles consist of tow carts powered either by an in-floor chain or by an overhead chain. Control systems for tow line vehicles can route tow carts from one work station to another, and can switch carts from the main line onto a spur where carts can accumulate until processed. Tow line systems are most advantageous when implemented in a relatively fixed-path, consistent-station application. Army depots are currently planning tow line systems to service stock-handling areas adjacent to the automated storage and retrieval systems (AS/RSs) at area-oriented depots (AODs). The \$13.1 million tow line system planned for the New Cumberland Depot will be the largest tow line system in the world, consisting of eight miles of in-floor tow line and 1500 switchcarts. Tow line systems are also used for material handling in production environments. For example, trucks are assembled on tow carts at Freightliner Corp. in Portland, Oregon, where approximately 15,000 trucks are produced annually. Tow line system technology is well developed and major changes in tow line systems are not expected within the next 10 years.

A more flexible form of automated transport is the AGV, which consists of self-propelled floor carts. Automated guided vehicles are ideally suited for flexible manufacturing systems. Unfortunately, the technology that supports AGVs has not progressed as rapidly as predicted, with the majority of the problems being in the areas of software and equipment standardization, cost, and adequacy of control systems. For example, SI Handling Systems, Inc. has estimated that using AGVs instead of tow lines at the New Cumberland Army Depot would have cost 50% more and would have caused severe control system problems (Kalb 1987).

The problems are being resolved, however, and implementation of AGVs within the next ten years will increase significantly. Control systems, guidance systems, etc., are also being improved. In pursuit of improved flexibility, guidance systems have expanded from the embedded wire systems commonly in use to optical, infrared, and inertial guidance systems.

Common AGV wire guidance systems consist of wires embedded in the factory floor, which is usually concrete. The wires are energized at low voltage. Each AGV has an antenna that detects the magnetic field surrounding the guide wires and this signal serves as input into the control system.

An alternative to wire guided systems is an optical guidance system. In this system the wire in the floor is replaced by a painted fluorescent line which is energized and which the AGV reads. Optical guided systems are more flexible than embedded wire systems, but require more maintenance because of the painted fluorescent line.

Two other alternative guidance systems currently being developed are inertially guided vehicles and infrared guided systems. Inertially guided systems store the distance and direction the AGV has moved and periodically check the accuracy of the AGV's location by infrared scanning of bar-code labels attached to reference points throughout the factory. Infrared guidance systems consist of an infrared beacon that rapidly sweeps a vertical beam of light off of reflectors suspended from the factory ceiling at regular intervals. These reflectors bounce return signals to an optical array on the AGV which serves as input into the control system.

In short, it is expected that highly cost-effective, flexible, autonomous AGVs will be available for modernization efforts. Material-handling applications of these systems in support of depot activities fall into the categories of supply and maintenance. In supply, the number of AGVs delivering parts in support of the maintenance function should increase as more applications are identified. In maintenance, the use of AGVs as mobile assembly platforms will probably be needed if parity with industry is to be achieved. For example, large automobile-body carrying AGVs that can raise cars several feet off their deck to give workers easy access are already in use (Zygmunt 1986). Other current applications include assembly platforms for engines, tractors, electronic assemblies, etc.

Exact positioning capabilities that will facilitate AGV interfaces with automated work stations are always under development. One solution that has

been developed to assist in AGV work-station positioning is an optical docking device that automatically compensates for minute deviations in AGV position. When the AGV approaches the work station dock, a laser on the AGV illuminates a one-inch strip of mirror attached to the dock. Photosensors on the AGV detect the reflection from the mirror's two outside edges, which provides input to the AGV's microprocessor that determines if positioning adjustments are needed. As completely autonomous systems are perfected, it is foreseeable that AGV applications could be extended to include ammunition handling in and out of concrete storage igloos.

Two factors affect the efficiency of depot material-handling operations in the area of supply. These factors are 1) the equipment used, and 2) the form of material handled. Equipment applicable to future depot material handling needs has been discussed earlier in this appendix; thus, we consider the second factor, i.e., the form of material handled and how future depot operations can be assisted by container and unit-of-issue technologies that are being developed by private industry.

A tour of depot packaging and preservation facilities reveals labor-intensive box shops, pallet shops and packaging areas that use a variety of packaging technologies (e.g., shrink wrap machines). For instance, an AMC pocket reference for packaging processes and materials lists more than 19 shipping container specifications and 28 methods of preservation.

Substantial work in other industries in the area of containers has shown that material-handling requirements can be substantially simplified. In particular, discussions with representatives of the Automotive Industry Action Group revealed ongoing work aimed at reducing the cost of shipping parts from suppliers to automobile assembly plants. Reusable containers that circulate between supplier and user are currently being developed. These containers consist of collapsible, rigid plastic boxes capable of handling loads up to 4000 pounds. One of the leaders in the development of these containers for the automobile industry is XYTEC Corporation.

Although Army depots currently reuse some shipping containers, future depot operations would benefit from using the widespread, coordinated reusable container/disposable dunnage system being implemented in the automobile

industry. Although the reusable shipping container system is not fully in place, Chrysler has reported savings of \$15 million through the elimination of 11,000 tons of cardboard and 700,000 wooden pallets (McElroy 1986).

Finally, together with standardized shipping containers, packaging supplies in unit-of-issue containers has the potential for assisting in automating future depot material handling. The unit-of-issue concept is to initially package material in the same quantities that will be distributed to the end users. While standardized containers would facilitate the use of specialized handling equipment, unit-of-issue packaging would reduce the number of individual items to be handled and would further assist in future depot automation efforts.

A.3 CONVEYOR SYSTEMS

Power-and-free conveying, while not a new technology, has the capability of transporting materials synchronously along multiple paths and can handle smaller unit quantities in fairly high volume. These characteristics are essential for supporting an FMS. Power-and-free conveying depot applications could support both future supply and maintenance depot functions.

Power-and-free conveying is an older material-handling technology that is ideally suited to future depot modernization. The power-and-free conveying concept consists of a chain driven "power" track built into a conveyor. A trolley device which transports the product to be moved can be connected or disconnected to the powered track. This results in a conveyor system where in-process material can move independently of other material on the conveyor, allowing in-process material to stop at work stations. This synchronous movement is ideal for flexible manufacturing and just-in-time production systems (NRC 1986).

The most common power-and-free conveyor is the overhead configuration, in which the product is suspended from the trolley. To facilitate robotic processing equipment, an inverted power-and-free conveyor configuration is available in which the product sits on a pallet or carrier-like device above the conveyor.

The addition of linear induction motors to power-and-free conveyor systems further enhances the conveyors' ability to support a high-speed flexible manufacturing system. The challenge of designing a material-handling system to support a flexible manufacturing process is to devise a system where robots do not have to wait for material. Power-and-free conveyors help achieve this objective by allowing in-process material to accumulate in the general vicinity of the robot station. Linear induction motor systems can further assist in eliminating robot station wait time by their ability to move in-process material carriers at high speeds with short acceleration and deceleration times. Building linear induction motors into power-and-free conveyors creates an extremely efficient material-handling system, because material can be moved out of the robot's work envelope while the next work-in-process is moved simultaneously into the work envelope at high speed.

Power-and-free conveyor carriers typically have some type of code mechanism (e.g., pin, bar-code, magnetic card code) which allows the manufacturing control system to identify and route the carrier to the proper destination. Carriers can be tracked through the system and such information as the location of the carrier and the processes it has or has not been through can be obtained at all times.

A recirculating loop configuration is ideal for balancing multiple work stations performing the same task, as product can be routed to any station on a demand basis. In addition, if work stations are down, carriers can be rescheduled and rerouted. This system could also serve manually operated work stations such as electronic assembly repair/testing stations common at electronic repair depots.

A.4 INVENTORY REDUCTION TECHNIQUES

Improved shipping containers and unit of issue methodologies can result in substantial material-handling savings for DESCOM. Practices between parts suppliers and assembly facilities in the automobile industry are applicable to the depot-field unit environment.

Another trend that will impact future material-handling systems is manufacturing cost reduction through reduced in-process inventories. Lower

in-process inventories result in the need for tighter control of parts in a material-handling system, less in-process storage capability, and faster throughput times for work in-process. The potential for reducing throughput times for work in-process is considerable; one study indicates that parts in a conventional machine shop spend only 7% of their time on a machine (Hutchinson 1984). The other 93% of the time, parts are either waiting or in transport.

In-process inventory reduction technologies (e.g., just-in-time inventory techniques) impact material-handling equipment needs by requiring faster response, greater versatility, and lower volume storage than do many material handling systems commonly in use.

A.5 ARTIFICIAL INTELLIGENCE

The development of artificial intelligence has shown that computers might someday be able to reason, learn and give logical responses to a multitude of problems. A subset of AI called expert systems has been somewhat successful with technology based on "if-then" reasoning. Expertise on specific subjects is embedded into the software that will be used in solving problems. The applications are written using symbolic languages (e.g., LISP, PROLOG) instead of the traditional procedural languages. This enables the computer to query the user on a specific problem until the computer has collected enough information to determine the proper solution. The application does not use human-like reasoning, but instead uses its embedded expertise and the responses it collects to narrow down the possible problems. For example, a computer might query a mechanic on a carburetor problem until it has collected enough information to logically determine the corrective action needed.

Currently, there are 1000 to 3000 expert systems in use; this number is expected to grow 50% per year (Linden 1988, p. 60). Applications of the technology include American Express' use of expert systems for making approvals on unusual credit requests, and IBM's use of expert systems to diagnose problems during final testing of large disk drives. The benefits that can be derived from such systems can be quite large. For example IBM initially invested \$100 thousand in a diagnosis system; the system now saves IBM \$12 million annually (Linden 1988, p. 61).

When expert systems are combined with natural language interfaces, the technology is referred to as cognitive systems. This allows the user to specify a problem in common textual phrases in response to the computers queries. This improves the technology as a whole since the users would not be required to know how to operate the system.

A.6 COMPUTER-INTEGRATED MANUFACTURING AND DESIGN

Computer-integrated manufacturing (CIM) can be defined as a system where all relevant data regarding a manufacturing system are collected and transmitted by computer to assist in the control and management of the system. The term "system" is meant to include all aspects of facility operations from controlling automated equipment through the processing of purchase orders. This automation of collecting, storing and distributing facility-wide information provides readily available data to include information links to customers and vendors.

Computer-integrated manufacturing serves to link all aspects of an operation, from initial product development to shipping and servicing. The purpose of this linkage is to eliminate system inefficiencies, make optimal use of data generated in-process, link product/process design to life-cycle performance, etc. One primary benefit is that before CIM can be implemented, firms are forced to do a review and integration study of their operations, a task which should be done regardless of CIM considerations, but which often is not.

Leading-edge plants are currently performing integration studies for their operations. The results of these studies are being used to develop a vision of an optimal CIM implementation to serve as a system-building goal. Once this goal is established, the various projects required to achieve total integration are outlined and evaluated on their own merits. By evaluating the individual CIM-related projects individually, facility staff can implement first those projects that have the greatest impact on system improvement. This approach results in the earliest possible realization of CIM benefits.

During the next 10 years, CIM implementation is expected to increase significantly. Using an incremental approach, many firms have currently implemented CIM in design and various automated work cells. One example of design

implementation is computer-aided design (CAD) work stations with different vendors sharing information via a command data base.

CIM implementation during the next 15 years will be facilitated by recently completed information system protocol standards that can be expected to remain essentially unchanged during this time period. In addition to the Manufacturing Automation Protocol (MAP) standard, discussed later, the Technical Office Protocol (TOP) standard will facilitate the automation of office-oriented information flow. Another standard related to MAP is the Enhanced Performance Architecture (EPA), which is designed for real-time control applications. These three standards will provide the equipment/protocol consistency needed to develop and install large-scale CIM systems.

Such straightforward CIM implementations are expected to be greatly expanded in the near-term. For example, Rolls-Royce is in the process of integrating product design information with expected production cost information. An engineer completing a design on a CAD system can obtain the expected cost of the new part by automatically accessing a group technology data base. The group technology data base has the detailed production costs for all part characteristics within a certain part family. If the new design is classifiable into an existing group technology part family, the estimated production cost is readily obtained. If the part does not fit into an existing part family, general cost data for the individual characteristics of the part are used to develop a production cost. This integration is designed to bridge the gap between the design and production engineers to assist in developing cost-effective designs.

State-of-the-art CIM implementation on the factory floor consists of integrating work cells with a material-handling system to develop a flexible manufacturing system. As CIM integration continues, pockets of CIM implementation will be integrated until the goal of total CIM implementation is achieved.

Total CIM implementation can only be accomplished using a hierarchical structure to deal with the volume of data and number of decisions needed to operate a manufacturing operation. Using distributed data bases and distributed processing, the hierarchical structure of CIM will strive to keep

data use and decision making at the lowest possible level. By passing only summary information and decisions that cannot be resolved from lower levels to higher levels in the organization, the information processing requirements of a CIM system become manageable.

The architecture of CIM systems reflects this hierarchical structure. Likely systems will consist of a mainframe computer serving as host computer to the entire factory, which is fed by multiple minicomputers. Each minicomputer serves as a host controller to an intermediate level manufacturing system. Below the minicomputers will be microcomputers to control work cells, etc.

The approach described above for CIM implementation: 1) perform integration study, 2) develop total integration goal, and 3) implement projects contributing to goal, is illustrated by the ongoing efforts of the Air Force Wright Aeronautical Laboratories.

A.7 AUTOMATED STORAGE AND RETRIEVAL SYSTEMS

Automated storage and retrieval systems (AS/RS) are essential for supply activities. Smaller systems also support the depot-level maintenance and overhaul function. In the future, these systems will be better integrated with automated stock selection and transportation systems. In addition, the trend towards mini-storage systems (reflecting reduced in-process stock) can be expected to continue.

Two future AS/RS trends will affect competitive private industry firms in the next 10 years. The first trend now beginning to emerge is towards automating single item stock selection from AS/RSs. This trend will eventually result in a need to retrofit large existing AS/RSs with automated single item stock selection equipment. Single item stock selection would use the robotic stock selection concepts presented earlier.

A second trend that is under way and that will continue is towards smaller in-process inventory, which will result in small AS/RSs being integrated into manufacturing activities. In large unit load systems, the multiple aisle stackers range from 50 to 100 feet high and are normally housed in their own

end of the facility. Smaller systems known as mini-load AS/RSs are increasingly used for work-in-process storage. Mini-load systems consist of one or two aisles at heights of 20 to 40 feet. An even smaller class of AS/RSs is emerging which has the potential for fulfilling a wide variety of work in-process storage needs. These smaller systems, known as micro-mini AS/RSs, are designed to be installed in the center of the production area, with work stations around the outside of the rack system. A retriever operating between two racks can pick up loads and deliver them through the racks and directly into the production work stations.

A typical depot application of mini AS/RS system might be a radio moving by power-and-free conveyor through each work station. At each work station, various components are disassembled and tested, and if parts are needed, the automated retriever between the racks pushes the appropriate bin of parts through the rack to the appropriate work station. When work at the station is completed, the carrier transporting the radio assembly is powered and transported to the next station. The bin is then returned to storage. If a known set of parts is needed at various work stations for each radio moving down the line, the rack system could be informed of this requirement via bar-code readers, etc., and it could automatically stock the appropriate work stations with the required parts. The addition of a mezzanine around the rack system would allow multiple production lines to be supported by the same rack system (Pierson 1984). Finally, sophisticated control systems will also allow for multiple retrievers in a single rack system, increasing the responsiveness of the system.

A.8 CONTROL SYSTEMS

Control technology for material-handling systems includes three functions: automatic identification, logic control, and physical control of material.

Automatic identification is one of the fastest growing control technology areas (NRC 1986). A number of sensors are being developed that could perform automatic identification in the depot environment within the next 10 years. These sensors include:

- bar-code technologies
- optical character recognition
- magnetic code readers
- radio frequency and surface acoustical wave transponders
- machine vision
- fiber optics
- voice recognition
- tactile sensors
- chemical sensors.

Bar codes have been the most widely accepted sensor technology because of their early development and standardization of codes and labels. Bar-code technologies and other identification technologies supply the data necessary for logic control systems to track material and to provide data input-output tasks. Logic controls interface with the physical control system to activate automated material-handling equipment.

The most important trend within the next 10 years in the area of material-handling control system technology will be improved interdevice communications. Improved interdevice communications will facilitate the development of computer-integrated manufacturing, and will be essential for flexible manufacturing systems. The development of the Manufacturing Automation Protocol (MAP) by General Motors and others is expected to provide a standardized data transmission link, allowing material-handling equipment and manufacturing hardware to communicate. Control systems have caused significant problems in recent modernization efforts and standardization efforts in this area should be well developed in time for future Army depot modernization efforts.

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