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A SYSTEMS APPROACH TO AUTOMATED PHARMACY DISPENSING

by

Michael James Buttarazzi

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APPROVED:

Robert L West Jr
Dr. Robert L. West, Chairman

Ben S Blanchard
Dr. Benjamin S. Blanchard

W. J. Fabrycky
Dr. Wolter J. Fabrycky

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Michael James Buttarazzi

Committee Chairman: Robert L. West

Mechanical Engineering

(ABSTRACT)

Application of production line techniques has resulted in the development of centralized unit-dose dispensing in hospital pharmacies. Although this process is more efficient than decentralized dispensing, it is still a labor and time intensive operation. Many of the tasks associated with this operation are rote and repetitive. Also registered pharmacists have been pulled away from patient care areas back to the pharmacy in order to supervise dispensing. As a result the role of the pharmacist as a drug information specialist has suffered.

The scope of this project is to develop a plan for automated dispensing of unit-dosed liquid and injectable medications as a partial answer to the needs of a modern hospital pharmacy. The plan covers conceptual design, including requirements specifications, functional analyses, requirements allocation, and preliminary cost analyses.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The nature of modern health care is changing rapidly as new technologies become available. The application of these technologies allow intensive care patients to survive and sometimes completely recover from severe illnesses or accidents. Often, recuperation requires lengthy stays in a hospital or a nursing home where daily medications and therapies are administered. Statistics gathered by the American Hospital Association show that the average number of beds in a community hospital in 1987 was 171, and the average occupancy was 64.9 % (American Hospital Association xvii-xxiii). The average length of a stay in a hospital in 1987 was 7.2 days. As the number of different drugs dispensed in hospitals and nursing homes have increased, pharmacists have been forced to devote more of their time supervising the distribution of daily medications. Thus the pharmacist's role as a drug information specialist has suffered.

Hospital pharmacy helps the hospital fulfill its role in modern health care. The role of the hospital in relation to the patient, the doctor, and the retail pharmacy is shown in Fig. 1.

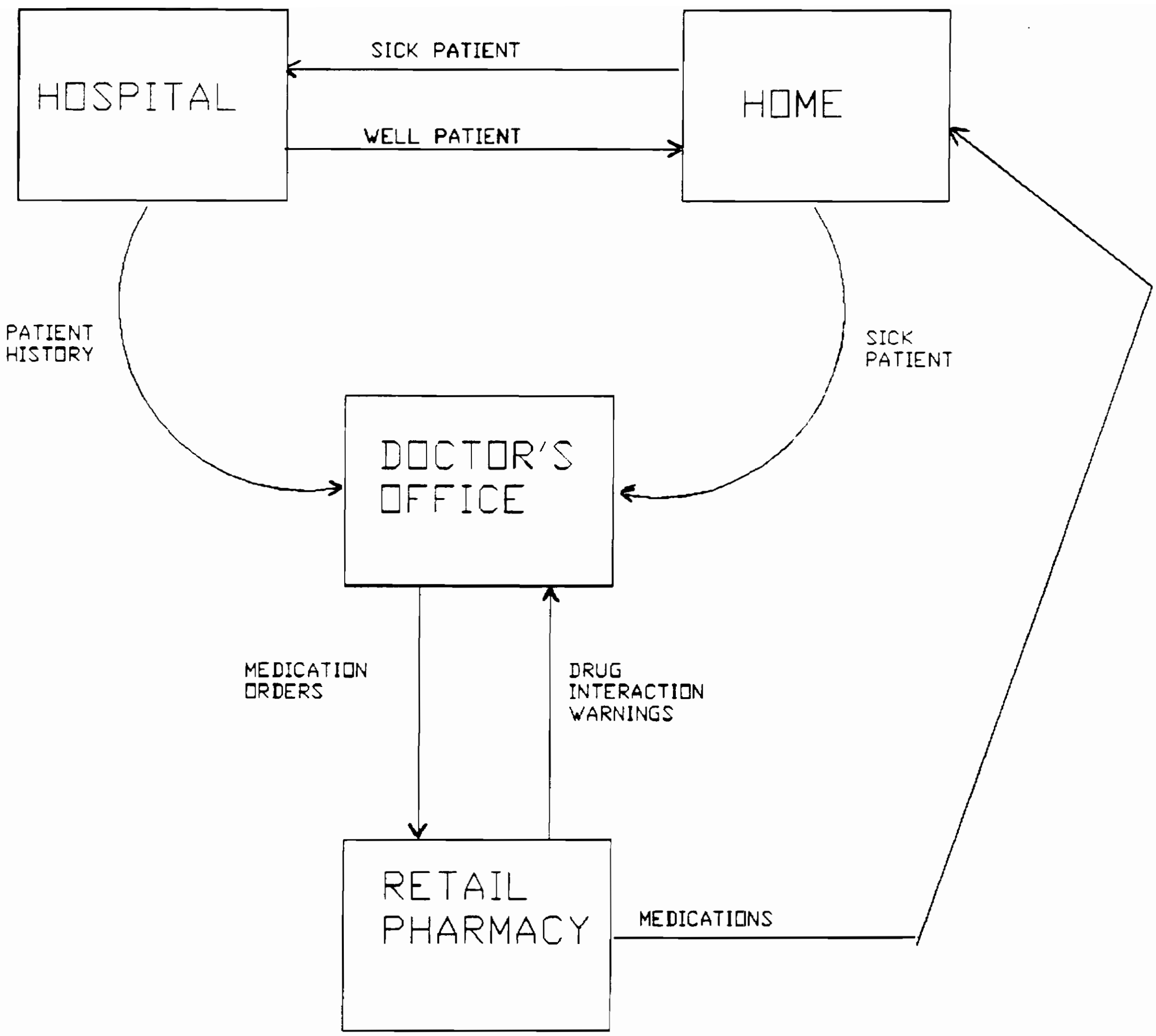


Fig. 1. Modern Health Care Systems

1.1 Dispensing Systems

In practice there are three main types of dispensing systems employed by hospital pharmacies. Floor stock dispensing is one method used in which medical supplies are stocked and dispensed on hospital floors. The advantages to this system are i) ready availability of supplies, ii) elimination of return of unused drugs, and iii) reduction in the number of required pharmacy personnel. The disadvantages are i) medication errors may increase due to lack of proper review of medication orders, ii) increased drug inventories on the floors, iii) greater opportunity for pilferage, and iv) drug deterioration due to improper storage (Hassan 267).

In individual prescription order systems, medication orders are filled by the pharmacy as they are requested. This method is most often used in small, private hospitals because of reduced manpower requirements. A major disadvantage of such a system are delays in obtaining medication and increased cost to the patient.

The third method of dispensing used in hospital pharmacies is unit-dose dispensing. A unit dose is described as -

> medication which is ordered, packaged, handled, and administered, and charged in multiples of single dose units...(Hassan 278)

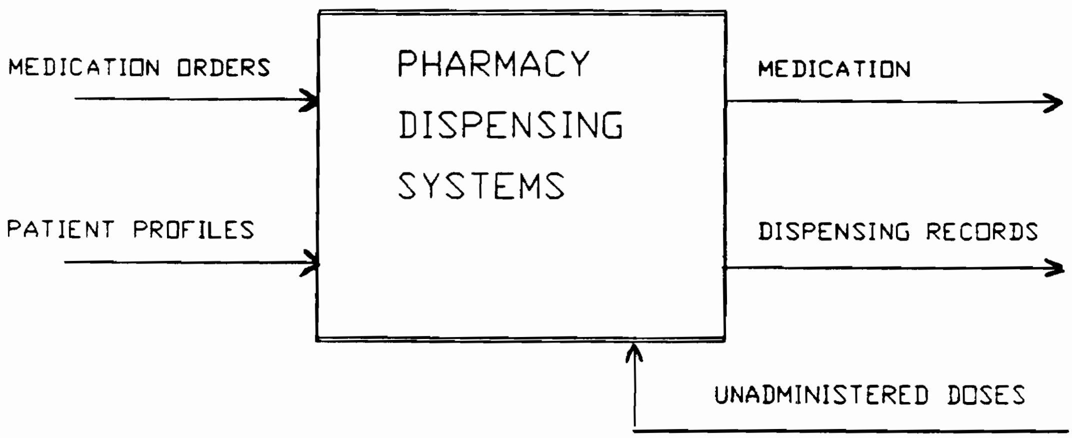
In unit-dose dispensing, the pharmacy usually distributes a twenty-four hour supply of doses to the patient care area. Most hospital pharmacies utilize unit-dose dispensing. According to the American Society of Hospital Pharmacist (ASHP) statement on unit dose dispensing, the advantages of this system are i) reduction in incidence of medication errors, ii) a decrease in cost of medication-related activities, iii) more efficient use of pharmacy personnel and nursing staff, iv) improved drug control and drug monitoring, v) more accurate billing for drugs, vi) pharmacist has greater control over pharmacy workload patterns and staff scheduling, vii) reduction in size of drug inventories located on the floor, viii) adaptability to computerized and automated procedures (Hassan 265)

1.2 Centralized Unit-Dose Dispensing

Many hospital pharmacies distribute unit dosed medications using what is called centralized unit-dose dispensing, Fig. 2 and 3. Under this method, prescriptions are sent to the hospital pharmacy from the hospital floors. Fill lists are then generated for each patient providing the patient name, room number, an identification number, and a list of prescribed medications. The fill lists are reviewed to determine the accuracy of the prescription and the quantities of medication needed for each patient over the next 24 hours. At a central cart-fill area (see Appendix A, Pharmacy Fixtures), each patient's prescription is reviewed and filled. The unit-doses are placed in patient drawers, which are then placed on carts (Fig. 4) and delivered to the nursing stations on each floor.

Before proceeding, a definition of unit dose packaging as opposed to single unit package is needed. According to the American Society of Hospital Pharmacists:

> A single unit package is one that contains one discrete dosage form,i.e. one capsule, or one 2 ml. quantity of liquid, etc. A single unit package becomes a unit-dose package, when the physician happens to order that amount for a particular patient. In either case, the package should be labeled and patient-ready so that the contents can be administered directly from the package.
> (Blisset, Webb, Stanaszek 52)



Medication Orders

* Patient Name
* Room Number
* Doses Prescribed
* Doctor's Name

Patient Profiles

* Patient Name
* Medications Administered
* Room Number
* Allergies
* Drug Interactions

Medication

* 24 hour unit-dosed medications
* Stat Orders

Dispensing Records

* List of items dispensed

Unadministered Doses

* Doses not administered due to dismissal of patient or change orde

Fig 2. Unit-Dose Dispensing

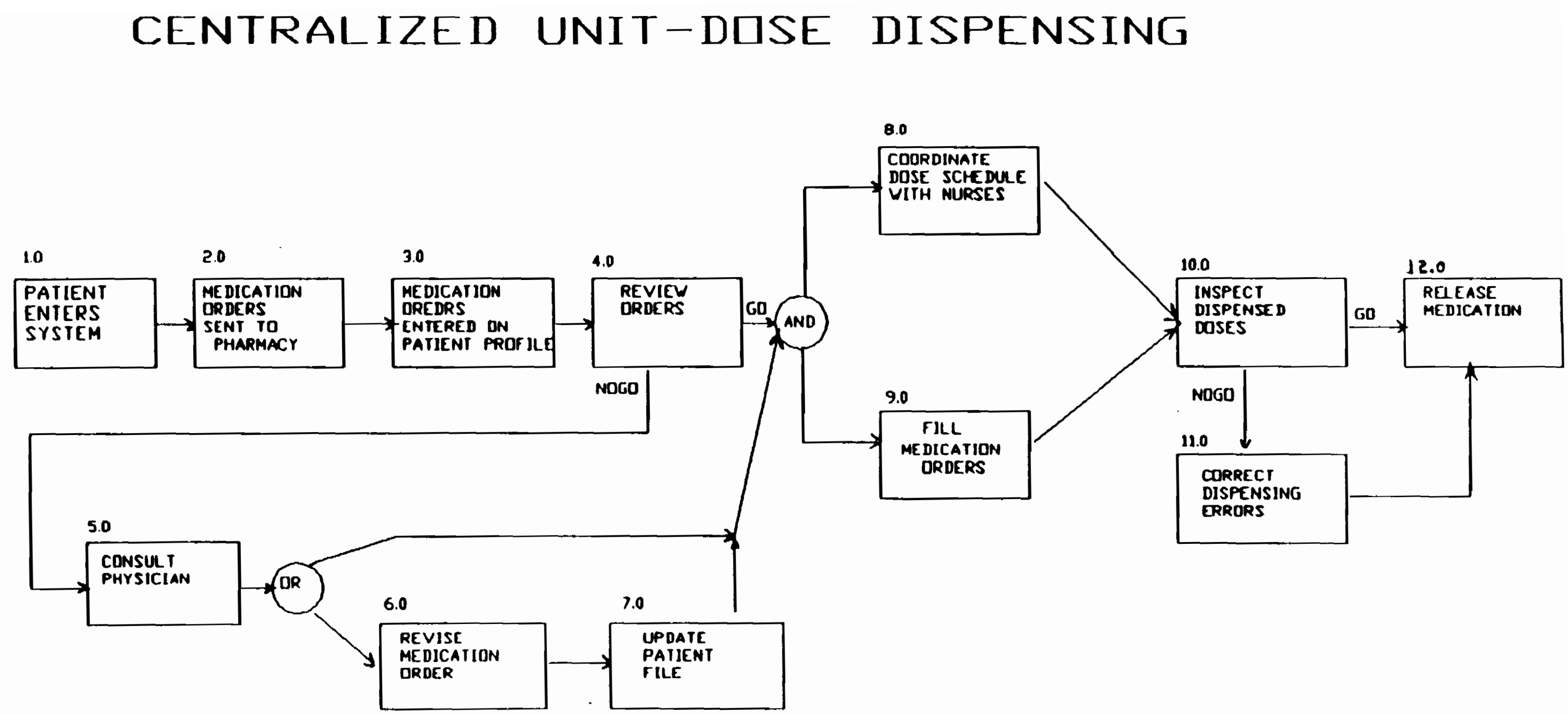


Fig. 3. Centralized Unit-Dose Dispensing

Fig. 4. Medication Cart

Fig. 5. Unit-Doses - Liquids, Injectables, and Solids

Centralized unit-dose dispensing saves time because medication carts containing 24 hour dose supplies for each patient can be prepared in advance of the actual dispensing. When the cart with fresh supplies is brought to the patient care area, the previous day's cart can be returned. Centralized unit-dose dispensing also allows for greater control of drug supplies than is the case in floor stock systems.

However, the centralized cart-fill system does have its drawbacks. Some prescriptions will vary from day to day, resulting in unit-doses being dispensed that will not be administered. Also, the tasks associated with this cart-fill operation are rote and repetitive to say the least. Pharmacists and pharmaceutical technicians are forced to do manual counting and monitoring of all unit-dose solids (pills), liquids, and injectable solutions that are distributed.

1.2.1 Dispensing to Nursing Homes

In 1987, 2,223 out of 5,611 community hospitals surveyed had less than 200 beds. Moreover there appears to be a general trend towards small, long term health care facilities (American Hospital Association xviii). Many of these small hospitals and nursing homes are without a full-time pharmacist. Often the pharmacy duties are performed by a larger hospital's pharmacy or by a retail pharmacy. More recently, companies have been formed to provide centralized pharmaceutical services to small hospitals and nursing homes. Some of these companies dispense unit-doses to over 40,000 beds a day. Whatever the case, dispensing to small clinics is still done on a centralized unit dose basis. The major difference is that the medication carts that are delivered will often carry 48 to 168 hour supplies of unit doses instead of a 24 hour supply.

1.3 Pharmacy Systems

In the past decade, several tools have been provided to aid hospital pharmacists in unit-dose dispensing. Ordering systems have been improved. Most hospitals now buy unit doses prepackaged from drug warehouses. Unit dose packaging machines have been made available to hospital pharmacies to convert bulk medications to unit dose form. Most recently, automated unit dose dispensing devices have been introduced. Appendix A provides some vendor information on pharmacy dispensing systems.

1.2.1 Ordering Systems

In the past, the most common method of placing a medication order was sending to the pharmacy a carbon copy of the physicians order sheet. As technology has advanced, so have the options available for ordering systems. Some of the methods now used are i) pneumatic devices which deliver the order to the pharmacy, ii) voice recorders, iii) fax machines, and iv) computer networks. The most valuable of these ordering methods is undoubtedly computer networks. Not only are computer networks used to place orders, but they are also used for prescription reviews, eliminating drug interactions, maintaining patient drug profiles, billing and inventory control. Also, computer-assisted ordering offers the potential for development of automated dispensing devices.

1.2.2 Packaging Equipment

Hospital pharmacies using unit-dose dispensing must have in place a means of obtaining the medications in unit-dose form. As stated previously, most hospitals purchase the majority of their medications in prepackaged unit dose form. Various types of packaging equipment are available to perform unit-dose packaging of items purchased in bulk form. Bard MedSystems produces a unit dose heat sealer which puts unit doses in a blister package, Fig. 6. Also vials of varying volumes can be filled using a programmable dispensing pump and a manual bench capper. Disposable glass syringes can be bought and filled in the pharmacy using a syringe filling stand and a transfer needle.

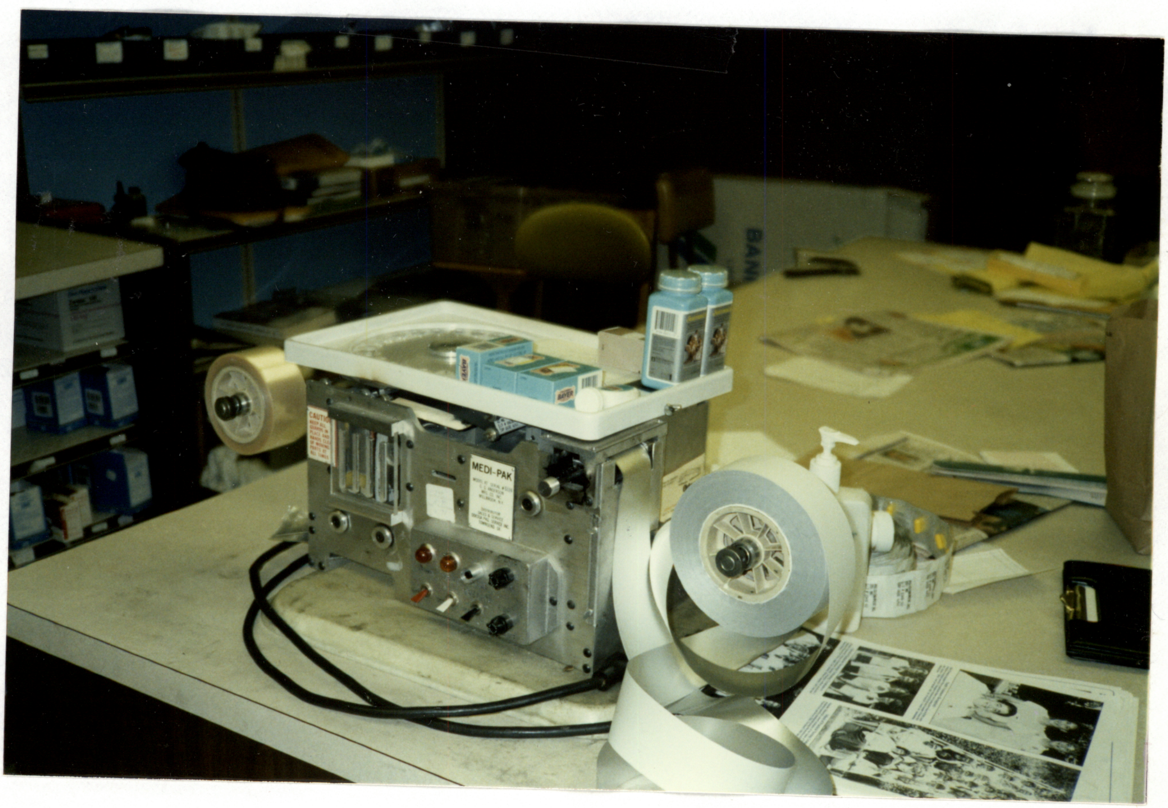


Fig. 6. Medi-Pak Heat Sealer

1.2.3 Automated Unit Dose Dispensing

In the past decade, Baxter Healthcare Corporation of Deerfield, Indiana developed and fielded the ATC 212 System, designed to assist a hospital pharmacy by packaging and dispensing medications as part of a computer-assisted centralized cart-fill system (Jones, Crane, Trussel). The ATC 212 is a microcomputer based system with the capability to package and dispense 212 different oral solid pills and tablets. This system is tied into a computerized ordering system so that the ATC can read the fill lists for each patient.

Once a day the ATC 212 Dispensing System is activated to package and dispense a 24 hour supply of solid medications for each patient. As the machine reads a patient's fill list it identifies the first drug required and locates a canister containing the pill. The canister ejects pills, one by one to be individually packaged in a continuous strip. The next drug is then identified and the process continues until each prescription has been filled. Each individual package is labeled with the type of medication, patient name, and other needed information.

At the same time Baxter Healthcare was fielding the ATC 212 system, ComPharm Systems Incorporated of Auburn, New York was developing the concept of automated dispensing of pre-packaged solid unit-dosed medications. This system was developed to meet the needs of those hospital pharmacies which purchase the majority of their pharmaceuticals in unit-package form.[1] The ComPharm dispensing system performs the following functions:

1) Automatically dispenses prepackaged pills into patient medication drawers.
2) Maintains Patient Records
3) Identifies significant drug interactions and possible allergic reactions to medications.
4) Maintains drug inventory and pricing records
5) Prints/displays inventory reports, patient profiles, drug interaction warnings, and billing information.

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[1] As of November 1990, ComPharm' Automated Pill Dispensing (APD) System was still in the prototype stage.

2.0 STATEMENT OF SYSTEM NEED

Hospital pharmacies that dispense unit-doses from a central area are forced to devote large amounts of manpower to maintain accuracy, accountability and efficiency in dispensing. As previously stated, the tasks associated with manual cart-fill operations are tedious and repetitious. In completing tasks such as the picking of unit doses off the shelf and placing them into patient medication drawers, there is a chance that the pharmaceutical technician may pick the wrong dose or place a unit-dose in the wrong patient drawer. To prevent errors from reaching the patient care area, a lot of manpower is allocated to inspecting cart-fill operations and correcting errors. In situations where the pharmacy is understaffed, their are fewer technicians forced to do the tedious job of picking doses, and fewer pharmacists to review the technicians work. Thus the probability for error is increased.

Obviously, current unit-dose dispensing operations are time and labor intensive. A survey done at a 300 bed teaching hospital showed that the average time to manually dispense one prepackaged medication was 4 minutes (Hassan 69). At another hospital with 280 beds, four pharmacy technicians and two registered pharmacists are required to perform manual cart-fill dispensing once every twenty-four hours.

In 1984 the Management Science Corporation of Bridgewater, New Jersey performed an evaluation study of a hospital pharmacy serving a daily census of approximately 200 beds. The study showed that implementation of an automated system of unit-dose dispensing such as ComPharm Systems Automated Pill Dispensing (APD) System) could:

1. Reduce pharmacy staffing requirements by 1 full-time equivalent pharmacy technician.
2. Reduce inventory control costs by 35%
3. Make one pharmacist more available in patient care areas for consultation

(Science Management Corporation)

Personal conversations with hospital pharmacists who utilize computer-assisted ordering, indicate that such systems have helped to increase the speed and accuracy of unit-dose dispensing. Furthermore, automated dispensing systems such as the ATC 212 have proven to be both labor and time savers. However, the ATC 212 system's role as both a packager and a dispenser of unit doses has proven to be a limitation. As described earlier, this system takes pills in bulk form, packages them and dispenses them as unit doses. One of the reasons that the ATC System has had trouble penetrating the market is that hospital pharmacies that service over 200 beds do not want to be involved in mass drug packaging programs because of the chance for error. Another limiting factor of the ATC System is the prohibitive cost. Thus, many hospital pharmacies continue to purchase the majority of solid and injectable medications in prepackaged unit-dose form and dispense them manually.

Companies such as APS Incorporated of Clifton, New Jersey which are engaged in large scale dispensing of unit doses to nursing homes and hospices have also been slow to embrace the ATC 212. Personal discussions with APS President Bob Palmer revealed that APS considered the use of technicians paid $6.50 an hour and unit-dose packaging equipment more cost-effective than the ATC 212 System.

On the other hand, ComPharm's Automated Pill Dispensing (APD) System was plagued by its inability to handle the variety of packaging styles that exist for solid doses, and the problem of what to do with unused doses that are returned to the pharmacy. However, by making some minor adjustments to the APD System, ComPharm should be able to meet the capacity requirements of the customer and to re-load returned doses.

2.1 Scope of Project

The essence of this project will be the development of a plan for a system to enhance the efficiency of cart-fill operations by seeking ways to improve dispensing of unit-dosed liquids and injectables. For the purpose of this project, we will assume that automated dispensing of liquids and injectables would be the most effective way of meeting the need for improved efficiency and accuracy in a hospital pharmacy, Fig. 7. The proposed system would be tied into a computerized ordering and inventory system, and would be capable of being integrated with other pill dispensing systems currently available, Fig. 8. The development of such an automated dispensing system offers an opportunity to increase both efficiency and accountability in pharmacy dispensing both for hospitals and nursing homes, while at the same time reducing errors. Thus professionally trained pharmacists will be able to reallocate more time to clinical duties.

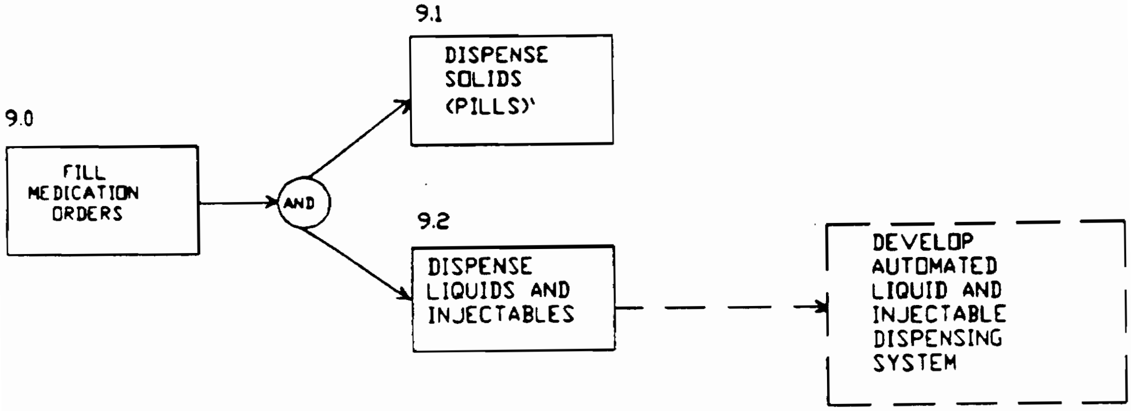

Fig. 7. Develop Automated Liquid and Dispensing System

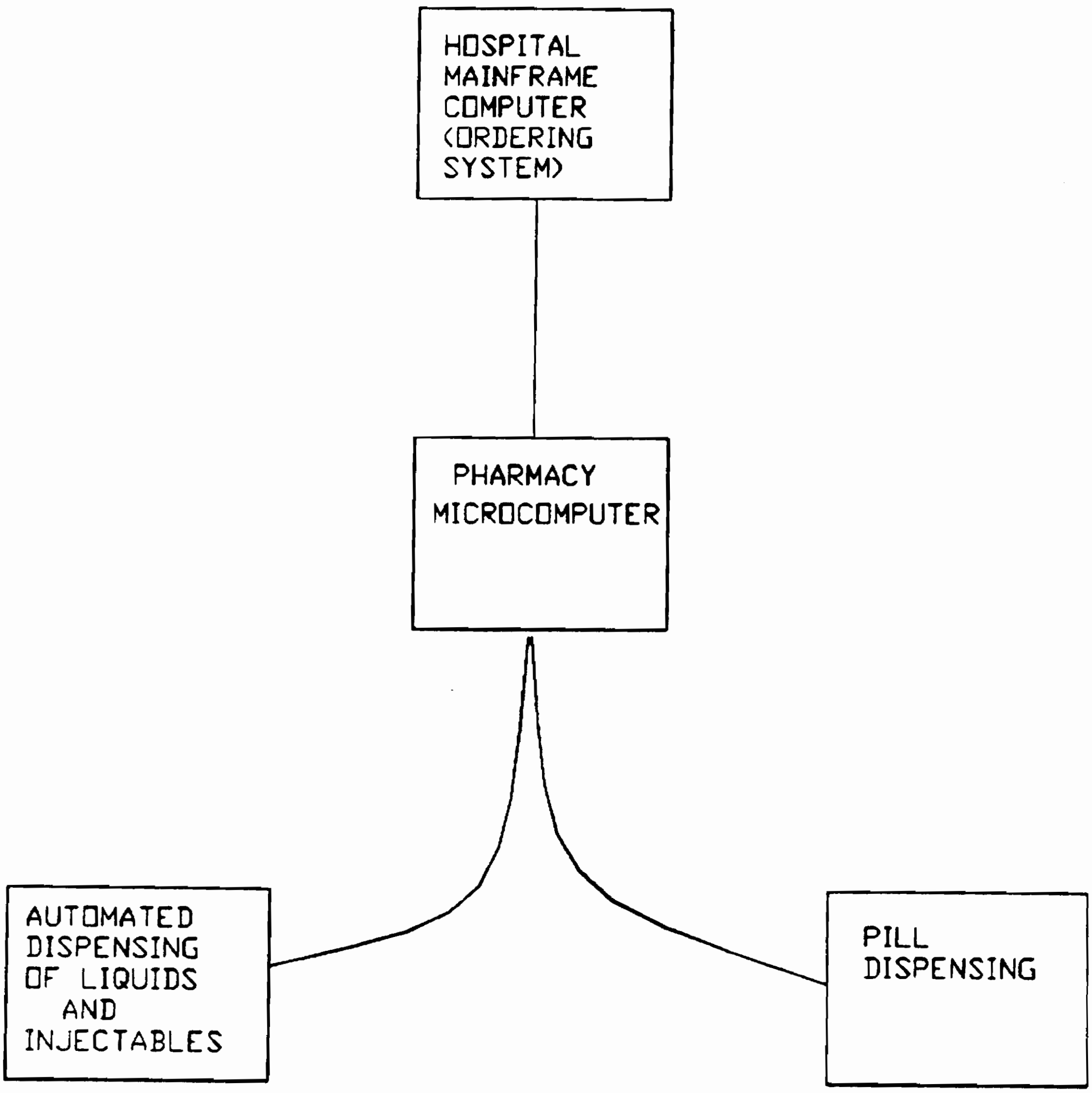

Fig. 8. Automated Liquid and Injectable Dispensing System

3.0 STATEMENT OF SYSTEM REQUIREMENTS

The Automated Liquid and Injectable Dispensing System for liquids (henceforth referred to as the ALID System) must meet several top-level requirements in order for it to be considered feasible in a central pharmacy.

3.1 System Objectives

The ALID System must meet certain objectives in order for it to be considered successful. The basic goals of the system are listed here.

3.1.1 Automated Dispensing: System should be able to dispense up to 90% of all prepackaged liquid and injectable line items in a central pharmacy. The ALID System's primary advantage will be the improved speed and accuracy of cart-fill operations.

3.1.2 Interface with Computer-Assisted Pharmacy: The ALID System should be suitable for integration with current computer-assisted dispensing systems. The system should also be designed so that it can be integrated with other automated unit dose dispensing systems that are available.

3.1.3 Dispensing Records: The ALID System should be designed to maintain records of liquid and injectable doses dispensed by the system for inventory control and billing purposes, and for improved accountability.

3.1.4 Ease of Maintenance: The dispensing equipment should be modular in design for easy reloading and uncomplicated repair at the organizational level. The system should also include a diagnostic testing capability to help locate failed components.

3.1.5 Life Cycle: ALID System equipment should be designed to provide automated liquid and injectable dispensing over a life span of 5 years with support services available over that time.

3.1.6 Efficiency / Accountability: The ALID Dispensing System should reduce the chance for error and increase accountability in cart-fill dispensing of liquid and injectable doses. The system should also reduce inventory control costs.

3.1.7 Allocation of Pharmacist's Time: The system should reduce the amount of time registered pharmacists have to spend supervising centralized unit-dose dispensing.

Thus the pharmacist will be able to reallocate the time saved to clinical duties, and to maintaining his role as a drug information specialist.

3.2 Operational Requirements

The design criteria for the ALID System are derived from an operational concept. The operational concept should describe how the system is to be used and in what kind of environment the system will be used.

3.2.1 Mission Requirements

Primary: Improve the efficiency and accuracy of cart-fill systems by automating the dispensing of unit-dosed liquid and injectable medications in a hospital pharmacy.

Secondary: Improve the inventory control in unit dose dispensing by automating the counting of items dispensed.

Operational Profile: In line with current manual unit-dose dispensing, the ALID System will:

1) read a valid medication order
2) identify patient
3) identify liquid, or injectable doses ordered

4) place doses in patient medication drawer
5) count doses dispensed
6) update dispensing record
7) place a copy of the medication order in patient medication drawer.

3.2.2 Performance and Physical Parameters

Size: The ALID System equipment will require approximately 80 square feet of space with a maximum height of 7 feet in a hospital pharmacy servicing 200 beds (8'x10'x7'). This size requirement is based on the area taken up by two manual dose picking stations.

Output Rate: The ALID System will be able to locate and dispense 6 to 12 items per minute (variable speed). This is the range of speeds considered necessary to fill an individual medication order in one minute according to Brad Worth, Director of Pharmacy at Auburn Memorial Hospital in Auburn, New York.

Capacity: From personal conversations with pharmacists at hospitals dispensing to a daily census of approximately 200 beds, it has been determined that the ALID System should hold a minimum of 80 different items.[2] The system will hold a minimum of 20 of each item. Capacity for an individual item can be increased in multiples of 20 to handle those items for which there is a high daily demand.

Critical Performance Factors:

* The ALID System must be able to hold a day's supply of at least 80 liquid and injectable line items. It will be left to the discretion of the hospital pharmacist to decide what items are dispensed by the ALID System.
* The ALID System will be one component of a computer assisted, centralized unit-dose dispensing system (computer-assisted ordering and order review, Fig. 3).

3.2.3 Operational Distribution

Production: The ALID System must be produced using "off the shelf" technology in order to keep costs down. No special tooling of components will be allowed.

Quantity of Equipment: The system will be designed so that a pharmacy serving 200 beds will start with one dispensing

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[2] This number represents roughly 90 % of all liquids and injectables in the hospital's formulary.

unit capable of holding and dispensing a daily supply of 80 different pre-packaged liquid and injectable line items. Capacity can be increased by multiples of 5 line items (20 of each item) by adding dispensing modules. A microcomputer will be used to drive the original and any additional dispensing units. The microcomputer will have the capacity to drive both the ALID System and any other microcomputer driven dispensing systems used by the pharmacy, Fig 8.

Personnel: The ALID System will be operated by a pharmacy technician and supervised by a registered pharmacist. Many states have laws requiring that a registered pharmacist inspect all doses dispensed before they are released. These personnel will undergo operational training prior to the system coming on line. Maintenance personnel will be provided for scheduled and unscheduled maintenance.

Facilities: The system is to be placed in a pharmacy with a typical temperature and humidity controlled environment.

Transportation: The system equipment will be packaged so as to avoid damage during initial shipment by truck to the user's facility. Once the system is set up it generally will not be transported again except for corrective maintenance.

Software: Software will be an integral part of the system and will be distributed to the customer along with system hardware. Initial distribution will consist of basic software necessary to access and convert the pharmacy database to the required form and software needed to run the ALID System. Report producing programs as well as drug interaction software will also be made available.

Time: Upon receipt of a contract, the ALID System hardware and software will be delivered to the customer, installed and brought on line within 1 year.[3]

3.2.4 Operational Life-Cycle

The ALID system will be designed for an operational life of 5 years.

Total Inventory Profile: Initial distribution to a central pharmacy servicing 200 beds will be one 80 item dispensing unit and 1 microcomputer. Additional dispensing modules will be available for increased capacity.

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[3]This time frame assumes that a computer-assisted cart-fill system is already in place.

Operators: The system will be operated by pharmacy technicians who will receive formal training to become familiar with its operation. Operation manuals will be provided.

3.2.5 Utilization Requirements

Operation Hours: In a hospital pharmacy serving 200 beds the system will be used approximately 3 to 4 hours a day to assist cart-fill operations.[4] The ALID System will also be available 22 hours a day for dispensing of change orders, emergency orders, and new orders.

On-Off Sequences: System will be kept on-line for 22 hours a day with 2 hours of down time for reloading and preventive maintenance. The down time will be scheduled preferably during late evening or early morning hours when demand on the pharmacy is small and dispensing can be done manually.

Operational Cycles: The system will be available for 31 days a month to meet the requirement in many hospital pharmacies for daily cart-fill operations.

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[4] If each patient requires an average of 6 liquid or unit dose items a day, and the dispensing device is run at 6 items per minute the time to fill all liquid and injectable orders in cart-fill will be 200 minutes or 3.3 hours.

3.2.6 Effectiveness Factors

The following system effectiveness parameters are established as figures of merit.

Reliability: The probability that the ALID system will operate with success over its life cycle is 99.8 %.

Mean Time Between Maintenance (MTBM): The average time between all maintenance actions (corrective or preventive) will be 24 hours.

Mean Active Maintenance Time (M): Average maintenance down time will be 2 hours.

Achieved Availability (A_a= MTBM/(MTBM+M): The probability that the system will operate satisfactorily at any given time under ideal support conditions is 92.3 %. This figure is based on a MTBM (Mean Time Between Maintenance) of 24 hours and a M (Mean Active Maintenance Time) of 2 hours.

Personnel Skill Levels:

Operators - ALID system operators must meet those minimum requirements for a pharmacy technician as set by the American Society of Hospital Pharmacists (ASHP) in the "Competency Standard For Pharmacy Supportive Personnel in

Organized Health Care Settings" (Hassan 76-80).

Supervisory Personnel: It is expected that a registered pharmacist will be required to inspect medication carts before they are sent out to the patient care areas.

Intermediate Maintenance Personnel: Service technicians will be required to have a high school education (or equivalent) with special training in electronics and digital hardware. A short training course in ALID System trouble shooting and module repair will be provided.

Operator Tasks: 1) Loading the dispensing unit.
2) Sorting Unused doses.
3) Restocking unused doses.
4) Initiating automated dispensing for cart-fill operations.
5) Delivering medication carts

Supervisor Tasks: 1) Data input of orders.
2) Checking automatically dispensed drugs for correctness.
3) Dispensing non-automated items.
4) Dispensing stat orders.

5) Maintain drug database- drug names, vendors, location in system, drug interaction profiles.

System Efficiency: As a figure of merit, the ALID System expects to be able dispense up to 90% of all prepackaged liquid and injectable line items. The efficiency of the system will be its ability to increase the speed and accuracy of unit-dose dispensing.

3.1.7 Environmental Factors

The ALID system will operate in the temperature and humidity controlled environment of a typical hospital pharmacy. The system will also be suitable for operation in a cool room (temperatures as low as 30 degrees Fahrenheit) to handle heat sensitive items. The system will be packaged so as to prevent damage to equipment during initial shipment and set up.

3.3 System Maintenance and Support

Life cycle support for the ALID system will exist at three different levels of maintenance.

3.3.1 Organizational Maintenance

Organizational maintenance will include loading and re-loading the dispensing unit, pre-operation checks, visual inspection, and cleaning of equipment. The dispensing unit will be modular in design with the intent that failed modules can be easily identified and replaced. In the event that system failure cannot be solved by on-site personnel, the cart-fill operations will be carried out manually until service technicians solve the problem. Manual dispensing of liquids and injectables will be done during all times that the ALID System is not being used.

System Operating Personnel: As part of a system orientation course, operating personnel will learn basic maintenance and trouble shooting procedures. Maintenance manuals will be provided.

Pre-operation Checks: At the start of each day, ALID System equipment should be visually inspected to make sure everything is in order. An automated check may be run from the computer terminal that will identify faulty modules and any medications that need to be loaded into the system.

Unscheduled Maintenance: The system will be designed with removable dispensing modules. Failure of one module will not cause complete system failure. A technician should be able to remove and replace the failed module with a working one. If a general system failure occurs which cannot be solved by the operator within a short period of time, intermediate service technicians will be made available.

3.3.2 Intermediate Level Maintenance and Support

Intermediate service technicians will be made available to the customer to conduct a detailed inspection of system equipment once a year, major servicing of the system, and replacement of major system components. These personnel will be skilled in troubleshooting and repairing ALID System equipment beyond module replacement. This maintenance level will also be responsible for spare parts inventory and distribution to the user. Intermediate maintenance will be located at the production facility and will travel to the customer site to perform repairs.

3.2.1 Depot Level Maintenance

Depot level maintenance will be performed at the production facility. The depot will be responsible for module and component repair, and major equipment overhaul. The depot will also be responsible for supplies of spare parts to the intermediate level of maintenance.

4.0 FUNCTIONAL ANALYSIS

The Automated Liquid and Injectable Dispensing System will be one component of the centralized unit-dose dispensing system shown in Fig. 3. As stated previously, the prime mission of this system will be to improve the efficiency of process of filling medication orders. The major life cycle functions of the system are shown in Fig. 9. In order to better view how this system will operate and be supported throughout its life, blocks 9.2.8 and 9.2.9, **Operate System** and **Maintain System** will be expanded downward several levels.

4.1 Operational Functions

Block 9.2.8.0 Utilize System: System will be used over its life cycle to dispense pre-packaged liquid and injectable unit doses, Fig. 10.

Block 9.2.8.1 Fill Individual Orders: System will dispense new orders, emergency orders, and change orders for liquids and injectables when prompted (most hospitals fill new orders either by the hour or every other hour). See Fig 11.

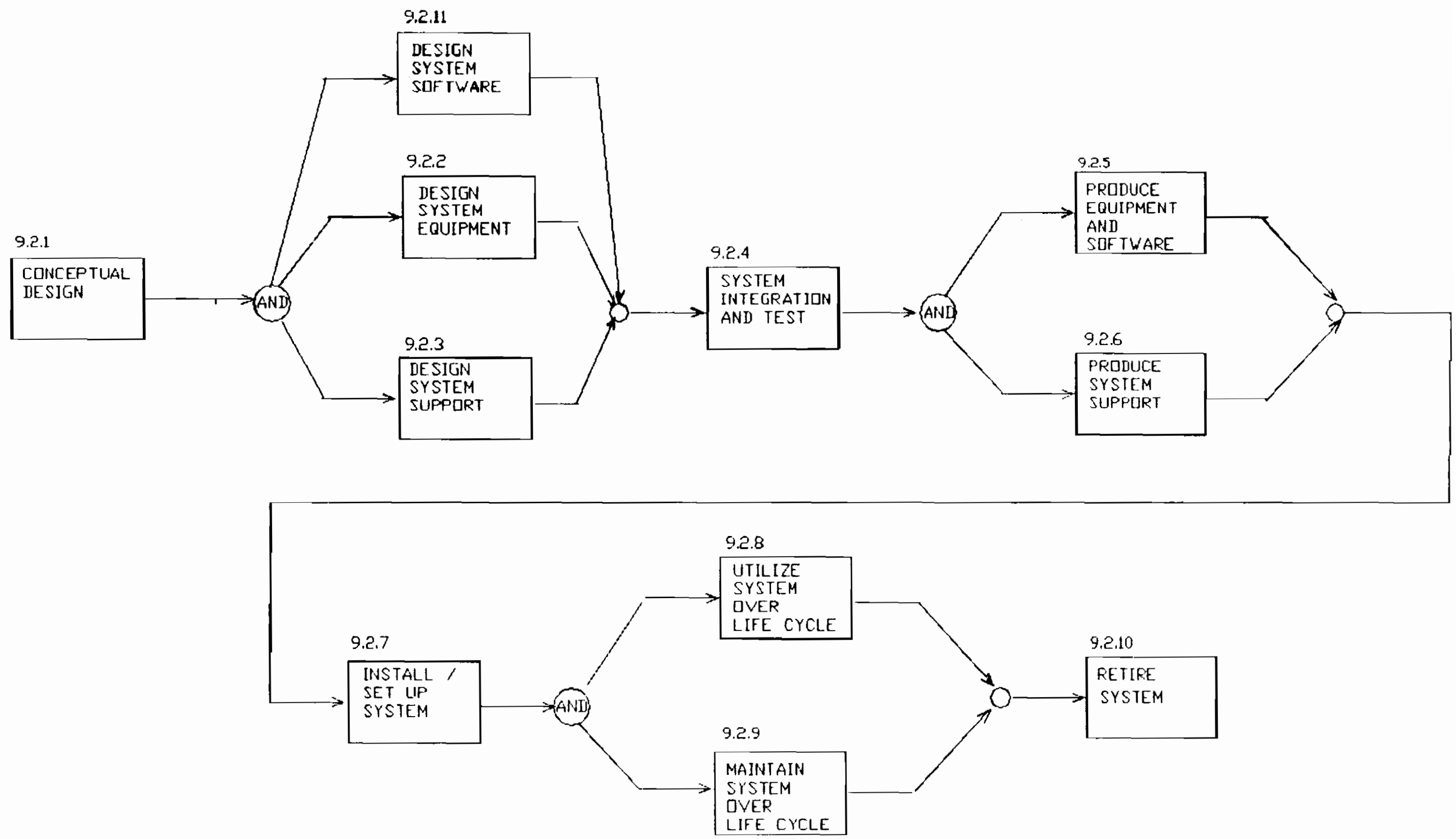


Fig. 9. ALID System Life Cycle

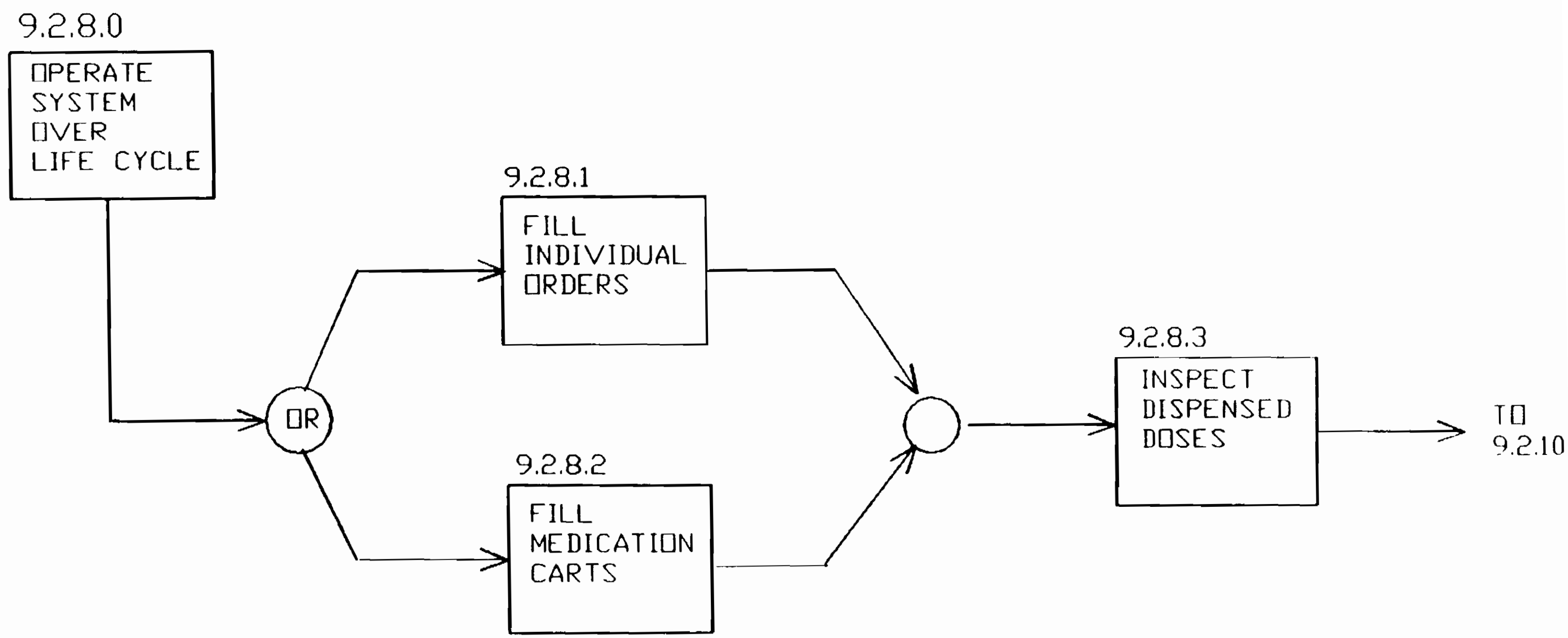


Fig. 10. Operate System Over Life Cycle

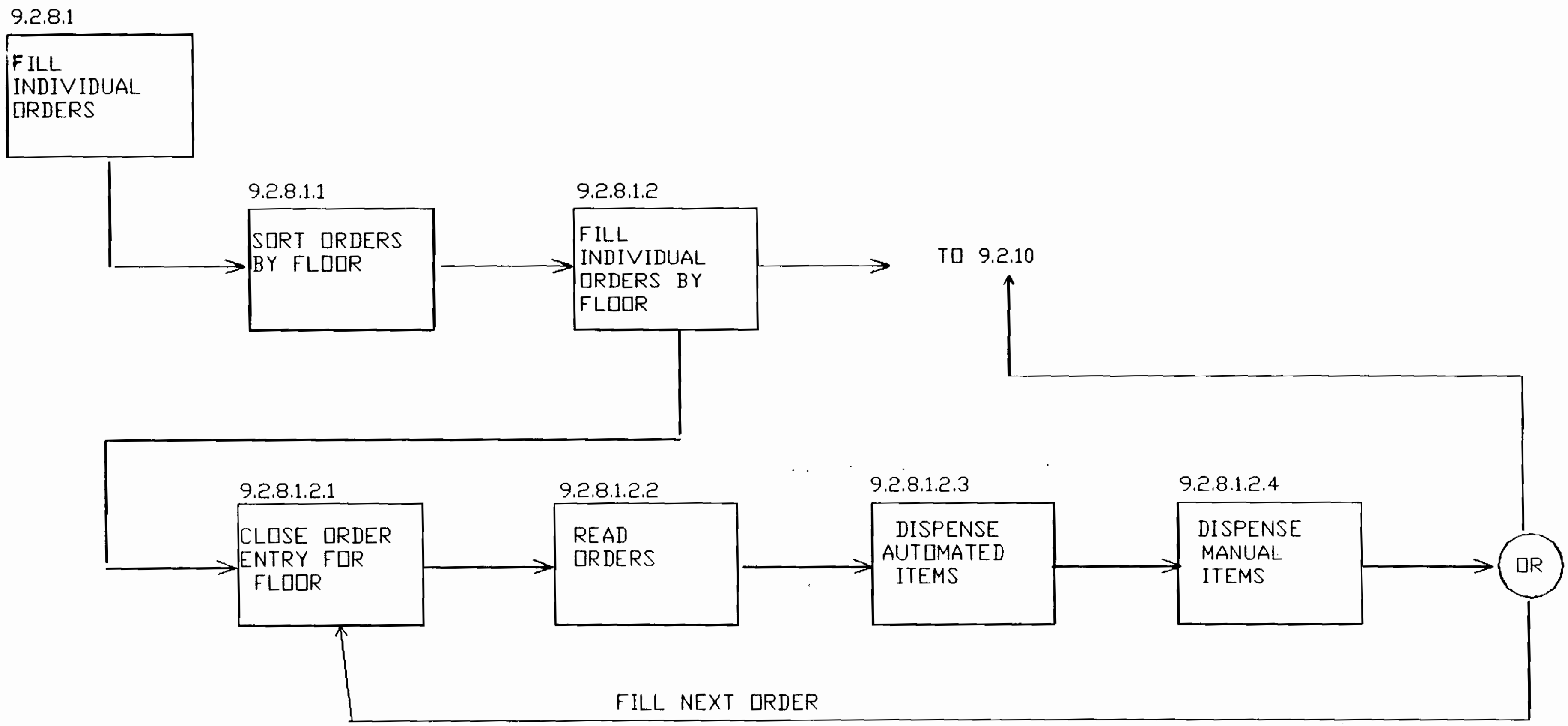


Fig. 11. Fill Individual Orders

9.2.8.1.1 Sort Orders:

* Orders are sorted by floor and by room number so that they can be filled sequentially.

9.2.8.1.2 Fill Individual Orders By Floor: The following steps will be performed for each floor.

* Close order entry for floor.
* Read individual order. Identify patient by name and room number and identify required liquid or injectable unit-dose. Identify and display on a monitor a list of manual versus automated items.
* Dispense automated items, Fig. 12.
  Locate required liquid or injectable item.
  Deliver proper dose to technician, and update dispensing record to indicate what was dispensed, to whom, and unit price.
  These steps are repeated until all the automated items on the order are dispensed.
* Dispense manual items. If required items are not held by the dispensing machine, a technician will go through the function of locating and dispensing the required item.

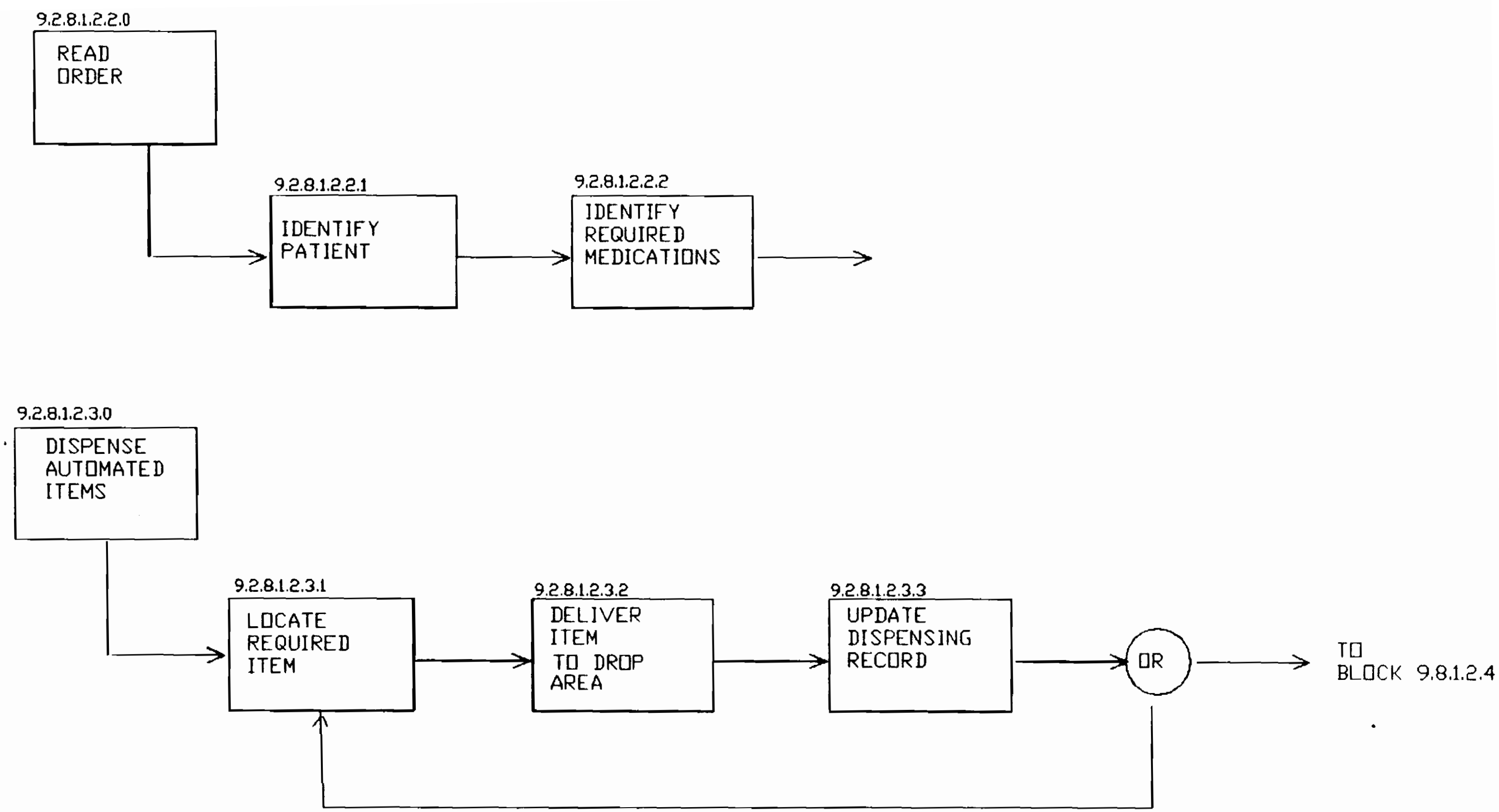


Fig. 12 Read Orders, Dispense Automated Items

Block 9.2.8.2 Fill Medication Carts: Once a day, patient medication drawers which are held on medication carts are filled with the required unit-doses to last for the next 24 hours. The ALID System will dispense each patient's required liquid and injectable doses into a patient drawer. See Figure 13.

9.2.8.2.1 Sort Orders By Floor

* Orders are sorted by floor and by room number so that they can be filled sequentially.

9.2.8.2.2 Fill Medication Carts By Floor: The following steps are performed for each floor.

* Close Order Entry For Floor
* Read Order. Identify patient by name room number and billing number. Identify required liquid and injectable doses. Identify and display a list of manually versus automatically dispensed doses.
* Position patient drawer to receive medications in drop area.
* Dispense automated items, Fig. 14. Locate and deliver the required liquid and injectable doses to the drawer. Update the dispensing

record to indicate what was dispensed and to whom.

* Move drawer into manual dispensing area and go back to Read Order to start automatic dispensing of next order.
* Print dispensing record and place it in medication drawer.
* Dispense Manual Items. After the ALID System is done automatically dispensing liquid and injectable doses into the patient drawer, the pharmacy technician will locate and place in the drawer all items that are not held by the dispensing machine. The technician will also update the dispensing record to indicate what was dispensed and to whom.
* Remove patient medication drawer from system and replace it on medication cart.
* Fill the next drawer or else reopen order entry for present floor and move on to the next floor.

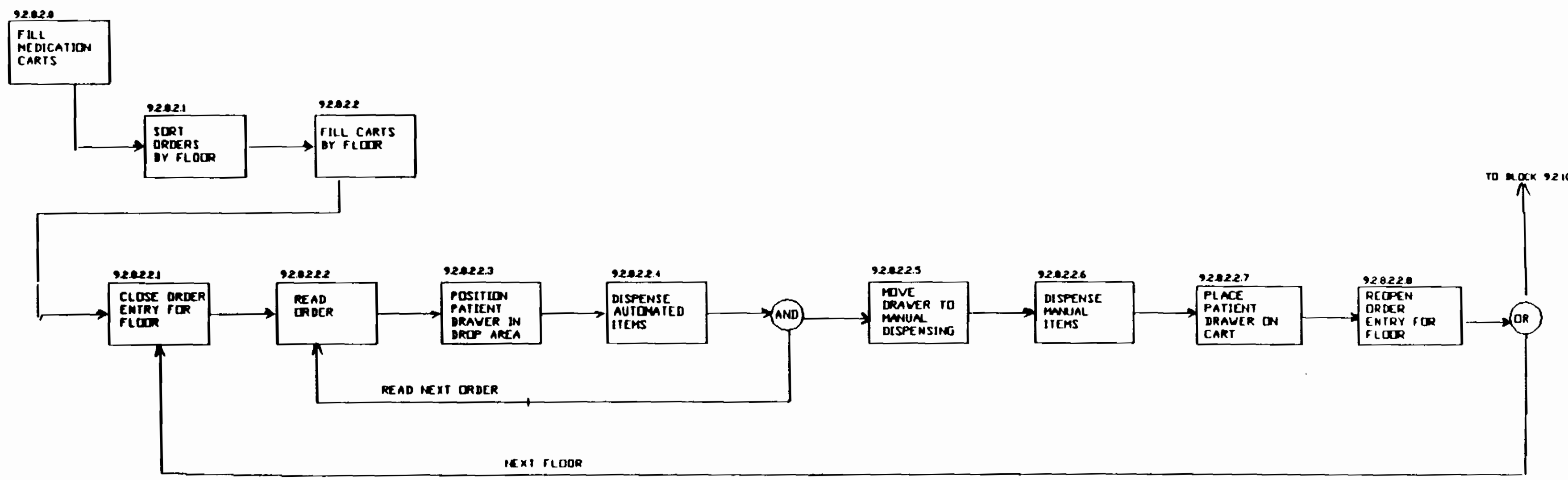


Fig. 13. Fill Medication Carts

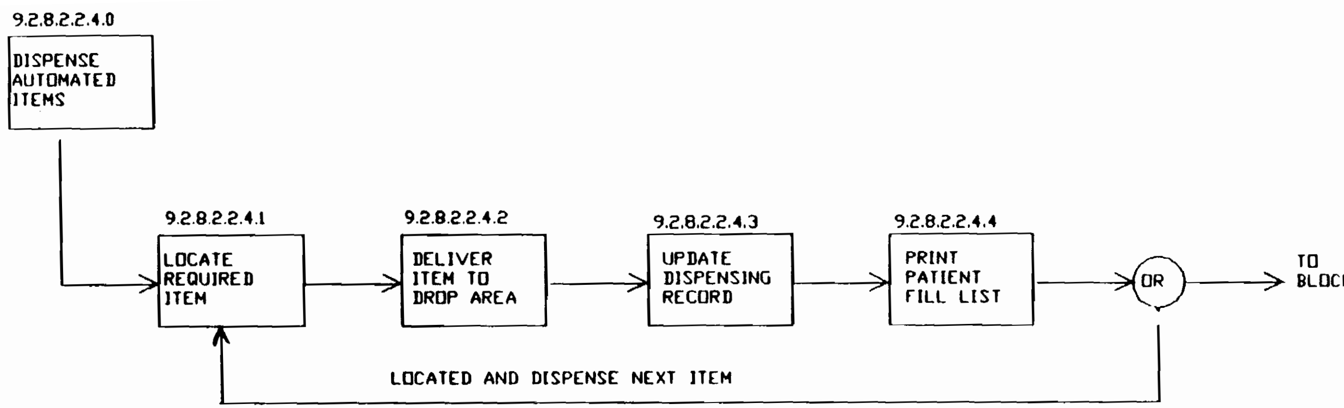


Fig. 14 Dispense Automated Items

4.2 System Maintenance and Support Functions

Block 9.2.9.0 Support System Throughout Life Cycle

The maintenance concept calls for support to be designed in order to keep the system operating over a period of 5 years, Figs. 15 through 20.

Block 9.2.9.1 Test / Inspect Equipment: This function should be run daily prior to performing cart-fill operations to ensure that the ALID System is performing properly. See Fig. 16.

9.2.9.1.1 Visual Inspection: Inspect system equipment for the following:

* All cables connections are tight.
* No broken items present.
* All items in dispensing unit are stored in dispensing modules (i.e. there should be no loose items).
* Equipment should be clean.

9.2.9.1.2 Load Dispensing Equipment:

* A printout will be made listing the amount of each item in the dispensing machine. Items which need to be loaded into the system will be flagged, and

a technician will restock the system.

9.2.9.1.3 Run Dispensing Test: ALID System should read and fill 16 test orders. Each order will be for 5 different automated items. If a disruption in the following sequence of actions occurs the functional flow will be diverted to **block 9.4 Isolate Failed Module.**

* Read test order. Identify test name, test room number, test billing number, and 5 automated items to be dispensed.
* Position drawer to receive Test Items
* Dispense automated items: Locate and deliver required items to the test drawer. Update a test dispensing record to indicate what was dispensed and the test account which should be charged.
* Remove drawer from dispensing machine. Fill next order.

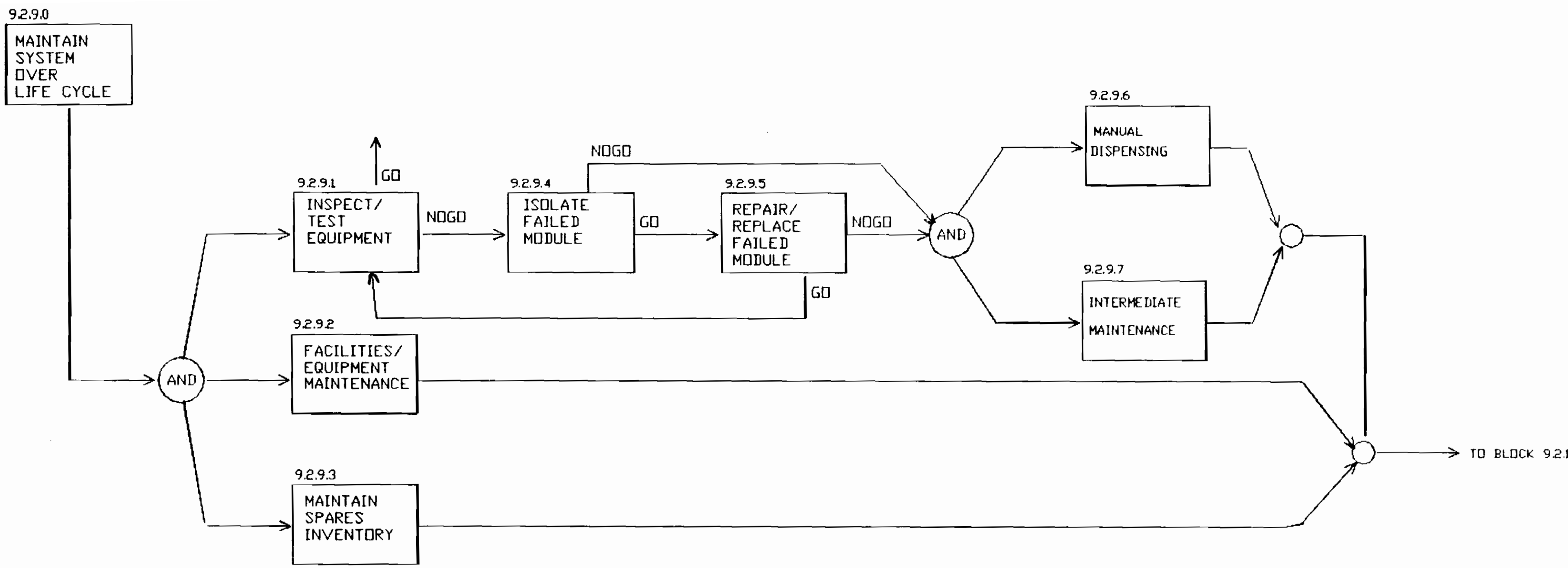


Fig. 15 System Maintenance

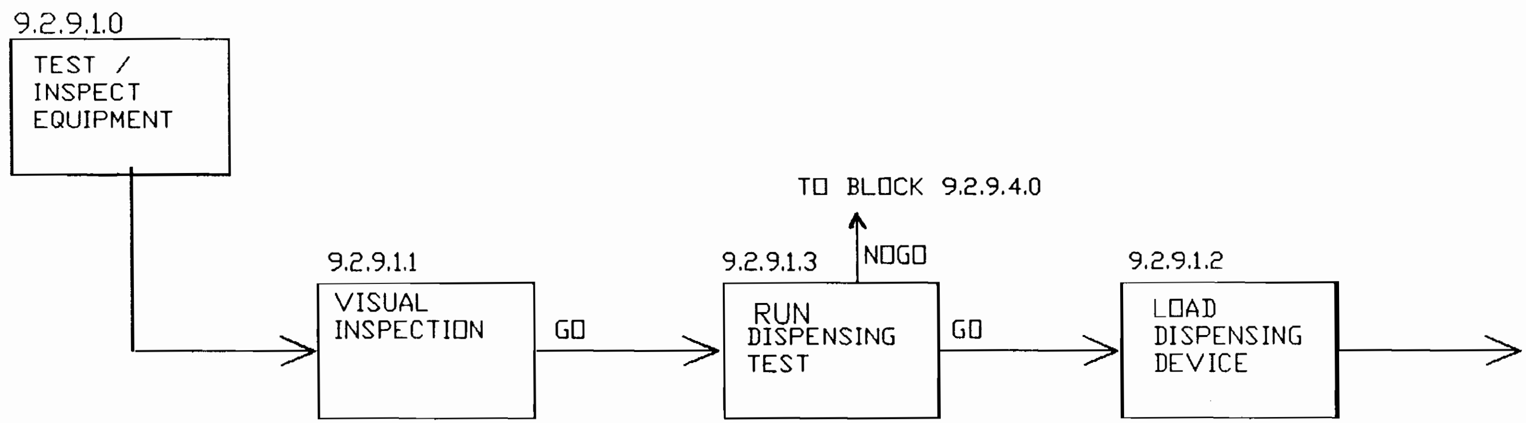


Fig. 16. Test / Inspect System Equipment

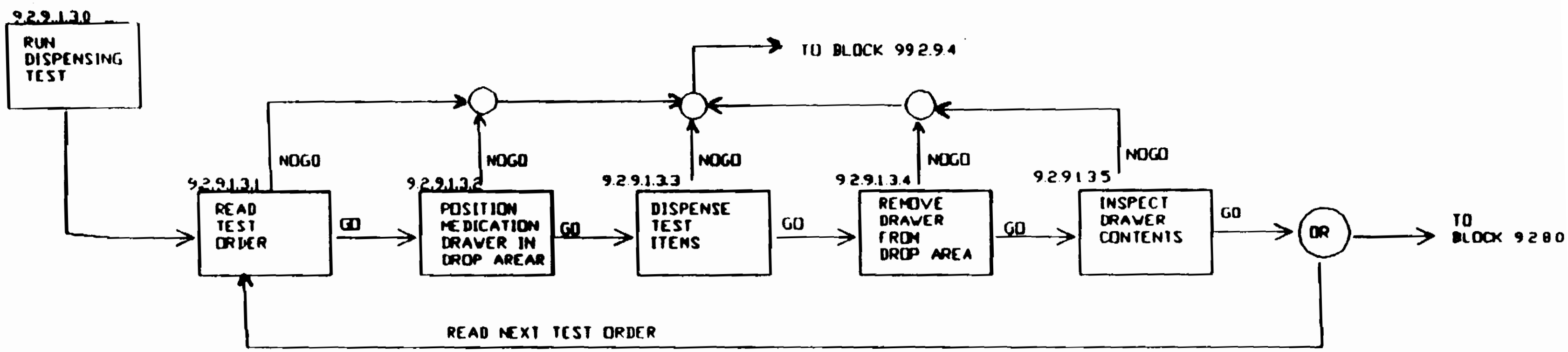


Fig. 17 Dispensing Test

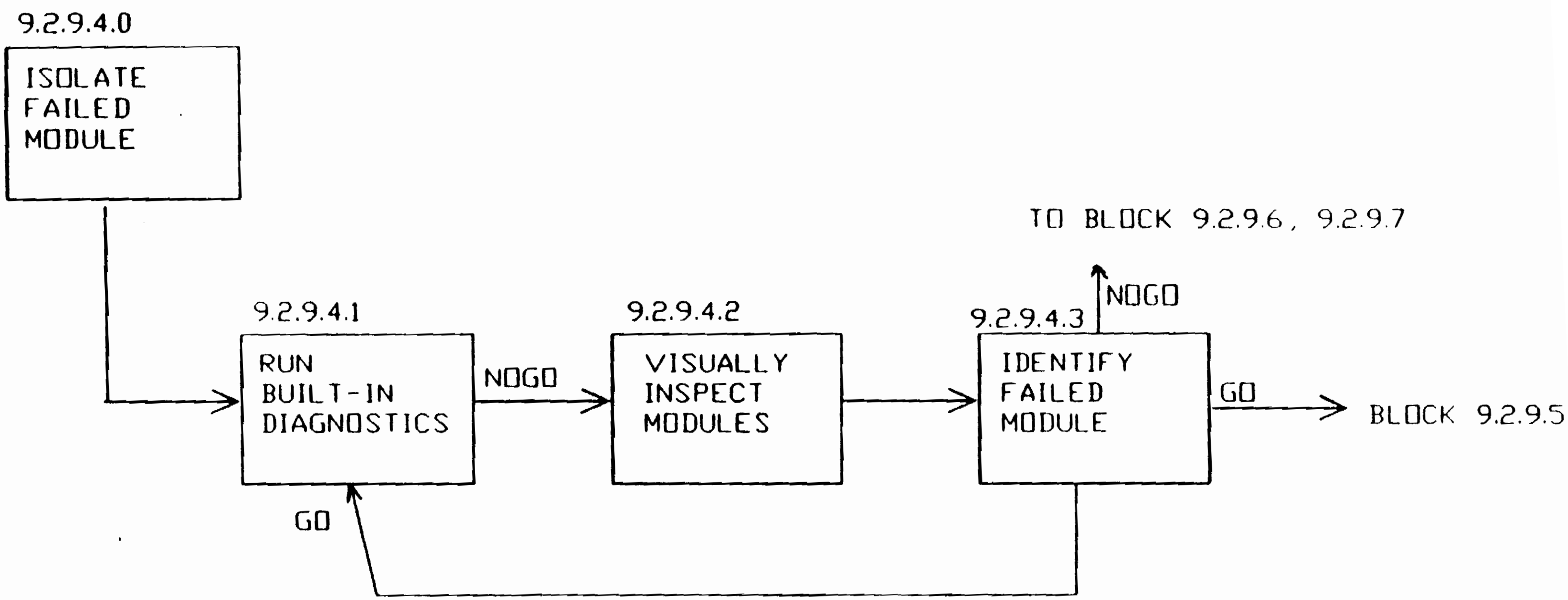


Fig. 18. Isolate Failed Module

Block 9.2.9.2 Facilities/Equipment Maintenance

9.2.9.2.1 Clean Equipment

9.2.9.2.2 Control of Medications Held By Dispensing Unit:

* Monitor dated or perishable medications. A record of dated items will be kept and notice will be given when an expiration date is reached.
* Monitor system contents. Notice should be given when an item dispensed by the system has been discontinued.
* Remove expired and discontinued Items.

9.2.9.2.3 Maintain Environment:

* Maintain sterile environment.
* Maintain proper temperature.

9.2.9.2.4 Add Dispensing Equipment:

* Additional liquid and injectable dispensing modules may be added for increased capacity.
* Automated pill dispensing equipment may also be tied into the system to further improve efficiency.

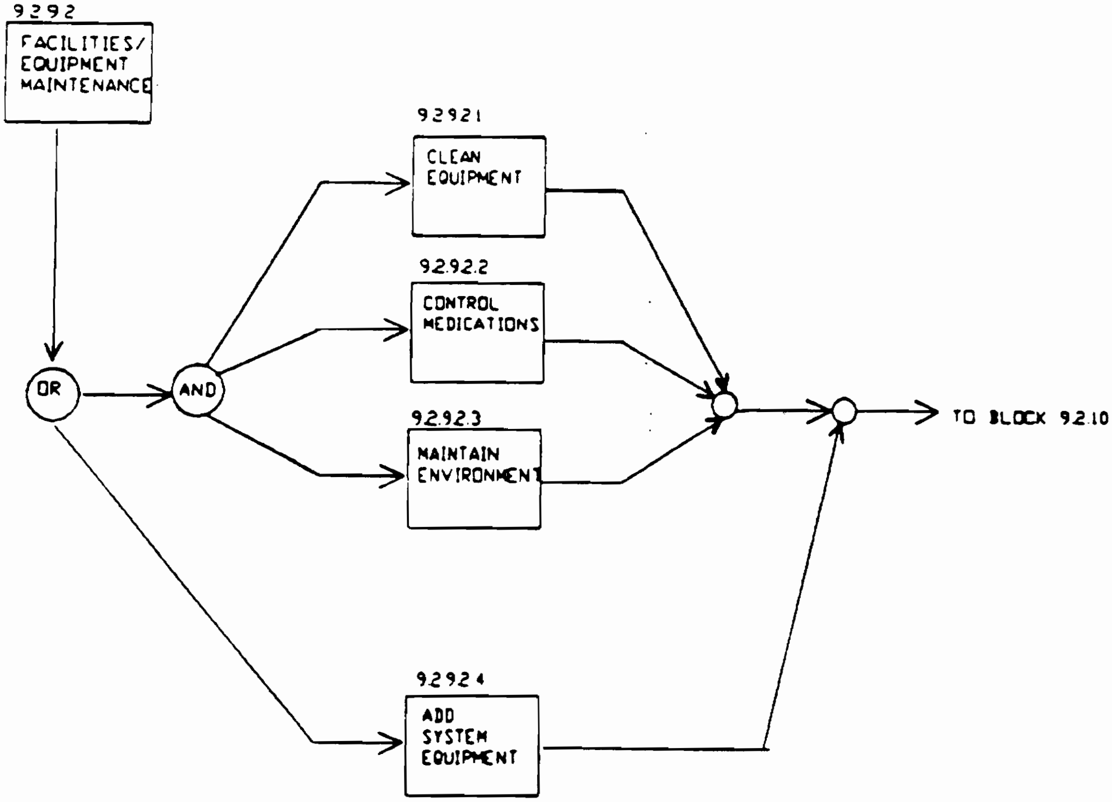


Fig. 19. Facilities/Equipment Maintenance

Block 9.2.9.3 Maintain Spares Inventory

An adequate supply of spare modules and components should be maintained at the organizational level of maintenance to minimize down time due to logistics delays.

Block 9.2.9.4 Isolate Failed Module: The following functions (Fig. 18) will be performed immediately upon a failure in any mode of the dispensing function.

9.2.9.4.1 Run Built-In Diagnostics

* The system will perform diagnostic testing to indicate where a failure has occurred.

9.2.9.4.2 Visually Inspect Modules

* Inspect the failed modules.

9.2.9.4.3 Identify Failed Module

Block 9.2.9.5 Repair/Replace Failed Module

Once the failure has isolated at the modular level, the operating technician should replace the failed module if possible and retest the system. If the failure cannot be isolated or if the module cannot be replaced, an intermediate service technician should be called to make repairs, and manual dispensing set up.

Block 9.2.9.6 Manual Dispensing: The pharmacy will maintain a manual cart-fill area to back up the automated dispensing system.

Block 9.2.9.7 Intermediate Maintenance (Fig. 20)

9.2.9.7.1 Call Service Technician

9.2.9.7.2 Isolate Failed Module:

* The service technician should run the diagnostics program again.
* Isolate failed component using a standardized troubleshooting procedure.
* Replace Failed Component.

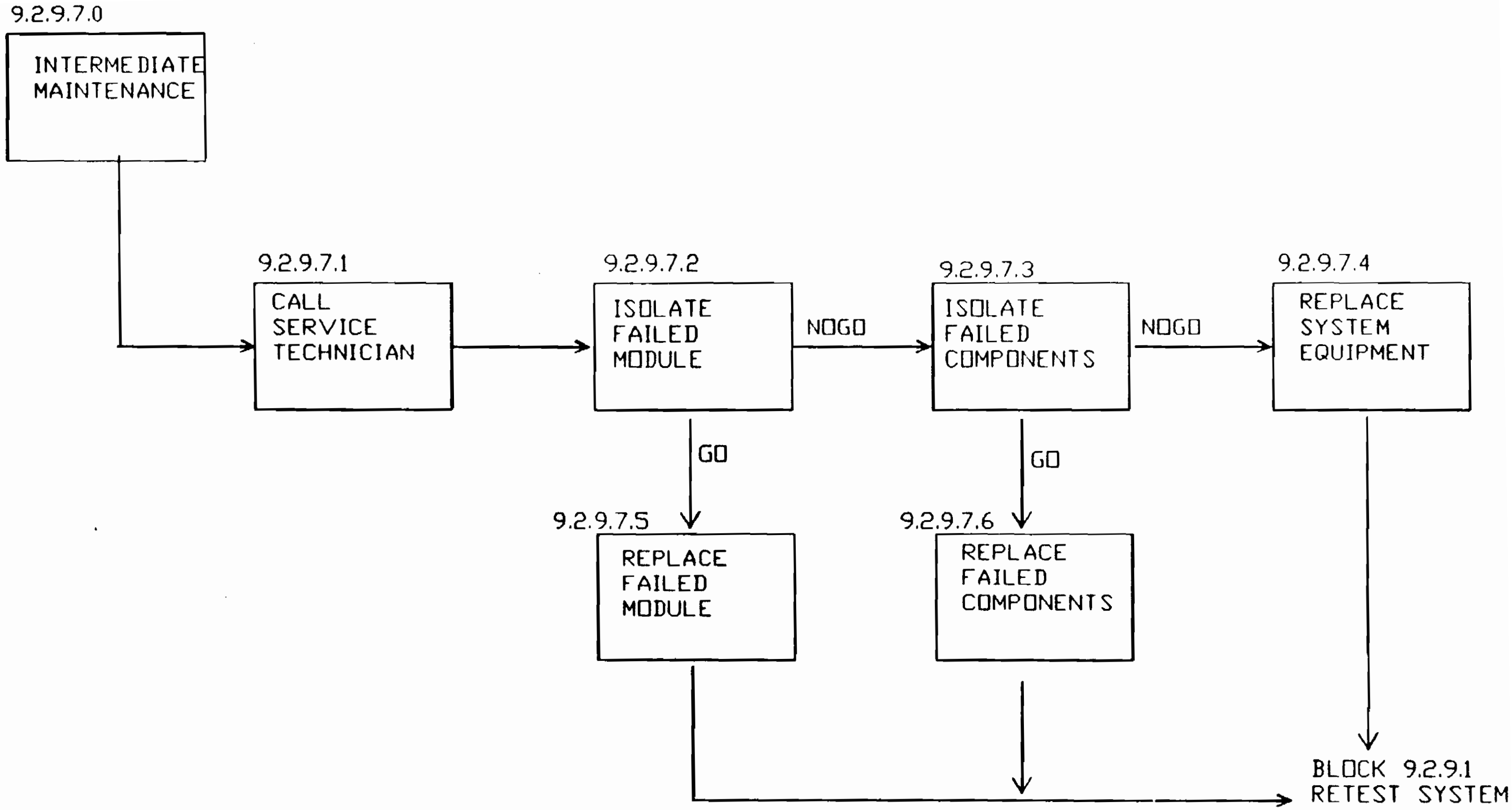


Fig. 20. Intermediate Maintenance

5.0 SYSTEM CONFIGURATION

Based on the functions described in the previous section and the top line requirements initially established for the ALID System we can now describe a basic system configuration consisting of two major subsystems, the **dispensing device** and the **control system**, Fig. 21.

5.1 Dispensing Device

The dispensing device will be capable of dispensing up to 80 different items. The main components of this device are described in the following sections.

5.1.1 Liquid Dispensing Modules

There will be a minimum of ten of these modules. Each of these modules will have 5 addresses or locations. Each location holds a minimum of 20 unit packages of a liquid item. The function of a module will be to advance an item which it holds to the **Delivery System.** Additional modules may be added to handle those items for which demand is greater than 20 doses a day. Each module should be easily accessed for the purpose of loading liquids into the system. The module should also be easily unplugged and removed from the device for repair.

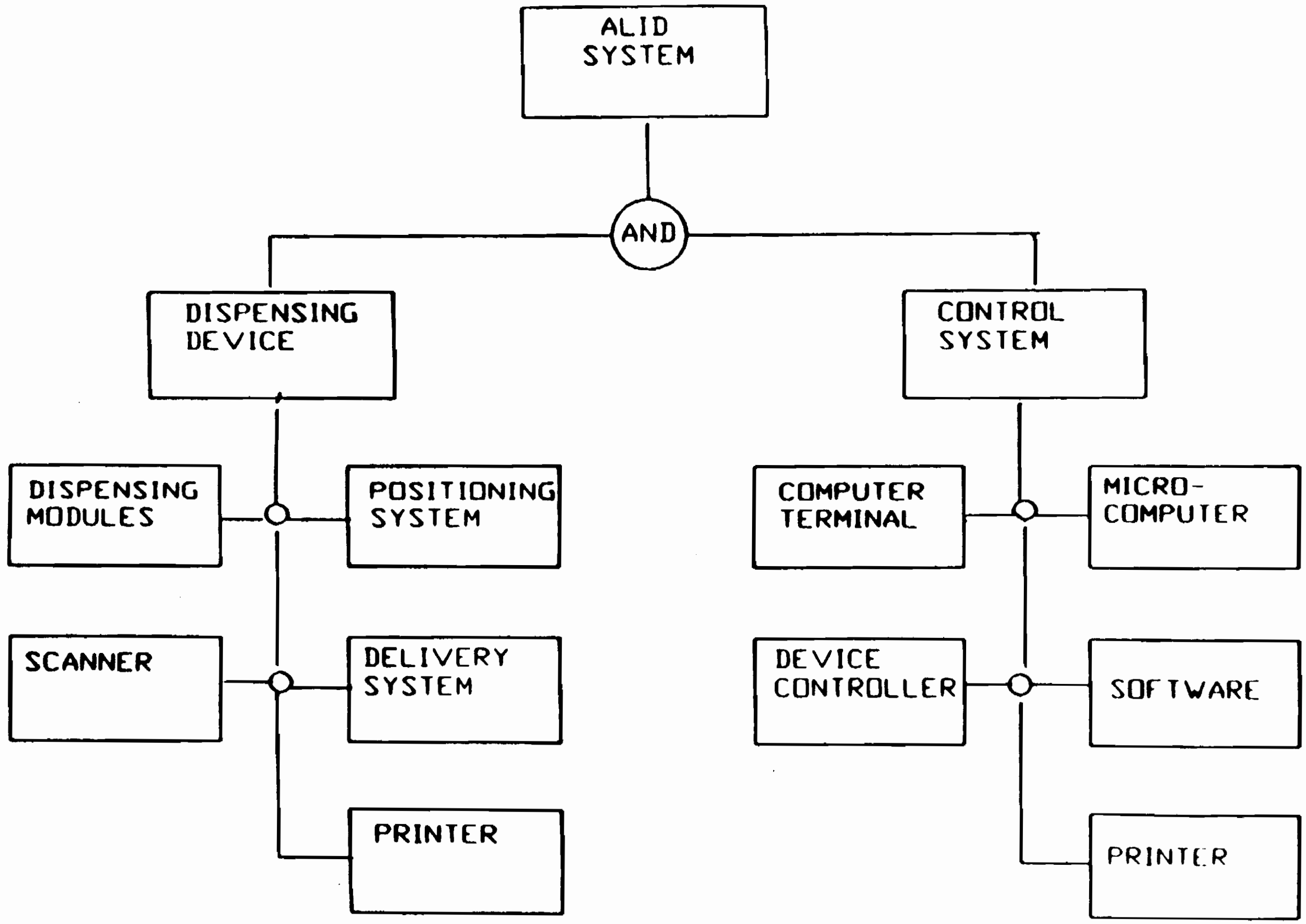


Fig. 21. System Configuration

5.1.2 Injectable Dispensing Modules

There should be six of these modules. Each module will have 5 locations, each capable of holding a minimum of 20 prepackaged injectable items. Additional modules may be added to handle those items for which more than 20 items are dispensed in a day. Again the modules will serve to store items and to advance items to the delivery system. Each module should be easily reached for reloading and should be removable for repair.

5.1.3 Positioning System

The **positioning system** will serve to place patient medication drawers in the medication drop area. This system should hold a minimum of 14 medication drawers in a queue. After all of the required automated items have been delivered to a patient drawer, the **positioning system** should advance the drawer to an unloading area.

5.1.4 Scanning System

A scanner will be used to read a bar code located on the patient medication drawer. The signal from the scanner will be used to identify the patient and to call up the patient's fill list from the pharmacy database located on the **control microcomputer**.

5.1.5 Delivery System

This system will be responsible for delivering items from **dispensing modules** to the drop area safely. Design of this system must take into consideration the fragile nature of most of the items.

5.1.6 Records Printer

A printer should be located on the **dispensing device** so that after an order is filled, a copy of the physicians order list for the patient will be printed out and dropped into the medication drawer.

5.2 Control System

The **control system** will be designed to monitor and control automatic dispensing of liquid and injectable items either to a medication drawer or to a drop area. This element of the dispensing system can also be used to display and print dispensing records and inventory records.

5.2.1 Computer Terminal

The **computer terminal** (keyboard and monitor) can be used for the following functions:

1) Order review
2) Enter new Orders / Update Orders
3) Display locations of medications in the **Dispensing Device.**
4) Update locations of medications in the **Dispensing Device.**
5) Run ALID System test and diagnostics software.
6) Identify manual versus automated items.
7) Display/update patient profile.
8) Initiate cart-fill process or individual order filling.
9) Display billing and inventory records.

5.2.2 Microcomputer

A microcomputer will be provided to run device control software, diagnostics software, and report producing programs, and to store item location databases, dispensing record databases, inventory records.

5.2.3 Printer

A **printer** can be used to print any of a number of reports of use to the pharmacist.

1) Dispensing Records
2) Fill lists
3) Medication locations (in or out of the **dispensing device**)
4) Inventory records
5) Pharmacy billing.

5.2.4 Device Controller

This element of the dispensing system provides an interface between the **control system** and the **dispensing device.** The controller will receive inputs from the computer terminal and convert them into command signals for the device to act on. The **dispensing device** will also send feedback signals to the **controller** that will be used to monitor the various actions performed by the device. Feedback will be used to i) identify the patient whose medication drawer is to be filled, ii) track location of drawers in the device, and iii) indicate delivery of medication to the drop area.

5.2.5 Software

Software will be provided to be run on a microcomputer. The following types of programs will be furnished :

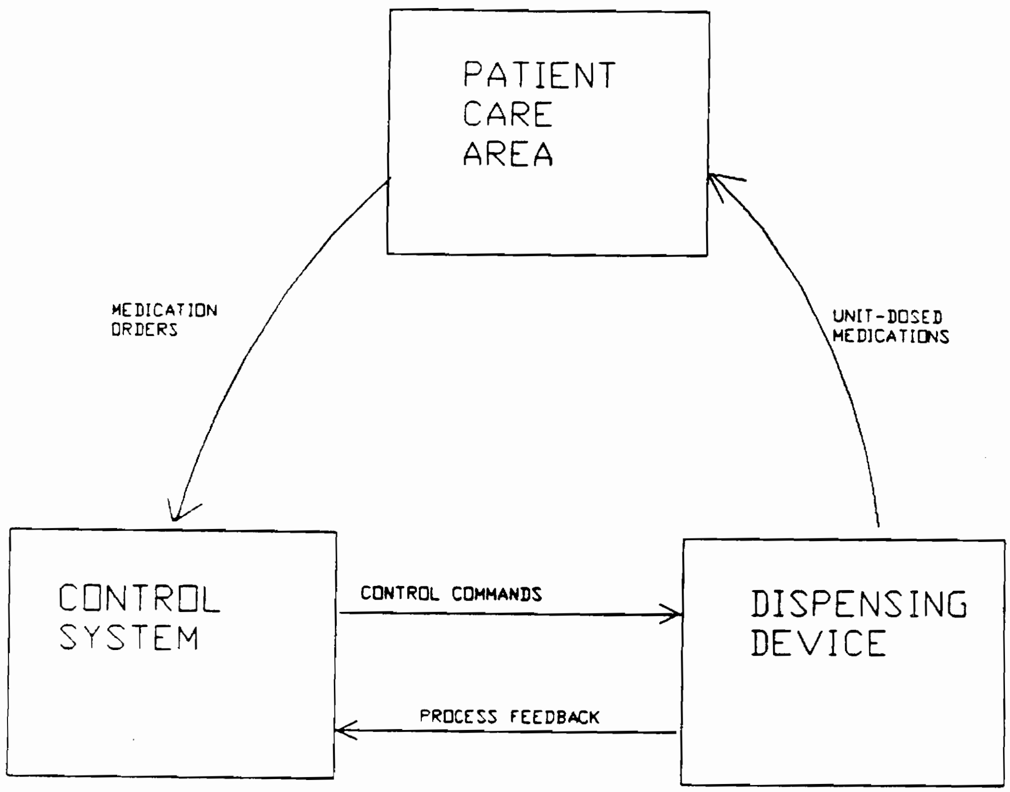
1) Test Run Software

2) Device controlling software.

3) Diagnostics programs.

4) Database retrieval software.

5) Report producing programs.



CONTROL COMMANDS

DISPENSE ITEMS
TEST SYSTEM
PROCESS COMMANDS

PROCESS FEEDBACK

PATIENT AND ORDER VERIFICATION
COUNT ITEMS DISPENSED
PROCESS INFORMATION

Fig. 22. Functional Packaging

6.0 ALLOCATION OF SYSTEM LEVEL REQUIREMENTS

The system configuration described in the previous section was derived from the functional analysis performed in section 4. In order to provide design teams with guidelines, it is necessary to allocate certain top level criteria to the two major subsystems, the **dispensing device** and the **control system**.

The following physical parameters will be used:

* Capacity for up to 80 different items (50 liquids and 30 injectables).
* Minimum volume of 1600 items (20 of each item) with the capability to add volume in multiples of 100.
* Space required for system equipment equals of 8'x10'x7'.
* Variable output rate of 6 to 12 items per minute.

These criteria should be used to ensure that the system and its components are designed to meet the physical requirements.

The following system effectiveness parameters will be used:

* Achieved availability of 92.3 %.
* Mean time between maintenance of approximately 24 hours.
* Mean active maintenance time (average) of approximately 2 hours.
* Mean time between failure of 2,948 hours.

Fig. 23 shows the establishment of subsystem and component effectiveness criteria. It is noted that at times it will be difficult to meet some of the criteria in a cost-effective manner, however these breakdowns should be used an initial baseline for design control.

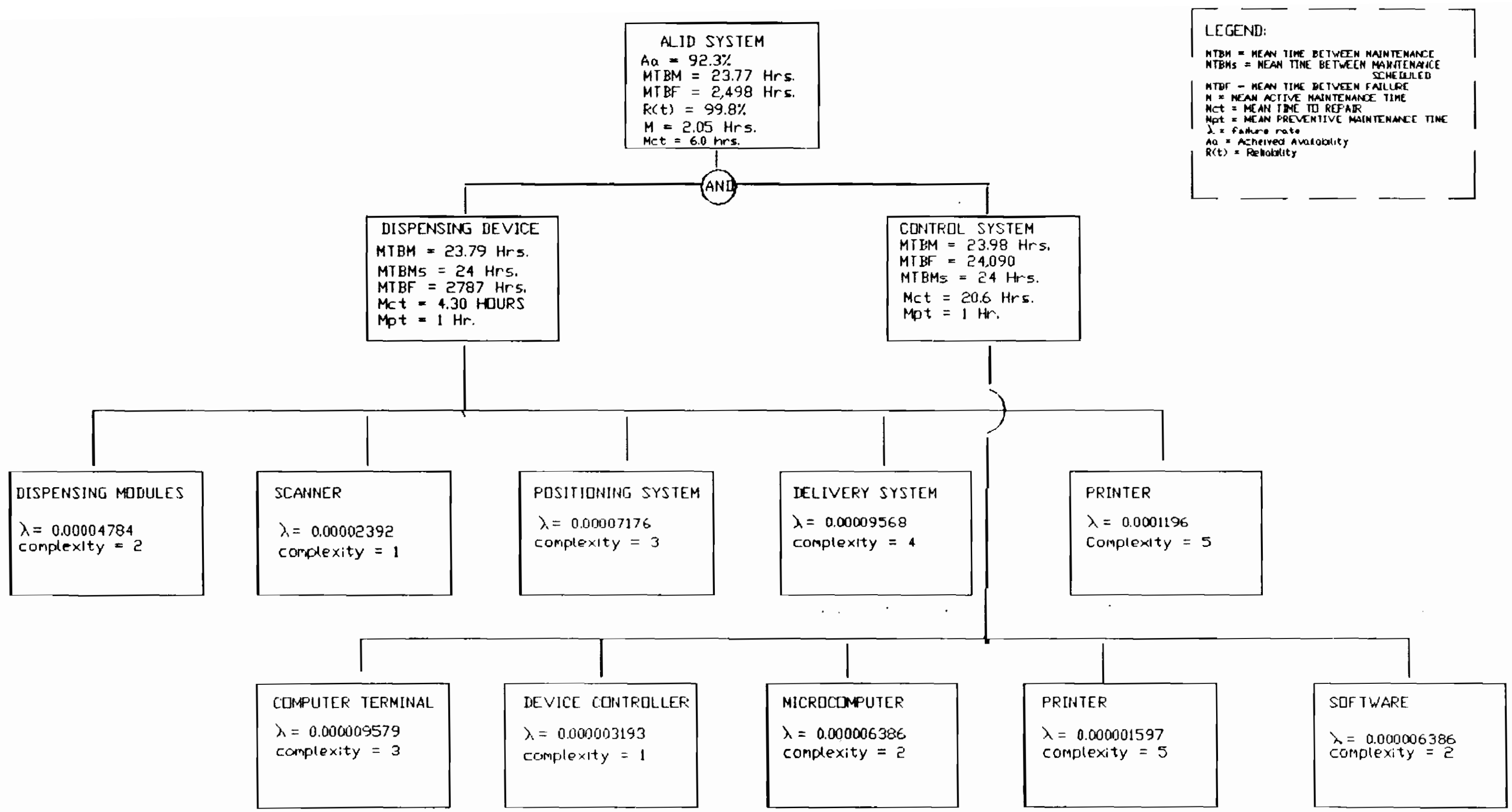


Fig. 23. Allocation of Effectiveness Requirements

6.1 Control Computer Storage Estimates

Computer storage requirements for ComPharm's APD System are used as a model for the estimation of storage requirements of the ALID System.

Patient Data Storage

Patient name	40 Bytes
Patient Age	3
Doctors name	40
Allergies	100
Room number	5
Identification number	5
Floor number	2
Admission date	6
* SUBTOTAL	201 Bytes

Patient Drug Information

National Drug Code	11	
Maximum Drugs Dispensed	5	
* Storage per Prescription SUBTOTAL		55
National Drug Code	11	
Item Count for billing period	2	
Drug types on bill (maximum)	20	

* Storage for billing	SUBTOTAL	260

Total storage per patient	516 bytes

Maximum number of patients = 300

Total Patient Storage Required	**154800 bytes**

Drug inventory and Pricing

National Drug Code	11 bytes
Quantity on Hand	4
Quantity in machine (0 if none)	3
Cost per item	3
Price per item	3
Reorder Quantity	4
Total Storage per drug	28

Maximum number of drugs = 1600

Total Inventory and Pricing Storage	**44800 bytes**

Program Storage Estimate	3000000
Operating System	250000

MASS STORAGE REQUIREMENT	**3,449,600 Bytes**

7.0 LIFE CYCLE COST ANALYSIS

For the purpose of conducting a life cycle cost analysis, the following scenario is assumed. In response to a need for improved efficiency in their hospital pharmacies, the Veterans Administration has decided to investigate two different automated dispensing systems. The ALID System dispenses liquids and injectable items automatically and is completely integrated with a computer-assisted order and review system (including drug interaction alerts). The ALID/APD System dispenses unit-dosed liquids and injectables and unit-dosed pills and is also completely integrated with a computer-assisted order and review system.

Based on the information to be provided, life cycle cost analyses will be performed for each of the proposed configurations to compute the savings generated by each system. Using the results, a preferred approach will be selected.

7.1 System Profiles

For the purpose of this analysis it is assumed that the Veterans Administration has decided to automate dispensing in 25 hospital pharmacies (each serves approximately 200 beds).

Table 1 provides a profile of systems in operation. Each system will be designed for an operational life of 5 years.

Table 1. Profile of System Use

PROGRAM YEAR	1	2	3	4	5	6	7	8	9
SYSTEMS IN USE	0	0	5	15	25	25	25	20	10

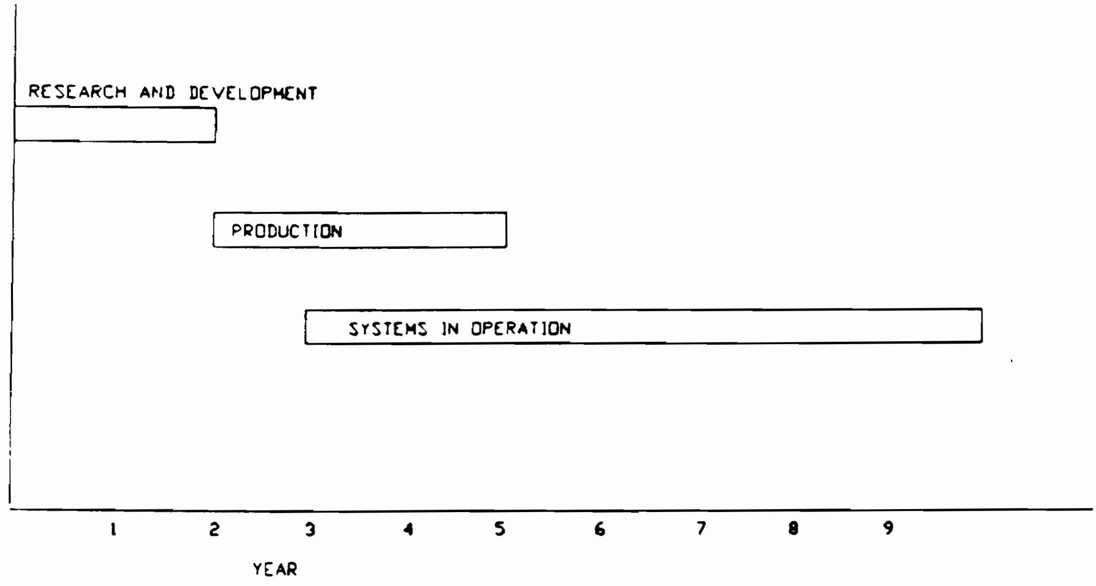


Fig. 23. Schedule of Major Activities

7.2 Reliability and Maintainability Factors

The predicted reliability and maintainability factors associated with each of the two candidate systems are given in the table below.

Table 2. Maintenance and Reliability Factors

Parameter	ALID System	ALID/APD System
System Level		
MTBM	23.77	23.74
MTBF	2,498.00	2,200.00
MTBMs	24.00	24.00
M	2.05	2.05
Mct	6.00	7.00
Dispensing Device		
MTBM	23.79	23.77
MTBF	2,787.00	2,455.00
MTBMs	24.00	24.00
Mct	4.30	5.13
Mpt	1.00	1.00
Control System		
MTBM	23.98	23.97
MTBF	24,090.00	21,216.00
MTBMs	24.00	24.00
Mct	20.00	22.00
Mpt	1.00	1.00

LEGEND: MTBM = Mean Time Between Maintenance
$MTBM_s$ = Mean Time Between Maintenance Scheduled
MTBF = Mean Time Between Failure
Mct = Mean Corrective Maintenance Time
Mpt = Mean Preventive Maintenance Time
M = Mean Active Maintenance Time

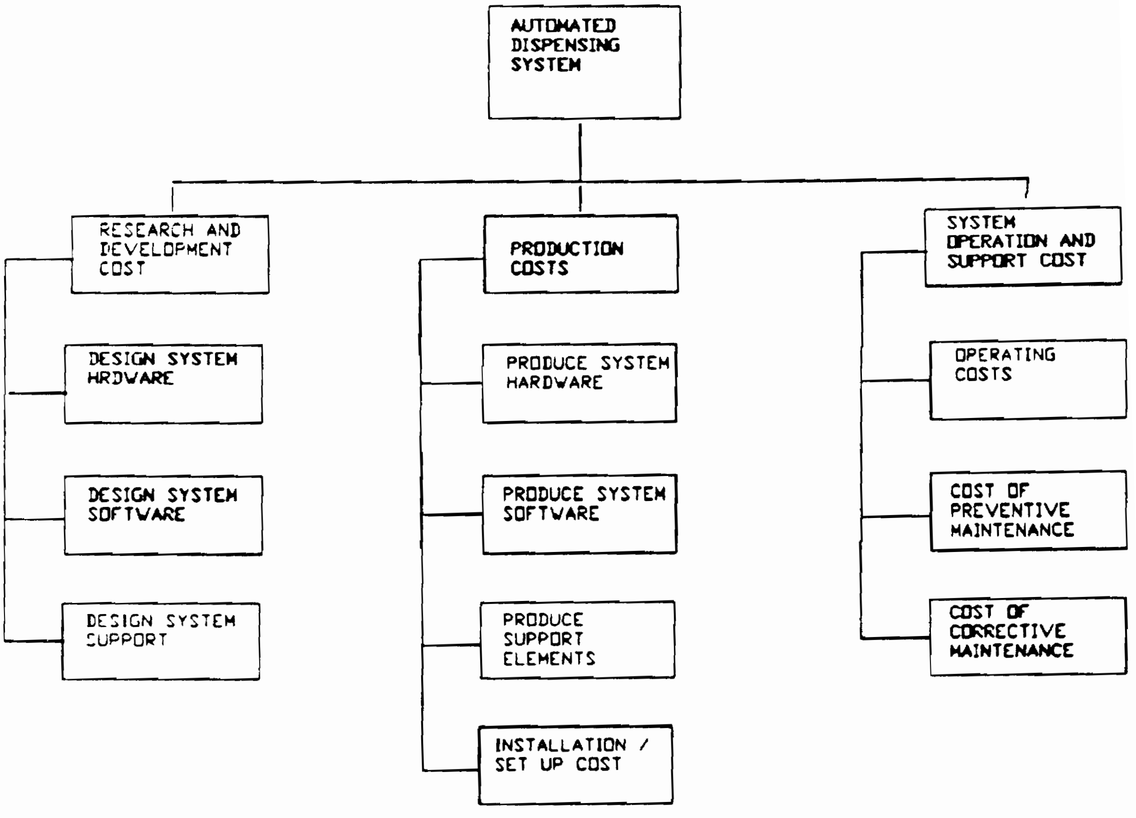


Fig. 24. Cost Categories

7.3 Research and Development Costs

Research and design work will be done in the first two years, and will include development, test and evaluation of prototype equipment. An assumed cost break down for design and development work is given in Table 3.

a. ALID System

It is assumed that the cost to design the ALID System hardware will be $60,000 ($40,000 in year 1, 20,000 in year 2). Software development will cost $15,000 ($10,000 in year 1, $5,000 in year 2). Design of support elements (maintenance and training programs) will cost $15,000 ($5,000 in year 1 and $10,000 in year 2). These costs are assumed to be non-recurring after year 2 and are comprised of management and engineering labor as well as material costs.

b. ALID/APD System

The design cost of combining the ALID System equipment with the APD System equipment will be $80,000 ($50,000 in the year 1, $30,000 in year 2). Software costs will be $12,000 in year 1 and $6,000 in year 2. Design of support elements will cost $7,000 in year 1 and $14,000 in year 2. These figures assume that the APD System has already been designed and need only be modified to work in union with the ALID System.

Research and development expenses constitute management and engineering labor and material costs.

7.4 Production Costs

The required number of operational dispensing systems will be produced, delivered and installed in the year prior to the need (i.e. 5 systems are produced in year 2, 10 systems in year 3, and 10 systems in year 4).

a. ALID System

The assumed cost to the Veterans Administration to produce system hardware and software will be $ 50,000 per unit. Production of support elements such as spare parts supplies and training programs will cost $20,000 in year 2, $15,000 in year 3 and $5,000 in year 4. Installation and set up will cost $5,000 per system[5].

b. ALID/APD System

The assumed production cost for ALID/APD System equipment will be $90,000 per unit. Production of support elements will cost

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[5]Assumes that adequate space is available for system equipment and that computer assisted dispensing is already in place.

$30,000 in year two, $15,000 in year 3, and $15,000 in year 4. Installation and set up will cost $9,000 per system.

Table 3. Research and Development Cost summary

	PROGRAM YEAR		
	1	2	TOTAL ($)
ALID SYSTEM			
DESIGN SYSTEM HARDWARE	40000	20000	60000
DESIGN SYSTEM SOFTWARE	10000	5000	15000
DESIGN SUPPORT ELEMENTS	5000	10000	15000
TOTALS ($)	55000	35000	90000
ALID/APD SYSTEM			
DESIGN SYSTEM HARDWARE	60000	30000	90000
DESIGN SYSTEM SOFTWARE	12000	6000	18000
DESIGN SUPPORT ELEMENTS	7000	14000	21000
TOTALS ($)	79000	50000	129000

Table 4. Production Cost Summary

	PROGRAM YEAR				
	1	2	3	4	TOTAL($)
ALID SYSTEM					
PRODUCE SYSTEM	0	250000	500000	500000	1250000
PRODUCE SUPPORT	0	20000	15000	5000	40000
INSTALLATION / SET UP	0	25000	50000	50000	125000
TOTALS ($)	0	295000	565000	555000	1415000
ALID/APD SYSTEM	0	450000	900000	900000	2250000
PRODUCE SYSTEM	0	450000	900000	900000	2250000
PRODUCE SUPPORT	0	30000	15000	10000	55000
INSTALLATION / SET UP	0	45000	90000	90000	225000
TOTALS ($)	0	525000	1005000	1000000	2530000

7.5 System Operation and Maintenance Costs

Each dispensing system will be on line for a maximum of 22 hours a day for 365 days a year. Based on this information, the system profile (Table 1), and reliability and maintenance factors (Table 2) we compute the number of hours of operation per year, the number of corrective maintenance acts per year, and the number of preventive maintenance acts per year (Table 5).

Hours of operation = (number of systems)(365)(22)

Corrective Maintenance Acts = Operation Hours / MTBF

Preventive Maintenance Acts = Operation Hours / $MTBM_s$

Table 5. System Operation and Maintenance Acts

	PROGRAM YEAR								
	1	2	3	4	5	6	7	8	9
SYSTEMS IN USE	0	0	5	15	25	25	25	20	10
MAXIMUM OPERATING HOURS	0	0	40150	120450	200750	200750	200750	160600	80300
CORRECTIVE MAINTENANCE ACTS									
ALID SYSTEM	0	0	16	48	80	80	80	64	32
ALID/APD SYSTEM	0	0	18	55	91	91	91	73	37
PREVENTIVE MAINTENANCE									
ALID SYSTEM	0	0	1825	5475	9125	9125	9125	7300	3650
ALID/APD SYSTEM	0	0	1825	5475	9125	9125	9125	7300	3650

7.5.1 Operation Costs

As seen in the system profile, the first five systems will be fielded by year number three. At this point we can begin to compare operating costs of manual dispensing to the proposed automated systems. Table 6 gives a summary of the operating costs (labor) for manual dispensing, dispensing using ALID Systems, and dispensing using the ALID/APD Systems. The staffing requirements are estimated based on present staffing costs of a hospital pharmacy that serves 200 beds a day..

a. Manual Dispensing - Staffing Requirements

The following daily dispensing costs are assumed. A technician is paid $ 9 per hour and a registered pharmacist makes $ 18 per hour.

* 4 Technicians from 8 AM to 4 PM = $ 288
* 2 Registered Pharmacists(RPh), from 8 AM to 4 PM = $ 288
* 2 technicians from 4 PM to 12 PM = $ 144
* 1 RPh from 4 PM to 12 AM = $ 144
* 2 technicians from 12 AM to 8 AM = $ 144
* 1 RPh from 12 AM to 8 AM = $ 144
* **Total labor cost for manual dispensing = $ 1152 / day**

b. Dispensing Using ALID System - Staffing Requirements

The following costs for daily dispensing assisted by the ALID System are assumed using technicians paid at $9 per hour and registered pharmacists paid $18 per hour.

* 3 technicians from 8 AM to 4 PM	= $ 216
* 2 RPh from 8 AM to 4 PM	= $ 288
* 2 technicians from 4 PM to 12 AM	= $ 144
* 1 technician from 4 PM to 10 PM[6]	= $ 54
* 1 RPh from 4 PM to 12 AM	= $ 144
* 1 technician from 12 AM to 8 AM	= $ 72
* 1 RPh from 12 AM to 8 AM	= $ 144
*** Total staffing cost using ALID System**	**= $ 1062 / day**

c. Dispensing Using ALID/APD System -Staffing Requirements

The following staffing costs are calculated for a hospital pharmacy serving approximately 200 beds using the ALID/APD System. Pharmacy technicians will cost $ 9 per hour and a registered pharmacist costs $ 18 per hour.

* 2 technicians from 8 AM to 4 PM	= $ 144
* 2 RPh from 8 AM to 4 PM	= $ 288
* 1 technician from 9 AM to 1 PM	= $ 36

[6] This technician will be allocated to preventive maintenance from 10 PM to 12 AM.

* 1 technician from 4 PM to 10 PM	= $ 54
* 2 Technicians from 4 PM to 12 AM	= $ 144
* 1 RPh from 4 PM to 12 AM	= $ 144
* 1 technician from 12 AM to 8 AM	= $ 72
* 1 RPh from 12 AM to 8 AM	= $ 144
*** Total staffing cost using ALID/APD System**	**= $ 1026 / day**

Table 6. Staffing Costs

	PROGRAM YEAR							
	3	4	5	6	7	8	9	TOTAL ($)
MANUAL SYSTEM								
TECHNICIANS	1051200	3153600	5256000	5256000	5256000	420480	2102400	26280000
PHARMACISTS	1051200	3153600	5256000	5256000	5256000	420480	2102400	26280000
TOTALS ($)	2102400	6307200	10512000	10512000	10512000	8409600	4204800	52560000
ALID SYSTEM								
ALID OPERATOR	328500	985500	1642500	1642500	1642500	1314000	657000	8212500
MANUAL TECHNICIANS	558450	1675350	2792250	2792250	2792250	2233800	1116900	13961250
PHARMACISTS	1051200	3153600	5256000	5256000	5256000	420480	2102400	26280000
TOTALS ($)	1938150	5814450	9690750	9690750	9690750	7752600	3876300	48453750
ALID/APD SYSTEM								
ALID/APD OPERATOR	328500	985500	1642500	1642500	1642500	1314000	657000	8212500
MANUAL TECHNICIAN	492750	1478250	2463750	2463750	2463750	1971000	985500	12318750
PHARMACISTS	1051200	3153600	5256000	5256000	5256000	420480	2102400	26280000
TOTALS ($)	1872450	5617350	9362250	9362250	9362250	7489800	3744900	46811250

7.5.2 Maintenance Cost

In both the ALID System and the APD system there will be 2 hours down time each day for preventive maintenance acts (restocking the systems, and running pre-operation checks). The ALID System will require one technician for the two hours of preventive maintenance at a cost of $18 per day. The ALID/APD System will require one technician for 1 hour to reload the dispensing devices and one technician for 1 hour to perform system checks. Total cost of preventive maintenance for the ALID/APD System will be $ 18 per day.

For the purpose of this analysis we will assume that each corrective maintenance action requires one repair technician at $ 35 per hour for the full mean corrective maintenance time (6 hours for the ALID System, 7 hours for the ALID/APD System). We also assume a $ 200 material cost and a $ 25 maintenance report cost for each corrective maintenance act. Decentralized dispensing will be used in case of system failure. One additional pharmacist ($18 per hour) and one additional technician ($ 9 per hour) will be required needed to assist in dispensing while the system is being repaired.

Table 7. Preventive Maintenance Cost Summary

	PROGRAM YEAR							
	3	4	5	6	7	8	9	TOTALS ($)
ALID SYSTEM								
RESTOCKING	16425	49275	82125	82125	82125	65700	32850	410625
SYSTEM CHECKS	16425	49275	82125	82125	82125	65700	32850	410625
TOTALS ($)	32850	98549	164250	164250	164250	131400	65700	821250
ALID/APD SYSTEM								
RESTOCKING	20531	61594	102656	102656	102656	82125	41063	513281
SYSTEM CHECKS	16425	49275	82125	82125	82125	65700	32850	410625
TOTALS ($)	36956	110868	184781	184781	184781	147825	73912	923906

Table 8. Corrective Maintenance Cost

	PROGRAM YEAR							
	3	4	5	6	7	8	9	TOTALS ($)
ALID SYSTEM								
LABOR	3360	10080	16800	16800	16800	13440	6720	84000
MAINTENANCE REPORTS	400	1200	2000	2000	2000	1600	800	10000
EXTRA PERSONNEL	2592	7776	12960	12960	12960	10368	5184	64800
MATERIALS	3200	9600	16000	16000	16000	12800	6400	80000
TOTALS ($)	9552	28656	47760	47760	47760	38208	19104	238800
ALID/APD SYSTEM								
LABOR	4410	134750	22295	22295	22295	17885	9065	111720
MAINTENANCE REPORTS	450	1375	2275	2275	2275	1825	925	11400
EXTRA PERSONNEL	4536	13608	22680	22680	22680	18144	9072	113400
MATERIALS	3600	11000	18200	18200	18200	14600	7400	91200
TOTALS ($)	12996	39458	65450	65450	65450	52454	26462	327720

Table 9. Life Cycle Cost Summary

	PROGRAM YEAR									
	1	2	3	4	5	6	7	8	9	TOTAL ($)
ALID SYSTEM										
1. RESEARCH AND DEVELOPMENT										
A. DESIGN SYSTEM HARDWARE	40000	20000								60000
B. DESIGN SYSTEM SOFTWARE	10000	5000								15000
C. DESIGN SUPPORT ELEMENTS	5000	10000								15000
2. PRODUCTION										
A. PRODUCE SYSTEM EQUIPMENT		250000	500000	500000						1250000
B. PRODUCE SUPPORT		20000	15000	5000						40000
C. INSTALLATION		25000	50000	50000						125000
3. OPERATION AND MAINTENANCE										
A. OPERATION COST			1938150	5814450	9690750	9690750	9690750	7752600	3876300	48453750
B. MAINTENANCE COST			42402	127206	212010	212010	212010	169608	84804	1017640
TOTAL ($)	55000	330000	2545552	6496656	9902760	9902760	9902760	7922208	3961104	50976390
DISCOUNTED TOTAL (I = 15%)	47826	249527	1673742	3714484	4923422	4281236	3722814	2589784	1125993	22320829
ALID/APD SYSTEM										
1. RESEARCH AND DEVELOPMENT										
A. DESIGN SYSTEM HARDWARE	50000	30000								80000
B. DESIGN SYSTEM SOFTWARE	12000	6000								18000
C. DESIGN SUPPORT	7000	14000								21000
2. PRODUCTION										
A. PRODUCE SYSTEM		450000	900000	900000						2250000
B. PRODUCE SUPPORT		30000	15000	15000						60000
C. INSTALLATION		45000	90000	90000						225000
3. OPERATION AND MAINTENANCE										
A. OPERATION COST			1872450	5617350	9362250	9362250	9362250	7489800	3744900	46811250
B. MAINTENANCE COST			49952	149856	249760	249760	249760	199808	99904	1098944
TOTALS ($)	69000	575000	2927402	6772206	9612010	9612010	9612010	7689608	3844804	50543194
DISCOUNTED COST (I = 15%)	60000	434782	1924814	3872031	4778868	4155537	3613511	2513746	1092933	21353290

7.6 Economic Analysis

The problem presented here is to select the most favorable approach to pharmacy dispensing. To simplify the problem, we will evaluate the cost effectiveness of one ALID System used in a hospital pharmacy versus one ALID/APD System used in a hospital pharmacy.

Using data from the previous section, the Initial Cost (IC) to a pharmacy installing one ALID System is calculated to be $ 60,200. The Initial Cost (IC) to a pharmacy installing one ALID/APD System is calculated to be $106,360.

The Net Annual Savings (NAS) generated by one system can be calculated in the following manner:

$NAS = (OC_m - OC_{sys})(365)$

NAS = Net Annual Savings,

OC_s = Daily Operating Cost of Manual Pharmacy,

OC_{sys} = Daily Operating Cost of Pharmacy Using New System

For a pharmacy using the ALID System,

NAS = ($1,152 - $1,085)(365) = $24,555

For a pharmacy using the ALID/APD System,

NAS = ($1,152 - $1,053)(365) = $36,135

The criteria we will use to judge the cost effectiveness of the ALID and the ALID/APD Systems are ;

1) payback evaluation

2) present-worth evaluation

7.6.1 Payback Evaluation

Each system under consideration has an assumed operating life of 5 years. It is desired that the system purchased will pay back the initial investment in savings within those 5 years. To determine the payback period the following formula is used:

n = IC / NAS

where n = number of years

IC = Initial Cost

For the ALID System,

n = $ 60,200 / $24,455 per year

= 2.5 years or 2 years and 6 months

For the ALID/APD System,

n = $ 106,360 / $36,135 per year

= 2.9 years or 2 years and 11 months

In order to include consideration for the time value of money in measuring the payback period, the discounted payback method is used. The system will have paid for itself when the discounted amount of savings generated is equal to the initial cost.

$$IC = NAS\ (P/A,i,n)$$

$(P/A,i,n)$ is the equal-payment-series-present worth factor

$$(P/A,i,n) = [(1+i)^n-1] / i(1+i)^n$$

i = time value of money

n = number of years

Using this formula and numerical iteration, the payback periods are calculated over a range of interest rates for the ALID System and ALID/APD System, Table 10.

Table 10. Payback Analysis

INTEREST RATE	PAYBACK (YRS)	
	ALID	ALID/APD
0.01	2.51	3.01
0.02	2.55	3.07
0.03	2.60	3.13
0.04	2.65	3.20
0.05	2.70	3.27
0.06	2.75	3.34
0.07	2.80	3.42
0.08	2.85	3.49
0.09	2.91	3.58
0.10	2.97	3.36
0.11	3.03	3.75
0.12	3.09	3.85
0.13	3.16	3.95
0.14	3.23	4.06
0.15	3.30	4.17
0.16	3.38	4.29
0.17	3.46	4.42
0.18	3.54	4.56
0.19	3.63	4.71
0.20	3.72	4.88

7.6.2 Present Worth Evaluation

The present worth method converts future cash flows into the equivalent present value using a desired interest rate. The interest rate used is the rate of return expected on the initial investment. In this case, it is assumed that the Veterans Administration expects a rate of return of 15% on any investment made to automate pharmacy dispensing. The following formula will be used to evaluate the present worth of both the ALID System and the ALID/APD System.

$$PW = - IC + NAS\ (P/A, 15\%, 5)$$

where (P/A,15%,5) = the equal-payment-series present worth factor for savings generated at a 15% rate for 5 years,

$$(P/A, 15\%, 5) = [(1.15)^5 - 1] / 0.15(1.15)^5 = 3.3522$$

For the ALID System,

$$PW = - 60,200 + 24,455\ (P/A, 15\%, 5) = \$\ 21,778$$

For the ALID/APD System,

$$PW = - 106,360 + 36,135\ (P/A, 15\%, 5) = \$\ 14,771$$

Since the present worth of each system is positive, we conclude that both systems offer the required rate of return. It appears that the ALID System will offer a better return over 5 years.

7.6.3 Evaluation of Alternatives

Both the ALID System and the ALID/APD System pay back their initial costs within their estimated life spans. For a life span of 5 years, the ALID System offers a better return. Since we know, that the ALID/APD System offers better annual savings at a higher initial investment, it might be of interest to see how long it will take before it offers a superior return. To do this we equate present worth values of each system, leaving the number of years unknown.

$$PW_{ALID} = PW_{ALID/APD}$$

$$-60,200 + 24455(P/A,15\%,n) = -106,360 + 36,135(P/A,15\%,n)$$

$$11,580(P/A,15\%,n) = 46,160$$

$$(P/A,15\%,n) = 3.952$$

This present value factor exists for a discount rate of 15% between years 6 and 7. By interpolation we can figure the life span required to make the present worth of the ALID/APD System equal to the present worth of the ALID System.

$$(P/A,15\%,6) = [(1.15)^6 - 1] / 0.15(1.15^6) = 3.7845$$

$$(P/A,15\%,7) = [(1.15)^7 - 1] / 0.15(1.15)^7 = 4.1604$$

$$(P/A,15\%,n) = 0.3759n + 1.5291$$

$3.952 = 0.3759n + 1.5291$

n = 6.444 years or approximately 6 years and 5 months

If the life span of the ALID/APD system can be increased to 7 years without a major change in acquisition cost or effectiveness parameters, it would become the preferred alternative based on its present worth.

It is also of importance to know at what rate of return does the ALID/APD system become a better option. To find this value the present worth of both alternatives are set equal, leaving the interest rate, i, unknown.

$-60,200 + 24,455(P/A,i,5) = -106,360 + 36,135(P/A,i,5)$

$(P/A,i,5) = 3.9521$

This present value factor exists an interest rate between i = 8% and i = 9%. By interpolation we can figure the interest rate at which both systems have an equal present worth.

$(P/A,8\%,5) = [(1.08)^5 - 1] / 0.08(1.08)^5 = 3.9927$

$(P/A,9\%,5) = [(1.09)^5 - 1] / 0.09(1.09)^5 = 3.8897$

$(P/A,i,5) = -0.1030 + 4.8167$

$3.9521 = -0.1030i + 4.8167$

i = 0.0839 or 8.39%

For interest rates below 8.39%, the ALID/APD System has a higher present worth than the ALID System. At rates above 8.39%, the ALID System is the preferred option. Table 11 shows the present values of the ALID and ALID/APD Systems over a range of interest rates.

Table 11. Present Worth Analysis

INTEREST RATE	ALID PW ($)	ALID/APD PW ($)
0.01	58491	69019
0.02	55068	63961
0.03	51797	59128
0.04	48669	54506
0.05	45677	50085
0.06	42813	45854
0.07	40070	41801
0.08	37442	37917
0.09	34921	34193
0.10	32504	30600
0.11	30183	27191
0.12	27955	23899
0.13	25814	20735
0.14	23756	17694
0.15	21777	14770
0.16	19873	11957
0.17	18040	9248
0.18	16275	6640
0.19	14574	4128
0.20	12935	1706

8.0 PLAN FOR IMPLEMENTATION

As stated previously, this report is intended to expand the conceptual design into a document that can be used as a plan for the evolution of a fully integrated automated dispensing system. If this plan is to be carried out, the next step would be to obtain the funding needed to thoroughly develop the ALID System concept and to perform the necessary design and integration work. If funding is secured, a preliminary design will be completed, establishing a preferred system configuration. Preliminary design will be followed by detail system design and production of a prototype. A test and evaluation plan will be developed and used to ensure that system requirements are met before full scale production is implemented.

8.1 Design and Build System

As stated in the initial requirements, the design of the ALID System should be accomplished using "off the shelf technology". The design work would be carried out by a design and build contractor under the management of ComPharm Systems. The contractor will be directed to research available technology and select the most cost-effective means of meeting system requirements. Specific vendors will be selected to supply system components and spare/repair parts based on the quality and cost of components, business reputations, and general ability to meet system component requirements.

The design and build contractor will be responsible for preliminary and detail design of the system, production of system operating and maintenance manuals, and assembly and testing of a system prototype. Figure 25 shows the consumer-producer-supplier relationship that should exist for control of the producer's (ComPharm Systems) activities with component suppliers and for overall administration of system acquisition.

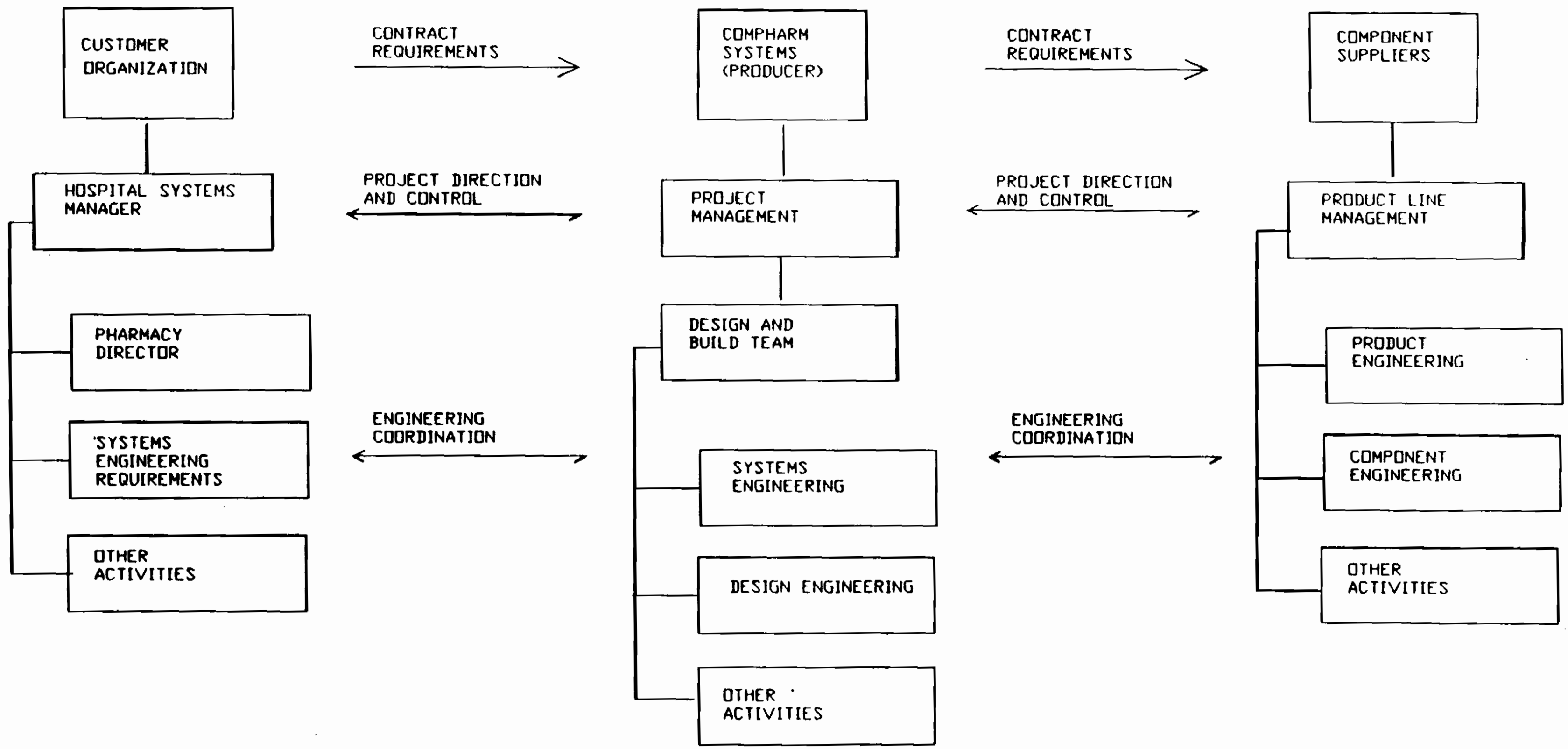


Fig. 26. Consumer-Producer-Supplier Relationships

8.2 System Test and Evaluation

A system test and evaluation plan should be drawn up as a guide to analyzing system performance and identifying areas where corrective action should be taken. Such a plan should

1. Define and schedule test requirements.
2. Define organization and control responsibilities.
3. Define test conditions and logistics resource requirements.
4. Describe formal testing.
5. Establish conditions for a retest.
6. Establish methods of reporting test results.

(Blanchard, Fabrycky 301)

Testing will be done on i) engineering models of components early in detail design, ii) prototype models, and iii) field models. Figure 27. shows a plan for test and evaluation.

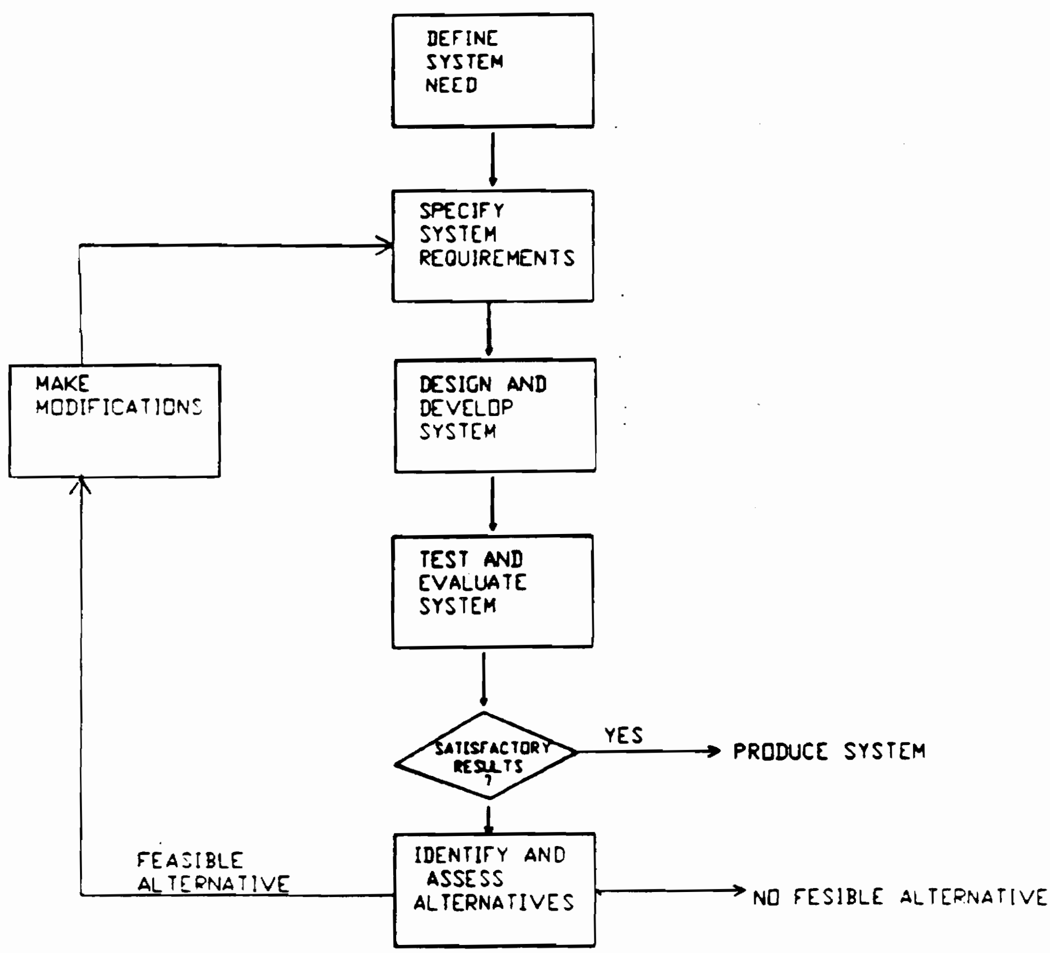


Fig. 27. Test and Evaluation flow

8.2.1 Engineering Models

During the early phases of detail design, models of system components will be built and tested to verify performance and physical characteristics. Elements of the system to be tested should include dispensing modules, positioning systems, delivery systems, and control systems. This is the phase of testing where changes in the detail design can be effected with the least cost.

8.2.2 Prototype Testing

Towards the end of detail design prototype dispensing equipment will be produced to be tested at the design contractor's facility. The prototype system will be tested to verify performance, reliability, and maintainability characteristics. Specific parameters that will be measured are dispensing speed, failure rates, and mean preventive and corrective maintenance times. Verification of personnel requirements will be accomplished. Operating and maintenance procedures (operating and maintenance manuals) will also be evaluated at this stage of testing.

8.2.3 Field Testing

Six months after in-house prototype testing is started a field site should be established for evaluation of a prototype system under more realistic conditions. The system should be tested in the field for a minimum of 12 months. At this stage, compatibility of prime equipment with logistics support is evaluated. Specific values to be measured are turnaround times on repair of modules, logistics transportation times, personnel effectiveness factors, operational availability, and dependability. This will be the first time that all system equipment will be operated on an integrated basis (Blanchard, Fabrycky 306-307).

8.3 Corrective Actions

System modifications that are determined necessary as a result of test and evaluation will be handled through a formalized engineering change procedure. The change procedure must take into account that a change in one element of the system is most likely going to affect other elements of the system. The feasibility of a system modification will depend on the extensiveness of the change, the impact on ability of the system to accomplish its primary mission, the time in the life cycle when the change can be incorporated, and the cost of making the change (Blanchard, Fabrycky 317).

9.0 CONCLUSIONS

As previously stated, the extent of this project and report is to address the shortcomings in manual dispensing of unit-dosed medications in a hospital pharmacy. Manual dispensing of unit-doses is imperfect in many ways. Specific tasks such as picking doses off shelves and placing them in patient medication drawers are labor intensive and wearisome to the technicians who perform such work. Manual unit-dose dispensing is also a time intensive task. In a hospital pharmacy serving a daily census of roughly 200 beds, cart-fill operations require four technicians (dose picking and delivery) and two pharmacists (supervision, inspection, and correction) for three to four hours a day.

This report concludes that the best way to answer the problems of inefficiency in manual dispensing is automation of the picking and counting of unit-dosed liquid and injectable medications. Automation can reduce the number of errors and decrease the time required for cart-fill operations. This conclusion was reached after conversations with hospital pharmacists, observation of manual cart-fill operations, and in-depth study of hospital pharmacy operating procedures.

Many hospital pharmacies already have computer-assisted ordering and order review , and technology is available to make automated pill dispensing a viable option. Integration of a system such as the Automated Liquid and Injectable Dispensing (ALID) System with other facets of a modern hospital pharmacy offers the greatest opportunity for improvement in speed, accuracy and overall efficiency in unit-dose dispensing.

Time limitations forced some assumptions in this report. In the life cycle cost analysis, the research and development costs and the production costs used are rough estimates based upon costs of developing and producing ComPharm's Automated Pill Dispenser. Also the allocation of system effectiveness parameters in Section 6.0 was done as example of how requirements allocation is performed. The parameters obtained there may be unreachable.

An area of merit in this project is the specification of system requirements in section 3.0. The guidelines established help to break down the statement of need into what needs to be done in order to automate dispensing of liquids and injectables. These parameters were established after careful study of dispensing in hospital pharmacies.

The functional analysis performed in section 4.0 further decomposes the statement of need and the requirements specification into a step-by-step analysis of how automated dispensing would be done. The functional analysis leads to the establishment of a system configuration in section 5.0. The system configuration identifies the major subsystems and components of the ALID System.

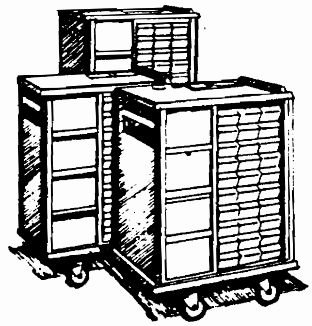
Technology is available to develop the ALID System, and this report offers a guideline for such development. The next step would be a careful study of the procurable technologies to determine the most cost-effective configuration. It is highly recommended that any automated dispensing capability be integrated with computer-assisted order review, computer-assisted inventory, and computer-assisted billing. It is hoped that this report will spur further investigation into automated dispensing in an effort to reduce costs and increase the efficiency of modern hospital pharmacies.

Appendix A

Pharmacy Systems

Lionville® Products

for optimum medication management on the nursing unit



Medication Carts for acute care units.

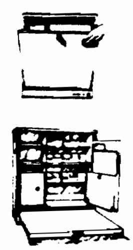
Innovative carts designed to save nurses time by streamlining med rounds. Four distinctive styles with a complete line of accessories are available to adapt to the requirements of each nursing situation.

Medication Carts for extended care.

Modular ECF carts with the capacity required to support one to thirty day distribution systems (punch card, Rx box, individual drawers). Modular carts convert from one system to another when the need arises.

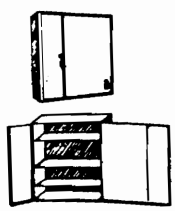
Primary Care Cabinets for patient rooms.

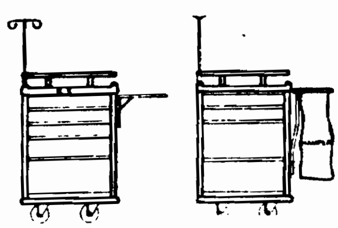
Secure cabinets provide storage space for medications and charting records in the most convenient location for the primary care nurse - the patient's room. Adequate space for two or four patient's meds in each cabinet. Custom designs available.



CS Lockers for controlled drugs.

For maximum drug protection, steel CS Lockers feature double-walled, overlapping doors with tamper resistant piano hinges and snap-close Best locks. Ample storage space inside for floor stock "narcotic" supplies.





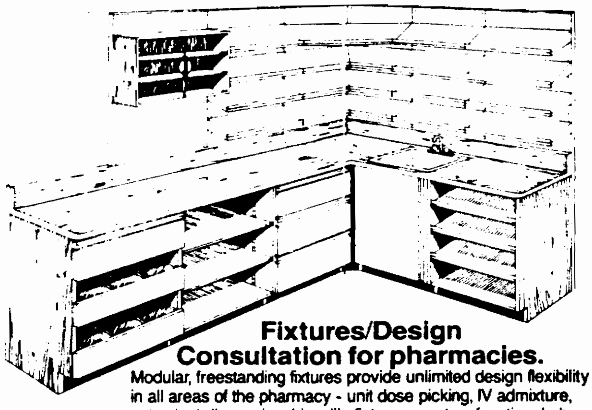
QC 90 Specialty Carts for emergency, etc.

Multipurpose cart/accessory packages developed for a variety of applications - emergency, isolation, treatment, anesthesia. Economically priced, QC 90 carts merit consideration wherever there's a need for mobile storage.

Lionville Systems, Inc.
311 COMMERCE DRIVE
EXTON, PENNSYLVANIA 19341
800/523-7114 (in PA 215/363-9100)

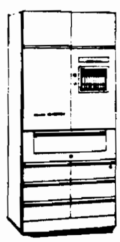
Lionville Products

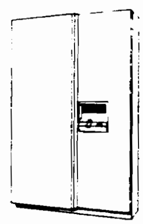
for optimum medication management by the pharmacy



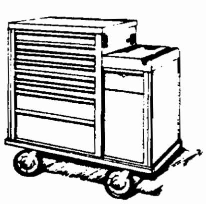
Fixtures/Design Consultation for pharmacies.
Modular, freestanding fixtures provide unlimited design flexibility in all areas of the pharmacy - unit dose picking, IV admixture, outpatient dispensing. Lionville fixtures create a functional pharmacy environment with style.

CD Module for OR controlled drugs.
A computerized issuing system for controlled substances required by anesthesia personnel. Easy, "user friendly" operation provides automatic monitoring and detailed record-keeping of drug withdrawals 24 hours a day.



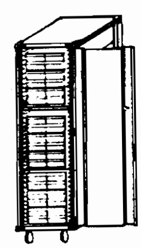


DocuMed® Night Cabinet for after-hours.
A patented system to control and organize medications required when pharmacy is closed. It documents who, when and what - DocuMed®, the only night cabinet with built-in memory.



DP-1000 Carts for decentralized unit dose.
A mobile pharmacy on wheels developed exclusively to support the decentralized pharmacist. With a wide variety of drawer combinations, the unique, bi-level DP-1000 has capacity for a formulary of 400 to 500 different drugs.

Transfer Carts to transport materials.
Selection includes a fully enclosed cart with front and back doors for secure storage/transport of unit dose cassettes, or, open shelf carts in a wide variety of styles and configurations.



Packaging Systems for unit dose.
Choice of heat sealed or pressure-sensitive equipment and materials for preparing individual blister packs and 30 day punch cards. Ideal systems for any low volume packaging operation.

Lionville Systems draws upon 30 years of experience in developing cost effective equipment that enhances efficiency and performance.

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Lionville®

DRUGSEAL PACKAGING PRESS

DESCRIPTION

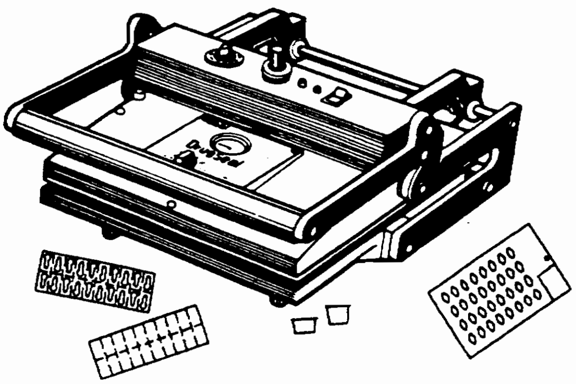
The DrugSeal press is a table-top, manually operated, heat press that utilizes even heat and pressure to seal medication doses. The DrugSeal develops 860 pounds of pressure on its 18½" x 15½" platen. A heavy duty thermostat and heating element will provide consistent and professional results.

APPLICATION

The Lionville DrugSeal press is a high quality unit designed to heat seal medication blisters. The DrugSeal is capable of sealing four-20 dose keyhole blister packages (80 doses), or four-32 dose punch cards, per operation. Optional tooling is available to seal six-30 or 45 ml liquid aluminum cups. All packaging materials are available from Lionville.

FEATURES/BENEFITS

- Heavy-Duty Thermostat: High-quality, snap-action thermostat for accuracy and reliability.
- Extended High Temperature Range: Control adjusts from 150-400°F (66-205°C) to cover a wide range of operating temperatures.
- Extra Wide Opening: Opens a full 10" (25.4cm) to provide easy access, even to the rear of the press.
- Non-Stick Surface: Platen is specially treated to help keep adhesives from sticking.
- Fast Operation: Commercial quality heater quickly brings the platen to uniform temperature.
- Temperature Readout: DrugSeal comes with a direct temperature readout for precise control.
- Minute Timer: Manually resettable 60-second timer with bell signal for timing operation.
- Rugged Construction: Steel cantilevers increase durability and allow maximum pressure on work within the press. Top and base of press are made of metal for added ruggedness.
- Warranty: The DrugSeal is guaranteed against any defects or inoperative parts, excluding the pad, for six months. The Drug Seal's thermostat and heater element is guaranteed a full twenty four months.
- Typical sealing temperature/time ·
  —Keyhole Blisters–250°, 5 seconds
  —Punch Cards–250°, 7-10 seconds
  —Liquid Cups–250°, 5-7 seconds



SPECIFICATIONS

Catalog Numbers:
#8388 B (keyhole); #8388 P (punch card)
—both with tooling
#7413-B Liquid Cup tooling (optional)

Work Area:
18½" x 15½" (47 cm x 39.4 cm)

Dimensions:
19" W x 23" D x 11" H (48 cm x 58 cm x 28 cm)
20" (51 cm) high in open position

Shipping Weight:
58 lbs.

Power Requirements:
120V AC, 50-60 Hz, 12.5 amps
Europe—Transformer required for 220V DC, 50 Hz

Power Consumption:
1500 watts

Lionville Systems, Inc.®

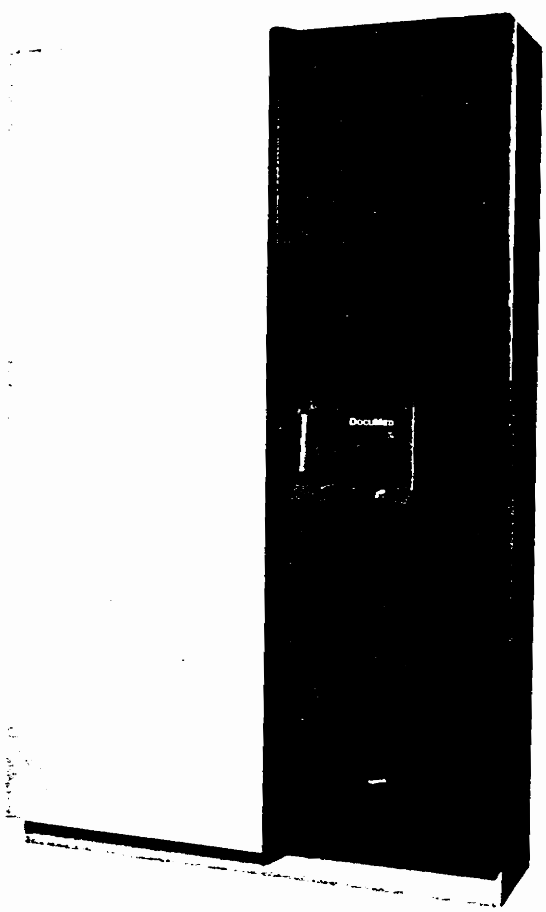
311 Commerce Drive, Exton, PA 19341 USA
1-800-523-7114 (in PA 215-363-9100); FAX 215-524-7934

Printed in USA 1/89
Rev. 10/90

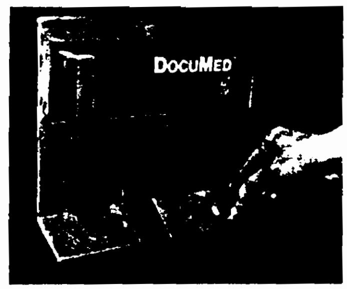
How DocuMed® meets the need for pharmacy control after hours

"...drugs should be kept in a separate cabinet, closet or other designated area and shall be properly labeled. A record of such withdrawals shall be made by the authorized individual removing such drugs and shall be verified by the pharmacist."

Standard IV
JCAH Accreditation Manual



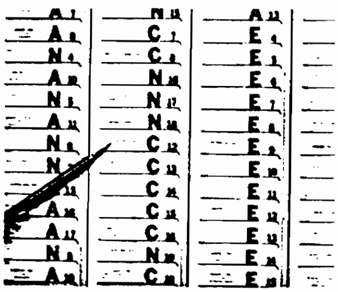
1 The DocuMed cabinet is fabricated of heavy 18-gauge steel with a textured baked enamel finish.



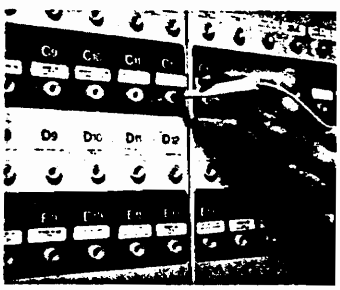
2 Only an authorized operator can open the DocuMed by inserting a coded DocuKey. When the key is inserted, the date, time and operator's number are automatically printed on a secure internal tape and the door is electronically unlocked.

3 When the doors are open, the operator can withdraw one or more of approximately 400 different drugs, (liquids, tablets, or ampoules), prepacked by pharmacy. There are compartments for small quantities of more than three hundred different medications in the upper section of the DocuMed; bulk items and liquids are stored in the drawers below.

- Electronically limited access
- Secure, organized storage for more than 400 different drugs
- Accurate, easy operation
- Complete reconciliation, charge control
- First-in, first-out turnover of prepacked inventory



4 To locate an item, the operator consults the alphabetical listing located inside each door. The drug name is listed on the left side of the alphabetical tab and its letter/number location on the right. Tabs can be easily removed and rearranged to accommodate changes in the DocuMed's inventory.

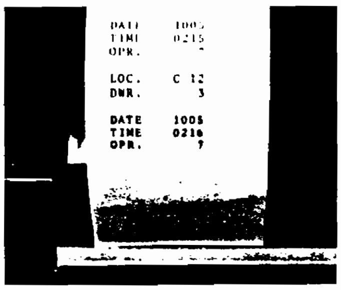


5 The appropriate location is clearly labeled on the selector panel to facilitate selecting the correct medication.

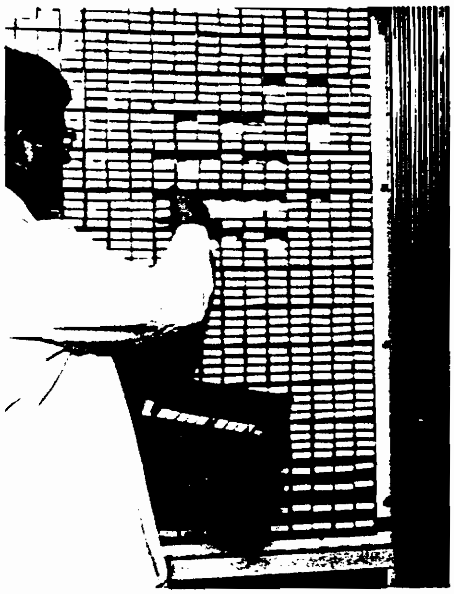
When the DocuPen is inserted at the correct location, the box of medication is pushed out and drops to the delivery shelf. Simultaneously, the item's identifying number is automatically printed on the internal tape.

A secure storage area is provided for copies of confirming physician's orders or vouchers, which can then be processed according to hospital procedures.

6 The pharmacist's master key bypasses the electronic admittance system and unlocks the outer door. It also provides access to the area in which the internal tape and supporting documentation are located. The tape and documentation can be collected at the same time for reconciliation. If documentation (either a voucher or copy of the physician's order) is missing, the tape pinpoints when and by whom the error was made.



7 Each withdrawal is recorded on the secure internal tape. On the sample tape shown, for example, Operator 7 opened the DocuMed at 2:15 am on October 5 and removed a medication from location C-12. An item also was removed from Drawer #3. Operator 7 closed the DocuMed at 2:16 am on the same day. By checking the tape against the paperwork, the pharmacy can validate withdrawals and create a convenient restocking list.



8 When restocking, the pharmacist uses the master key to unlock the outer and inner doors. Honeycombed compartments present an orderly array of the DocuMed's inventory and clearly indicate which items need restocking. Usage is assured on a first-in, first-out basis.

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