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BAR CODING IN MASS TRANSIT OPERATIONS AND MAINTENANCE

Bar Code Application Guide Book

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CHAPTER ONE - INTRODUCTION

BACKGROUND

This application guidebook was developed under TCRP Project G-2, entitled *Bar Coding in Mass Transit Operations and Maintenance*. The purpose of this project was to provide stimulus to the transit industry to make more extensive use of bar coding as a productivity and cost containment tool. This was done by evaluating the specific applications of bar coding in transit, identifying the appropriate technology and providing a managerial road map for the implementation process.

This document is designed to serve as a reference for the transit industry professional who desires to evaluate bar coding for use in their own operations or who wishes to expand an existing bar code application. It is not designed to provide direction, but rather to provide a framework for creative thought relative to the dynamics of a transit properties own operational scenario. This guidebook serves as an adjunct to the final project report and is a more streamlined presentation of the report's most pertinent information. For those desiring additional information, the complete final report is available and provides additional information such as the results of a transit industry survey relating to bar coding use and case studies of five (5) current bar coding users. Included among these five users are four (4) transit properties.

This document is organized into five (5) chapters. The first chapter is an overview of transit bar coding applications. These applications are based on discussions with existing transit bar code users and the project researchers' views based on existing bar coding technology. While this chapter provides a full range of applications, it is hoped that it will also serve to stimulate thought and creativity in the creation of new applications. Chapter Three is an overview of bar code system elements and technology. The information presented in this chapter is structured according to the sequence in which the system elements should be selected. This sequence begins with the identification of the encoding requirements and proceeds into selection of a bar code media printing technology and selection of a scanner type. At the end of the chapter, a description of methods for interfacing the bar codes to management information systems is provided. Appendix A is a listing of bar coding information resources which can be used to identify suppliers of bar code equipment and software.

Chapter Four provides a description of the management process which can be applied to the development of a bar code system. In general, this process is a subset of the process associated with the development of management information systems since bar coding is a portion of the user interface of these systems. For this reason, this process stresses involvement of the planned user community in the development process. During discussions with transit properties during the course of the research, it was determined that very few performed cost justification or payback analyses during the specification and development of their systems. This process is the norm among commercial industries and is most often required before funding is approved. Performing these exercises can aid transit managers in developing enthusiasm within their organization for these projects and can aid in obtaining financial support.

Chapter Five of this guidebook addresses the process of performing these cost justifications and payback analyses. It includes methodologies and guidelines which can be applied to any transit properties operations and will provide results regardless of the operation size. In addition, these guidelines are general enough to allow their application regardless of the specific operational methodologies employed by a transit property.

BAR CODING APPLICABILITY

The most basic question related to bar coding is where can and should it be used in the collection of data. Bar coding is highly suited for cases where a bounded number of information items are collected on a repetitive basis. It allows virtually all transit property workers to integrate Management Information Systems (MIS) systems directly into their own work without extensive formal training or a high degree of computer literacy. The most significant benefit of bar coding is the productivity enhancements it facilitates based on reliable, accurate and high speed data entry coupled with relatively low implementation costs. Most often used in conjunction with database driven computer systems, bar coded information forms the core of numerous information systems with diverse applications.

It is important to keep in perspective, however, that bar coding is only one element of a management information system. Bar coding only provides information and data to these systems. While bar coding provides its own benefits as described above, the overall benefit of these systems depends heavily on how the data is used. In particular, the degree of integration of applications is important. As an example, it is possible to use a bar coded maintenance work order number to track repair status, repair labor expenditures and materials used to make the repairs. While the bar coded work order number is the vehicle for this, the Management Information System must be able to use the work order number for multiple purposes.

TRANSIT INDUSTRY BAR CODING ISSUES

While performing the research related to this project, the investigators identified a number of issues related to the use of bar coding. These issues were raised by transit properties and provided guidance for the balance of the research. The most fundamental of these issues were a lack of knowledge of bar coding. Another basic issue raised by transit properties is a lack of knowledge as to how to proceed with evaluating bar coding for their own use. Both of these issues have been directly addressed by this document. Appendix A of this report also lists sources of bar coding information which will help a transit property to develop a base of bar coding information and knowledge.

Other more specific issues were raised by transit properties that have performed preliminary explorations of bar coding for potential use or are current users. These issues were afforded significant consideration by the investigators as they represented universal institutional barriers to bar coding usage. The paragraphs which follow identify each of these issues and provide recommendations as to how they can be addressed.

MANAGEMENT OF BAR CODE IMPLEMENTATION

Some non-users indicated that they recognized the benefits of bar coding but were unclear as to how to proceed with implementation. This problem was particularly observed with small and medium size properties with limited resources and which do not have dedicated MIS, materials management or operations groups. As a result, these properties are unlikely to have personnel who understand the capabilities of bar coding and who would be able to develop workable management plans implementation plans for bar coding. This concern is addressed in Chapter Four of this report which provides approaches to the management of the implementation of bar coding and the evaluation of bar code applications for transit operations scenarios.

COST JUSTIFICATION

Another problem which became obvious to the researchers is the lack of cost justifications and payback analyses performed by bar coding users in the transit industry. In very few cases did a transit authority perform either analysis prior to or during system development. These analyses could help transit properties realize the benefits of bar coding and strengthen the resolve of both operations and management personnel to implement bar coding. Cost justifications were described by the non-transit users as a routine requirement associated with requests for capital expenditures. Chapter Five of this report outlines a procedure for the evaluation of bar code applications including the preparation of cost justifications. Included in this procedure are examples showing its application to transit operations scenarios to aid transit managers.

REQUIREMENTS DEFINITION

In a number of cases, transit properties reported experiencing difficulties in the development of the functional requirements for a bar code system. This is a very basic issue and can have significant bearing on the ultimate efficiency and usefulness of a bar coding application. These problems manifested themselves in a number of ways. One property reported difficulty in conveying functional requirements from the system user community (material management, property management, maintenance, etc.) to the MIS group which would ultimately implement the system. It is the researchers' view that it is necessary to separate the bar coding and software aspects of the system. Bar coding applies only to the user interface of the systems where it is applied. It has no real influence on the functionality of the system (i.e., reporting capabilities, material planning, etc.). Other properties indicated that systems did not meet functional requirements following implementation. In this later case, most of the properties reporting problems had systems based on commercial products. In these cases, functional requirements are often compromised thorough the use of a generic commercial product that does not address the nuances of a property's operations and culture. The bar code implementation process discussion in Chapter Four of this report provides further guidelines to be used during the development of system requirements.

MATERIAL AND ASSET BAR CODING

A major issue in the implementation of a bar coding system is the labeling of the items and materials to be brought under control. Where bar coding is used for materials management, the problem is compounded by the number of different items and the associated quantities. While it is possible to use the supplier's bar code markings, there is no uniformity in the type and format of the markings except where UPC codes are used. In addition, labeling of items which do not come from the manufacturer with bar codes is costly and time consuming. While these are real problems, a number of properties have overcome them. As an example, a number of transit properties label storage locations rather than individual material items. As examples, NJ Transit and Connecticut Transit have implemented this scheme. In addition, there are industry initiatives to standardize materials labeling. The most significant of these is pursuing the use of the B-10 Trading Partner Label developed by the Automotive Industry Action Group (AIAG). Information provided on this label could be extremely useful in receiving and materials management applications.

In addition, transit industry non-users believe that document printing methodology will need to be modified to allow utilization of bar coding. While this is true if a completely integrated approach is desired, it does not always need to be the case. As an example, materials receiving applications use bar coded purchase order numbers. Rather than changing the printed purchase order to include the bar code, a label with a pre-printed bar code representation of the purchase order number could be affixed to the document. As purchase orders are serialized documents, the use of pre-printed bar code labels could be administered easily. Similarly, pre-printed bar code labels could be used on vehicle defect tickets and pair work orders. Chapter Two of this report discussed a number of application scenarios within the context of transit operations and includes recommendations for labeling methods.

SOFTWARE COSTS OF BAR CODING IMPLEMENTATION

Virtually all transit properties indicated that they have management information systems which are used for functions such as materials and maintenance management functions. In most cases, these systems are based on commercial software packages provided by firms such as Multisystems, Jakware, Ron Turley Associates, Worthington Software, and others. In most cases, these packages have inherent bar code capabilities but their use is not mandatory. It was revealed to the researchers through the survey process that most non- users have these capabilities built into existing software. ~~but do not use them.~~ Among the transit properties reporting the use of bar coding during the survey, a number indicated that bar coding was implemented at relatively low cost. This suggests that the approach to the implementation of bar coding taken by these properties was to add hardware which used the inherent capabilities in the software. In these cases, the software costs associated with the use of bar coding were very low at most.

Another approach to the implementation of bar coding which required minimal or no software costs is the use of scanners interfaces with terminals through a wedge. The wedge translates the scanned bar codes into equivalent keyboard keystrokes which can be directly interpreted by the application software without modification. During the research, it was also determined that portable terminals could be used in a bar code system with minimal application software modifications. This is done by having the terminal develop files consisting of packets of data which emulate terminal based transactions. This includes the transaction control information, data and cursor control characters to move between data entry fields. The challenge in the implementation of this scheme is transferring the information to the computer. This can be performed by establishing a link to the computer which emulates the link provided to a normal terminal. Using this link, the file can be transferred from the portable terminal with the data appearing to be individual transactions performed from a terminal. While the interface aspects of this scheme are not trivial, it can be implemented through the terminal session management facilities of the operating system of the management information system rather than through modifications to the application software. Chapter Three of this document provides details of interfacing methods including software considerations.

APPLICATION INTEGRATION

In the majority of cases, maintenance operations are material intensive. For both preventive and remedial maintenance actions, parts and consumable items are generally always used. As a result, it can be beneficial to relate material usage to repair actions for purposes of cost accounting, material planning and to track the specific location (i.e., vehicle number) of re-buildable or warranty items such as engines, transmissions and wheelchair lifts.

Addition of labor expenditure information collected from time and attendance systems could be integrated to allow detailed repair costs for specific classes of vehicles or even a single vehicle to be developed. In addition, more detailed maintenance manpower planning and budgeting could be performed.

In reality, this issue arises from Management Information Systems, however, by bar coding appropriate data, the process is facilitated.

Based on the questionnaire responses and discussions with non-transit industries, integration has been achieved through the implementation of systems such as Material Resource Planning (MRP). Similar integration of functions by transit properties will significantly compound the benefits provided by the use of bar coding.

CHAPTER TWO - TRANSIT BAR CODING APPLICATIONS

TRANSIT BAR CODE APPLICATIONS

There are a large number of bar coding applications which are suitable for transit property use. The bar coding applications are as suitable for smaller properties as they are for larger properties. This assertion is not constrained by the size of the transit property.

The only significant difference between large and small properties will be the scope of the application. As an example, a smaller property may implement an application using a single, dedicated PC-based workstation while a larger property may use a main-frame computer or a network of PCs. In either case, the user interface and the way in which the bar codes are employed, will be the same. The sole difference will be the number of individuals provided access to the application.

All bar coding applications in transit and other industries serve to provide data to database-driven management information systems. As was indicated previously in this report, bar coding is most suited for the collection of a bounded number of data items on a repetitive basis. In all cases, there needs to be a relationship between the bar coded information and a larger set of data items which completely define a person, item or process. Most often, bar codes themselves do not provide all required information but rather serve as a pointer to the larger set of data items. The only logical way to retain all this information is a database. For this reason, all bar coding applications described in this report are predicated on the use of bar coding in conjunction with a database-driven information system.

The paragraphs which follow describe a number of bar code applications appropriate for transit property use. In each case an overview of the application is provided as well as a suggested approach to the definition of the user interfaces. When reading these descriptions it is important to remember that the functionality will be defined by the application software. The purpose of the descriptions provided is to outline where bar coding can be integrated into the processes. It is also important to consider the extent of integration between applications. Information collected by applying to bar coding can often be used by other bar codes. Similarly, once bar codes are used, the same bar codes may be used in multiple contexts. As an example, bar codes used for purposes of material issues and transfers can also be used for inventory accuracy verification. It is important to view the "big picture" when using bar codes. Generally, the work required to integrate additional applications is small, relative to the benefits which will be realized.

PHYSICAL ASSET MANAGEMENT

Physical assets are procured by organizations to enhance their productivity. These can include vehicles, major components such as engines or fareboxes, and tools. Their purchase expends highly valuable capital which when allocated properly can yield significant benefits. For this reason, it is highly desirable to have a detailed understanding of both asset inventories and the rate of utilization of these assets. Bar coding can be used in both cases.

Figure 2-1 shows the general functional structure for a physical asset management system utilizing bar coding. The functionality of the systems is variable but can include the following:

- Asset Assignment Tracking (Persons, Departments, Facilities/Depots, etc.)
- Asset Value Tracking (including depreciation and amortization)
- Warranty and Service Agreement Management (Is a particular asset under warranty?)
- Maintenance Requirements (scheduled maintenance, calibration, etc.)
- Purchase History (Acquisition Date and Cost)

The ultimate functionality of the application will be determined by the structure and contents of the database, and the types of reports the system can produce. As is the case with numerous bar coding applications, greater efficiency in asset tracking can be realized by integrating it with other applications. As an example, the asset database can be used in maintenance operations to determine calibration schedules for items such as test equipment. Reports can be developed based on information in the asset database to determine which

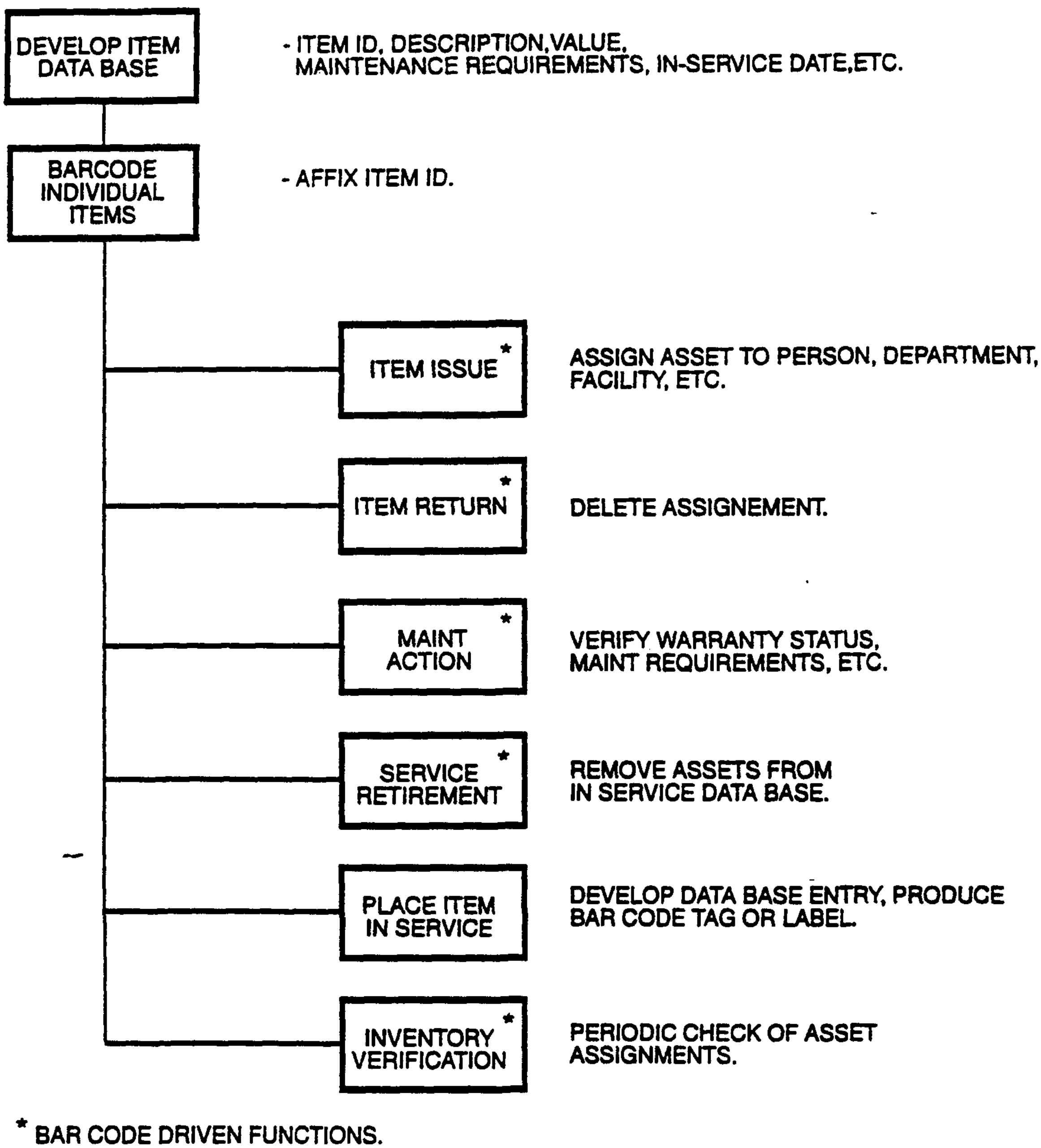

Figure 2-1. Physical Asset Management System Functions

units are scheduled for calibration in a given week or month. Information in the asset database can also be used during assessments of capital expenditure requests. When assessing expenditure requests, inventories can be checked to see if like or similar items are in inventory and available for use. In addition, acquisition cost histories can be extracted.

As is shown in Figure 2-1, asset management systems can make use of bar coding in a number of places. As prerequisites, the items to be inventoried must be marked with a bar code, and a data relating the item ID designation to the item description, location and other pertinent information must be created. When an asset is issued, bar codes can be used to record the item ID and the recipient. The bar codes can be scanned from the item itself or can be scanned from menu listing common items. The recipient information can be scanned from ID badges for persons or from a menu for departments or facilities. This information is then used to update the appropriate fields in the database record for each item. When an item is returned, the item ID is scanned and the database record can be updated to break the linkages between the item and the individual user or organization. A similar process can be used when an item is retired from service.

Physical asset management tasks are not time critical. This is to say that the information is not used to make immediate decisions regarding asset locations and allocations. For this reason, asset management tasks need not be performed on a real time basis. This is beneficial since asset management system resources need to be mobile to allow transactions to be performed at the asset's location. Portable terminals are well suited to this application. These devices are battery powered and allow information for a number of transactions to be collected. The transaction information can then be uploaded to the main asset inventory management system and processed on a batch basis. Details of these portable terminals and their use is provided in a later section of this report.

MATERIALS MANAGEMENT

The process of materials management consists of a number of interrelated activities. These activities cover the life span of the material from receipt to consumption. Nearly all transit properties surveyed have computerized material management systems which implement the functions required to manage these life spans.

Most material is used in quantity and is handled multiple times during its life span. For this reason, material related activities are very suitable for the application of bar coding. As the data collection requirements are similar during the various handling activities, integration of material management functions is warranted at the management information system and bar coding levels. Common material management activities include receiving, issues and transfers, location management and inventory verification. The application of bar coding to each of these activities is detailed in the following paragraphs.

MATERIAL RECEIVING

When material is received, the information collected will establish that the material is available for consumption, identify where it is to be stored and indicate that the supplier has met the terms of the purchase agreement and can be paid. This information becomes the basis for all other material related transactions. Availability information is the basis for inventory inquiries and issue transactions, while storage location assignments are used during inventory accuracy verification and for guiding material management personnel during picking activities. Receipts can be processed on a batch or real time basis. Real-time data collection is more desirable for receiving, however, as it allows material needed to fill open requirements to be routed to waiting users more quickly. Based on observations made during the site visits, this can help to cut up to two days of the receipt issue cycle when material is backordered.

In virtually all cases, material is procured using a purchase order or some other formal document. A copy of the purchase order is commonly used during the receiving process to verify item identification (part number, etc.) and quantities. The purchase order can include single or multiple items which are most often referred to as line items. Associated with each line item is a part number and a quantity. For this reason, the purchase order number and line item can be used as pointers to more detailed information stored in material management system databases. A simple scenario for the application of bar coding to material receiving operations can be developed based on the bar coding of the purchase order number. This can be accomplished in one of the following ways:

- Printing of a bar coded representation of the purchase order number on the document – Using preprinted purchase order forms with bar coded numbers
- Printing bar coded representations of numbers on labels and applying them to the purchase order document
- Applying pre-printed labels with bar coded representations of the number to the purchase order document

The ultimate solution employed will depend on the volume of purchase orders handles and the current method used for their generation. As an example, an organization currently printing purchase order forms using their material management system should be able to modify the program to print a bar code of the form at minimal cost.

Figure 2-2 illustrates the application of bar coding to the material receiving process. When processing a receipt using bar codes, the bar code number will be scanned first to identify the order including the vendor. This is then followed by processing of the individual line items. A menu containing bar coded representations of numbers could be used to automate this process. For each line, the material clerk will be required to verify the quantity received. Again the bar coded representations could be used. Other material specific information, such as shelf life codes, can be entered using bar code menus or manually from a computer keyboard. The format of the information and the number of variations will dictate the most preferable approach.

MATERIAL ISSUES *I* TRANSFERS

Once material is brought into inventory, it can be issued for consumption. In the case of larger transit properties with multiple locations and stockrooms, material can also be transferred from one location to another. In either case, it is important to account for the material to maintain local inventory levels, to determine when reorders are required, and for purposes of cost accounting. Due to the repetitive and data intensive nature of these operations, bar coding is appropriate.

Material issues are most often made to the individual or organization that will consume the material. As an example, maintenance material is most often issued directly to the mechanic performing a repair or preventive maintenance action. Transfers are a characteristic of larger transit properties with multiple facilities. As an example, NJ Transit has a central storeroom in Newark and eighteen satellite garages throughout the state. When material is required at the satellite locations, it is transferred from the central storeroom in Newark. **Figure 2-3** illustrates the flow of a material issue transaction.

The issue transaction is invoked through a keyboard entry or by scanning a bar coded transaction menu. The operator is then prompted to scan the part number bar code. There are a number of ways that this can be accomplished. Some transit properties, such as NJ Transit and CT Transit, have bar coded storage locations. The location bar codes are either the part number or a pointer used to access the part number in the material management system database. As an alternate, the items to be issued can be individually bar coded. This entails requiring suppliers to bar code items prior to shipment or bar coding of individual items upon receipt, while often used in commercial industries, this later approach is not often used by transit properties.

Once the part number information has been captured, the operator is prompted to enter the issue quantity. This can be done through manual keyboard entries or by using a menu containing bar coded numbers. The next step is to enter any required accounting information. Again this can be performed from the keyboard or by using a bar code menu. The process of material transfers is very similar. In effect, the material is issues to the satellite location rather than to a user. In this case, the accounting information will

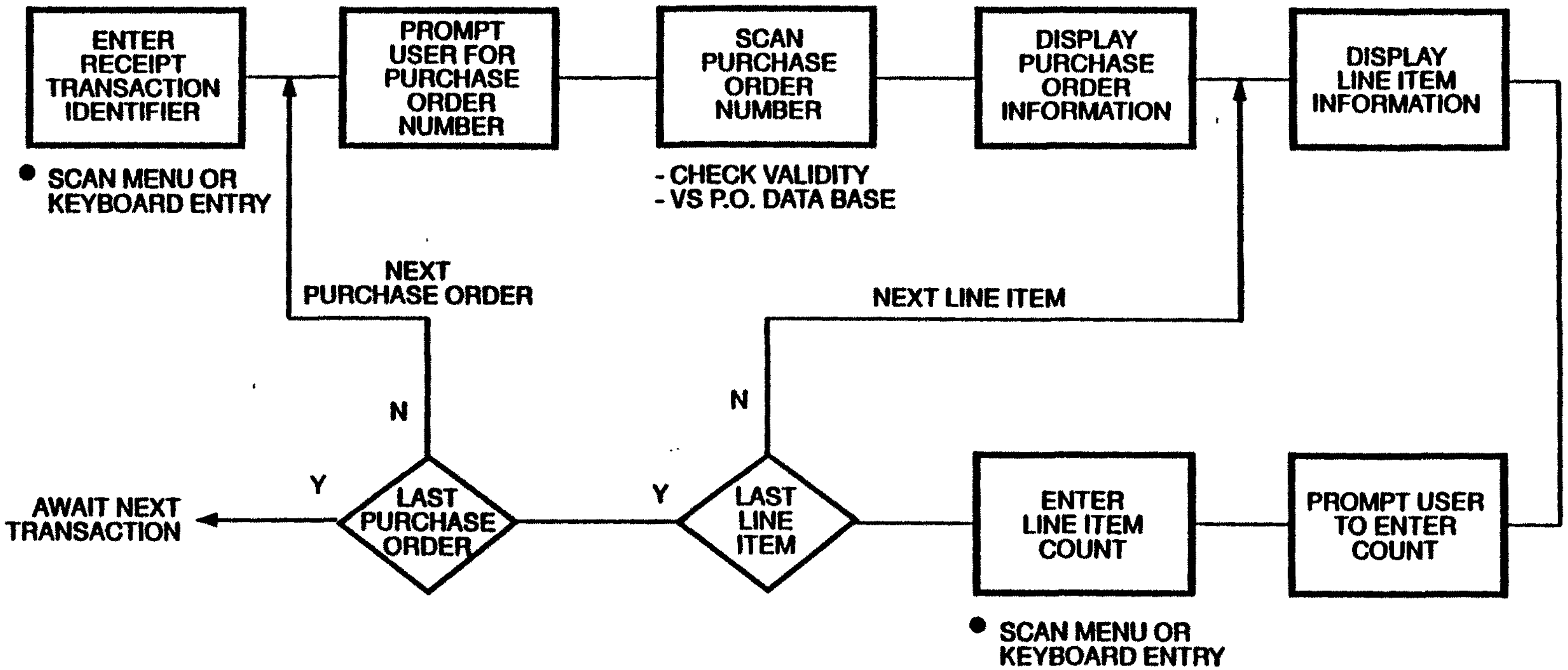

Figure 2-2. Material Receiving Function Flowchart

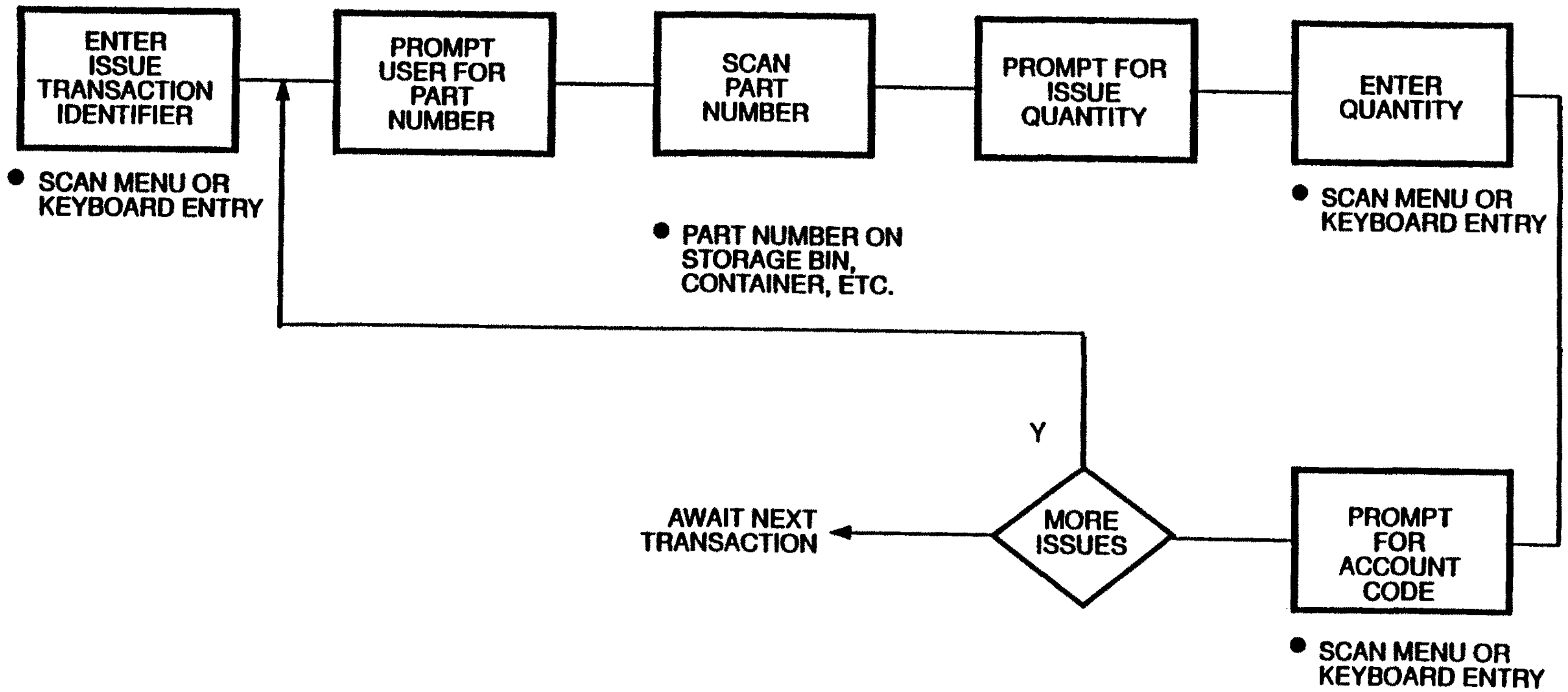

Figure 2-3. Material Issue Function Flowchart

reflect the change or another step will be added to the transaction to reflect the location the material is to be transferred to. This process is also applicable to material overstocked in the satellite storeroom that is returned to the central storeroom.

Depending on the nature of the transit property's operations, material issues and transfers may occur on a real time or batch basis. As an example, material issued to a mechanic performing a repair is issued on a real- time basis to avoid having the mechanic idle. The collection of data for the issue can be handled in either a batch or real time mode. As an example, CT Transit makes material issued using batch portable terminals. The data from these devices is uploaded to the material management system on a periodic basis. Generally this will occur two (2) or three (3) times each day.

Material transfers are often effected by having the remote location initiate a requisition on-line through the material management system. Such requests lend themselves to batch operations since requests for a remote location can be accumulated. Transfer lists sorted by location can be developed and loaded into portable terminals. These devices can then be used by warehouse personnel in lieu of pick lists and allow issue transactions to be completed at the storage location rather than by bringing the material to a fixed terminal. NJ Transit employs this approach in their Newark central storeroom. When the picks have been completed, confirmation is uploaded to the material management system and a shipping manifest is generated. The shipping manifest can be used to verify the contents of the order when the material is prepared for shipment to the satellite location.

INVENTORY ACCURACY VERIFICATION

Inventory Accuracy Verification is an essential element of a sound material management strategy. In principle, if material handling procedures are followed to the letter, inventories will always be accurate. In practice, human error and failures to adhere to material handling procedures enters the picture and inaccuracies arise. For this reason, periodic audits are made of inventory accuracy, and any required adjustments in inventory levels and locations are made.

Two (2) types of inventory verification procedures are employed. These include physical audits and cycle counting. A physical audit is an a periodic event and is generally comprehensive. They will often include an entire storeroom or a major section of a storeroom. Cycle counting effectively schedules each storage location for inventory on a periodic basis. The frequency of cycle count varies but is generally once a year for slow moving commodities and twice a year for fast movers. The material inventory management system will randomly generate a list of the locations to be cycle counted on a daily or weekly basis. In most cases, the material management system will lock these locations to prevent material removals until the count has been performed. Attempts to issue material from locked locations will generate an exception message or the material management system will not schedule issues for the location until the cycle count has been completed. In this way, a baseline for the count is established and material clerks are encouraged to complete cycle counts in a timely fashion to insure access to all storage locations. These systems will track the status of each location to insure that cycle counting frequency requirements are met. Most often, cycle countcodes are assigned which determine the frequency. As described previously in this report, PACE uses frequency codes of A and B to indicate quarterly and semi-annual counts respectively.

Regardless of the inventory verification approach employed, the activities performed during the inventory data collection process are essentially the same. The inventory control clerk will go to the storage location and count the number of items there. In performing the transit property site visits, the researchers observed two different approaches to inventory tasks. NJ Transit uses their material management system to develop lists of inventory tasks which are downloaded to scanner equipped portable terminals. Inventory management clerks are then directed to perform each task sequentially (by storage location). At the location, the clerk is directed to scan the bar code label on the bin location which will provide information including the part number. The worker is then instructed to enter the item count. This count is compared to the count provided by the inventory management system and if a discrepancy is detected, the clerk is instructed to recount the location. Figure 2-4 is a flow chart illustrating this process. This information is then stored in the portable unit and uploaded to the material management system when the inventory tasks have been completed.

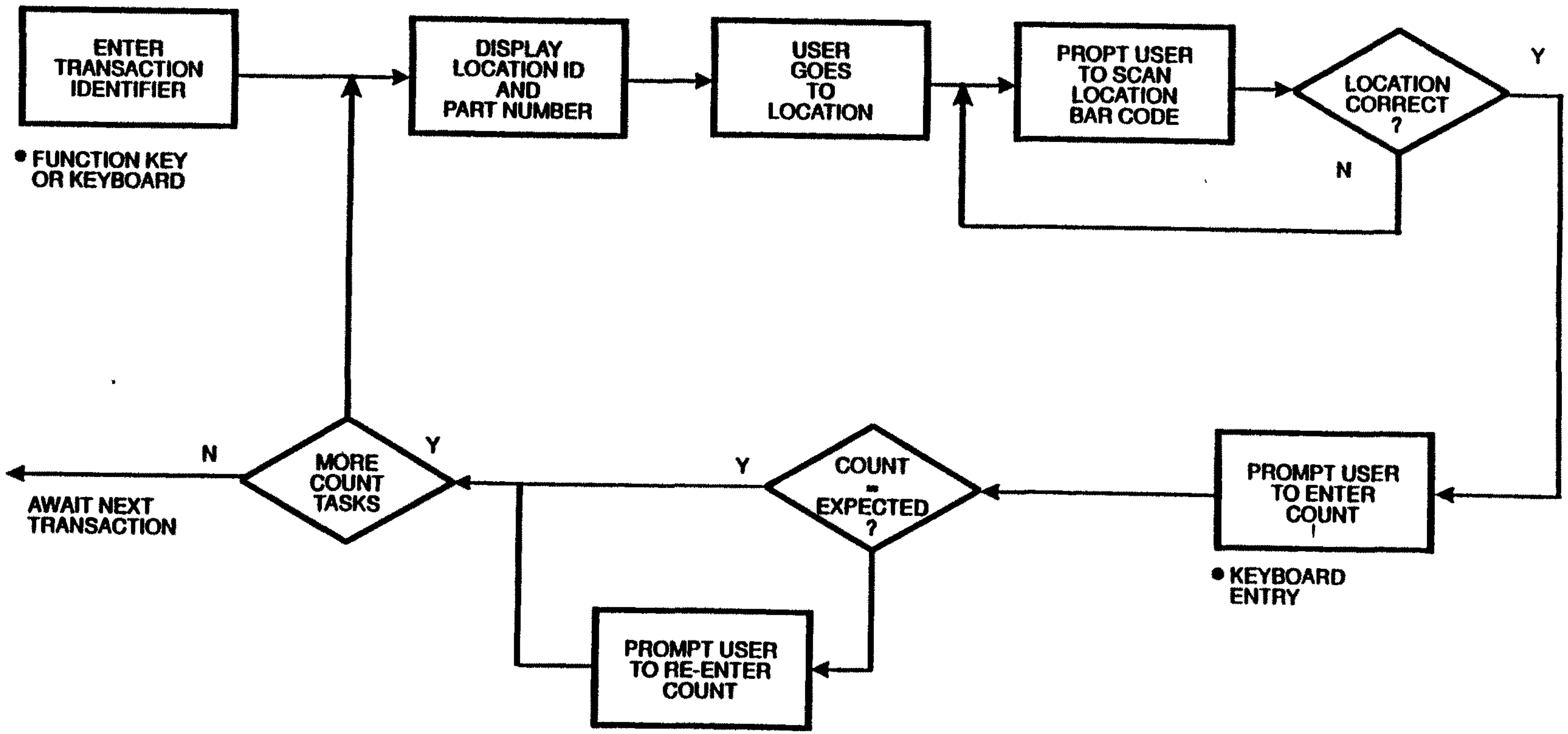

Figure 2-4. Cycle Count Function Flowchart

NJ Transit's material management system has the ability to produce inventory exception reports to allow discrepancies to be researched.

Another approach to inventory verification is used by PACE Suburban Transit in Chicago. Like NJ Transit, PACE uses their inventory management system to produce lists of locations to be counted. Rather than loading these lists into portable units, hard copy lists are produced. Figure 2-5 is an example of a hard copy cycle count list showing the SKU, item description and bin locations.

These lists include the storage location ID, a description of the item, the anticipated count and part number as test and a bar code. The procedure employed in this case is for the material clerk to take the list to each location and record the count. When all counts are completed, the clerk will go to a material management system terminal to enter the information. As a part of this process, the bar code will be scanned using a wand connected to the terminal. This simplifies the process since the clerk is required to enter only the count using keystrokes. In addition, it will enhance the accuracy since part numbers can often be complex alphanumeric sequences and as a result, can be prone to transcription errors.

MAINTENANCE MANAGEMENT

Next to material management, maintenance management is the most popular bar coding application among transit properties. Maintenance actions can be data intensive and as a result lend themselves to bar coding. The diversify of maintenance related data makes it a prime candidate for integration with other applications such as material management, and time and attendance data collection. By doing so a comprehensive picture of a repair action including the materials required to effect the repair and the labor required can be developed. This information can then be used to produced detailed repair costs. Similarly, the repair information can be used to develop maintenance histories for vehicles and components. This information can be used to identify latent defects and equipment design flaws, maintenance material requirements and produce life cycle cost profiles for use in acquisition planning.

These scenarios are indicative of how additional data can be used to provide significant benefits. As bar coding can enhance the quality of this data and allow it
to be collected at lower cost, it is an important element of maintenance management. In addition, this scenario is also indicative of the importance of functional integration at the management information systems level.

Common maintenance management activities include repair/work order processing, item history management, shop work loading and repair cost collection. The application of bar coding to each of these activities is described in the following paragraphs.

REPAIR *I* WORK ORDER MANAGEMENT

Repair or work orders are the vehicles used to establish repair requirements, assign work to mechanics, record repair activities and insure completion of required work. Work orders are initiated when a vehicle or piece of equipment is taken out of service due to a defect reported by the user. In addition, work orders are also generated by maintenance supervisors or automatically by computerized maintenance management systems to initiate periodic or preventive maintenance. For tracking purposes, work orders have an identifier which is either numeric or alphanumeric. These identifiers can be bar coded and form the basis for tracking of the work order. In addition, there are other items such as line numbers for multi-step repair processes involving multiple crafts which lend themselves to bar coding.

As an example, CT Transit uses a three-part defect card that serves as the repair order in its maintenance activities. Each defect card has unique serial number printed on it as well as the corresponding bar code. At the end of a run, the bus operator notes of any problems or equipment failures on the card and a copy is given to the repair foreman. The foreman will scan the bar code on the card using an infrared wand scanner attached to the terminal in his office via a wedge. This is done as part of a transaction which opens a formal work order in their computerized maintenance management system. A mechanic is assigned to the repair and is given the defect card.

When the actions needed to repair the defect have been determined, the mechanic takes the card to the stockroom to obtain the required repair parts. The storeroom clerk will scan the defect card bar code and

PROGRAM: MMR0998
RUNDATE 04/26/95
RUNTIME 12:42

PACE SUBURBAN BUS SERVICE
MATERIALS MANAGEMENT SYSTEM
INVENTORY ITEMS TO BE COUNTED FOR PACE - RIVER STOREROOM

PAGE 2

BAR CODE	SKU #	DESCRIPTION	ABC CODE	U/M	1ST BIN LOCATION	2ND BIN LOCATION	DATE COUNTED	QUANTITY COUNTED	INITIALS	DATE LAST COUNTED
040189	040189	CAMSHAFT:FRONT BRAKE-C/S	C	PC	09-E2A		______	______	______	02/02/94
040072	040072	SPRING:RETURN-REAR BRAKE	A	PC	11-C2A		______	______	______	01/24/95
070258	070258	HORN:HIGH PITCH,24VDC	B	PC	20-A2A		______	______	______	11/21/94
070259	070259	HORN:LOW PITCH,24VDC	B	PC	20-A3A		______	______	______	11/21/94
070246	070246	SWITCH:CONTROL, 4 POSITION	B	PC	23-B2E		______	______	______	12/16/94
070254	070254	GAUGE:WATER TEMPERATURE	B	PC	23-B3A		______	______	______	10/21/94
070655	070655	RESISTOR:30 OHMS, 35 WATT	B	PC	23-D2A		______	______	______	11/10/94

* - DENOTES PRIOR PERIOD SELECTION

Figure 2-5. PACE Cycle Count Listing

each part bar code given to the mechanic using a portable hand held terminal equipped with a laser scanner. Where portable terminals are not used, the defect card could be scanned using a wand attached to the material management system terminal via a wedge. Part numbers for the items issued could be entered manually or using menus of numbers for fast moving parts.

Where portable terminals are used, the stored issue transactions are batch uploaded to the material management system periodically. The mechanic can also use the defect card or work order bar code to enter the hours they expended on the repair into the maintenance management system. Figure 2-6 is a flow chart illustrating potential uses of bar coding for this purpose. This process can also be modified to include entry of cost account numbers if repair costs are segregated in this way. Figure 2-7 illustrates a menu of bar coded cost account numbers used by MARTA for this purpose.

Similar procedures are also applied to preventive actions, however, the defect card would not be used. In these cases, the work is scheduled and assigned by the foreman. As in the case of the repairs, these tasks are entered into the computerized management system to establish a work order. To provide a vehicle for the tracking of material and the accrual of labor hours, a repair order could be generated. One type of repair order could be used for component rebuilds with another type used for miscellaneous repairs. A designator prefix could be added to the repair order number to differentiate among the various types. In this way it would be possible to segregate the costs for different types of repair actions.

ITEM HISTORY MANAGEMENT

During maintenance operations, it is often useful to understand the maintenance history of the vehicle or unit being repaired or those similar to it. This historical information can speed the diagnosis of failures, identify habitual or latent defects and be used to manage unit warranties. In general, this information can be obtained by querying the maintenance management system database. These queries are made using information such as the unit part number, serial numbers or vehicle IDs. The accuracy of this information can be enhanced if the items or vehicles have bar coded identifiers. One example of this is the bar coded vehicle identification numbers on motor vehicles such as automobiles. Another example is bar coded identifiers on major subassemblies.

While they are not currently used, the Long Island Railroad has future plans to use bar coding for maintenance management at multiple levels. This is reflected in the fact that the LIRR is requiring suppliers to bar code the equipment provided for their new bi-level coaches. As an example, electronics such as communication system subassemblies are required to be bar coded. Ultimately, these bar codes will be used to track the warranty of these components as well as remedial maintenance activities.

WORK LOADING

Most transit properties have maintenance planners or foremen. Their primary role is to insure that repairs of buses, rail cars and other vehicles are make quickly so they can be returned to service. Maintenance activities include predictable and scheduled activities such as preventive maintenance as well as remedial repairs which are unscheduled and unpredictable. For this reason, the foremen need to have a clear picture of the resources available to them to perform these actions.

The primary resource used in their activities are the maintainers or mechanics. Management of the work loading of these resources can be facilitated through the use of information derived from the work orders such as mechanic assignments and average times required to complete a given repair action. This information can be derived from the work order management system described above and the time and attendance data collection system described in the following paragraph.

The use of bar coding for the entry of data to these applications will insure that the maintenance planner will always have an accurate picture of the resources available.

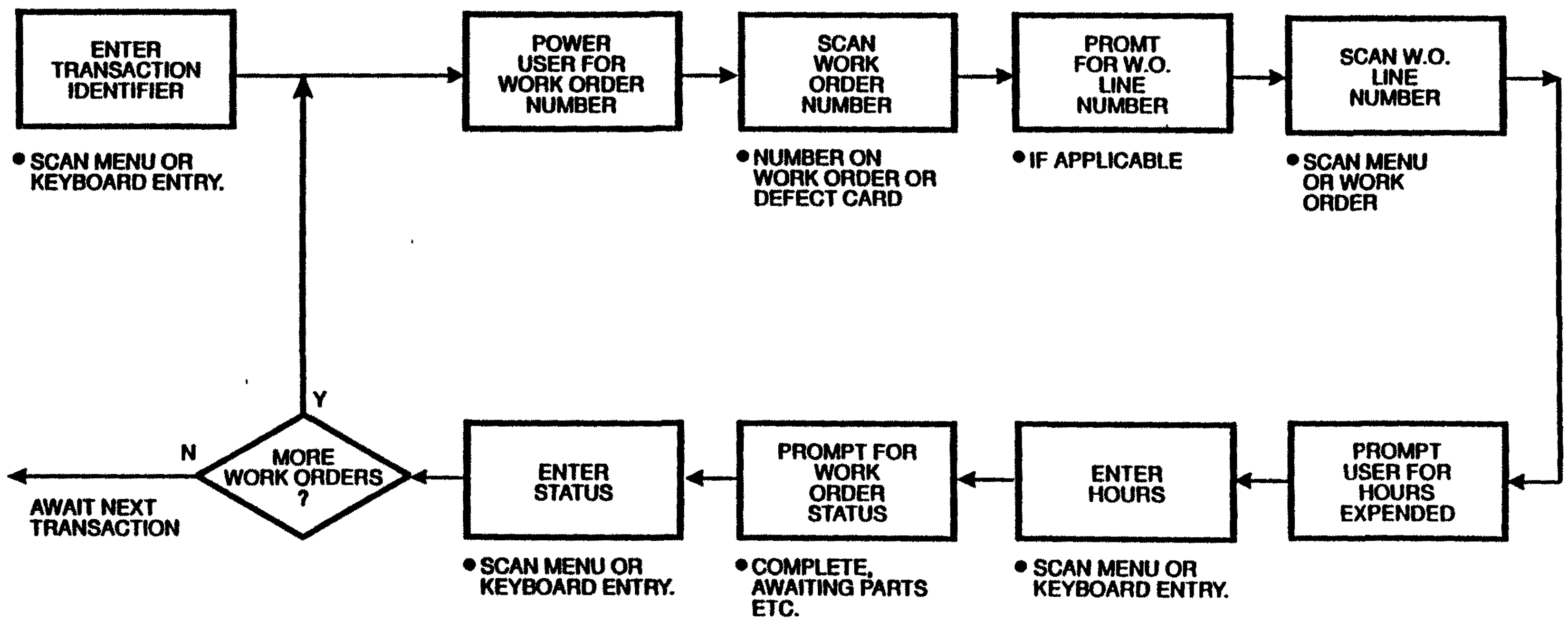

Figure 2-6. Work Order Labor Entry Function Flowchart

AVONDALE BAR CODE CHART

COST CENTERS & Account codes for Repair of Revenue Vehicle

INSPECTION 63241-531005	LABOR ACCOUNT 63241-503500
LIGHT REPAIR 63244-531005	LABOR ACCOUNT 63244-503500
HEAVY REPAIR 63243-531005	LABOR ACCOUNT 63243-503500
TRUCK SHOP 63246-531005	LABOR ACCOUNT 63246-503500
ELECTRONIC SHOP 63530-531005	LABOR ACCOUNT 63530-503500
CENTRAL	CENTRAL PHONE
YARD TOWER	YARD PHONE

Figure 2-7. MARTA Bar Coded Cost Account Menu

TIME AND ATTENDANCE DATA COLLECTION

In 1994, the MTA-NYCT spent over 75% of its annual operating budget on labor and benefits for its work force of 50,000 people. Other transit properties spend proportional amounts for labor and benefits. From this it can be seen that labor and benefits represent a significant portion of a transit system's annual budget and that it represents fertile ground for cost reductions through productivity enhancements. In addition, it can be seen that there is significant work involved in the process of time and attendance collection. In the case of many properties, this task is compounded by the fact that most properties have multiple unions with each having its own contract provisions and work rules. As a result, there is considerable labor involved in the process of collecting time and attendance information and the preparation of each week's payroll. Any efficiency realized in this area will provide significant benefits to a transit property.

For this reason, a number of transit properties and industrial organizations have implemented automated time and attendance collection systems. Among the bar code users visited, MARTA and United Airlines have automated time and attendance data collection systems. In both cases, these systems are based on the use of fixed location bar code terminals, as shown in Figure 2- 8. Descriptions of these devices are provided in Chapter Three of this document. Most often, fixed location terminals used for time and attendance applications feature a slot scanner which controls the scan path and helps to insure high-first read rates are attained.

Generally, these systems use bar codes employee badges as the identification medium. To prevent unauthorized logging in and out, the bar codes on these badges are often covered with a transparent red film. This film will prevent the reproduction of the bar codes using xerographic techniques but allows the bar code to be red by a standard LED or laser scanner. When using film, it is important to insure that it is compatible with the operating wavelength of the scanner being used. User transactions for these systems are very simple. One common approach is to have function keys on the terminal for logging in and out. MARTA uses this approach and the function keys used are shown in Figure 2-8. In this case, in is used when an employee arrives and out is used when an employee is leaving. A second approach is to have the time and attendance system application software automatically discriminate between arrivals and departures. In this case, the first scan of the bar coded badge is interpreted as the arrival while the second scan is interpreted as the departure. Error checking could be performed based on the shift an employee is assigned to or work schedules stored in the system database.

User acceptance is a significant issue when applying any type of automation. This problem is compounded in the case where it is applied to time and attendance systems due to its relation to employee salaries. One transit property responding to the researcher's survey questionnaire indicated that a time and attendance system was installed and later abandoned due to very low user acceptance.

For these reasons, it is recommended that employee representatives be a part of the development efforts for time and attendance systems from the very early stages. In this way, real and perceived employee problems and issues can be identified and responded to before system installation.

OPERATIONS

FARE COLLECTION

Transit systems derive their operating revenue from a combination of federal, state and local grants and from fares collected from passengers. While the amount of revenue provided by fares varies widely, it is still significant. Close monitoring of revenues allow a transit property to obtain an immediate picture of its revenue flows which can facilitate financial planning.

In general, automatic identification technology has a significant place in fare collection. As an example, WMATA uses a fare card system based on magnetic stripe technology for its heavy rail operations. As this system has a progressive fare structure with the cost varying according to the length of the trip, an automated system was essential.

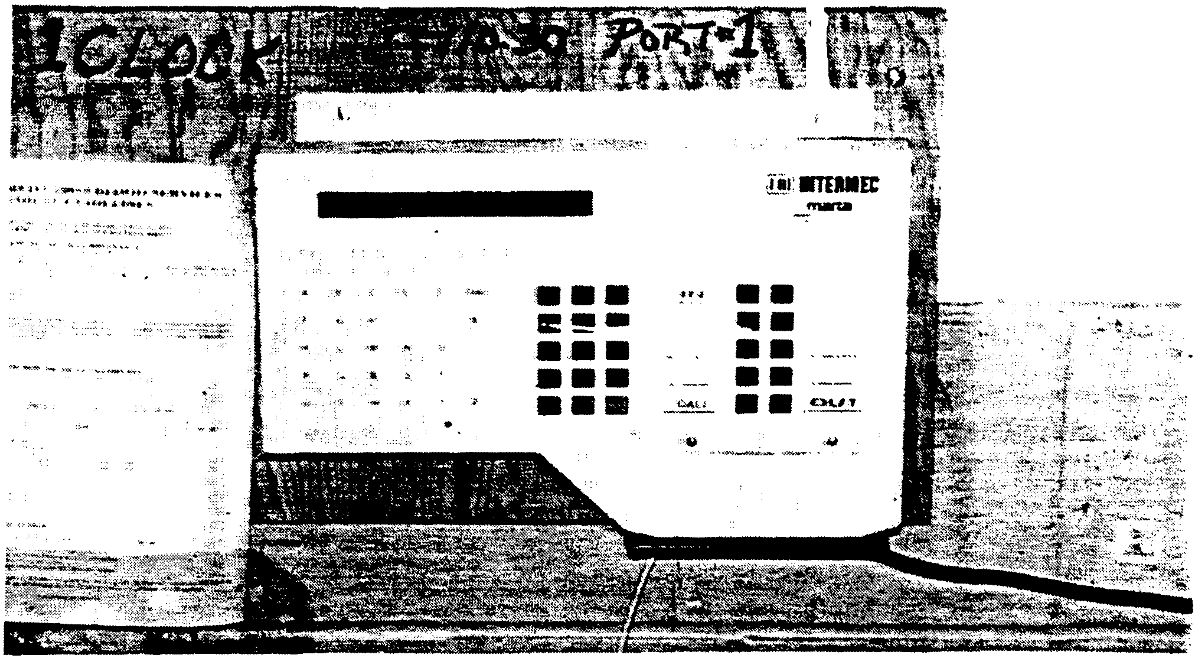

Figure 2-8. MARTA Bar Code Terminal

This system uses the read-write ability of the mag stripe cards to record where a passenger enters the system and to deduct the fare from a pre-established balance. In addition, these fare cards can also be used on WMATA's buses which have a fixed fare structure, and plans are underway to allow their use in park and ride lots. Similarly, the MTA-NYCT has recently placed a fare card system in operation. This system deducts a fixed amount from the fare card balance each time a passenger enters a subway station or bus.

As they do not feature the read-write ability described above, bar codes have limited applications in fare collection. A potential use of bar codes in fare collection is to implement daily, weekly, monthly or other time limited passes. At the time of entry to a station facility or a vehicle, the bar code could be scanned and the validity of the pass checked. These same bar codes could be used at the time the pass is issued for revenue reporting and pass accounting purposes. In this application, the bar codes could be used to manage the passes as if they were assets.

It should be noted that a number of transit properties have performed trials of systems that use bar codes for fare collection purposes. None of the systems performing trials have placed such a system in full scale operation. Generally, this has been due to the fact that the bar code based system was found to provide limited benefits and that establishment of a distribution network for the passes was difficult.

CHAPTER THREE - BAR CODING SYSTEM ELEMENTS AND TECHNOLOGY

BAR CODE TECHNOLOGY

SYSTEM DEVELOPMENT GUIDELINES

Bar code systems do not exist as separate entities. Where used, they are an adjunct to a variety of forms of management information systems where they provide efficient and accurate collection of data. Within most bar code systems, there is little manipulation of information. In essence, the only activities performed by a bar coding system are the identification of items and the creation of the markings (bar codes) used in this process.

Based on this definition, the most basic aspects of bar code technology are the hardware devices used to capture information, and the identification media. Bridging these two elements is the design of the bar code including the symbology format and the information which it encodes. Figure 3-1 illustrates the relationships among the general aspects of a bar code system. The data requirements are based on the encoded information which, in turn, is based on the information input requirements of the software applications the MIS system executes. Once the information requirements are defined, the appropriate bar code symbology format can be selected. This symbology format will establish the bar code printing requirements. Depending on the bar code encoding methodology and printing methodology, an appropriate scanning device is selected to return information to the MIS applications.

The ultimate success of a system employing bar coding hinges on the interaction of these elements in a systematic fashion. For example, if the characteristics of the scanner are not matched to the design of the bar code symbology, low first scan read rates will be realized. This will result in low system efficiency, increased user workload and most likely low user acceptance of the system. The paragraphs which follow are designed to provide technical guidance to transit property managers who are considering applying bar coding to their operation. It contains descriptions of technology options along with guidance in selection of the appropriate option. In addition, issues influencing bar code systems are included. This information is provided as a sequential road map to guide the user through the process of designing bar coding applications.

INFORMATION ENCODING

One of the most basic decisions that must be made in designing a bar de system is define the data to be bar coded. To do this the general nature of information system data requirements must be understood. When interaction with information systems, users are required to enter two different types of information when conducting transactions. The first type is control information which tells the system what function the user wants to perform. In well designed systems, this information is entered using menus or mnemonics and is checked by the system software. If the information is incorrect, unrecognized, or out of limits, the software will reject it and advise the user. As a result, the potential for user error is relatively low and where errors occur, they are revealed to the operator.

The other part of the transaction information is data describing the processes or objects under control of the system. In most cases, the range of possibilities for this information makes all but cursory context checking possible. As a result, there is significant potential for errors to be made. Where this information is entered via keystrokes, it is an accepted industry norm that one (1) error will be made for every 300 keystrokes. While the exact figure is dependent on the amount of data entered as a part of a transaction, it is not unrealistic to expect one (1) of every 10 transactions to contain some form of error. For the types of information systems most commonly used in the transit industry, this can result in lost and unaccounted material, inventory discrepancies and unrecorded maintenance actions.

Where bar coding is employed, priority should be given to the entry of data falling into the later category as it will yield the most beneficial results. Selection of the information to be bar coded requires analysis of the user interface of the Management Information System application software. This analysis should focus on repetitive actions and longer data items which are prone to transcription errors. When entering data into the system, the operator is required to transcribe the information from a document or to enter it from memory.

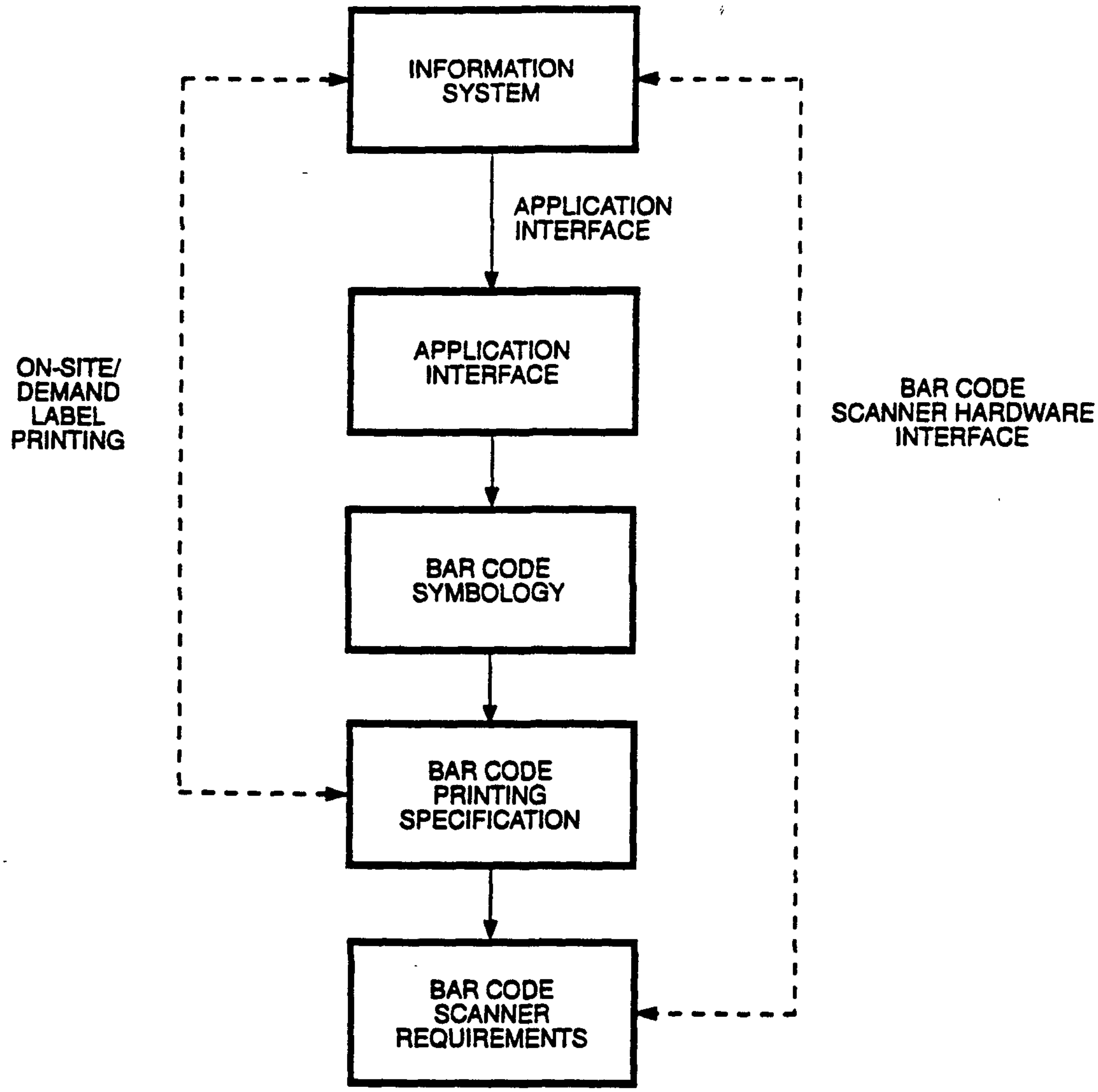

Figure 3-1. Bar Code System Elements

Generally, numeric data items exceeding 7 digits are more prone to errors. This is due to the fact that most computer users can read a 7 digit number as if it was a phone number and transcribe it correctly.

Similarly, most data items consisting of only alpha characters can be viewed as a word simplifying transcription. Where data consists of a combination of alpha and numeric characters or exceeds 7 digits/ characters, the probability of error increases significantly and such items should be bar coded.

It is also possible to encode the control information described above. By doing so, it is possible to use bar coding as the sole means of data input for transactions. Where transactions require standard input codes for indications of processes or other common activities and a bar coded transaction menus can be used. The menu can be collocated with the system terminal for ready user access. This practice is growing in use in industrial environments and can be readily adapted to transit operations. The uniformity of the data entry process will simplify user training requirements and will allow accuracies to approach 100%. During the case study site visits, this approach was observed in heavy use at United Airlines and to a lesser extent at NJ Transit, CT Transit and MARTA.

BAR CODE SYMBOLOGIES

There are a large number of bar code symbology types. These include the more common, general purpose symbologies as well as the specialized symbologies developed to meet the challenges imposed by selected industries or even a single users operations.

In general, they can be classified as two (2) types: linear and stacked codes. Linear and stacked symbologies are related, as stacked codes consist of groups of linear codes. In selecting a symbology for incorporation into a system, the user must assess how the bar code will be used in their operations. This assessment includes determinations of how much data needs to be contained in the bar code and the type of information (numeric or alphanumeric). Based on these determinations, the user can select an appropriate symbology. In addition to the character set and data density, there are general characteristics which are inherent to all bar codes.

Table 3-1 illustrates, the most common types of bar codes and their general characteristics. During the re-search, a number of bar code symbologies were evaluated by the researchers. The goal in this evaluation was to identify a set of symbologies which are suitable for transit applications. This set is shown in the table. The only exception to this is PDF417, which is a form of stacked code with a very high density that in reality transcends bar codes. Details of this symbology are provided in a subsequent section of this report.

For the symbologies listed in the table, the type of information they can encode (alphanumeric or numeric only) and the relative data density are shown. While stacked codes appear to have significantly higher data densities, they contain multiple rows and have between 2 and 14 rows making them significantly taller than the other linear codes which are only a single row high. Where two data density values are shown, the symbology has a double density capability which uses restricted encoding. As an example, Code 128 double density will only support numeric data encoding.

Table 3-1

Bar Code Symbology Comparison

Code	Encoding Ability	Data Density (Char/In)
Code 39	AN	9.8
Code 128	AN	12/24
UPC	N	12
I 2 of 5	N	18
49	AN	93/154
16K	AN	146/293

The paragraphs which follow provide details of the characteristics of bar codes in general and detailed information on the specific characteristics of the bar code symbologies listed in the table above.

GENERAL BAR CODE CHARACTERISTICS

There are basic components that characterize all bar codes regardless of the specific symbology. These components include data characters, leading and trailing quiet zones, and start, stop and optional parity characters. Figure 3-2 illustrates these components. While the arrangement of these components are addressed by bar code printing software, there are user selectable options so it is important to understand the implications so appropriate selections can be made for a specific application. Definitions of these parameters, their ranges of values and guidelines for their selection are provided in the following paragraphs.

The most basic component of a bar code are the bars and spaces. Individual bars and spaces are comprised of elements. Combinations of these elements are used to encode individual characters which are referred to as modules. Figure 3-3 illustrates a single bar code module and shows how the elements comprise the bars and spaces. The width of these bars and spaces has a significant effect on the ability of the scanner to achieve high first read rates. The first read rate is a measure of the efficiency of the bar code system and is the rate at which the user is able to capture the data in the bar code without rescanning.

Regardless of the bar code type, the minimum element width is a variable which must be addressed in the design of the system. For practical applications of bar coding, the minimum bar widths range from 5 to 50 mils (thousandths of an inch). In the majority of cases, the greater the bar width, the better the readability of the bar code will be. In selection of the bar width, however, there is a trade-off between the bar width, the data encoded and the label size. Another factor involved in this process is the resolution of the printer generating the labels. In general, for short range scanning (i.e. scanner 12 inches or less from the bar code), the bar width should generally be in the range of 5 to 15 mils. For longer range scanning (i.e., greater than 12 inches), the bar width should be as large as is practical.

The process of scanning a bar code consists of making a number of sensitive measurements of reflected light. It is important that the scanner start and stop this process at the appropriate locations of the bar code label or it is possible that erroneous data can be collected. To accomplish this, a quiet zone is employed both before and after the bar code. The quiet zone is defined as an area where there is printing or other markings.

Generally, this, area is 10 times the minimum width of a bar. As an example, where a bar width of 20 mills is specified, the quiet zone leading and following the bar code should be a minimum of 0.200 inches in length. It is important that the quiet zone be fully contained on the bar code label and not employ the background or object to which the bar code is applied. This is due to the fact that it is possible to interpret the edge of the label as bar which will provide erroneous data.

It is also important to provide maximum contrast between the elements of the bar code (bars and spaces) to insure accurate data is read. In most cases, bar codes are defined as black bars on a white background (provided by the label printing media) which has sufficient contrast to provide reliable reads of bar codes.

As the light used to scan bar codes is almost exclusively red, it is important to avoid bar code media with a significant blue component as this will reduce the contrast between the bars and spaces. While the consumer goods industry has been successful at applying bar codes to a variety of packaging, black bars on a white background is the best solution for transit applications.

Bar codes emulate serial computer data communications in that they employ start, stop and parity characters to frame the data. A significant benefit of the start and stop characters is that they allow the bar code to be read in either direction (i.e., left to right or right to left, and top to bottom or bottom to top). This helps to make bar code scanning more user friendly and helps to enhance first read rates.

In most cases, the start and stop characters are consistent for a specific type of bar code and are automatically generated by bar code printing software. There are exceptions such as Codabar and Code 128 bar codes which use different stop and start bits to differentiate varying forms of data.

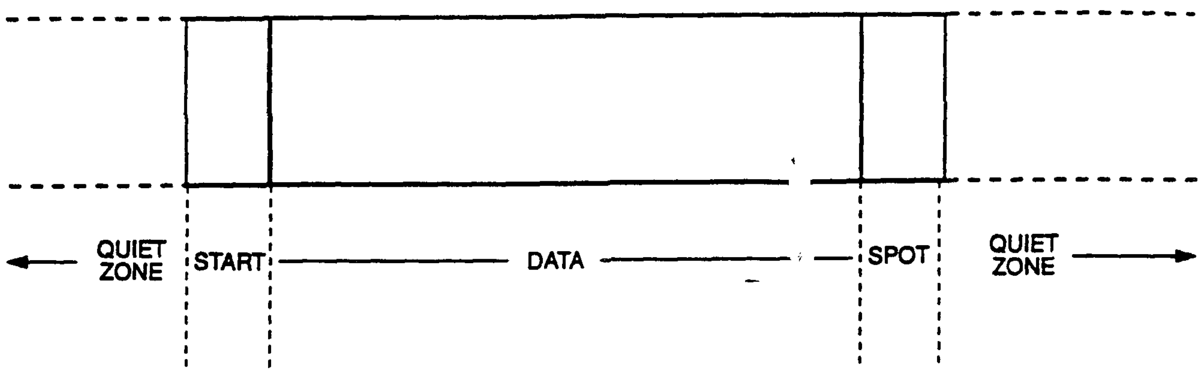

Figure 3-2. Bar Code Symbol Components

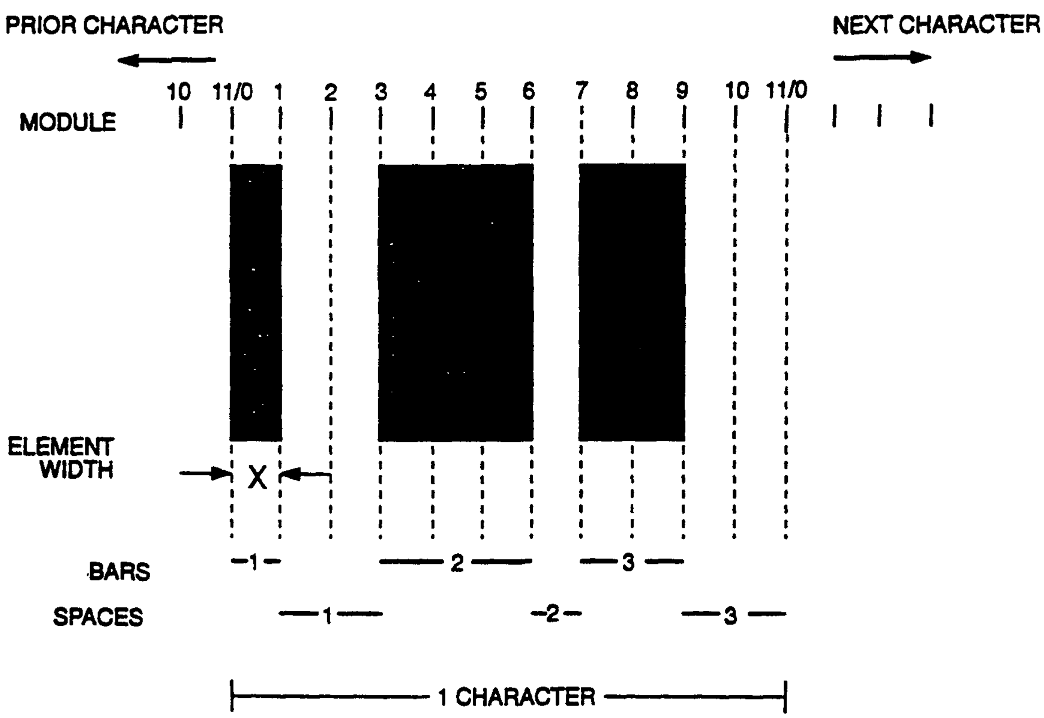

Figure 3-3. Bar Code Symbol Module

Parity characters are used to verify that the data contained in the bar code was collected properly. While bar codes are highly reliable, the printed media can become contaminated due to smearing or dirt which will result in data errors

Such errors can occur even when the label defects not visible to when the naked eye. Parity characters are generated through the application of a mathematical relationship to the numeric values of the data characters contained in the bar code.

While parity characters are generally optional, it is strongly recommended that they be employed. Parity characters are only used at the time the bar code is read and decoded and are stripped from the information before it is passed to the management information system application software.

BAR CODE SYMBOLOGY TYPES

As was indicated previously, there are numerous types of bar codes. These include bar codes designed for general applications such as Code 39 which is widely used in industry and other types designed for use in structured environments such as the Universal Product Code (UPC) used in the grocery and retail industry. All major bar code symbologies are recognized by the Automatic Identification Manufacturers (AIM) which is a trade organization dedicated to insuring uniformity of bar coding standards and products. AIM develops documents referred to as Uniform Symbol Specifications (USS) which define the characteristics of a bar code in detail. These documents have been issued for all bar code types reviewed in this document. When selecting a bar code for use it is recommended that only those recognized by AIM be used. This will insure compatibility of system hardware and software elements.

Bar code can be segregated into subsets based on their general characteristics. The two major subsets are linear and stacked codes. Further segregation is provided by the type of information the code can represent including alphanumeric or numeric information. As was indicated previously, the researchers have reviewed a large number of bar code symbologies to identify those most suitable for transit applications. The paragraphs which follow provide information on these symbologies.

It should be noted that it is not absolutely necessary to select a single symbology for use in a system. Many bar code scanners and decoders have auto-discrimination capability which allows them to recognize and decode several symbologies. A potential application of this capability is in material management. A number of commercial automotive products are used in bus and support vehicle maintenance. Most of these products come from the manufacturer with UPC codes intended for use retail point of sale applications. The ability to recognize these UPC codes in conjunction with a more general purpose code used for other types of material can allow the benefits of unit labeling to be realized. This will come without the cost and labor of producing and applying the unit labels. If this approach is pursued, however, it is recommended that the number of codes used in the system be restricted to no more than two. In addition, it is recommended that Code 39 and 12 of 5 symbologies not be used together since under some circumstances, a partial scan of an 12 of 5 symbol can be interpreted as a valid Code 39 scan.

LINEAR BAR CODY SYMBOLOGIES

In a linear bar code, the characters are ordered sequentially on a single line. Figure 3-2 illustrates the general arrangement of a linear bar code symbol. These are the most extensively used types of codes. Linear codes include both numeric and alphanumeric types of bar codes. Alphanumeric codes include those capable of presenting all 26 alpha characters along with 10 numeric digits. Some alphanumeric codes provide additional flexibility by including both upper and lower case characters. Generally, both types of codes include some forms of punctuation symbols. The paragraphs which follow provide details of the most commonly used linear alphanumeric and numeric bar codes.

LINEAR ALPHANUMERIC SYMBOLOGIES

The most common linear alphanumeric bar code symbologies include Code 39 and Code 128. Both of these symbologies can encode both numbers and alphanumerics giving them the necessary flexibility to facilitate their use in a variety of transit applications. The benefit of alphanumeric codes is that they can be applied to a large number of processes and materials without changes to existing identifiers (part numbers, storage locations, etc.) as can be the case where numeric only codes are employed. Code 39 may have a slight edge as it has been adopted by the Automotive Industry Action Group for the marking of automobile parts and has found some use in the bus and truck industries. As a result, spare parts and other inventory received by transit systems may come from the manufacturer marked with Code 39 bar codes. There is cost savings to be realized in the event that the parts do not have to be bar coded upon receipt. In the event that these savings can not be realized through the use of Code 39, Code 128 may be preferable as it has greater density (i.e., encoded characters per inch of bar code label). The final selection will be driven the data encoding requirements and the space available for bar code labels. The paragraphs which follow provide details of the characteristics of these two types of bar codes.

CODE 39

Code 39 was first introduced in 1975 and accounts for 90% of non-retail bar coding use. Code 39 has been adopted by the Department of Defense for management of all materials used by the armed forces and is the subject of a Department of Defense standard. In addition, Code 39 has been adopted by the Automotive Industry Action Group (AIAG) to identify materials used in the automotive industry. For this reason, spare bus parts may be shipped to transit systems bearing Code 39 bar codes.

A significant feature of Code 39's acceptance is its ability to encode data using the full alphanumeric character set. Code 39 is based on nine element (i.e., bar and space) wide characters, with three (3) of the nine (9) elements being wide and the remaining six (6) being narrow. The ratio of the wide to narrow elements is variable and is in the range of 2:1 and 3:1. This ration is commonly referred to as the "n" ratio. For symbols with a bar width less than 20 mils, the "n" ratio must not be less than 2.2:1. Generally the greater the ratio, the more reliable the reading of the bar codes will be. In addition, Code 39 specifies an inter-character gap which is commonly one (1) bar width.

Each of the encoded characters is made up of five (5) bars along with four (4) corresponding spaces. The encoded character set includes 26 upper case alpha characters, 10 numeric digits and six symbols including"-", ".", "$", "/", "+", and "%". It is possible to encode the entire ASCII character set using Code 39, however, the resulting bar code symbols are very large and cumbersome to use. For this reason, this practice is seldom employed.

The length of Code 39 bar codes is variable based on the number of characters encoded. In general, Code 39 bar codes should be no greater than 25 characters in length for purposes of practicality and to insure high first scan read rates.

The overall length of a bar code employing Code 39 can be calculated based on the parameters described above. The applicable formula is as follows:

$$L = 2\ (10W) + (X+2)(3R+6)W + (X+ 1)G$$

Where:

L = Length of the bar code including the quiet zones

W = Element with (bar/space)

X = Number of Data Characters

R = Wide to Narrow Element Ratio

G = Inter-character Gap

As an example, for a bar code with 10 encoded characters, an element width of 20 mils, a wide to narrow ratio of 2.2 and an inter-character gap of one element width, the total length of the bar code will be equal to 3.64 inches. As can be seen from the formula, Code 39 bar code labels can become extremely long which represents their most significant drawback. A variant of Code 39, Code 93 was developed to address this problem and yields labels which are approximately 30% shorter in length. In general, however, Code 93 has seen very limited use. Where greater density is desired in a linear alphanumeric bar code, Code 128 is most often employed.

Code 39 uses identical start and stop characters with the character "*" being most commonly used. In addition, Code 39 is self-checking and does not commonly employ a check character assuming high resolution bar code printing is employed. For bar coding applications requiring high degrees of data security and integrity, it is possible to specify an optional module 43 check character. One example of the use of this check character is the Health Industry Bar Code Council (HIBCC) use of Code 39 for health care applications. Generally, the use of a check character is not required, however, applications employing dot matrix printers or low resolution laser printers (150 DPI or less) will achieve increases in data accuracy through the use of a check character.

Code 39 is unique in that there is considerable test data available which substantiates its error rates. A substitution error rate of I in 70 million can be obtained using Code 39 if high quality bar code symbols conforming Grade A as defined in the ANSI publication "Guideline for Bar Code Print Quality" are employed. Generally, a high resolution printer using laser or thermal printing techniques is required to achieve this grade of quality. For labels printed with a standard dot matrix printer, a substitution error rate of 1 in 3 million will be realized.

CODE 128

Code 128 was introduced in 1981 and provides encoding of the full ASCII character set. This code has a number of unique features which are making it a preferred choice for new bar code applications. A variant of Code 128 has been adopted by the Uniform Code Council (UCC) for use in distribution applications where serialized containers are used.

Code 128 has a character structure consisting of 11 modules with each character having three bars and three spaces. Figure 3-3 illustrates the Number 0 represented in Code 128 illustrating the three bars and three spaces. The width of individual bars and spaces may range from one (1) to four (4) modules. Single start and stop character are employed. Code 128 is highly flexible in that it actually encodes three separate ASCII character sets with the character set selection made via the start characters. Start Code A indicates that the data includes numeric, upper case alphanumeric and selected ASCII control characters. Start Code B indicates that the following data includes numeric, both upper and lower case alphanumeric characters and ASCII control characters. Start Code C indicates that the data which follows is a sequence of number pairs ranging from 00 to 99 providing a double density representation of numeric information. The start and stop characters differ from the data characters in that they are thirteen modules wide and are comprised of four bars and three spaces. The final two modules of the stop character are used to form a termination bar making the stop character 13 modules wide. In addition, Code 128 includes a check character used to verify that the data scanned is correct. The check character is calculated mathematically and is equal to the module 103 sum of the start character value and the weighted values of the data characters. Code 128 does not employ an inter-character gap like Code 39.

As with Code 39 labels, the length of Code 128 labels is variable based on the length of the encoded data. The overall length of a Code 128 symbol can be calculated based on the parameters described above. The applicable formula is as follows:

$$L = 2\,(10W) + (11+11+13)W + (11X)W$$

Where:

L = Length of the bar code including quiet zones

W = Element width (bar/space)

X = Number of Data Characters

As an example, for a bar code with 10 data characters and an element width of 20 mils (0.020), the total length of the bar code will be equal to 3.30 inches as opposed to 3.64 for an equivalent Code 39 label. Additional efficiency is obtained in cases where the double density numeric information can be used. For this reason, Code 128 is most often employed when greater data density is required.

LINEAR NUMERIC SYMBOLOGIES

The most common linear numeric symbologies include Universal Product Codes (UPC) Codes and Interleaved 2 of 5 Code. These symbologies are limited to representing numeric information only and do not include any symbols or other characters. While other linear numeric symbologies such as Code 11, Codabar and Code 2 of 5 exist, they are limited in their applications in industry and are used mostly in industries unrelated to transit. As an example, Code 11 has found extensive use in the telecommunications industry for labeling small components due to its high density and resulting ability to pack large amounts of data into a small label. Codabar has been adopted by Federal Express for coding air bills and has also seen use in libraries and blood banks. Code 2 of 5 was developed in 1968 and is characterized by low density. This symbology has been supplanted by the Interleaved 2 of 5 code which is more dense.

Of the linear numeric symbologies, Interleaved 2 of 5 is the most suitable for use in transit applications due to its high density. As was introduced previously, UPC codes may play some role in transit applications as it is used to mark commercial products such as automotive parts and cleaning solutions which see use in transit operations. Though not suitable for use as the main bar code in a transit application, it may be desirable to have equipment which can read and decode the UPC symbols to exploit the existing bar codes on these commercial produces. The paragraphs which follow provide details of the linear numeric symbologies suitable for transit applications.

UPC CODES

Universal Product Codes were originally developed for use in the grocery industry but been applied in all types of retail applications. As a result, UPC codes are used on all types of automotive products. There are a variety of UPC codes including UPC-A, UPC-D, and UPC-E. The most significant difference between these types is the number of digits which are encoded. UPC-A bar codes are the most commonly used form and are fixed in length at 12 characters including a check character. UPC-D bar codes have a variable length code up to 27 data characters in length. UPC-E codes are six (6) characters in length and employ a zero suppression technique to optimize the information carried on the label. In addition, a set of supplementary UPC symbols were developed to encode the publication date for periodicals such as newspapers and magazines.

UPC codes consist of two parts: a five (5) digit manufacturer identifier and a five (5) digit product identifier code. The manufacturer and product identifiers are unique and are assigned by the Uniform Code Council. The two parts of the code are separated by two center guard bars. Similarly, the entire symbol is enclosed by pairs of guard bars at the leading and trailing ends of the bar code. The data in a UPC code is framed by a leading number system digit which is used as a product category designator, and a trailing check digit mathematically derived from the preceding 11 digits of data within the guard bars. A weighting scheme is used in the calculation of the check digit which helps to prevent against transposition errors in the event the data needs to be entered manually as is sometimes done in supermarkets and other retail establishments.

Digits within a UPC bar code consists of two (2) bars and two (2) spaces contained within seven modules. This code has a total of twenty unique patterns which can be created although only ten are used in current UPC variants. The width of bars and spaces in a UPC code may vary from one (I) to four (4) modules in width. The normal size of a UPC module (bar/space) width is 13 mils (( )13). Reduction or magnification of UPC bar codes in e range of 80% to 200% are specified to allow a vary of printing techniques to be employed in the reproduction of the codes. Because of their fixed data content, UPC-A codes are fixed in length at 1.469 inches assuming magnification is not used. A quiet zone of 0.117" is specified for both the right and left sides of the bar code making the total length of a UPC-A bar code label 1.703". A UPC-E symbol is only 0.871" in length and is designed for use on small packages.

INTERLEAVED 2 OF 5 CODE

Interleaved 2 of 5 code (1 2 of 5) was developed from the original 2 of 5 code introduced in 1968. A drawback of the original 2 of 5 code was that it had low density which the development of the 1 2 of 5 code addressed. 1 2 of 5 code has seen significant use in ware-housing and distribution operations and was recommended by the Distribution Symbology Study Group for the labeling of corrugated shipping cartons.

Each 1 2 of 5 character actually encodes two separate digits. For this reason, only numbers with an event number of digits can be encoded. Where the number to be encoded has an odd number of digits, a leading zero can be added. One digit is coded in the bars with the second coded in the spaces. Each character includes five (5) bars with three (3) being narrow and two (2) being wide. There are also five spaces in each character with two (2) being wide and three (3) being narrow. Within a stream of data to be encoded, the even positions are encoded in the spaces while the odd-numbered positions are encoded in the bars. An 1 2 of 5 character has only two element widths. The ratio of the element widths (i.e., wide to narrow) is within the range of 2.0 to 3.0. As with other bar codes, the element width is also variable with the practical minimum being 5 mils. The data in an 1 2 of 5 bar code is framed by a start code consisting of two (2) narrow bars and two (2) narrow spaces, and a stop code consisting of a wide bar, narrow space and a narrow bar. As with other bar codes, a quiet zone of 10 times the minimum element width should be employed.

A drawback of the 1 2 of 5 code is that a partial scan (i.e., scan not including both quiet zones) can be decoded as a valid but shorter bar code. The primary reasons for this situation is the simplicity of the start and stop codes and the fact that they can be confused with portions of 12 of 5 patterns for the numbers 0 through 9. For this reason, 1 2 of 5 bar codes often use a module 10 check digit in the final position. In addition, protection bars touching and perpendicular to the lines and spaces of the code are also used. In the event that the path of the scan enters or leaves the bar code symbol through the top or bottom protection bar, an invalid stop or start code will be read.

As with other symbology types, the length of 1 2 of 5 bar code labels varies with the number of digits encoded and element widths. The overall length of an 1 2 of 5 symbol can be calculated based on the parameters described above. The applicable formula is as follows:

$$L = 2 (10W) + (X (2R + 3) +6 +N) W$$

Where:

L = Length of the bar code including quiet zones

W = Element width (bar/space)

R = Wide to Narrow Element Ratio

X = Number of Data Characters

As an example, for a bar code with 10 encoded characters, a wide to narrow ratio of 2.2, and an element width of 20 mils (0.020), the total length of the bar code will be 2.04" as opposed to 3.30" for a Code 128 label and 3.64" for an equivalent Code 39 label. Based on this comparison, it can be seen that Code 1 2 of 5 provides greater density than Codes 39 or 128.

STACKED CODES

Stacked bar codes were developed as a means to further increase bar code symbol density. In addition, stacked bar codes are a means to overcome the inherent length limitations of linear bar codes. Based on industry experience with bar coding, it takes between six (6) and eight (8) years for a new symbology to gain widespread use. As the first stacked bar code was introduced in 1987, they have yet to enter into the mainstream of bar coding applications.

In general, line bar codes are suitable for transit applications such as he management of assets, material and maintenance operations. Stacked bar codes are somewhat specialized and should not be used as the main bar code in a system. They may be useful where it is desirable to keep maintenance and configuration information for larger units such as engines, transmissions, air conditioning units, fareboxes and traction motors with the unit at all times. Using a dense stacked bar code such as PDF417, a fully detailed unit history can placed on a tag which is kept with the unit, rather than using a log book or other documentation which must be stored separately. Stacked bar codes may also be useful in material management applications where multiple pieces of data are required to identify an item. An example of this is a shelf life item where the expiration date is important or serialized items.

Stacked bar codes must be read using a modified moving beam (laser) scanner. The scanner must be able to reconstruct the entire message following the read of the last line. The lines can be read in any order with the scanner performing the appropriate re-sequencing during the process of reconstructing the message. Such scanners are more costly due to the required processing and data storage capability which must be built into the unit. The paragraphs which follow provides information on the three (3) most common stacked bar codes including Code 49, Code 16K and PDF417.

CODE 49

Code 49 is the oldest of the stacked bar code symbologies and was introduced in 1987. Code 49 is an alphanumeric symbology which includes the entire ASCII character set. The symbols can contain between two (2) and eight (8) rows with separator bars between each. Each row of the symbol contains eighteen (18) bars and is seventy (70) modules in length. The rows contain a start character consisting of two (2) modules, four (4) data words encoding eight (8) alphanumeric characters including a row check character, and four module wide stop character. Code 49 also has a numeric mode where three (3) characters are used to encode five digits. The first n-I rows of the code contain the data while the final ("n" th) row includes an encoded representation of the number of rows in the symbol as well as the symbol check words. Symbols with 7 and 8 rows have three (3) check words which are included in the last row while symbols with less than 6 rows employ two (2) check words. As a result, the data encoding capability of various formats of Code 49 symbols are as shown in **Table 3-2:**

Table 3-2

Code 49 Data Encoding Capability

Number of Rows	Number of Alphanumeric Characters	Number of Numeric Characters
2	9	15
3	16	26
4	23	38
5	30	50
6	37	61
7	42	70
8	49	81

Code 49 requires asymmetrical quiet zones with the left zone being a minimum of ten (10) modules in width and the right zone being a minimum of one (1) module in width. The minimum width for a modules in a Code 49 symbol is 7.5 mils with a minimum row height of 8 mils. As a result, Code 49 symbols have a maximum density of 170 characters per square inch which exceeds its maximum encoding capability as presented in the table above.

CODE 16K

Code 16K was developed as an alternative to Code 49 and introduced in 1989. It employs the general structure and encoding techniques of Code 128 described previously in this report. Code 16K is similar to the structure of Code 49 in that it employs rows separated by barrier bars, however the basic capability of

Code 16K includes a maximum of 16 rows as opposed to eight for Code 49. Each of the rows is 70 modules long and contains five (5) ASCII characters. Code 16K employs a reverse encoding scheme based on Code 128 where bars and spices are reversed (i.e., bars are white and spaces are blank). Each row starts and ends with a single UPC character which is used to identify the row number an scan direction. These characters differ for each row in the symbol and form unique combinations. As an example, the start characters for rows 7 and 16 are the same but they employ different stop characters. Code 16K differs from Code 49 in that it does not employ row check characters. The last row of the symbol includes two (2) check words.

For small size labels (8 rows or less), Code 49 symbols can achieve a greater density than Code 16K. Where a larger label is employed, Code 16K surpasses the density possible with Code 49. The relative capacities of Code 49 and Code 16K labels for a given number of rows is provided in **Table 3-3**:

Table 3-3

Comparison of Code 49 and Code 16K

Number of Rows	No. of Alphanumeric Characters		No. of Numeric Characters	
	Code 49	Code 16K	Code 49	Code 16K
2	9	7	15	14
3	16	14	26	24
4	23	17	38	34
5	30	22	50	44
6	37	27	61	54
7	42	32	70	64
8	49	37	81	74
9	-	42	-	84
10	-	47	-	94
11	-	52	-	104
12	-	57	-	114
13	-	62	-	124
14	-	67	-	134
15	-	72	-	144
16	-	77	-	154

Where fewer characters or numbers are required, a pad character is used to fill out the final row of the symbol. In addition, the pad character can be used within the symbol to define multiple data fields. As an example, this feature can be used on a component to define the model number, part number, serial number and other pertinent information within a single code.

Code 16K also includes an extended mode where up to 107 sixteen (16 row) symbols can be concatenated together to provide a total capacity of 8,025 ASCII characters or 16,050 numeric characters. Where this mode is employed, the first three characters of each individual symbol are used to define the character set employed, the sequence number of the individual symbol in the entire block, and the number of symbols in the block.

The minimum element size for a Code 16K symbol is 7.5 mils. This results in a maximum symbol density of 208 alphanumeric or 417 numeric characters per square inch. This compares to 170 alphanumeric characters per square inch for Code 49. As in the case of Code 49 symbols, Code 16K symbol's maximum density exceeds its encoding capability.

As with any other stacked bar codes, Code 16K must be read using a moving beam scanner. Code 16K differs from Code 49 in that the rows can be read in any order. In addition, the hardware is simpler since any scanner that can decode Code 128 symbols can be adapted to Code 16K with little effort. For this reason, most commercial scanners that have the ability to decode Code 128 symbols also have the ability to decode Code 16K symbols.

PDF417

PDF417 was introduced in 1990 and represents an entirely different approach to bar coding. PDF is an abbreviation of Portable Data File which captures the essence of its capabilities. Normally, bar codes are used as indices for database files which contain more information about the item which was bar codes. The idea behind PDF417 is to encode the database information so it can travel with the object that it describes. It is envisioned that PDF417 symbols could provide major benefits when used for component assemblies that need to have their configuration and/or complete maintenance history tracked. A maintainer needing details of the unit history need only insert the PDF417 symbol into a reader to recall the, information. Similarly, following a repair action, a new PDF417 symbol can be generated to update the history.

PDF417 is based on equal length code words consisting of 17 modules. Each of the modules contains four (4) bars and four (4) spaces of widths ranging from two (2) to six (6) modules. Like other bar codes, PDF417 has a minimum module width of 7.5 mils. As a result of the encoding scheme, 10,480 unique code words may be represented. Currently, PDF417 employs only 929 of these code words, allowing for significant growth. The symbols are arranged into rows similar to other stacked bar codes with each row containing a checksum. Additional data security is provided by two error detection codes which are part of each symbol. Start and stop characters are used with these characters extending the full height of the symbol.

PDF417 is highly flexible in that it has a total of fifteen (15) operating modes. These modes are essentially different character sets including standard predefined modes, reserved modes for future applications and user definable modes. PDF417 functions by decoding a symbol and then performing a look-up in a table to determine the meaning of the code word. The drawback to this flexibility is that the required scanners are complex as they need significant amounts of memory to store the look-up tables.

All of the other bar code standards described in preceding sections of this document are in the public domain and available for use by manufacturers in the development of bar code system hardware and software. In no case were any of these standards patented by the developer. PDF417 is different as it was patented by its developer. Until very recently (May 1994), there was considerable uncertainty as to whether or not PDF417 could be used without obtaining a license or paying a royalty to the patent holder. This had the effect of limiting the growth of PDF417 by stifling the development of products employing the standard. This situation was rectified when the patent holder released a statement indicating that PDF417 symbology as presented in the

AIM specification is in the public domain and free from any form of usage restriction, licenses and fees." With this situation resolved, the path is clear for the development of PDF417 based components which can be integrated into bar coding systems.

BAR CODE SCANNERS

A bar code scanner is used to extract the information contained in a bar code symbol. All existing bar code scanners use electro-optic techniques where the scanner light source illuminates the label and measures the reflected light to identify the presence of a space or a bar. Once the label is read, the scanner converts the information to a format which can be used by a computer system or stored for later use. Figure 3-4 illustrates the general scanning process and shows the output wave-form which is converted to data.

Several issues must be considered in the selection of a scanner type. The first consideration is related to how bar codes will be used in the system. Additional considerations include the environment in the facility where the bar codes will be used, and work procedures employed. It is also important to note that the selection of the scanner has a bearing on the bar code label printing process, printing equipment and media on which the symbols will be printed. These subjects will be addressed in later portions of this document. The paragraphs which follow provide an overview of scanner characteristics and provides details of a variety of scanner types.

SCANNER CHARACTERISTICS

There are basic characteristics which are common to all scanners. In the selection of a bar code scanner, these characteristics must be reviewed in detail and related to other elements of the bar code system (symbology, print methodology, etc.) if high first read rates are to be realized. These characteristics include scanner spot size, scan rate, depth of field, and scanner pitch and skew.

Regardless of the technology it employs, every scanner projects light which is used to measure the ref
lectance of the bar code label. Measurements of the reflected light are made using either single photodetectors or arrays of photodetectors. In all cases, the resolution of the scanner is deter lined by the size of the detector or spot. As was introduced above, each bar code consists of a number of bars and spaces (elements) which have a minimum width characteristic. This minimum width has a practical range of to 50 mils. The size of the scanner light spot must be related to this minimum element width to insure high first read rates. Generally, the scanner spot should be between 75 and 100% of the minimum element width. As an example, for a minimum element width of 10 mils, the spot should be approximately 8 mils or 0.080" in diameter. If the size of the spot is much less than the minimum element width, it is possible that small spots and printing voids in the bars will be interpreted as bars and spaces reducing the first read rate. This is of particular concern when using symbols generated with dot matrix printers. If the spot is larger than the minimum element, it is possible that it will cover multiple elements simultaneously and they will not be individually distinguished. The shape of the spot includes both circles and elongated ovals. Generally, the elongated oval is preferable since it helps to reduce the effects of minor printing defects. The elongated oval spot works best where the long axis of the spot is parallel to the edges of the symbols bars.

As indicated above, scanners operate by measuring the amount of light reflected from the bars and spaces of a symbol. The color of the light becomes an important factor in the selection of the scanner and also the printing technique to be used for the labels. As an example, if the bar code symbol consists of red bars on a white background and the scanner used red light, there will be virtually no contrast between the bars and spaces and the symbol will not be read. The color of the light is directly related to its wavelength. Most bar code scanners operate at a wavelength of 633 or 900 nanometers. Light with a wavelength of 633 nm is in the red region while 900 nm light is in the infrared region. The interaction between the scanner and the printing process employed for the bar code labels is a factor which must be considered. As examples, labels printed with carbon-based ink can be read by both 633 and 900 nm light while some thermally printed labels have sufficient contrast when used with a 633 nm scanner. Another factor to consider in the selection of the scanner is the visual cues required to help the human operator aim the scanner at the label.

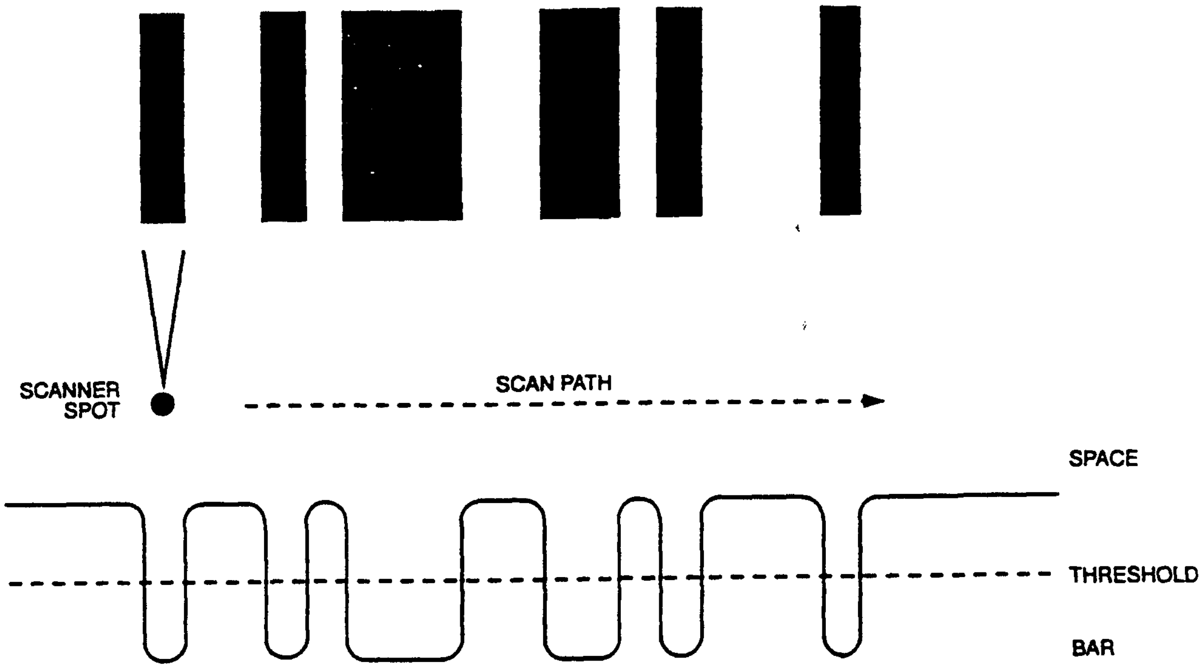

Figure 3-4. Bar Code Scanning Process

The human eye operates over a range of 450 to 750 nanometers which covers the visible light range. The operator will be able to see the beam created by a 633 nm scanner making it easier for the operator to aim. If a 900 nm device is used it should have a visible beam of light or similar feature to assist the user in aiming.

Laser and CCD scanners have a characteristic scanning rate. For a laser scanner, this is defined as the number of times per second that the light beam sweeps across the bar code symbol per second. For a CCD scanner, this is defined as the number of times per second that the data register collects information from the photodetector array. For a LED wand scanner, the sweep rate is a mechanical process determined by how fast the user moves the wand across the symbol. A moving beam or laser scanner will sweep across the label an average of 40 times per second. Using this type of device, the first read rate becomes a non-issue since the operator will not really be aware if the first or second read is unsuccessful. An infrared CCD image scanner approaches 50 scans per second and again the first read rate is a non-issue. At the other end of the spectrum, a LED wand will have an approximate scan rate of one (1) per second. If the first read is not successful, the operator will need to repeat this mechanical process. Another problem with wand type scanners is that the scan path is determined by the sweep of the user's arm which as the length of the label increases, becomes a perceptible arc. This arc shaped scan path gives rise to the possibility that the scan may start or end outside the quiet zones resulting in a failed or erroneous read. This is enough of a problem that the 1 2 of 5 symbology specification includes provisions for border bars at the top and bottom of the symbol to allow a bad scan path to be detected.

Another factor in the selection of a bar code scanner is its depth of field. The depth of field is a measure of the maximum distance between the label and scanner that will yield a successful symbol read. Depth of field is defined by the optics of the scanner which are used to focus the spot used to read the bar code symbol. A related parameter is the optical throw or the distance that the scanner can project its light source. The optical throw is the determining factor of the maximum point of the depth of field. The light source focusing optics determine the minimum point of the depth of field. There are significant differences in the depth of field and optical throw for the various types of scanners. Laser scanners can read labels from distances of a few inches up to several feet. High performance laser scanners are available which allow labels to be read from a distance of up to 30 feet. Other devices such as infrared CCD and LED wand type scanners have depths of field less than one (1) inch. For this reason, these two types are referred to as contact scanners. In the case of a warehouse application with bar coded location identifiers, a laser scanner is often preferable as it will make it easier for the operator to scan the location label. An example is the case where pallet racks are used to store major assemblies such as traction motors or gearboxes. Most often, the operator will store the material using a fork truck and will not have close range access to the location bar code label. For other applications such as maintenance management, time and attendance collection and asset management, a wand or CCD device is more suitable since the bar coded documents or objects involved are readily accessible to the user and contact scanning is possible.

As the operation of a scanner depends on reflections of light from the bar code symbol, the orientation of the scanner relative to the symbol is important. Generally, bar code labels are printed on matte finish material which results in diffuse reflectance of the light beam. Diffuse reflectance is characterized by an even distribution of the light in all directions. This is as opposed to specular reflection, such as the case of a mirror, where the angle of incidence of the light is equal to the angle of reflection. In the case of diffuse reflectance, the intensity of the reflected light varies with the cosine of the angle of incidence. Generally, the angle of incidence of the scanner to the label should be less than 45 degrees off a line perpendicular to the label. In this way, approximately 70% of the incident light will be reflected back to the scanner. As the orientation of the scanner relative to the label for hand held scanners is determined by the user, this issue is more one of training rather than the scanner hardware characteristics. For this reason, orientation of the scanner relative to the label should be a part of the training afforded the users of the bar code system.

SCANNER TYPES

There are three major classifications into which bar code scanners fall. These classifications are based on the light source and reflection measurement technology the device employs and includes, LED, CCD and Laser scanners. In selecting these devices for an application, consideration must be given to the process of data collection which can vary greatly from location to location. It is not uncommon for multiple types of bar code scanners to be used within a single bar coding application. Selection of a scanner for use is not the key technological decision in the design of a bar code system. It is important, however, in that it has significant bearing on the ease of use of the system and as a result, impacts the system productivity In selecting a scanner, it is important to fully underground the environment in which the scanner will be use One key environmental factor is the accessibility of the bar code label to the system user. If the user has direct access to the symbol and can place a scanner in contact with it, a relatively lower cost LED or CCD scanner can be employed. On the other hand, if the user must read the label from a distance, a laser scanner will be required. The paragraphs which follow provide details of each of these types of scanner as well as guidelines for their use.

LED SCANNERS

LED scanners use a Light Emitting Diode (LED) as the bar code illuminating light source. Scanners employing LEDs are generally packaged as wands which are designed to emulate a writing instrument in operation and required contact with the bar code label to perform a scan operation. Some LED scanners are configured as a slot reader. These scanners are fixed in location and the user passes a bar coded document or card through the slot to perform the read. In selected applications these scanners may result in greater first read rates since the slot guides the bar code past the scanner insuring a good scan path.

The design of LED scanners is very simple, and as a result, they are very rugged. LED scanners generally operate in the 660 nm (red visible light) region although some devices operate at a wavelength of 940 nm (infrared). One possible use for an infrared LED wand scanner is time and attendance or access control systems where a red film is placed over the bar code on an employee badge to prevent reproduction resulting in fraud. In the event that an infrared LED scanner is selected, it will be necessary to employ high-carbon content ink when printing the labels to insure high first read rates.

LED-based scanners are available with optical resolutions (spot sizes) of 4 mils, 6 mils and 13 mils making them suitable for use with bar codes having minimum element sizes in the range of 5 to 16 mils. LED-based wand scanners have virtually no depth of field, however they are capable of reading through a protective film applied over a bar code label for protection. To insure that labels are read properly with an LED wand scanner, it must be held at an angle of approximately 30 to a line perpendicular to the surface of the label. This position is easy to attain since it is approximately the position in which most people hold a writing instrument. As an LED wand user is required to move the device across the label to complete a scan, the operators must be trained to move the scanner from quiet zone to quiet zone to achieve high first read rates.

LED scanners have achieved widespread use in industry for applications including time and attendance data collection, and manufacturing work-in-process management. They are useful in similar applications in transit as well as applications such as maintenance management where a mechanic is required to scan a repair order or similar document for labor collection. Wand scanners are not recommended for use with stacked bar codes due to the dense nature of these bar codes and the fact that the entire code must be read to decode the symbol.

As this process spans several rows, it is best accomplished with a moving beam laser scanner. As a rule, LED scanners are suitable for applications where the operator can place the wand indirect contact with a bar coded object. Their small size makes them particularly suitable for use with smaller data collection devices such as portable terminals and fixed location data collection terminals.

In the event that LED wand scanners are selected, it is recommended that preventive maintenance procedures be applied to the tip of the wand. The tip of the wand often has a plastic window which can become scratched or clouded following repeated contact with bar code labels. To insure high first read rates, the tips should be replaced periodically.

CCD SCANNERS

Charge Coupled Devices (CCD) have seen significant growth in their use in recent years. CCDs are used in a variety of imaging applications are were a key technology in the development of economically priced Camcorders for the consumer market as well as low cost CCTV equipment. CCD scanners represent a completely different approach to scanning from those of wand and laser scanners. While wand and laser scanners examine individual elements of a bar code, the CCD device is able to image the ntire bar code simultaneously. As shown in **Figure 3-6**, CCD scanners are relatively simple in design and as result are very rugged.

Figure 3-6 is a block diagram illustrating the major components of a CCD scanner. CCD scanners operate by illuminating the symbol with light which can be either visible or infrared. To eliminate problems induced through motion of the device during the scan process, some CCD devices use strobed light sources which tend to freeze the image of the bar code, making it easier to scan. The reflected light is then read by a linear array of photodetectors. This process is performed when the trigger on the device is actuated by the user. The number and size of the individual elements in the photodiode array is such that a minimum of two photodiodes are covered by the narrowest element of the bar code. In practice, it is desirable to have four photodiodes per element.

A benefit of this approach is that CCD scanners are able to average out localized bar code label print defects. The size of an individual photodiode is analogous to the optical resolution associated with wand and laser scanners. The output of each photodiode is then captured into a data register to assemble the pattern of bars and spaces in the symbol. This process occurs approximately 50 times per second. The decoder electronics will analyze the information provided from the register to determine if it represents a valid bar code read. In the event the read is not valid, the process will continue until a valid read is performed or until the user releases the trigger. Most CCD scanners will produce a beep or tone when a successful scan is made as a cue to the operator.

CCD scanners have a very limited depth of field (less than 1 inch) and produces the best results when placed in contact with the bar code label. For this reason, CCD scanners are limited in the length of the bar codes that they can read. This length limitation is due to the fact that the entire bar code must be positioned under the photodiode array simultaneously. For most applications this limitation will not pose a problem since most CCD scanners have an array width on the order of four (4) inches.

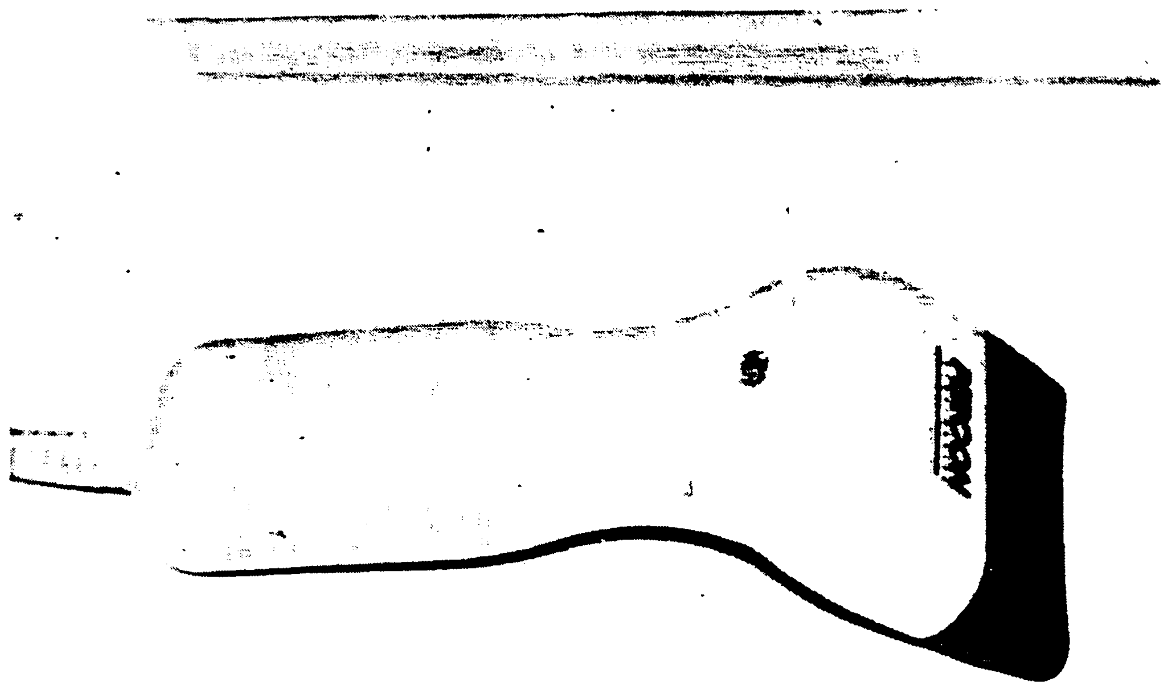

Figure 3-5. CCD Bar Code Scanner

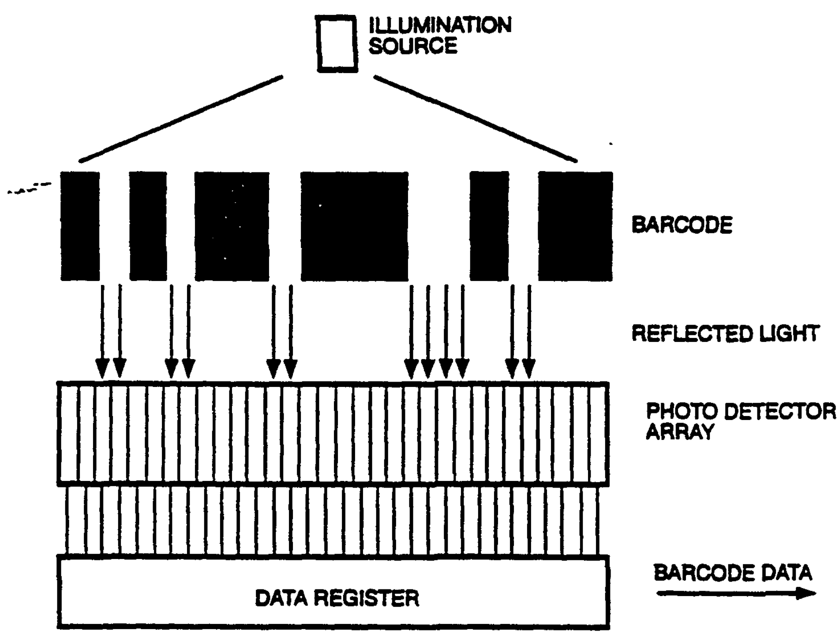

Figure 3-6. CCD Scanner Components

In general, CCD scanners are suitable for the same applications as the LED wands described previously in this report. While the CCD scanner is capable of compensating for print defects, the user must be careful to insure that the scan head is positioned over the entire bar code label. A significant benefit of CCD scanners is that they are much easier to use than wands. This is due to the fact that the user is not required to move the device across the label to scan the symbol. As a result, the user training requirement are less than that of the case where a wand is used. As with wand scanners, CCD scanners are not recommended for use with stacked bar codes.

LASER SCANNERS

There are a variety of laser scanners used in bar code systems. Included among these are fixed position high speed scanners used in throughput intensive applications such as automatic sortation systems at ware-houses and distribution centers. Another example of a laser scanner is the flat bed type used at check-out counters in supermarkets and other retail establishments.

The most common application of laser scanners, however, is hand held, gun-type units used with computer terminals, portable data collection devices and fixed data collection terminals. Figure 3-7 illustrates a common gun-type laser scanning.

Laser scanners are a beam of high-energy light to illuminate the bar core. Generally, laser scanners produce one (1) milliwatt of energy. They operate by using a HeNe (Helium-Neon) laser tube, an infrared laser diode or a solid state laser diode to project a beam of light onto a moving prism or mirror. The HeNe and solid state lasers produce visible light which provides visual cues to the operator to assist in the scanning of labels. Infrared diode based devices commonly have a visible marker light beam to assist the operator. The motion of the mirror or prism creates a linear oscillation of the spot of light which sweeps across the bar code label. Laser scanners can scan bar code labels at a rate of 40 scans per second with the spot appearing to be a line due to the rapid motion. While a bar code label in good condition can be read in a single pass, damaged or poorly printed

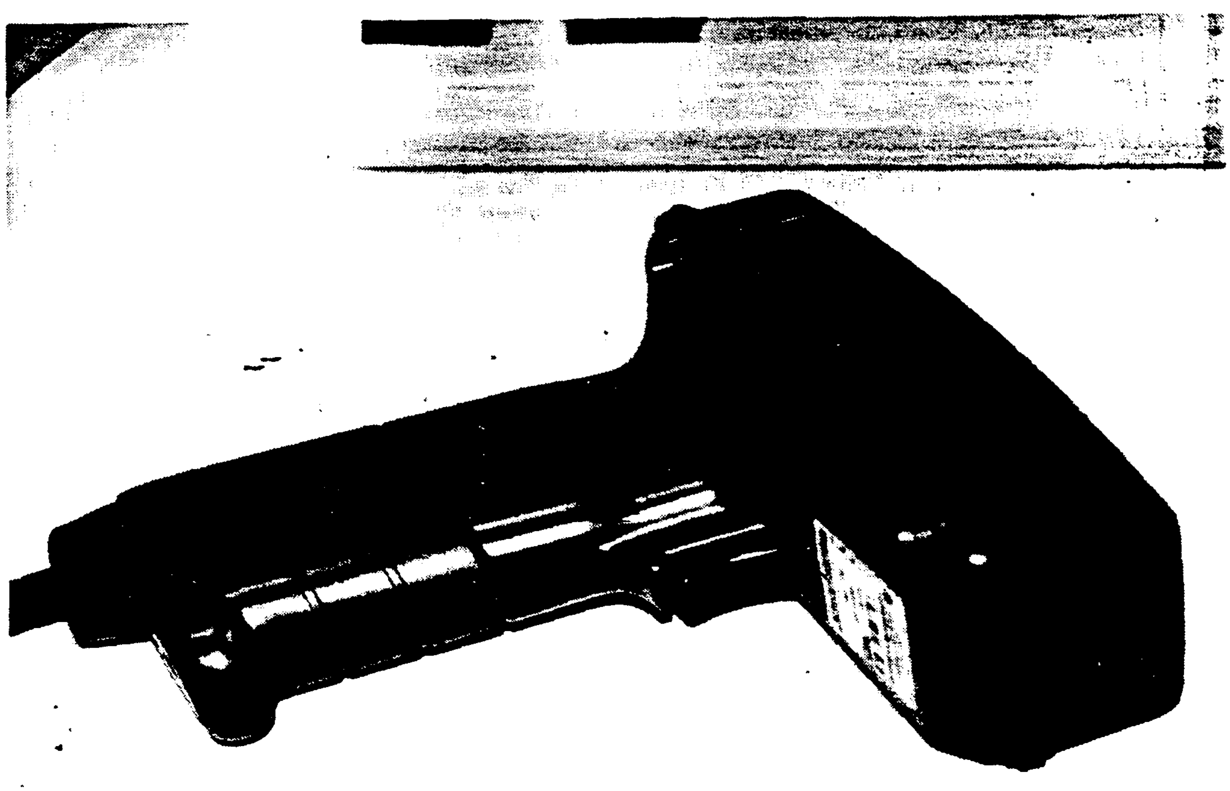

Figure 3-7. Laser Bar Code Scanner

labels will require multiple passes to find an acceptable scan path. As this will be done automatically, it will be transparent to the user. This is as opposed to the case of LED wands where the operator will be required to manually rescan the bar code.

Because of the relative complexity of the optics in a laser scanner, they are less rugged than the wand and CCD scanners described above. Most laser scanners are designed with high impact plastic cases to enhance their durability. Generally, a good quality laser scanner will survive a six foot drop onto a concrete floor without damage. More durable units are beginning to enter the marketplace with internal and external cushioning.

Hand-held laser scanners include a trigger which activates the laser and starts the scanning process. Each time the spot moves across the bar code label, a frame of data is generated. Decoding algorithms within the scanner evaluate this pattern to determine if it represents a valid bar code. In the event that there is a match scanning will stop and the scanner will provide an audible tone to the user indicating that the read is complete. At this time, the laser will be deactivated. This process also prevents multiple copies of the same data from being sent to the computer or data collection device.

Laser light is highly concentrated and, if handled improperly, can cause injury to the user. The human eye is particularly vulnerable to injury from laser light. Two (2) types of laser scanners are available based on the degree of protection they provide. Class I scanners do not carry warning labels and are equipped with features that automatically shut the laser light off. These devices turn the laser off after a period of approximately five (5) seconds and inhibit it from being turned on for several more seconds. Class II scanners carry warning labels and allow the scanner to remain on indefinitely and do not have an inhibit function. Where a damaged or poorly printed label is being scanned, a Class I device may shut off before a good scan can be made. The time delay before a rescan can be attempted may result in inefficiency on the part of the user. In the event that sufficient training is provided to system operators regarding the dangers of laser light, Class II devices can be employed.

By nature, the spot of light produced by the laser will be small. For a laser scanner, the greater the minimum element width, the greater the distance from which the label can be read. The spot tends to disperse over distances and become larger. As a result, it remains matched to the element width for larger labels over greater separation stances. As an example, a label with 10 mil elements can be read with a laser scanner at a distance up to 8 inches. A label with a 50 mil element width can be read from approximately two (2) feet. Some manufacture, produce long range scanners with special optics that increase the scanning range to approximately 25 feet. A newer type of laser scanner has an auto-focus feature that allows it to adjust to varying ranges of separation between the scanner and label. These scanners generally cost between 10 and 20% more than conventional fixed focus laser scanners.

A drawback of laser scanners is that they have a minimum read distance. In general, the scanner must be more than three (3) inches from the scanner. This is due to the fact that the closer the scanner is to the label, the less the scan pattern will spread out. A laser scanner held close to a label may not be able to sense both quiet zones and as a result will not be able to correctly read the label.

Laser scanners are more costly than the other types. In general, laser scanners will be approximately eight (8) times the cost of a wand and approximately double the cost of CCD scanners. For this reason, it is best to carefully analyze the application to determine where laser scanners will be most suitable. Laser scanners are best suited to applications where the operator does not have direct assess to the bar code label. An example of a beneficial application for a laser scanner is material management where large bin or rack structures are employed. Another potential application is asset management applications where assets vary in size and shape, and the location of the identification label can preclude direct access to the bar code label.

BAR CODE LABELS

There are a number of variables associated with the generation of bar code labels. The first of these is where the bar code labels will be generated. Bar code labels can be either printed off-site by a firm specializing in label production or printed at the transit property's facility. In the event that the labels are printed at the transit property's facility, the print methodology and print label media must be considered. Ultimately, the goal is to produce bar code labels which are compatible with the operational requirements of the system and will support the attainment of high first read rates. The paragraphs which follow provide details of all aspects of bar code labels.

BAR CODE LABEL QUALITY

An important consideration in establishing a high first read rate for bar codes is the quality of the bar code label. This quality is a function of the label printing methodology, and the bar code label media or substrate. While bar code standards define symbol element dimensional tolerances and interrelationships, there are variations induced by selections of label printing processes and materials. These variations are compounded by the interaction of the printing materials and processes. An example of these variations is the differences between specular and diffuse reflectivity and their influence on the contrast difference between the bars and spaces of a bar code symbol. More often than not, problems with bar code systems can be traced directly to the quality of the label. For this reason, it is necessary to establish metrics for comparative analysis of the quality of bar code labels.

The American National Standards Institute (ANSI) developed a document entitled "Guidelines for Bar Code Print Quality." This document defines bar code print quality in terms of grades with the range being A through F. This document defines a specific evaluation procedure for bar code labels. This procedure includes performing a sequence of 10 scans of a label at heights equally spaced over its height. The results of each scan are then compared against defined metrics for label criteria such as contrast, decodability and defects. These grades are used to develop a grade for the individual scan with the overall label grade being a weighted average of the individual label scans. In addition to the grading system, the ANSI document provides quality guidelines based on specific label defects. As an example, the standard defines allowable print defects as follows:

1. A size covering no more than 25 percent of the area of a circle with a diameter equal to 80% of the minimum element width and:
2. Not completely covering a circle with a diameter equal to 40% of the minimum element size

While this document is comprehensive, there are no easy ways to implement testing to evaluate all the criteria it defines. For this reason, it is more applicable off-site printing where the label producer can invest the testing process. In addition, it is applicable to the manufacturers of bar code label printers.

There are simpler approaches to verifying the quality of bar code labels at an end user site. The first of these is to perform basic readability tests for the label using the scanning devices employed in the user's system. This can be done periodically on a sampled basis with defective labels subjected to more detailed analysis. Another approach is to use a bar code verifier. A verifier is a commercially available device used to make detailed assessments of bar code label quality. These devices are able to perform testing according to individual aspects of the ANSI standard and can operate with a variety of barcode scanners which allow the testing to emulate operations. Verifiers are also able to perform traditional testing including print quality, wide to narrow ratio, print contrast, reflectance, decode and symbol format verification. These devices are designed for highly flexible testing and can support numerous bar code standards. More advanced bar code verifiers have the ability to log data which can then be retrieved to produce more detailed results. Generally, bar code verifiers cost any-where from one to three times the cost of an individual laser scanner.

BAR CODE LABEL GENERATION METHODOLOGIES

There are a wide variety of ways to produce bar code labels. In the most general terms, a user can print their own labels or purchase them from a commercial supplier of pre-printed labels. In the event that the user elects to produce their own labels, there are a number of alternatives which are possible.

It should also be noted that there are bar code production technologies which do not rely on printing. These include laser and chemical etching of bar codes. These techniques are used in cases where a label or tag cannot be attached to an object, and where the environment where the items will be used would render the label unreadable. Examples of the application of non-printed bar codes include tools or vehicle components exposed to high temperatures, dirt. or solvents.

OFF-SITE PRINTING

In lieu of printing their own labels, transit properties can purchase labels from a printing vendor. These vendors can supply standard labels or can produce a label designed to meet the specific requirements of a transit system. Most label vendors can supply labels using any symbology and containing any type of information. In addition, these vendors will work with the customer to provide an appropriate label medium, adhesive or other means of attaching the label and any type of printing technique.

Vendors of bar code labels will work with their customers to establish the precise requirements for the bar code labels. These requirements include not only the label information requirements but also the requirements imposed by the use of a specific scanning methodology. The experience of these organizations in establishing these requirements may be highly beneficial to a new user of bar coding.

For the majority of bar code or management information systems, duplicate identifications are not supported. For this reason, it is important to manage the database of bar coded identifiers used to insure that duplication does not occur. Most bar code vendors will perform this service for its customers, however to avoid errors, quality assurance checks of labels received from suppliers should be performed.

A number of factors need to be evaluated when making the decision to print labels or buy them from a supplier. These include the following:

- ***Bar Coded Information Content****:* Depending on the functionality of the management information system which will used the bar coded information, the required label content will be consistent or variable. As an example, for a material management system using bar coded storage locations, the information on the label is consistent and predictable. Conversely, if each item of material is to be bar coded, the label information content will depend on the material in inventory and the label requirements can not be accurately predicted. As another example, if defect cards are sequentially bar coded as is done by CT Transit, off-site printing is a viable alternative.

- ***Label Media Requirements****:* If the application requires a specialized label media to compensate for environmental or other conditions, off-site printing may be the only viable alternative. On-site printing is limited to a smaller range of label media.

- ***Specialized Label Content****:* In the case where the information contained on the label is highly specialized, off-site printing may be more desirable. Examples of specialized content includes small bar code element widths, high label density and complex label formats.

- ***Label Quantity Requirements****:* In the event that material storage locations are to be bar coded, a large number of labels will be required at the time of system operational conversion. In this case it may be beneficial to purchase the labels as opposed to printing them. Relatedly, the speed of most printers used for on-site applications is relatively small. As a result, the production of large quantities of labels may be prohibitively time consuming.

- ***Label Quality****:* Label printing requires strict adherence to printer periodic maintenance schedules. As an example, the print head will need to be cleaned on schedule and the printer ribbon will need to be watched closely. Adherence with these requirements will require a conscientious effort and assignment of personnel to the task if the labels are printed on-site. These activities will not present a problem for an off-site printer, however, it may be desirable to require test samples on a periodic basis for the label supplier.

- ***Cost***: Depending on the number of labels required, it may be more cost effective to purchase the labels rather than printing them. When making this assessment, costs such as the printer, print media and label design and generation software must be taken into account.

SITE PRINTED LABELS

A number of technologies are available for the production of bar code labels at a transit property's premises. These technologies include dot matrix, laser and thermal printing. The paragraphs which follow address each of these technologies.

DOT MATRIX PRINTERS

Dot matrix printers were developed as a low coat means of providing for hard copy output from computer systems. They use an array of pins which contact with an inked ribbon to produce printed characters on paper or another substrate. Figure 3-8 illustrates this approach. The pins of the print head are pushed out into contact with the ribbon and paper. Each time the pins of the print head are activated a portion of a character is formed. Large characters are formed by multiple passes of the print head. Generally these pins are circular. Dot matrix printers are suitable where the minimum bar width is 15 mils. The factor which limits the bar width for dot matrix printers is the size of the pins which comprise the print head.

When printing bar codes with a dot matrix printers, there are a number of factors which must be considered. The first factor relates to the way that they form the characters and shapes they are printing. As is shown in Figure 3-9, dot matrix printer output consists of patterns of dots which intersect and overlap. In some cases, it is possible that the dot pattern will leave voids which can be interpreted as spaces resulting in read errors. As the pins are moving as can not touch each other, the overlap must be produced by other factors. This is accomplished by the interaction of the paper and the ink. Porous paper or other print media will cause the ink dot to briefly spread just following contact of the pin. In the event that the ink spreads out too much, the minimum element size of the bar code will increase. If the ink does not spread enough the voids described previously will exist. For these reasons, it is important to insure that an appropriate print media is used and that the ribbon is fresh.

Dot matrix printers have been in use for many years. Even when other types appeared such as laser printers, dot matrix printers remained in use due to their low cost. In more recent years, advanced printing technologies have become more affordable. For this reason, it is not recommended that dot matrix printer be used in new bar coding applications. In the event that they are used, it is recommended that minimum bar widths smaller than 15 mils are not used and that periodic maintenance of the printer is emphasized. In the course of the research, Citizens Area Transit (CAT) in Las Vegas, Nevada reported that they had experienced significant read problems with bar codes produced on a dot

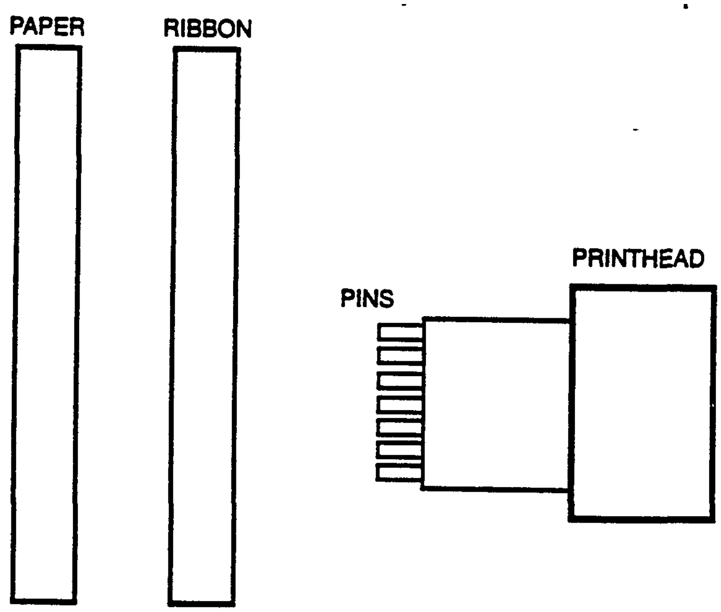

Figure 3-8. Dot Matrix Printer Components

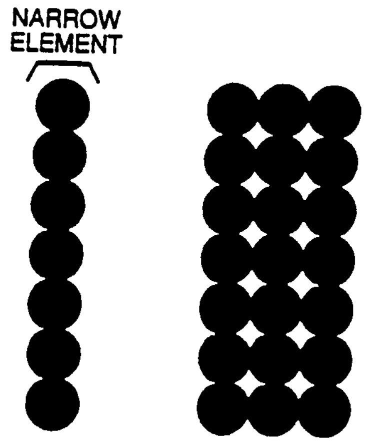

Figure 3-9. Dot Matrix Bar Code Output

matrix printer. As a result of these problems, CAT suspended the use of bar codes until a new printer was purchased.

THERMAL PRINTERS

Thermal printers operate by using heat to form characters and graphics. This is accomplished by the use of a print head containing very small heaters. These heaters are generally in the form of in the form of small squares or rectangles as opposed to the circular shapes used by dot matrix printers. There are two types of thermal printers. The first of these is the direct type uses heat to form characters on media which is impregnated with a chemical which discolors when exposed to heat. The formation of the images is due to a heat induced reaction in this chemical rather than burning. This reaction occurs at temperatures of approximately 450 degrees Fahrenheit. The result of the reaction is dark colored characters (blue or black) on a light substrate. The second type is the thermal transfer variety. These printers use a special ribbon that is in contact with the substrate media. When exposed to heat, the pigmenting material on the ribbon will be transferred to the media. Generally, these ribbons have a wax or resin based ink.

Regardless of the type of thermal printer, they can produce labels with minimum bar widths of 5 mils and maximums up to 50 mils. Thermal printers are well suited to printing labels as they can accept adhesive backed media. In addition, they commonly print on smaller media than most laser printers. Where labels will be printed on-site, each day, thermal printers are a good choice. One concern with direct thermal printers is aging of the substrate or paper. Most of the paper used in thermal printers is photo reactive and will yellow when exposed to daylight or certain kinds of artificial light. In addition, the images on the substrate will fade to the point where the contrast between the bars and spaces is not sufficient to allow a good read of a bar code.

Generally, it is best to keep direct thermal labels away from UV light. Images produced by thermal transfer printers do not suffer from this problem. They are stable and not damaged by temperature or exposure to ultraviolet light. A drawback of the thermal transfer printer is the need for the ribbon which is a consumable items needing periodic replacement.

LASER PRINTERS

Laser printers operate in the same way as copier machines. The image to be produced is written onto an electrically charged, photosensitive drum using a controlled and highly focused laser light source. Toner particles are attracted to the areas on the drum where the image was imposed. The toner image is then transferred to paper and fused in place by heat or pressure.

Because the laser light source can be closely controlled and focused, it is possible to obtain high resolution images. Common laser printers have resolutions of 240 or 300 dots per inch (DPI) while higher performance units can print up to 600 DPI. With bars that are three dots wide, a minimum element width of 10 mils is realizable with 300 DPI printers and 5 mils can be achieved with 600 DPI printers.

Laser printers are highly suitable for use in bar coding applications. They are particularly suited for the generation of documents incorporating bar codes. It should be noted that most laser printers do not have built-in fonts for bar codes. As a result it is necessary to use a plug-in font cartridge or font software to produce bar codes with most printers.

BAR CODE INTERFACING

For bar codes to provide benefits, an interface must be established between the bar code readers and the management information system.

This interface provides a conduit for the delivery of information to the management information system application software. In the event bar coding is included in the initial deployment of the management information system, the issue of the interface will not be problematic. For cases where bar coding is added to an existing information system, this interface is often the most costly and problem prone element of bar coding implementation. Finding the appropriate solution for this interface becomes complex as it must be both electronically and software compatible with the management information system. Central to this interface is a device which decodes the bar code to produce information in a usable format. In addition, this device will perform error checking and notify the user when a valid read of a bar code has been made.

The problem of providing an electronic interface is somewhat abated since there are a bounded number of potential solutions which are defined by mature standards. The software interface does not enjoy this luxury since the functional design of software is more of an art with a greater range of possibilities. Compounding this problem is the fact that the interface must work on both the system and application software levels. The system software (operating system, communications drivers, etc.) must be able, recognize the bar code reader devices. As will be described in detail later in this section, there are multiple approaches to this interface. In some cases, the interface will be transparent to the system software while in other cases it will not. Selection of a particular approach depends on the degree to which bar coding will be used in the system and often is based on a tradeoff between functionality and implementation costs. Where the management information system is based on a commercial software package, the inherent capabilities of the software must be considered. During the transit property survey described in chapter two, a number of instances were identified where properties had MIS systems based on commercial software. In some cases, the properties indicated that the software had inherent bar coding capability but it was not in use. Where this situation exists, the capability of the software should be explored and the appropriate interfacing methodology identified.

Regardless of the system aspects of the interface, it is necessary to fully understand the application software's data requirements. The application software must see correctly formatted data or it will be ignored or induce errors. Development of the required understanding can require working with the original developer of the software or possession of detailed software design documentation. Regardless of whether or not the use of bar coding is contemplated, it is a good management practice to obtain or develop detailed application software documentation at the time a system is implemented. This will facilitate maintenance of the system as well as the incorporation of enhancements over the course of its life.

Two forms of integration of bar coding with management information systems are possible. The simplest of these is to add bar code reading capability to existing information system terminals. This is referred to as terminal level integration in this document. A major benefit of this approach is that it generally does not require modifications to information system application software. In most cases, this can also be accomplished without modifications to system software. This approach will retain the existing functionality of the application software and aspects of the user interface while providing the benefits of bar coding. The second approach is based on building the application with bar coding as its principal data input vehicle. This approach is referred to as system level integration within this document.

Bar coding implementations employing system level integration can exploit the benefits of bar coding by revamping the user interface to allow the use of bar coding for virtually all data input actions. In addition, this approach allows mobile data collection techniques to be employed. This in particular will be more efficient as it allows the computing resources to be taken to the location of the work. While this is a more radical approach, the benefits are more pronounced. These benefits will include enhanced data accuracy, simplified user training and greater worker productivity.

The paragraphs which follow provide details of both of these approaches to the integration of bar coding with management information systems. In each case, the hardware requirements are presented and operational scenarios including user interface descriptions are included.

TERMINAL LEVEL INTEGRATION

Terminal integration represents the simplest approach to the implementation of bar coding in a new or existing management information system. In these systems, the bar coded information is accepted at the terminal and converted to a format equivalent to the input data stream that the terminal normally provides. As result, the bar coding is completely transparent to the management information system and the system software does not need to be modified. A number of transit properties have used this approach to interfacing bar coding with their information systems. Among these properties are MARTA, CT Transit and PACE. It is also interesting to note that Denver's RTD indicated in their response to the survey questionnaire that they regret not using the terminal integration approach. This is due to the problems they experienced with interfacing bar code terminals to their Prime Computer using system level integration technique. Based on discussions with RTD personnel, it is the view of the researchers that the reported problems were due to nuances of the Prime hardware and software and do not represent broad problems with interfacing bar code terminals.

Implementation of terminal integration is performed using a device called a "wedge." An example of a wedge is shown in Figure 3-10. Wedges can be used

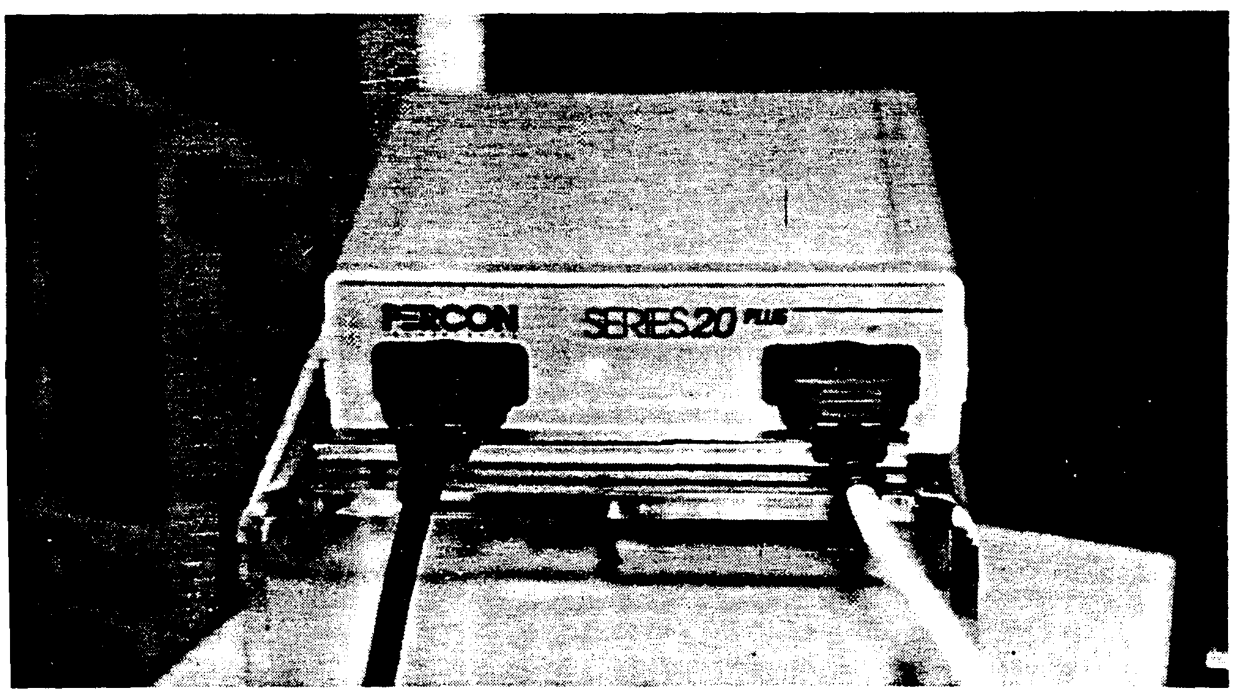

Figure 3-10. Bar Code Wedge Interface

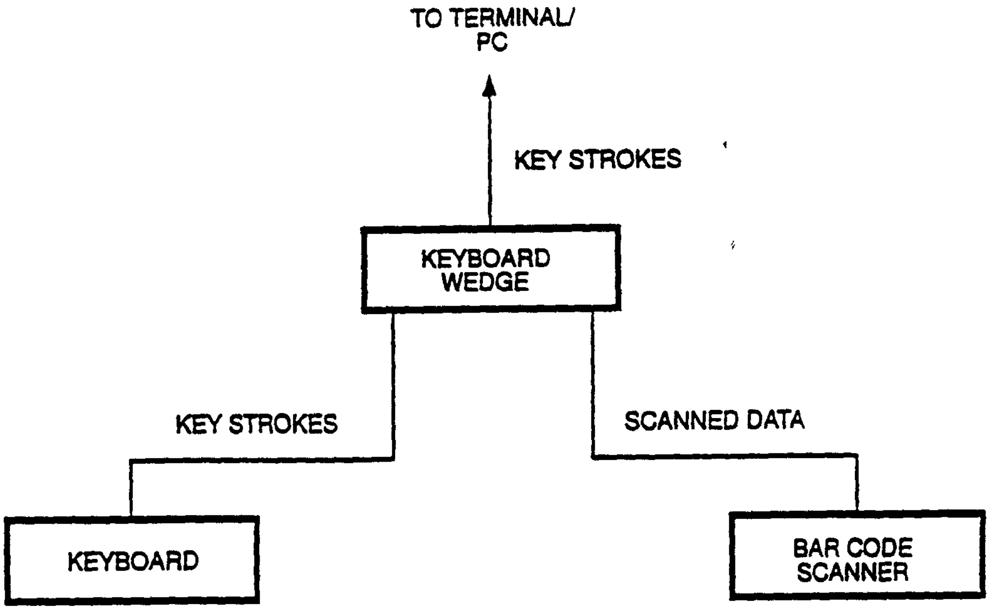

Figure 3-11. Bar Code Wedge Installation

with conventional computer terminals as well as standalone or networked Personal Computers (PCs). Two types of wedge are available including keyboard and ASCII wedges with the keyboard wedge being the most common. Keyboard wedges can be used with terminals or PCs which have external connections for the keyboard. ASCII wedges are used with terminals that do not have external keyboard connections but are equipped with auxiliary serial interface ports. Terminals with integral keyboards and CRT displays are an example of a device which will require the use of an ASCII wedge. By using keyboard or ASCII wedges, bar code capabilities can be added to virtually all terminals and PCs currently in use. When using a wedge, data can be entered using the scanner or keyboard interchangeably with no difference in the information ultimately passed to the system application software. This can prove beneficial in cases where a deteriorated or dirty bar code label can not be scanned. In this case, the user can enter the bar codes human readable information using the keyboard.

Figure 3-11 illustrates how a keyboard wedge is used. The wedge can accept information from either the keyboard or the bar code scanner. Keystroke information received from the keyboard information passes directly through the wedge. Information received from the bar code scanner is converted to equivalent keystrokes and passed to the terminal or PC. As different types of terminals and PCs handle keystrokes in different ways, the wedges are configurable for a variety of individual manufacturer's units. This configuration is established at the time the wedge is installed and in most cases, is performed using bar coded menus included in the wedge documentation.

Virtually any type of scanning device can be used with a wedge including LED wand, CCD and laser scanners. Depending on the type of scanner used, power for the wedge can be provided via the keyboard or serial port connector. For scanners requiring higher power levels, a separate power supply can be used with the wedge. Generally, LED wand scanners require low power and will not need a separate power supply. Laser and CCD scanners require an average of 300 ma and will generally require an external power supply.

Most wedges include additional serial input ports which enhance their usefulness. As will be described in detail later in this chapter, there are battery-powered portable terminal units which have bar code capability. These devices have the ability to collect data which can be uploaded to the management information system on a batch basis. As most of these portable terminals use a serial port for the uploads, they can be interfaced through a wedge serial port. In the event that this course is pursued, the software program running the portable terminal must be able to create files containing the collected information which emulate the way the application software performs transactions and receives data. When the files are uploaded, it will appear to the management information system that the user at the wedge equipped terminal is performing multiple transactions.

When terminal integration techniques are applied to an existing system it will have the benefit rapid operational conversion and limited user training requirements. A wedge and scanner can be installed and configured on a terminal or PC in significantly less than one (1) hour. In addition, there are no specialized cabling or installation requirements. In the event an external power supply is required, an AC adapter which plugs directly into a standard outlet can be used. User training requirements are limited by the fact that the transactions will be exactly the same. This does assume, however, that the users are computer literate relative to the existing applications. New user training required for implementation of a terminal integration bar coding application will be limited to what data is to be collected using bar codes and proper procedures for scanning bar codes. An important element of this, and in reality any, bar code system training is to teach the user how to deal with exception conditions such as bar code labels which can not be read. The user must understand how to proceed and overcome these problems if productivity is to be maintained.

SYSTEM LEVEL INTEGRATION

The terminal integration approach described above is a compromise based on the desire to achieve bar coding capability at a relatively low cost. As a result, the full scope of the productivity benefits available through the use of bar coding are not achieved. In addition, the terminal level integration approach does not take full advantage of the available interfacing technologies. As a result, the computing assets provided at the user terminals may not provide the right capabilities for their assigned task and may exceed the terminal functional requirements. Relatedly, the user interface for the transactions performed at the terminal may be more complex that what is required. As an example, a full screen display is not required for time an attendance applications where a terminal is used to collect information relative to employee arrivals and departures.

System level integration can be accomplished using either mobile or fix terminal resources. The appropriate selection is a function of the application, the nature of the work tasks to be performed at a given terminal, and the extent of the data needed by the worker performing transactions. Another factor which warrants consideration is whether or not the information to be collected is required in real time or if patch collection with periodic updates provided to the management information system is sufficient. Table 3-4 illustrates bar coding applications appropriate for transit and makes general suggestions regarding user interface devices by employee categories. For purposes of this table, the types of devices referenced are defined as follows:

- ***Fixed Bar Code Terminal:*** A fixed location device allowing bar coded information to be input. These device may or may not be equipped with a keypad for data entry. In the event that they are equipped with a keypad, they provide only a few keys rather than the entire ASCII character set.

- ***Fixed Full Screen Terminal:*** A standard computer terminal or PC used as a terminal. These devices feature full screens (24 columns by 80 rows minimum) and a full keyboard. Depending on the application design, these terminals may be equipped with provisions for reading bar codes via a wedge.

- ***Batch Mobile Terminal:*** A battery powered, portable device with the ability to collect and store information. User intervention is required to upload or download information to/from these devices on a periodic basis. Often this is accomplished at the beginning or end of a shift These devices are generally equipped with full ASCII keypads and a LCD display with the ability to display up to four (4) lines of 20 characters. In addition, they may be equipped with LED Wand, CCD or laser scanners. Some of these devices have the scanner built-in to the unit's case to enhance user ergonomics. Batch mobile terminals are programmable to provide prompting to the user for the data collection process, formatting of collected information and control of information uploads and downloads.

Table 3-4

Transit Bar Coding Application Data Collection Devices

	FIXED BAR CODE TERMINAL	FIXED FULL SCREEN TERMINAL	BATCH MODULE TERMINAL	REAL TIME MOBILE TERMINAL
TIME AND ATTENDANCE				
EMPLOYEES	X			
SUPERVISION/PAYROLL		X		
ASSET MANAGEMENT				
INVENTORY CLERKS		X	X	
SUPERVISORS		X		
MATERIAL MANAGEMENT				
STOCK CLERKS		X	X	X
SUPERVISORS		X		
MAINTENANCE MANAGEMENT				
LINE MECHANICS	X	X	X	
FOREMAN/SUPERVISORS		X		

Generally, the uploading and downloading of information is accomplished using a serial interface with the physical connection made via a cable or through a cradle equipped with contact pins.

- ***Real-Time Mobile Terminals**:* Real-time mobile terminals have the same general configuration as the batch mobile terminals described above. The only exception is that the real-time terminals include radio transceivers which provide information to the management information system instantaneously rather than periodically. Similarly, the real-time terminals can receive information instantaneously. As a result, they can provide all of the functionality of a fixed location device.

As shown in the table, Time and Attendance data collection is best supported by a combination of fixed bar code terminals and full screen terminals. The fixed bar code terminals can be located at the points where employees enter and exit facilities, and their movements can be recorded using simple actions such as single scans of bar codes on identification badges. These employees will not need to receive information from the system. Supervisors and payroll personnel will often be required to perform research to correct discrepancies and errors and will require access to detailed information which will necessitate the use of full screen terminals.

Asset management applications are best served by a combination of fixed and portable terminals. The fixed terminals will be used by inventory clerks to enter assets into inventory, to retire assets from inventory, and to record asset reassignments. Supervisors will use fixed terminals to review top level statistical information such as inventory levels and values as well as to research discrepancies. When inventories are verified, the use of batch mobile terminals will be warranted. These activities will take place at the location of the item which can be within a single or multiple facilities. As asset inventory levels are not critical to any aspect of transit operations, the use of higher cost real time mobile terminals is not warranted.

Data collection requirements of material management applications are very diverse. This is due to the differences in the individual tasks which make up the material management process. For this reason, the data collection requirements of material management applications are best served by a combination of fixed and mobile assets. Fixed full screen terminals can be used by stock clerks in the process of receiving material. Generally, material is received at a single location and the receiving process often purchase order information which is best presented on a full screen terminal. Where the data display requirements are not extensive, mobile terminals can be used. Material management supervisors will also require full screen terminals to perform research into inventory levels and to research inventory discrepancies. Actions such as stock picking, physical inventory and cycle counting are best supported through the use of mobile terminals since these activities are most often performed at the material's storage location. Depending on the criticality of the material movements, these terminals can be batch or real time devices. If there is a significant incidence of material movements which are time critical, real time terminals may be the most desirable solution.

The data collection terminal requirements for maintenance management operations are best served by fixed terminals. For the line mechanics, the type of terminal depends of the information that they will be allowed to access. As an example, MARTA has a combination of full screen and bar code terminals used for the collection of labor information during maintenance operations. While the mechanics time could have been entered using a bar code terminal, the full screen terminals were put in place to allow the mechanics to have access to maintenance related information. This allows the mechanics to research similar problems to the one they are currently working on and to review the maintenance history of vehicles or major components. By empowering the mechanics to perform their jobs better in this way, MARTA has realized a higher degree of system acceptance. It is also possible to use portable batch terminal to collect labor information for maintenance operations however this is not the most cost effective approach when compared to a fixed terminal.

A significant feature of all the types of bar code terminals referenced above is their programmability. This feature enhances the power of the device significantly and allows some of the application functionality to be embedded in the terminal rather than relying on the MIS computer for all processing. Depending on the terminal device, it is possible to implement databases, user prompts, file management routines, error handlers and customized communications routines within the terminal. Numerous benefits can be realized in this way including localized error checking and tolerance to communications and other faults which could otherwise preclude data collection. Programming languages vary among terminal manufacturers. While some devices are MS-DOS based and can be programmed in conventional languages such as C, Basic and PASCAL, other units use proprietary languages optimized for the terminal device's hardware characteristics. Programs are developed on the units themselves or a personal computer with the appropriate software and interface hardware. Programs are tested and debugged as required before being loaded into EPROMs in the terminal itself.

FIXED LOCATION DATA COLLECTION TERMINALS

Figure 3-12 illustrates a common fixed location data collection terminal. While this unit is equipped with a slot-type LED scanner, terminals are available which will support any type of scanner. In addition, these units often have interface ports which allow the connections of other peripheral devices such as printers and scales. The terminals are commonly equipped with displays which use either light emitting diode or liquid crystal displays.

Generally these displays present between one (1) and four (4) lines of text with a maximum of 40 characters per line, however there are units which are not equipped with displays. These units rely on sound generators to provide feedback to the user. The terminals are also equipped with keypads of varying configuration. Generally, these keypads provide only function or numeric keys but some units are equipped with full ASCII keypads. In addition some units, such as those observed by the researchers in use at United Airlines' San Francisco Maintenance Base, have no keypads. Operators using these units are required to enter all information using bar codes. To support this practice, menus providing common functions are collocated with the terminal.

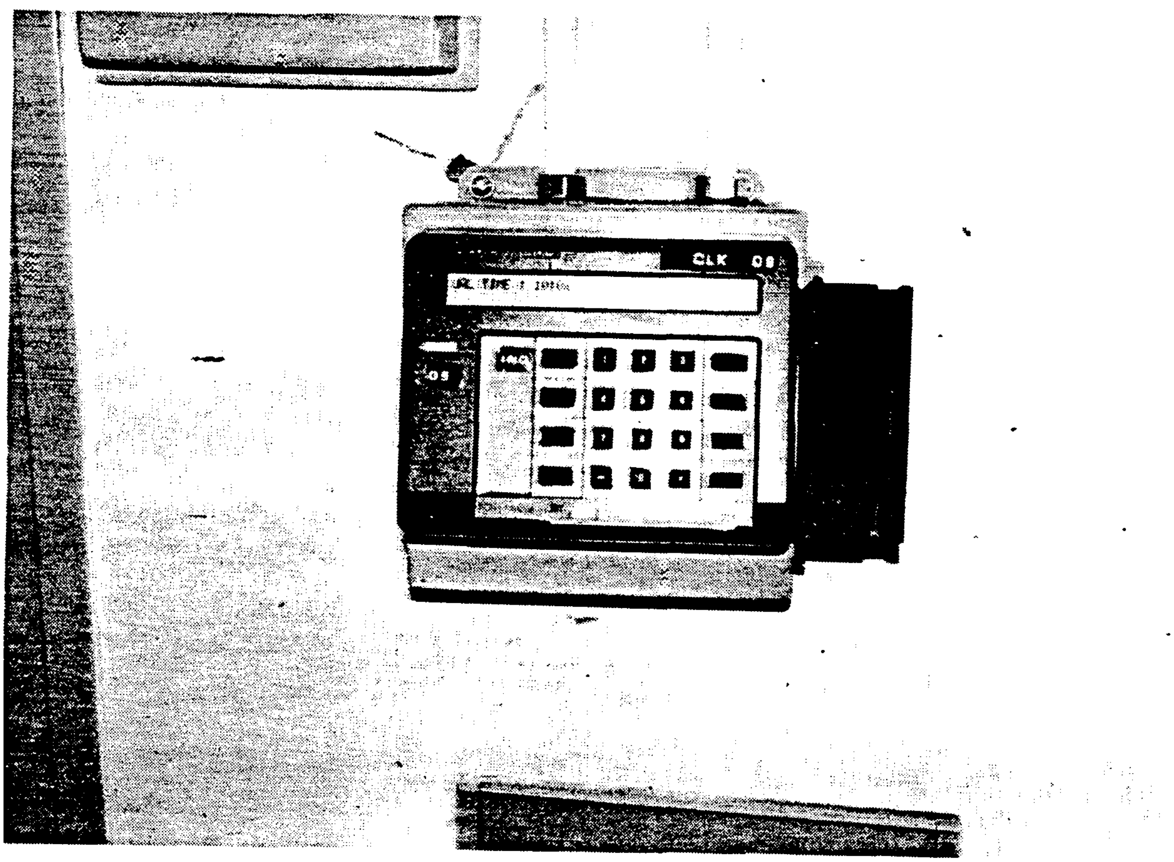

Figure 3-12. Fixed Location Data Collection Terminal

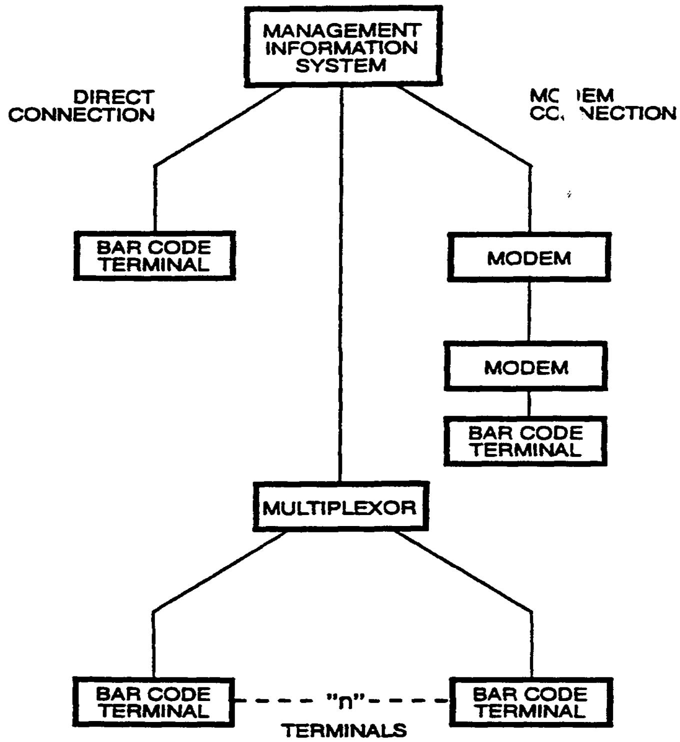

Figure 3-13. Fixed Location Terminal System Integration

When selecting the configuration for a fixed location data collection terminal, the user interface for the application must be considered. The user must be able to input the full range of information that the application requires. In addition, the terminal must be able to display all messages required to prompt the operator for inputs and to indicate error conditions requiring operator action. Where a new system is being designed and latitude exists in the definition of the user interface, it is best to maximize the use of bar codes. In this way the productivity and data validity benefits of bar coding can be fully exploited. Except in the case of very simple applications with minimal data input requirements, it is best to have a display on the unit to provide feedback to the operator. This will help to reduce errors when performing transactions by providing prompts to the opera- tor as well as providing feedback to the operator in the event an error does occur.

Various options are available for interfacing these terminals to the management information system. As shown in Figure 3-13, these options include point-to-point connections as well as multi-drop configurations using multiplexers or terminal network controllers. These schemes are implemented using the RS-232, RS-422 and RS-485 standard communication protocols.

The majority of the existing systems observed use point-to-point communications implemented using the RS-232 or RS-422 standards. RS-232 interfaces will generally support communications over distances of 50 feet or less. In the event that a greater distance is required, a pair of modems or communications using the RS-422 standard will need to be employed. RS-422 communications will support distances of up to 4,000 feet without modems.

Multi-drop configured terminal networks are employed where a multiple terminals are located in a single facility. As an example, a multi-drop configuration is often used where multiple terminals are used in a single facility for time and attendance information collection. Multi-drop networks are implemented using the RS-485 communications protocol and as a result can realize high data transfer rates. These networks use a common cable backbone with Tee connections at the terminal locations. The interface between the multi-drop network and the MIS computer is provided by a unit designated as the master. Under the multi-drop scheme each device has its own address and listens for master unit broadcast messages addressed to them. During this time, the slave units have their transmitters turned off. In the event a message requiring a response is received, the transmitter is turned on and the response is broadcast.

MOBILE DATA COLLECTION TERMINALS

As was introduced above, Mobile Data Collection Terminals are battery powered, portable devices which allow the computing resources to be brought to the location of the work. For selected applications this can have a significantly beneficial impact on productivity.

Most mobile data collection terminals are equipped with full ASCII keypads and a LCD display with the ability to display up to four (4) lines of 20 characters. They can be equipped with LED Wand, CCD or laser scanners and some of the newer units have the scanner built-in to the unit's case. Figure 3-14 illustrates a mobile terminal with an integral laser scanner. Both types of terminals are programmable allowing them to be configured for the specific application. The programmability allows prompting to the user for the data collection process, formatting of collected information and control of data transfers.

Batch terminals are equipped with serial interfaces which allow the uploading and downloading of information. The interface is made using a cable or through a cradle equipped with contact pins. As was introduced previously, this interface can be made using a wedge or can be made through a PC. NJ Transit makes extensive use of batch portable terminals in their Newark Central Stores Facility as well as their satellite locations. At each location, a PC's provided with a serial interface cable to implement the interface between the mobile unit and their material management system. Specialized software on the PC controls communications with the mobile terminal. This PC receives lists of material to be picked from stores which are then downloaded to the terminals. These lists are generated by the material management system based on material requisitions. When the picks are completed, confirmation of the action is uploaded to the material management system. A similar process is used for cycle counting. Where material is removed from inventory at satellite locations for consumption, the pick is recorded in the mobile terminal and eventually uploaded to the material management system.

Real-time mobile terminals have the same physical configuration as the batch mobile terminals described above. The major difference lies in the fact that real-time terminals include radio transceivers which allow instantaneous interchange of information with the management information system. None of the transit properties responding to the survey questionnaire or visited are current users of real-time mobile terminals. As of the writing of this report, the MTA-NYCT was implementing a pilot program as a part of a new material management system which includes real-time mobile terminals. In addition, Denver's RTD indicated that they have future plans to implement real-time mobile terminals in their central warehouse.

Figure 3-15 illustrates the general configuration of a real-time mobile terminal system. Individual terminals communicate with the management information system through a radio frequency unit and a system controller. The radio frequency unit serves as the master radio transceiver for communication with the portable terminals. One or more antennas may be used to provide signal coverage. The system controller provides management of the terminal network and controls routing of information packets to individual terminals. Depending on the manufacturer of the equipment, the system con-

Figure 3-14. Mobile Data Collection Terminal

troller and radio frequency unit may be packaged together.

Real-time mobile terminals fall into two categories including Narrow Band and Spread Spectrum. Narrow band systems use fixed radio channels for data interchange. These systems operate in the VHF and UHF bands reserved by the FCC for Public Land Mobile Radio (PLMR) services. One channel is used for simplex operation while two channels are required for full duplex systems which can transmit and receive information

simultaneously. Narrow band systems are licensed by the FCC to operate on specific frequencies at a designated power level. These frequencies are limited to 25 KHz of bandwidth which restricts their data transmission capabilities but is sufficient for all but the most exhaustive applications. While often perceived to be an extensive and drawn out process, frequency licensing can often be completed in less than six months. Most manufacturers of narrow band terminal equipment will perform this process for a fee. It should be noted that this process will include a survey of the equipment in-

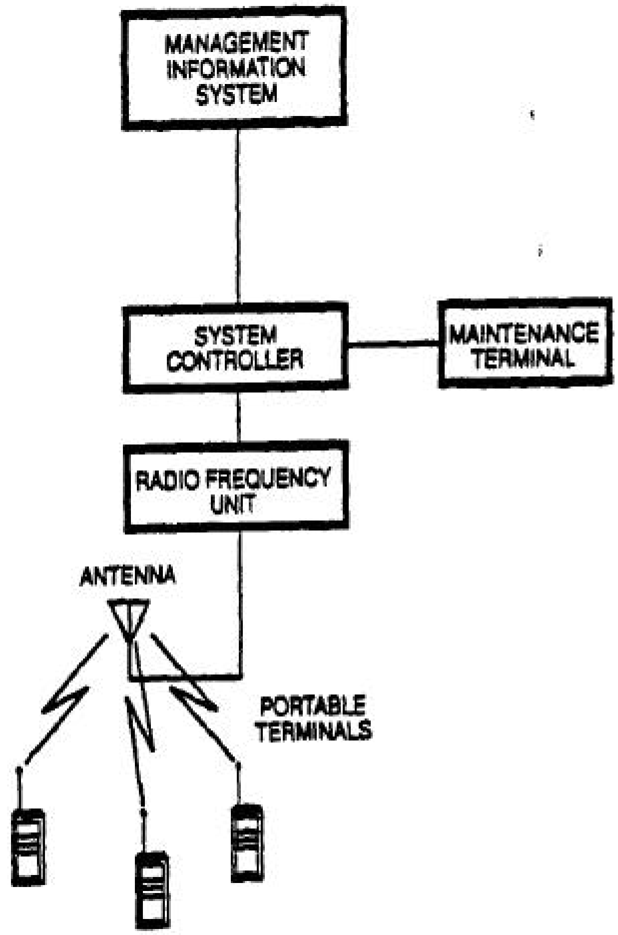

Figure 3-15. Real-Time Mobile Terminal System Configuration

stallation location to determine the operating range of the equipment, radio frequency interference sources and antenna requirements. A benefit of this approach is that the organization licensing the frequency becomes the exclusive user of that frequency in a given area. In the event that interference sources arise later, the FCC can issue a cease and desist order against the source of the interference. The previously mentioned MTA-NYCT pilot program is using spread spectrum terminals operating in the 900 MHz frequency band.

Spread spectrum systems are based on newer technology and make more efficient use of available frequency bandwidth. Most of these systems operate in the 902-928 MHz frequency band. A significant characteristic of spread spectrum systems is that they do not require a license for the FCC. As a result, protection from outside sources is not guaranteed. It should be noted, however, that there are system design techniques such as frequency hopping which aid interference rejection. Using spread spectrum techniques up to 26 MHz of bandwidth can be made available which far exceeds the requirements of any transit bar coding application.

There are two types of spread spectrum communications including direct sequence and frequency hopping. Direct sequence systems use the full bandwidth range to define either a single wide channel or several smaller channels. While these systems have high data throughput capabilities, these are highly susceptible to interference for which there is no recourse since the frequencies are unlicensed. While the system can be reconfigured to operate on an alternate frequency, this requires that the system be put out of service temporarily. Frequency hopping systems divide the available bandwidth into 50 or more separate channels. The system will then change channels at a rate of several times per second. As most radio frequency interference sources are not constant, there is a high probability that the interference will be missed and successful transmissions will occur.

While spread spectrum systems were originally higher in cost than narrow band systems, technology advances have narrowed the gap significantly. As a result, the decision as to which type of system to use can be based on technical factors. A significant factor to consider is the impact of the FCC's radio frequency refarming activities on the PLMR band and its availability for mobile terminal use.

With the rise in mobile communications, radio frequencies are becoming increasingly scarce. For this reason, the FCC has proposed to split existing frequencies. In the event that this proposal is adopted, the bandwidth available for narrow band systems will be reduced to 12.5 MHz or possibly even 6.25 MHz. While selected frequency bands will be grandfathered under the new rules, it is expected that new frequencies for data transmission in the VHF and UHF bands will become scarce.

For this reason, it is the view of the researchers that spread spectrum communications is the best approach. Furthermore, it is recommended that a frequency hopping approach be employed. While this type of system has lower bandwidth, it far exceeds the requirements of transit bar coding applications and will provide a high degree of immunity from outside interference.

CHAPTER FOUR - BAR CODING IMPLEMENTATION PROCESS

Bar coding is a tool that is used in the attainment of strategic goals. The strategy used in the attainment of goals consists of two equally important and related tasks. These include the implementation planning including the formulation of a strategy and ultimately the process used in the implementation of the strategy.

There are two options that can be pursued by a transit property for the implementation of a bar code system. The first of these is to design and implement the system using internal personnel. In this case, the entire process defined in the following paragraphs is applicable. The second alternative is to use outside suppliers, such as consultants or system integrators. In this case, the planning and requirements definition are most important for the transit property. The remaining activities will be performed by the integrator, but understanding of all phases of the process will help the transit properties to manage and evaluate the progress of the outside suppliers. During the survey of transit properties described in chapter two of this report, the researchers determined that most transit properties that are not bar code users have existing information systems. For this reason, the implementation process defined in the following process is centered on adding bar coding to existing systems. As a result, the approach to software is one of making the bar coded data work with the existing application soft- ware with little or no modifications. suppliers. During the survey of transit properties described in chapter two of this report, the researchers determined that most transit properties that are not bar code users have existing information systems. For this reason, the implementation process defined in the following process is centered on adding bar coding to existing systems. As a result, the approach to software is one of making the bar coded data work with the existing application software with little or no modifications.

IMPLEMENTATION PLANNING

Having made the decision to pursue implementation of a bar code system, it is necessary to define the required resources to be employed in the process and to define the goals, scope and context of the effort. The first step is to identify and assemble the project team. The second step is to define the strategic goals that the development of the system will address. The paragraphs which follow provide guidance for use in approaching these elements of the planning process. of a bar code system, it is necessary to define the required resources to be employed in the process and to define the goals, scope and context of the effort. The first step is to identify and assemble the project team. The second step is to define the strategic goals that the development of the system will address. The paragraphs which follow provide guidance for use in approaching these elements of the planning process.

PROJECT TEAM DEVELOPMENT

Before a bar coding project can be implemented, it is necessary to define the team which will define the strategic goals of the system and carry out the implementation process. This team will be multi-disciplinary with the size dependent on the number and scope of the bar coding applications to be addressed, and functional organization of the transit property. For a smaller transit property, the team may be only a few members while for a larger property, the team may have many members.

It will be the team's responsibility to determine the strengths and weaknesses of the organization and how the implementation of the system can address these characteristics. In specific managerial terms, the team will define the goals of the project and assess, redefine operating procedures in terms of available technology, baseline existing productivity levels, and ultimately assess the productivity attained by the new system. Using this information, the payback provided by the new system can be determined. On a technical level, the team will define the system's functionality, develop the system architecture, evaluate and select products to be used in the implementation, and finally install, integrate and test the system. While these functions are segregated on managerial and technical levels, they are interrelated and must be integrated.

The project team should include representatives of all functional groups who will be impacted by the bar code system with particular attention afforded to the user community. If the system is to be accepted and provide the greatest possible return, it is important that the needs of the user community be addressed. This is particularly true in cases where the system could be viewed as "Big Brother is watching" such as a time and attendance data collection system.

Regardless of the size and make-up of the team, a single leader should be designated. This person should be focused on obtaining the greatest possible benefit from the system while being impartial and capable of crossing organizational boundaries. Effectively, this person will serve as a mediator among the functions included in the team and negotiator focused on obtaining the greatest possible benefits. The leader will need to be sensitive to the personal values of the project team and insure that these values are addressed and accommodated to the largest extent possible.

STRATEGIC GOAL DEVELOPMENT

In classical management terms, strategy is process for attaining the goals or objectives of an organization. Strategy consists of policies and plans which must echo the organization's function. For a strategy to be progressive, the organization's function must be defined as an ideal to be attained rather than present conditions.

The first step in the process of strategic goal development to develop a generalized long range objective within the context of the organization's operations. Most often these goals will be implicit. They will be comprehensive and will often dictate multiple strategies for their attainment. As an example, enhanced materials management as a goal has multiple implications including enhanced inventory accuracy, reduced inventory levels and improved distribution. It is these lower level implications which provide the required granularity for the development of bounds that form the basis for individual project implementation strategies. Development of the goals must be an interactive process among the team members. In this way, the knowledge and experience of all team members contributes to the definition of the goal. Once the goal for the project is developed, it should be defined and documented in a written statement which is agreed to by all members of the project team.

IMPLEMENTATION PROCESS

The implementation of a bar code system requires making a number of decisions. If the implementation is to be successful, the decisions must be made in a logical sequence and must be based on appropriate and complete information. With this in mind, it is beneficial to define a standardized process for the development of a bar coding system. Figure 4-1 illustrates this process. Implementation of bar coding will take two forms. These include retrofits of bar coding to existing systems and inclusion of bar coding in new systems. In the case where a new system is being designed and implemented, the process of bar code system design becomes a subset of the user interface definition and/or system reporting depending on how bar coding is used. In this case, the procedures described in this document should be used in conjunction with the transit properties management in- formation systems development procedures. Where bar coding is being added to an existing system, the practices described in this document can be followed directly with special emphasis placed on integration with the existing system.

The paragraphs which follow provide details of the elements of the process outlined in Figure 4-1. In each case, the central issues are identified and approaches to their resolution are suggested. In addition, collateral issues which should also be considered are identified.

SYSTEM FUNCTIONAL REQUIREMENTS DEFINITION

As was indicated above, a multi-disciplinary team approach during the development of a bar code system is an absolute necessity. This is particularly true during the development of the system requirements. This phase is the most critical portion of the development process as it will establish the cultural foundation for the implementation and operational conversion of the new systems.

During the site visit to MARTA, one of the persons interviewed discussed the process of system development and how trade-offs in system design were made. At many times during the discussion, the person being interviewed indicated that various alternatives were dismissed as providing "No benefit to the worker." In the view of the researchers, this is a significant issue during the development of the system requirements. For virtually all users of a bar code system, data collection is relatively immaterial to their primary work tasks. As an example, a mechanic performing a repair is most interested in getting the vehicle back on the road. Similarly, a stock clerk is most interested in retrieving a part from a shelf and getting it into the hands of a waiting mechanic.

To get these persons to document their activities using a bar code system will require that they have a vision of the benefits that the system provides and how these benefits will affect them. For this reason, it is important that the viewpoints of the members of the planned user community be included in the definition of the system requirements. In doing so the potential for collateral benefits realized from the bar coded information should be considered. These collateral benefits should be assessed in terms of the users vision of their particular work tasks. As an example, MARTA provides mechanics access to vehicle maintenance history information which can help them to rapidly diagnose and repair vehicle failures. MARTA indicated that this helped to accelerate system acceptance and as a result, accelerated the system payback.

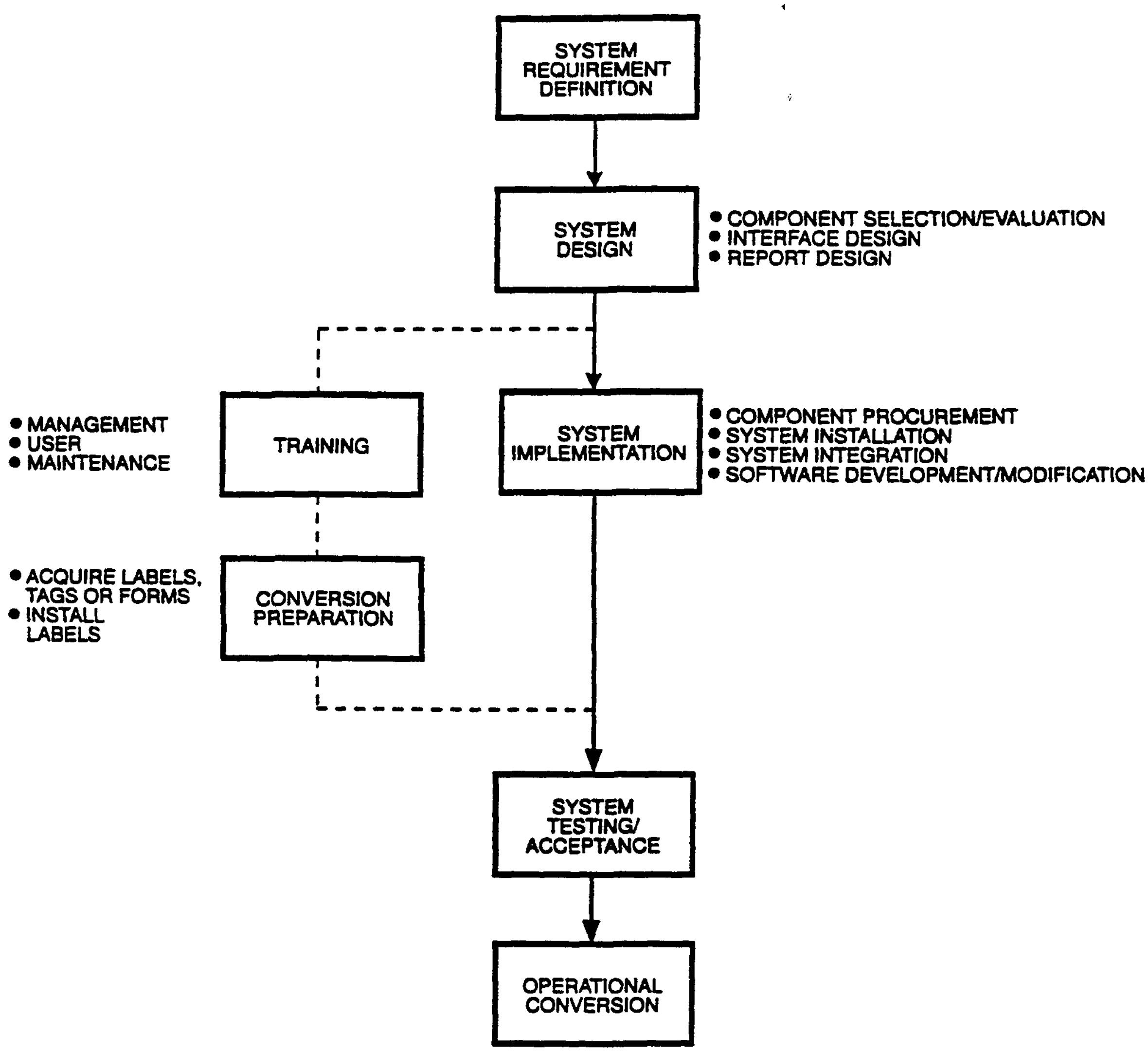

Figure 4-1. Bar Code System Implementation Process

During the development of the requirements, it is also important to look at the big picture and consider multiple uses of the same bar coded information. Bar coding delivers its greatest benefits when applications are integrated. As an example, CT Transit uses a bar coded defect card to track repair statistics, accrue labor, to track material issues, and to develop a database of vehicle history. One approach to evaluating integrated benefits is to assess the interaction of functions within an organization. In the case of CT Transit's application, the defect card approach reflects the interaction of maintenance, material management and vehicle engineering. Even if a single application is being implemented, a vision of future system enhancements and additions should be developed and the basic system designed to readily migrate to these expanded applications. Where bar coding or any form of a management information system is applied, it is used to automate a process. For a system to provide optimal benefits, the process being automated should be as efficient as possible. For this reason, the processes should be assessed and, as required, re-engineered during requirements definition. In this way the optimization becomes part of the system requirements. For cases where bar coding is being added to an existing system, optimization may not be feasible if extensive modification are required to the system software. On the other hand, if optimization can be achieved through simple procedural changes, significant payback can be realized. Examples of such enhancements include redesign, elimination or consolidation of forms, or physical routing changes. Changes such as these can be made within the context and functionality of the existing management information system application software at relatively low cost.

Figure 4-2 is a flowchart illustrating the optimization process. The first step is to make a detailed assessment of the current process identifying its strengths and weaknesses. Following this, the process should be benchmarked to establish a baseline of its existing efficiency. This is particularly important as it becomes the basis for comparison for the enhanced process and will determine the extent of improvement realized through the re-engineering of the process and the payback. In the event that the process is determined to be optimal, it can be employed in its current form. Regardless of this, it is often desirable to reevaluate business processes on a periodic basis. This is a significant element of continuous improvement and total quality management programs. In the event that the process can be reengineered, the desired changes should be identified. Again all members f the project team should be consulted and their views considered. Once the changes have been determined, the revised process should be benchmarked and compared to the original process be- fore the system is implemented. In this way, the degree of improvement and the payback from the reengineering can be assessed relative to the cost of implementation.

From a technical standpoint, the individual items of data to be bar coded are a major aspect of the system requirements. As is described in Chapter 3, two (2) types of data are entered into management information systems by the user. The first type is control information which tells the system what function the user wants to perform. The second type is application data describing the processes or objects under the control of the system. During the development of the system requirements, all data to be entered using bar codes should be logged to facilitate selection of an appropriate bar code symbology as described in chapter three of this report. This listing should include the definition of the data item, the transactions it is used during, whether it is numeric or alpha numeric, and the length. In addition, the frequency of collection of the data should be determined. In this way, if a trade-off is required during the selection of a symbology, the implications can be evaluated.

At the conclusion of the requirements definition process, the results should be documented in a system requirements document. This document should include the following:

- Definitions of data items to be collected
- Integrated of data collection into system transactions
- User interface equipment quantities
- System Transactional Throughput
- System Test and Acceptance Criteria
- User Training Requirements

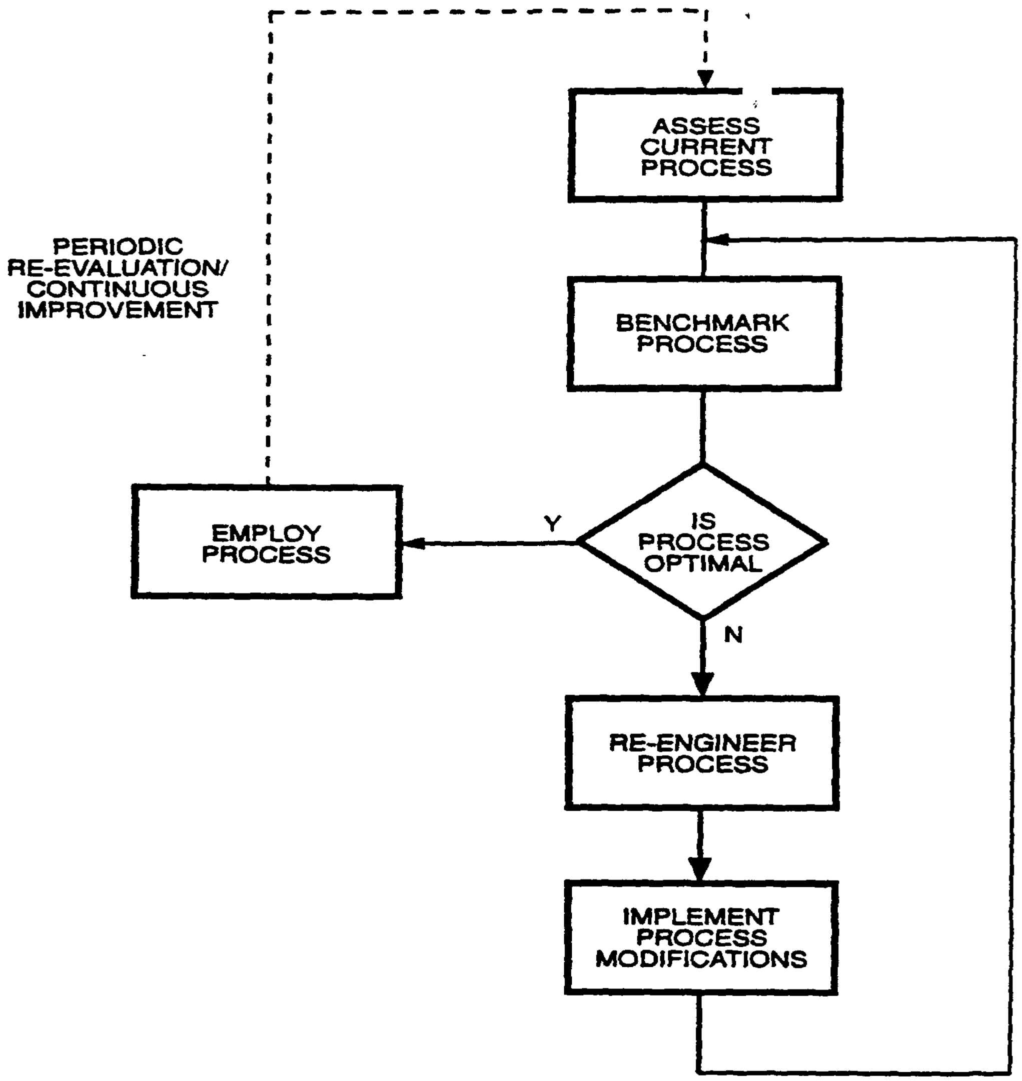

Figure 4-2. System Optimization Process

The integration of bar coding can be illustrated using process and transaction flow charts similar to those used in the Transit Bar Code Application descriptions provided earlier in this chapter. This system requirements document will be "living" in that it will evolve with changing system requirements as the implementation process proceeds. Again to insure that the needs and sensitivities of all project team members are addressed, this document should be reviewed by all members and agreed to prior to proceeding with development.

SYSTEM DESIGN

During the system design phase, the hardware and software needed to realize the previously defined system functional requirements is defined. For the bar coding aspects of the design, this includes selection of an appropriate bar code symbology, bar code label requirements, bar code scanners and bar code label production methodology. When performing these selections, the relationships between these items as illustrated in Figure 3-1 will need to be observed if the system is to function properly. For this reason, the selection sequence shown in this figure should be observed. Once the selections have been made, specifications for the system hardware elements can be developed and issued to potential suppliers for bids. At a minimum, these specifications should reflect the criteria described in chapter three. As an example, the specification for the scanner should include the following:

- Scanner Type; LED Wand, CCD, Laser
- Light Source Wavelength (ex. 633nm, 670nm, etc.)
- Aiming Aid Requirement
- Resolution in mils (i.e., dot size)
- Depth of Field (i.e., working distance requirements)
- Symbology Decode Requirement
- Minimum Scan Field Width (i.e., maximum bar code width)

As a part of this process, it may serve beneficial to review specification sheets from equipment suppliers to insure that complete specifications are provided. This will also help to insure that the specifications will be consistent with the capabilities of available products. As approaches are selected to meeting system hardware requirements consideration must also be given to the installation design. This will include providing power and signal interconnections for the equipment. For cases where a wedge is used to add a scanner to an existing terminal, the installation requirements will be trivial. For the case where fixed bar code terminals will be installed throughout a facility the installation requirements are more complex. One important consideration in this case is to insure that the maximum cable run distances are not exceeded. As examples, an RS-232 interface has a distance limitation of 50 feet while RS-422 interfaces will operate reliably over distances of 500 feet. In the event that these distances will be exceeded, modems or an alternate design approach will be required. Where portable real time terminals will be used, the antenna installation design must be considered carefully to insure that the terminals will be able to communicate throughout an installation. Most manufacturers of these systems will perform a site survey to define these requirements and the researchers strongly recommend that this approach be taken.

A significant aspect of the system design process is the definition of the hardware interface requirements. Depending on the nature of the system implementation, this process will vary greatly in complexity and may involve modifications or extensions to the system and application software. As one example, the use of a scanner with a wedge to perform terminal integration will be virtually trivial.

On the other hand, the use of a real-time mobile terminal system will be much more complex. In these cases, significant support from personnel responsible for the maintenance and operation of the management information system will be required. It will be necessary to determine what will be required to allow the system to recognize and interchange information with the terminals. In some cases, this may require support from the manufacturer of the computer or the operating software it uses. In addition, the software applications which will use the data collected via bar codes will need to have their interfaces assessed. It may also be necessary to redesign the application software user interface to reflect revised procedures implemented through the use of bar coding and the hardware limitations of portable terminal devices. As an example, most portable terminals have screens which are much smaller than the PCs or dumb terminals they will replace. As a result, displays used to prompt for information or inform the user of errors will need to be reduced to fit the smaller screen.

Finally, new operational procedures may need to be developed and incorporated into the overall system design. As an example, download and upload procedures will be needed for batch portable terminals. This will include both hardware and software as well as a definition of how the uploads and downloads will be integrated into operations. As an example, portable terminals are very suitable for use in cycle counting operations. In the event that locations are locked until the counts are completed, it will be desirable to expedite completion of the counts and uploading of the results. Where portable terminals are used for material issues, it may be desirable to download issue requests at multiple times during the day to accommodate emergency requests.

Upon conclusion of the design process, it is desirable to conduct a formalized design review. During this review each aspect of the system design should be reviewed with the appropriate members of the team to insure that the design is complete, all technical issues have been addressed and that the resulting system will support the strategic goals. This review should highlight the hardware/software interfacing requirements to insure computability with the management information system that the bar code data will support. In addition, the user interface should be reviewed in detail with the functional groups that will employ the system in their work activities.

SYSTEM IMPLEMENTATION

Once the design of the system has been completed, the implementation process can proceed. The first task to be performed during implementation is to procure the required system hardware and software. This can be done using the specifications developed during the design phase as described above and according to the transit properties standard procurement procedures. In parallel with the procurement of the material, the modifications to the system software can be modified and implemented. In the later stages of this process the new system hardware will become available and low level testing of the software modifications can be performed. By testing software at low levels, programming errors and incompatibilities can be isolated and corrected more easily than in later stages when the software is integrated into larger units.

When the system hardware become available, it can be installed. Where scanners are added to terminals using wedges, this will be a very simple process. For cases where fixed location bar code terminals are installed throughout a facility, more work will be involved. In these cases, the units will need to be mounted, and the required power and signal wiring installed. Again low level integration testing should be performed. As an example, the basic communications link between a host and a bar code terminal should be tested prior to application level testing. In this way, communications problems can be ironed out before applications are tested.

TRAINING

Regardless of how complex or simple a bar code system is, its users will need some form of training. This training will include the proper procedures for the use of the bar coding equipment itself as well as training in an changes or enhancements made to system operations. To insure that the system can be brought on line as quickly as possible, this training can be performed concurrent with system implementation.

Depending on the nature and complexity of the system, it may be desirable to perform training at a variety of levels. Foremost among the training requirements is to insure that the end users are well versed in the operation of the system. This training should include normal operating procedures as well as any exception conditions. In this way the user will be able to deal with all circumstances which may arise during system use. In addition, this training should include back-up procedures to be employed in the event of hardware failures. By training for these conditions, productivity will not suffer when these circumstances arise and data collection will continue. To the greatest extent possible, the users should receive hands-on training using the system equipment, software and procedures. It is important to note that training will be an ongoing process for the life of the system. This can include refresher training for existing employees and introductory training as new employees are added.

Supervisory personnel should also be trained in the use of the systems. While supervisors should be provided the same training as users, they should also be trained in the benefits of the system including any additional reporting the system will provide. This will allow the supervisors to use the bar code system as a decision making tool in their own activities. Finally, training should be provided to those persons who will maintain the system. Included in this will be the persons responsible for the maintenance of the system's hardware devices and the management information systems personnel who will maintain the system software and interfaces.

CONVERSION PREPARATION

Implementation of a bar code system will generally dictate changes in operational procedures. For this reason, there will be preparation required before full scale testing can be performed and before operations can be converted to use of the new system. These preparations will vary with the design of the system and the operational procedures it implements. One example of these preparations is to bar code material straggle locations for a material management system. An activity such as will be time consuming but is a prerequisite for system testing and operation. Other examples of preparations are the bar coding of employee badges for a time and attendance or work order system, and the bar coding of equipment for an asset management system. In addition, the logistics chain for the new system should be established. As apart of the logistics chain development, the maintenance concept for the system should be developed. Maintenance options include in-house maintenance or a service contract with an outside maintainer. In the event that in-house maintenance is to be employed, spare parts and other support requirements will need to be put in place. Also at this time, consumable materials such as bar code labels should be identified and provisions put in place to insure that a constant supply is available.

SYSTEM TESTING/ACCEPTANCE

Once the system has been fully implemented and all preparations have been made, testing can be performed. Depending on the nature of the system, testing may consist of multiple phases including functional testing and throughput testing. Regardless of the type, the test should be designed to stress the capabilities of the system. Any failures during testing will be corrected and a retest performed. As there is often functional interaction, it is important to ??etest any functions affected by the modifications. Where significant modifications are made, it may be necessary to restart testing at the beginning.

Functional testing should be performed to exercise all system capabilities. This includes all transactions involving bar coded data input as well as any features related to the bar coding such as management reports. To insure completeness, scripts for the testing should be developed using the system functional requirements as the basis. These tests should include normal procedures, all exception conditions and any failure back-up procedures. Acceptance tests should be performed by members of the project team with the team leader directing tests and individual functions being tested by their end users. As an example, testing of cycle counting tasks for a material management system should be performed by the persons who will be performing the counting activities.

In addition, the system should be tested to evaluate its transactional throughput. Most bar code systems will feature multiple simultaneous users. Some systems will operate well under light loads but will fail under normal or heavy loads. The purpose of this test is to assess the performance of the system under varying load levels. The number of simultaneous users should be included in the system requirements and should allow for future growth during the usable life of the system. Throughput testing should be performed using this number and should be performed for a sustained period of one (1) hour at a minimum to provide stress testing.

OPERATIONAL CONVERSION

Once the system has been tested and is ready for general use, operational conversion can be made. Operational conversion is the point in time where the existing or old system is abandoned and replaced with the new system. Where possible, this process should be performed gradually with the two systems operating in parallel. In this way, operations can continue even if there are problems with the new system. Once the new system is operating at an acceptable level, the old sys tem may be abandoned.

It is important to observe and be sensitive to the user base during the conversion process. This will be the point where the users will accept or reject the system and problems in this area must be dealt with quickly. The involvement of the user community in the system requirement development process will help to abate this problem but as the system will be exposed to the entire user base at operational conversion, there may be some isolated problems.

CHAPTER FIVE - BAR CODE APPLICATION EVALUATION

Depending on the scope of a bar code system, the development and implementation can be a costly exercise. Prior to committing to the expenditure of these funds, it is beneficial for transit managers to have a clear idea of the benefits to be accrued in both qualitative and quantitative terms. For this reason, the researchers developed a set of tools which can be used to evaluate potential applications within the context of a transit property's operations. These tools form a process which allows evaluations of bar code applications to be built in a logical sequence.

During the transit industry survey, a number of non- users of bar coding indicated that they had performed studies of bar coding. In general, these properties did not indicate that a structured process had been used in the evaluation. In other cases, properties indicated that they had not studied bar coding because they were unclear how to proceed. The process provided in this section of the report is targeted toward these properties and others which are contemplating the use of bar coding. It is important to note that the evaluation process alone does not provide absolute decision criteria. This was deemed by the researchers to be impossible for a number of reasons including differences in operational methodologies employed by transit properties and the varied functionality of the management information systems they employ. For this reason, the goal of the process is to provide the user with a methodology that they can use to evaluate the application of bar coding for their own circumstances.

Included in the process are a number of decision points where transit managers can assess whether the benefits of bar code implementation warrants continued consideration. In addition, the process description includes evaluations of a number of potential applications to illustrate individual aspects of the evaluations. The process described in this section of the report is segregated into the following steps:

- Goal Identification
- Bar Code Applicability Evaluation
- Operations Model Development
- Design Approach Assessments
- System Cost Analysis
- Economic Benefits Analysis

At the conclusion of this process, the transit manager can assist whether or not bar coding is appropriate for their specific application. In addition, an order-of-magnitude indication of the implementation costs and the benefits to be realized can be developed.

To provide illustration of the working of the process and to aid the user, prototypical application analyses are provided. These analyses were developed as a means of validation and are provided to illustrate its application. These analyses were prepared using target operations with parameters (numbers of vehicles, assets, employees, etc.) which are representative of actual transit industry operations.

As was indicated previously in this report, bar code systems do not exist as stand alone entities. Bar coding is only a means of providing data entry for management information systems. For this reason, bar coding must be used in conjunction with a management information system. Examples of such systems are material management, maintenance management, and time and attendance data collection systems. These systems must currently be in place or must be implemented concurrently with the bar code system which will provide their data.

The approach used by most transit properties is to procure their management information system application software from firms which specialize in providing systems for transit property or fleet management use. Examples of these firms include Fleet- Net Corporation, Jakware, Multisystems, Ron Turley Associates, The System Works and Versys. All of these firms produce software which is capable of accepting either bar coded or keyboard data input. In either case, the functionality of the software is the same and the difference lies in the user interface implementation. When these systems are introduced at a transit property, they will invariably result in cultural and operating changes. For this reason, it is best that bar coding be introduced simultaneously with the management information system. In this way the change is complete and the learning curve needs to be climbed only once.

Where the system was implemented to accept keyboard input, it is possible to retrofit bar coding at a later date. This can take the form of terminal integration where scanners are attached through the use of keyboard wedges. In addition, most commercial software has the ability to implement system integration of bar codes. This may require that a transit property purchase additional software modules or make some other modifications to the basic software. During the transit industry survey, one respondent described this process as simply "turning the bar code capability on."

During the description of the bar coding implementation process earlier in this report, the researchers emphasized the need for a team approach. A similar approach should be used in the initial evaluation of bar coding applications. For the evaluation process, the team does not need to be as large but again it will be beneficial for multiple viewpoints to be considered. As an example, material management personnel may determine that bar coding will help to enhance inventory accuracy. However, if the existing management information system does not have the ability to support interfaces to bar code readers, implementation is not feasible.

The paragraphs which follow describe the bar coding application evaluation process. The process is presented as a sequence of individual steps which should be followed sequentially. Where applicable, each step in the sequence includes examples of their application to various size transit operations.

GOAL IDENTIFICATION

Before the use of bar coding can be contemplated in detail, it is necessary to define what goal the user is trying to realize through its use. This goal may be the resolution of a specific operational problem or general improvement in operational efficiency. Regardless of the situation, the goal should be clearly stated and agreed to by all team members involved in the bar coding evaluation.

These goals do not need to be as specific as those described previously in this report as a part of the bar code implementation process. To the greatest extent possible, the goals could be defined in both qualitative and quantitative tests. In addition, they should identify the specific aspect operations that the transit property desired to address As an example, it is not a sufficient goal to state that the system will be designed to cut labor associated with data collection. A more appropriate goal is to state that the system will be designed to cut the labor associated with data collection for time and attendance or payroll preparation purposes by 75%. Another example of a goal is to raise materials inventory accuracy to 99%. In the event that the goals can not be stated as such, it is best if the bar code application be reconsidered at a later date when the goals can be concisely stated. Identification of the goals are an important first step in the evaluation of the use of bar codes or any form of automation. They provide a means of benchmarking the anticipated performance of the system and allow a comparative analysis of the system's benefits to be evaluated.

While the goals are established early in the evaluation process, it is often necessary to adjust them as the evaluation proceeds. It is better if the goal is overstated rather than understated. Transit managers should not be hesitant to set a goal which appears unrealistic. It is better to reduce overstated goals than to achieve understated goals. During later stages of the evaluation process, it may be determined that there are operational or technical reasons that will preclude the attainment of the goal as originally defined. In this case, the goal can be adjusted to reflect what is actually attainable.

BAR CODING APPLICABILITY

The first step in performing the analysis is to make a basic assessment of the applicability of bar coding. Reviewing the bar coding applications described previously in this report is a good starting point. In general terms, bar coding is appropriate for cases where a bounded number of data items are collected on a repetitive basis. As with any form of automation, the use of bar coding provides predictability and consistency, but in turn requires the same predictability and consistency.

The number of data items which makes the use of bar coding cost effective varies but can be as few as one. This depends on the length of the data item, its format, and its frequency of usage in transactions. Long and complex strings of data are prone to transcription errors when entered manually via a keyboard. Studies have shown that transcription error rates will average out to one error for every 300 keystrokes. Placed in context, for a data item which is ten (10) characters in length, one (1) out of each thirty entered will have an error. Generally, when data strings exceed seven characters in length, and are comprised of a random combination of alphanumeric characters, the frequency of errors will be unacceptably high. Some application software includes validity checks for input data. These checks can include comparisons against value limits and ranges of acceptable values. Regardless of this fact, the potential for errors will still exist within these limits and ranges.

The acceptability of these errors depends on their implications, the potential for their detection and the effort required to correct them. As an example, if a part number is incorrectly entered during the receipt of material, it can be assigned to the wrong storage location and effectively lost. As a result, this item will not be recognized by the material management system and as a result, will not be available for a remedial or preventive maintenance action. This can result in a vehicle being out of service unnecessarily. As another example, a part number or quantity transcribed incorrectly during a cycle count activity can result in unneeded material being ordered. Errors of this type will not be identified until a physical inventory of the location is performed or during the next cycle count. Depending on the timing of the physical inventory or cycle count, this error can remain in the system for periods exceeding one (1) year.

The frequency of entry of a data item is also a significant factor in the decision to use bar codes for its collection. A data item which is entered only a handful of times during a day or work shift is not a good candidate for bar coding. Other items, which are entered with high frequency, are good candidates. Transit related examples including estimated error rates for manual entry are as follows:

- Employee Identifications
- Part Numbers
- Storage Locations
- Purchase Order Numbers
- Work or Repair Order Numbers
- Maintenance Craft or Work Center Identifiers
- Asset Identifications
- Charge or Cost Account Numbers

It is possible to calculate the frequencies of use for these data items for specific applications and to develop an error rates based on transit system operational parameters. As examples:

- Time and Attendance Data Collection System
- Data Item: Employee Identification (7 Characters)
- Frequency of Use: Number of System Users x (work periods x 2)

In this case the work periods are determined by the number of times that an employee is required to log in and out during a shift. As an example, if an employee is required to log in/out at the beginning and end of the shift, there is only one work period. If an the employee logs in/out for lunch there will be two work periods (pre and post-lunch). This data will be collected in real-time when the employee logs-in or out.

Sample Calculations: Medium Property with 300 time and attendance system users. These employees are required to log in/out at the beginning and end of their shift and for lunch.

<u>Frequency of data item use:</u> 300 users x 4 transactions per shift = 1,200 transactions per day

<u>Total Characters:</u> 1,200 transactions x 7 characters = 8,400 per day

<u>Manual Entry Error Rate</u>*:* 8,400/300 = 28 transactions per day or 140 per five (5) day week

- Material Management System
- Data Item: Storage Location Identifier
- Frequency of Use: issues + cycle counts

Assumes that the storage location is linked to the part number via the material management system database. Storage location designators have seven characters. This information is captured in real-time when the issue or count is performed.

Sample Calculation: Large transit property performing 200 issues per day. Property has 5,000 storage locations with all having a 6 month count cycle. Cycle counts are performed on week days with an average of 21 working days per month

Cycle Counts: *5,000* Locations/(6 months x 21 working days) = 40 cycle counts per day

Total Transactions: 250 issues + 40 cycle counts = 290 transactions

Total Characters 290 transactions x 7 characters = 2030 characters

Manual Entry Error Rate: 2,030/300 = 7 transaction errors per day or 35 per five (5) day week.

Similar analyses can be developed for other applications and data items. In either case, the labor required for the data entry represents a significant cost. It is also important to consider that batch transactions for the entry of data may require more data entry than if the data is captured in real-time using bar codes. As an example, it may be necessary to enter the time of arrival or departure if salary differentials apply to overtime or work on different shifts. Where data is collected in real- time, this information can be captured by the application software immediately.

In the case of the time and attendance system described above, the amount of labor effort required to rectify the errors is a considerable factor. If it is assumed that it will take 15 minutes to identify, research and correct each of these hours, it would take 35 hours of labor which is essentially a full time person. Elimination of these errors could allow this person to be used in a more productive fashion. For the material management system, the effects of the errors cannot be directly ascertained since they will depend on the material management computer system and operational procedures in use. However, as an example, an error during a material issue can result in incorrect material inventory levels and issues of the wrong material. In the case of the cycle counts, the errors can result in material inventory levels higher or lower than expected. This, in turn, can result in delays in repairs because material will be unavailable or unneeded material being ordered.

OPERATIONS MODEL DEVELOPMENT

Throughout this document, the statement is made that bar coding is applied to a process. Where bar coding is implemented, it will become an integral part of this process. To allow the effects of the implementation of bar coding to be assessed, it is necessary to develop an operational model of the process. The model should be developed based on the existing process with additional versions prepared during the design approach assessments which reflect re-engineering through the incorporation of bar coding. In this way, the initial version of the model can be used to benchmark the productivity enhancements obtained through the use of bar coding during the design approach trade-off studies.

The operations model is best expressed as a detailed flowchart of the process to which bar coding will be employed. Figures 2-2, 2-3, 2-4 and 2-6 of this report are examples of these flowcharts. These should be designed to include as much detail as possible to facilitate detailed analysis. In addition, they should be all inclusive. As an example, if batch data collection is employed, the process flowchart should include all paper data collection as well as any data entry performed later. In addition, they should include all physical actions performed including actions such as a stock clerk walking to a storage location to perform a cycle count or a pick for a material issue. To insure that the model is sufficiently detailed, it should include a narrative description of the actions shown in the flowchart. Often flowcharts can be cursory and development of the narrative will help to insure that all aspects of the process are considered in the model.

Figure 5-1 is an operational model flowchart for a material issue. The narrative associated with this flowchart follows. This operational scenario will be carried through in the paragraphs which follow to illustrate the application of bar coding under a specific scenario.

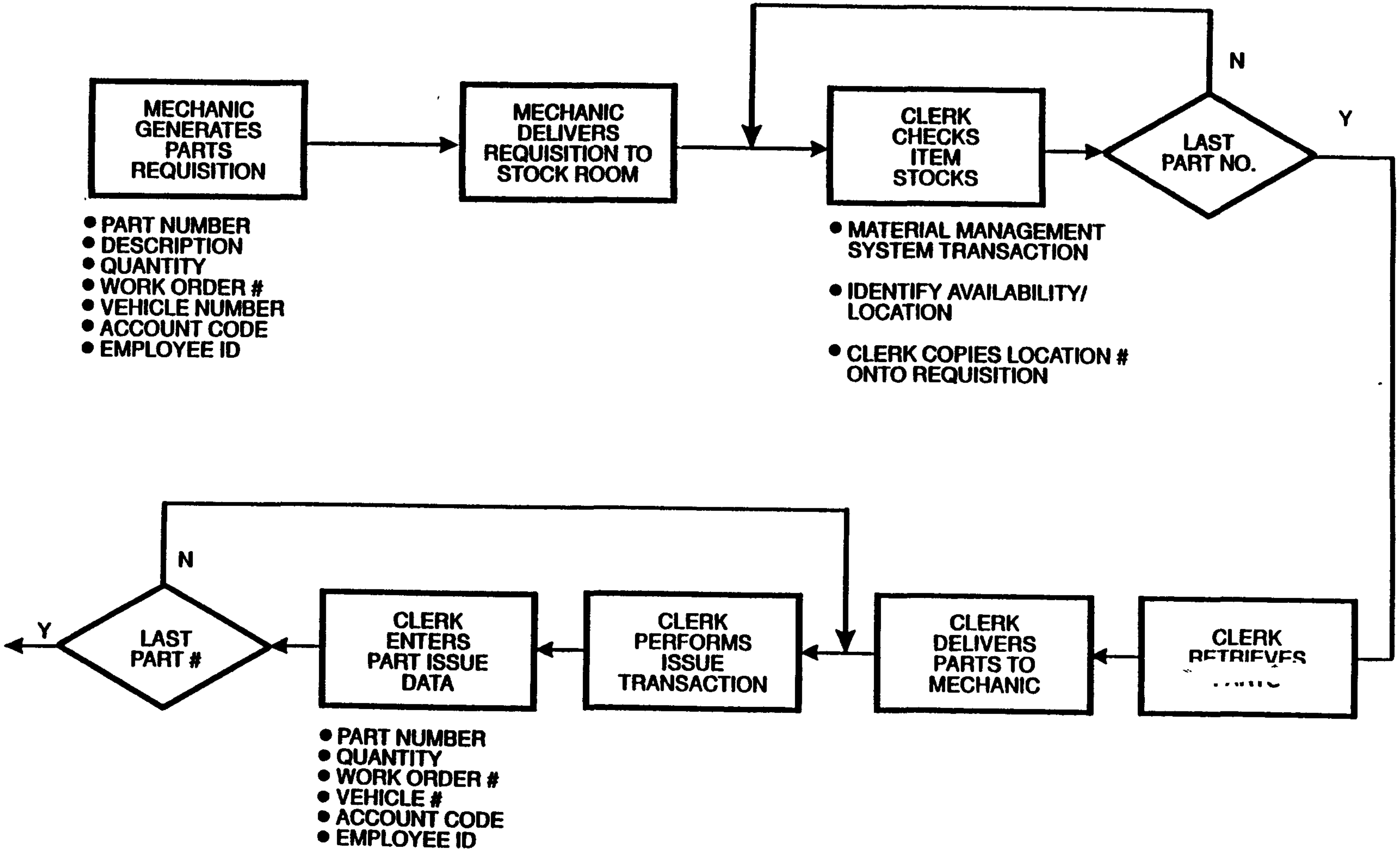

Figure 5-1. Material Issue Process Model

Once a problem with the vehicle has been diagnosed, the mechanic will fill out a parts requisition form. This form will include information such as part numbers, part descriptions, quantities, the work or repair order number that the parts will be used to close out, vehicle identification, the cost or charge account code, and the mechanic's employee identification number. The mechanic will give this form to the stockroom clerk who will then check inventory for these parts. If the stock clerk is familiar with the stockroom, this check can be made by going to the storage location. In other cases, the stock clerk will perform an inventory inquiry transaction through the material management system. Where an inquiry transaction is performed, the clerk will record the material storage location on the requisition form. Once the clerk has determined the availability and location of all material, the items will be retrieved and delivered to the mechanic. The stockroom clerk will then record the material issues by performing material issue transactions on the material management system. For each of these transactions, the stock clerk will enter all of the information recorded on the parts requisition form with the exception of the part description. The stock clerk will repeat this process for each part issued.

DESIGN APPROACH ASSESSMENTS

Based on the operational process models developed as described in the previous paragraph, an approach to the integration of bar coding into the process can be developed. Before this process can be considered, it is necessary for the user to understand the range of possibilities. These possibilities are only limited by bar coding technology. Chapter three of this report provides an overview of this technology. It may also be beneficial for transit properties to solicit further information from manufacturers and suppliers of bar coding equipment. Most often these organizations will be willing to discuss system design approaches, and hardware and software requirements at no cost. This is a potential resource that should be taken advantage of, however, the transit property should be sensitive to product biases. For this reason, it is best if discussions are held with multiple vendors or systems integrators.

Ideally, the design approach should represent the best possible application of technology. In reality, this must be tempered with a general sense of cost consciousness to avoid overkill. A significant element of this cost consciousness must be directed toward integration of bar coding with the management information system. A central issue in integration relates to the management information systems application software and whether or not the software will be modified for bar coding integration. This will dictate whether terminal integration or systems integration techniques are applied.

A significant consideration in evaluation of the software modifications will be the generation of reports for management and worker use. To reiterate a significant point uncovered during the research, bar coding is a means of capturing information. For it to be effective, the information captured via bar codes must be provided to users, be they management information systems, or transit property workers and supervisory personnel. These uses of the bar coded information will dictate the need and scope of the software modifications.

To illustrate the development of potential system design approaches, the researchers carried out multiple design exercises on the material issue process described previously. In each case, a design was synthesized and a revised operational scenario was built and assessed.

On performing an initial review of the process illustrated in Figure 5-1, significant potential for the application of bar coding was identified. The general process employed was to evaluate each step of the process, the data collected and the potential for the use of bar coding to collect that information. Bar coding can not be readily applied to the generation of the initial requisition as the parts to be issued are not consistent and can not be predicted. Repair actions are essentially random processes with different parts required for different of repairs. Similarly, bar coding can not be readily applied to the initial stock inquiry transactions that the stock clerk will perform as this would require a parts requisition with bar coded part numbers. While this could be generated, it would still require that someone (mechanic, stock clerk, etc.) enter the part numbers manually to allow the bar coded requisition to be printed.

Bar coding is highly applicable to the data collection that is required to record the material issue transactions.

There are multiple approaches to performing this and multiple degrees to which bar coding can be applied. This includes approaches which will work within the context of the existing parts issue transaction as well as others which will redefine and streamline the process. In the former case, the functionality of the existing software will be maintained while in the latter case, software changes will need to be made.

By applying the terminal integration technique described in chapter three, elements of the process can be automated within the bounds of the existing software. **Figure 5-2** is a flow chart illustrating one approach to accomplishing this. The final approach used will be a function of the design of the user interface for the material management system application software and may included the use of cursor positioning controls (tab, space, directional arrows, etc.) to move among the data entry fields on a screen.

As shown in the figure, the portion of the process which lends itself to automation is the issue transaction performed by the clerk. The elements of the process shown in Figure 5-1 up to where the clerk retrieves the parts remain the same. Bar coding is integrated into the process through the use of material identification tickets which will be provided for each storage location. These tickets will have a bar coded representation of the part number that the stock clerk can take to the terminal and use to record the issue. A similar procedure is used by retail chains such as Toys R' Us for purchases of items not stocked on shelves such as bicycles and video games. These tags have UPC bar codes for the item and are scanned at the checkout counters in the stores. Where this approach is used by a transit property for a parts issue, item quantities can be entered manually. In addition, menus can be used to provide information such as work order numbers, account codes and employee identifications. An analog to this in retail stores is where the magnetic stripe on the back of a credit card is scanned to obtain information such as credit card numbers and expiration dates. While this is not the most advantageous approach since it requires the use of issue tickets which represent consumable item costs, it does allow the benefits of bar coding to be realized with a small capital investment.

The most advantageous approach is to streamline the process by capturing data when the items are picked from their storage locations. In this way, the data capture becomes part of the process of picking the material from its storage location rather than a separate task performed later. One way to accomplish this is through the use of the system integration techniques described earlier in this report. Specifically, portable terminals can be used. **Figure 5-3** illustrates this approach. If a real time terminal is used, individual issue transactions can be performed each time material is picked using a procedure similar to the batch issue transaction described above. Another approach is to collect information using a batch terminal and periodically upload it to the material management system. In this case, the portable terminal can be programmed to create upload files of issues with the data in a format similar to the batch approach described above.

As the work order number, vehicle number, account code and employee identification are common for all parts issued under the requisition, this information only needs to be entered once at the beginning of the issue transaction. This information will be used as the header information that part numbers and quantities will be added to form complete transactions. Figure 5-4 shows how the transaction upload file will can be created. Individual data items can be placed in the file in any order to emulate the sequence in which the data needs to be entered. Where transaction fields are skipped, cursor control characters (tabs, spaces, etc.) can be included in the file. As part numbers and quantities will vary, they can be entered as the material is picked from the storage location. The best approach to this is to provide bar code labels at each storage location. Issue quantities can be entered manually due to the wide range of values.

A significant aspect of the design approach assessments is to determine the required quantities of system assets. As with any form of automation, bar coding will be most effective when all potential users have ready access to system assets. For bar coding, the assets which are used the most are the data collection devices. There are two approaches to assessing the required quantities of these devices. The first is to identify the maximum number of simultaneous system users. As an example, a transit property has a stock room with three clerks assigned. The material management system used in the stockroom is designed to use bar codes during material issue transactions.

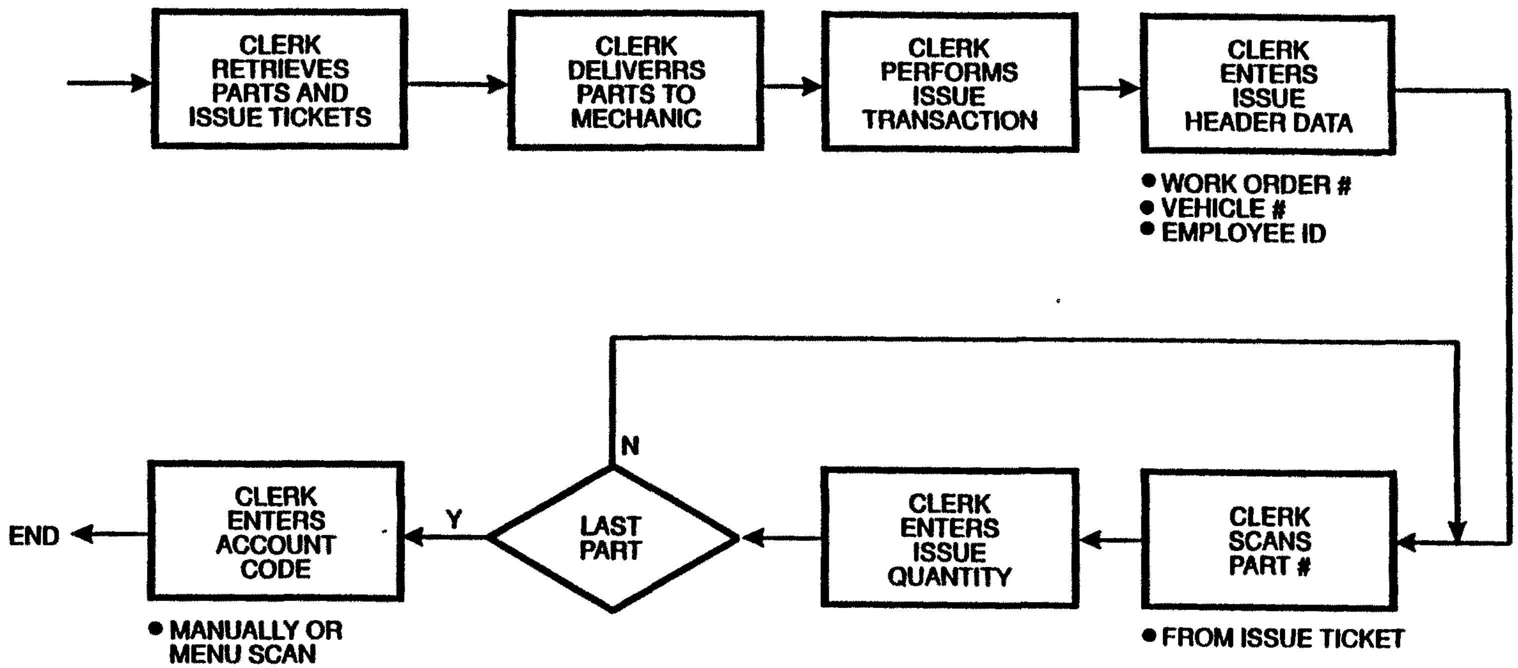

Figure 5-2. Bar Coded Material Issue Process Model

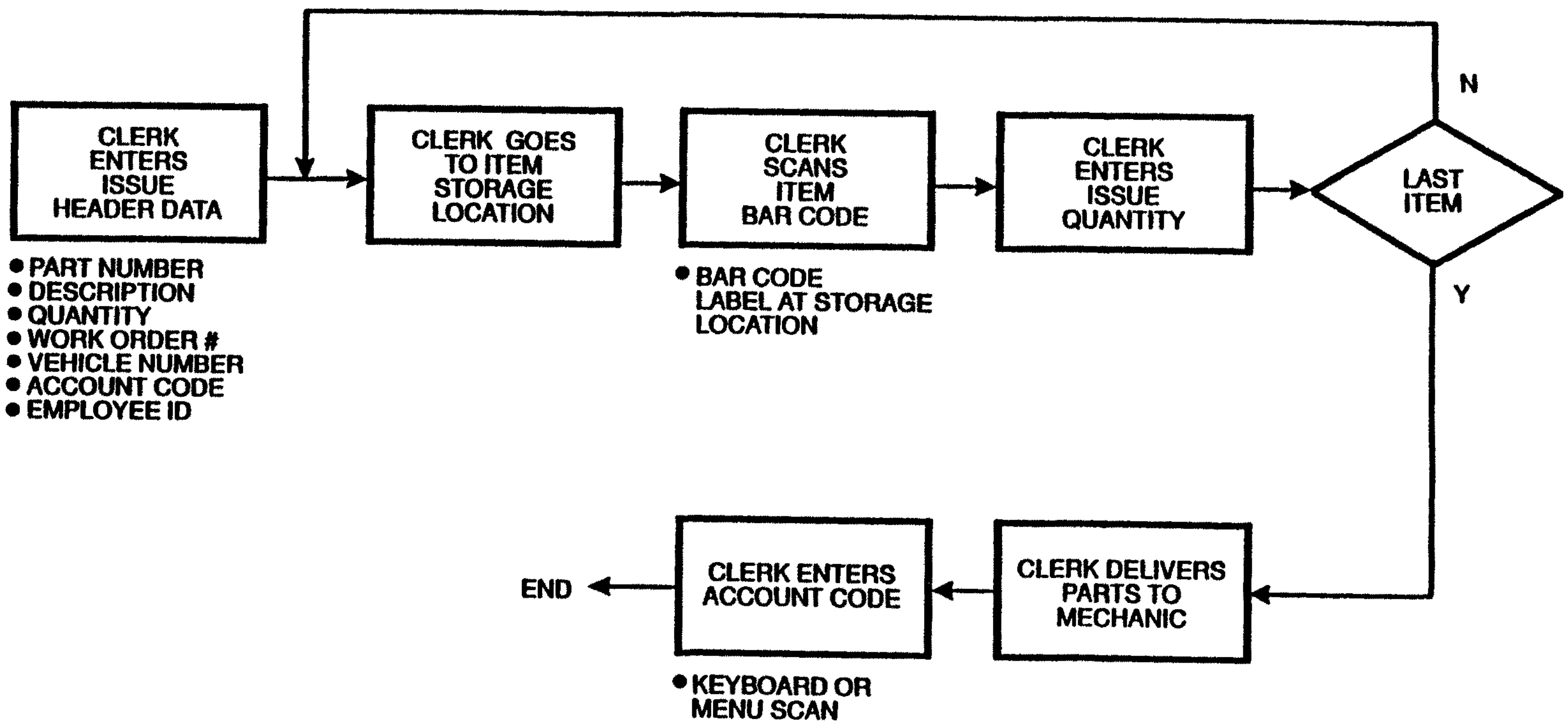

Figure 5-3. Batch Terminal Material Issue

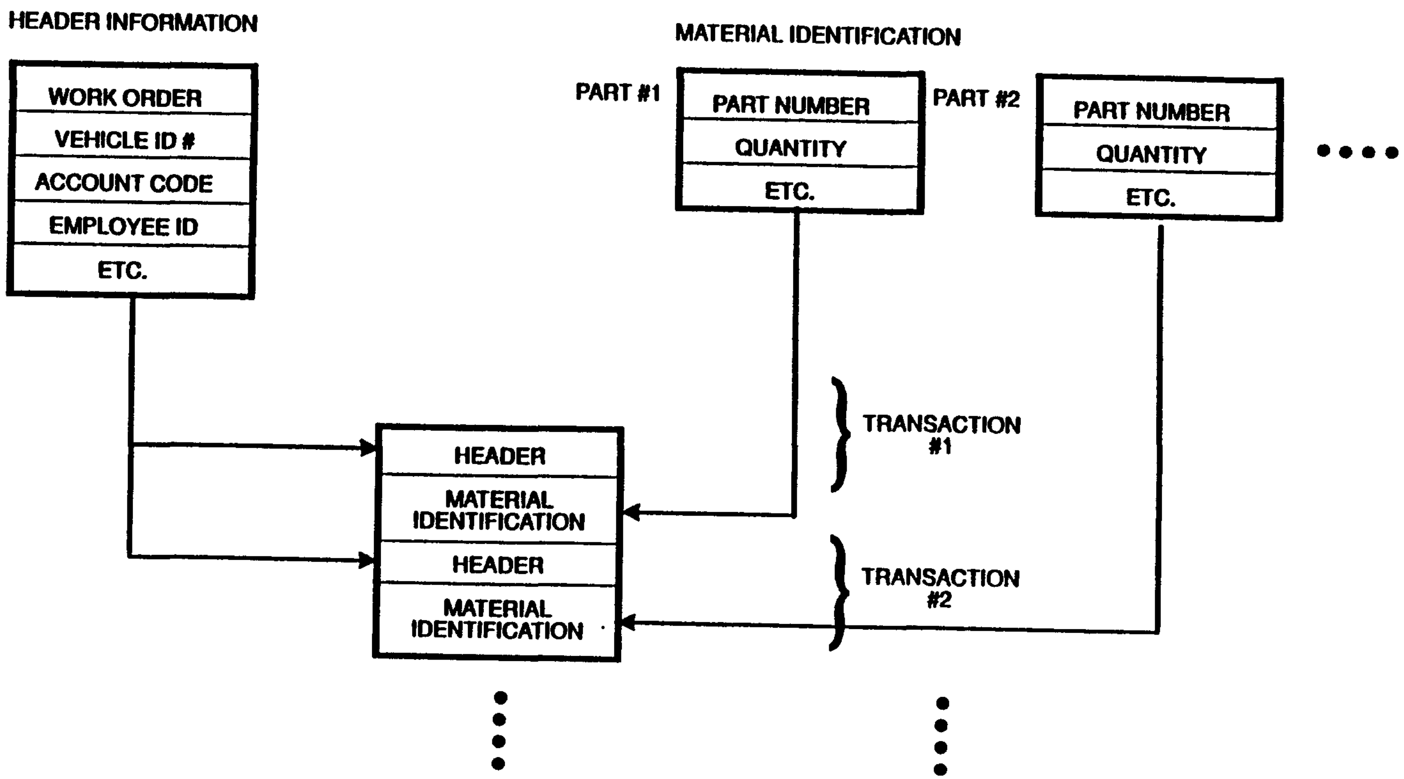

Figure 5-4. Upload File Creation Process

Generally, these clerks perform a mixture of activities including receipt processing and storage, inventory tasks, material issues and general stockroom maintenance. At most times, the clerks are performing different tasks, however there are times when all will be issuing material to mechanics. As this is the most critical function of the stockroom, it is mandatory that these requirements be serviced as quickly as possibly. For this reason, three (3) data collection devices should be provided for this application.

For other operations, the transaction requirements can be averaged over time and the number of data collection devices selected accordingly. As an example, a transit property uses bar codes to collect data during material receipts. The average number of daily receipts is 150 line items (i.e., part numbers) and the peak is 250 line items. All receipts are processed during a single 8 hour shift. It takes an average of five (5) minutes to completely process a single line item receipt. To insure that all receipts are processed during a single shift, the system design must account for the peak number of receipts. Based on this information:

- ***Peak Receipt Processing Time:*** 250 line items x 5 minutes per line item = 1250 minutes
- ***Minutes per Shift:*** 8 hours x 60 minutes/hour 480 minutes
- ***Number of Data Collection Devices:*** 1250 minutes receipt processing time */480* minutes per shift = 2.60 devices

Based on these calculations, it can be seen that a minimum of three data collection devices will be required for receipt processing. While the receipts could be stretched over more than one shift, it is best that the material be accepted into inventory as rapidly as possible to allow it to be used to fulfill requirements. As there is generally some investigation of purchase orders and open requirements to be performed during the receiving process, the approach to data collection most often used is to provide computer terminals with scanners interfaced via wedges. These applications bar code data items such as purchase order numbers and part numbers. Depending on the design an functionality of the receiving aspects of the material management software, other approaches can be used but they would require a greater degree of automation and more extensive bar coding of information.

As another example, a transit property uses bar codes to collect tin and attendance information. A total of 125 employees re required to pass their bar coded employee badge though a scanner when they arrive at the start of a shift and when they leave at the end of a shift. It takes approximately five seconds for each employee to pass their badge through the scanner. To achieve a high degree of employee acceptance of this system, it is desirable that the employees will have waits of less than three minutes to scan in and out. The minimum number of terminals required for the time and attendance system can be calculated as follows:

- ***Total Scan In/Out Time:*** 125 employees x 5 seconds/employee = 625 seconds
- ***Maximum Waiting Time:*** 3 minutes x 60 seconds per minute = 180 seconds wait time
- ***Number of Data Collection Devices:*** 625 seconds scan time/180 seconds wait time = 3.47 devices

To meet this requirement, a total of four (4) terminals are required. Generally, terminals used for this application are placed near the exits with one or more terminals at each.

A third example relates to the use of portable data collection devices in a material management application. In this case, the devices are used to perform cycle counting activities for a medium sized transit property with a total of 4,000 stock keeping units (SKUs) in inventory. This total includes 1,000 fast moving items which are counted quarterly, 1,500 items which are counted twice annually and 1,500 slow moving items which are counted annually. The required number of counts to be performed each year is as follows:

- 1,000 fast moving items x 4 counts/year = 4,000 counts/year
- 1,500 items x 2 counts/year = 3,000 counts/year
- 1,500 slow moving items x 1 count/year = 1,500 counts/year

Total: 8,500 counts/year

For purposes of the example, 25% of the slow moving items are large in size and are stored in low density storage. The balance of the items are small and are stored in high density storage. The layout stock room where this material is stored is shown in Figure 5-5. The material management system develops the lists of locations to be counted and has the ability to sort them according to storage location. This allows the worker to minimize travel between locations in the stock room by covering the area on a serpentine path as shown in Figure 5-5. Regardless of this fact, the worker will still cover a total walking distance of approximately 920 feet while performing the cycle counting tasks. The average person can walk at a rate of 3.5 feet per second or 2.4 miles per hour.

Counts are assigned on a weekly basis with all counts to be performed within a five (5) day period. Assuming that the cycle counts are performed during each of the 52 weeks in a year, a total of 163 counts will have to be made each week or 33 per day. The individual cycle count tasks consist of the sequence of operations as shown in Figure 4-36. It is estimated that the activities shown in this figure plus physically counting the items in the location will take the stock clerk an average of 40 seconds. This standard is based on observations made during the transit property site visits. The total time required to perform all weekly cycle count tasks can be calculated as follows:

- ***Walking Time:*** 920 feet/3.5 ft/sec. = 263 sec. Or 4.4 minutes
- ***Cycle Count/Time:*** 163 tasks x 40 seconds/task = 6,520 seconds or 109 minutes
- ***Total Cycle Counting Time:*** 113.4 minutes or 1.9 hours

As the cycle counting tasks will most likely not all be performed at the same time, there will be some inefficiency which will increase this time. Regardless of this fact, a single portable terminal will be more than adequate to perform all cycle counting tasks. Implementation of cycle counting using this scenario will require the bar coding of all material storage locations and the ability to upload/download information from/to the material management system. Since these measures are being performed, the use of portable terminals should be extended to other aspects of material management. This functional integration will increase the overall effectiveness and efficiency of the application.

SYSTEM COST ANALYSIS

Once a system design approach has been developed and optimized to the point where the benefits it provides are consistent with to originally developed goals, a cost analysis can be performed. For the costs to be realistic, they must include all aspects of the bar code system. This will encompass the system hardware and software, as well as related logistical elements such as training, maintenance, and installation. The total system cost will be the sum of these individual elements. Often times the costs of the logistical elements are overlooked and result in implementation costs exceeding original estimates.

Having performed the design analyses described above, it will be relatively easy to develop the costs of the system hardware. First a bill of materials including item descriptions and quantities should be developed for the system. This will include individual hardware items as well as the items which will be procured as a subsystem. Examples of subsystems include PC's to be used as terminals or upload/download interfaces for batch portable terminals, and real time portable terminals.

Functional specification packages can be developed for individual system components such as scanners or wedges as well as subsystems like batch and real time portable terminals. In general, these specifications should reflect the specifications and functional parameters provided in manufacturers literature for the item or subsystem. Caution should be exercised, however, to insure that the specification is not overly restrictive or slanted toward the product of a single supplier. This will help to promote open competition and yield the most advantageous pricing possible. A benefit of these documents is that they can be used as the basis for the technical portions of the contract or subcontract with the item supplier. Upon completion, these specifications can be distributed to suppliers to obtain pricing. When all pricing has been obtained, the system bill of materials can be used as the structure to develop the overall system cost.

Similarly, a specification can be developed for the modifications to be made to the software. This specification need not provide low level details of the

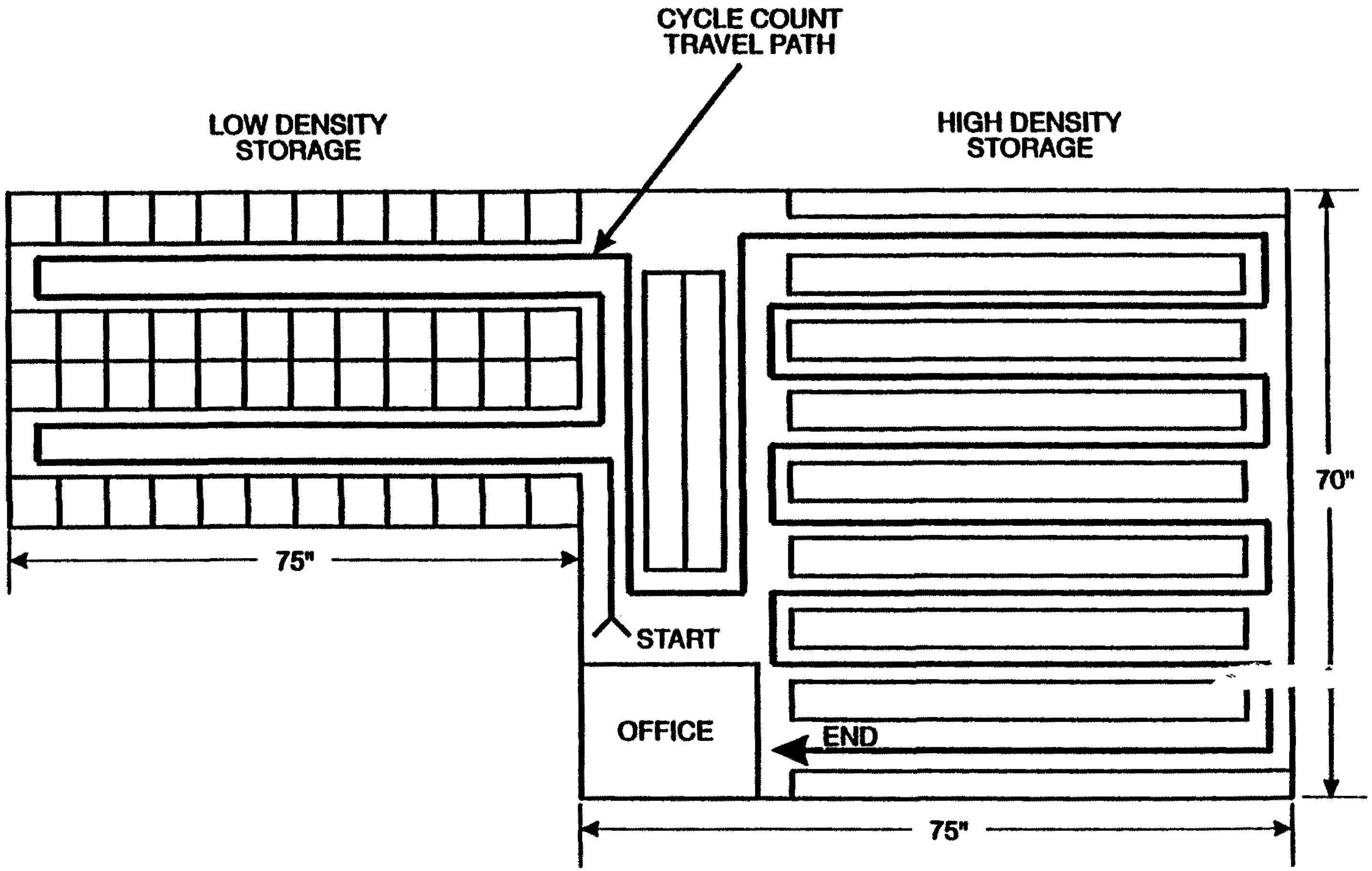

Figure 5-5. Stock Room Layout Example

workings of the software but rather should focus of the functional aspects of the required modifications. This should include any new software functionality as well as modifications to existing functions. Where applicable, this should include detailed specifications and functionality descriptions for user interface transactions as well as the desired format and content of any reports. As with the hardware specifications described above, the software specification can be used as the vehicle to obtain cost estimates from suppliers or the transit property's own management information systems group.

While often overlooked, the logistical elements associated with a new system can be a very significant contributor to the overall costs. Logistical elements and the factors associated with determining their cost are as follows:

Training: Training costs consist of two (2) parts including the cost of the training courses and the labor costs for the participants. Multiple levels of training are often provided including management, supervisory and user training. Most often the management training consists of an overview of the system designed to sensitize management to the general workings and benefits of the system. Supervisory training will provide the line supervisors of the system's users with an overview of the system functionality, how the system and the data it provides can be beneficially integrated into their activities, and how they can work with their charges to resolve system problems.

Often system maintenance training is provided. The depth of this training is dependent on the maintenance concept for the system. If maintenance will be performed by an outside organization, the amount of training required will be very limited. In essence, this training will consist only of preventive maintenance and work around procedures to allow production to continue in the event of a failure. If maintenance is to be performed by transit property personnel, more extensive maintenance training will be required. This will include problem identification, fault diagnosis and component repair or replacement procedures.

Often, the approach where outside training is provided is to train the trainers. Under this scenario, the outside trainers will train selected personnel at the transit property. These persons will then provide training to additional personnel within the transit property. Over the life cycle of the system, this may be the most cost effective approach where refresher training or training of new employees. required.

Training costs in be summarized as follows:

Training Course Development Costs: The cost of using internal personnel to develop training courses and materials or the cost of procuring these services from an outside organization. As a rule of thumb, the time required to develop the training course and materials will take four times as long as the training itself. As an example, it will take eight (8) hours to develop a two (2) hour introductory training course for managers.

Training Course Materials: This will be the production costs (reproduction, etc.) associated with the preparation of the training materials. Unless elaborate training aids are used, this cost will be minimal.

Training Course Delivery Costs: This will include the cost of providing the trainer and the labor cost for the trainees. The cost of external trainers will be a flat rate which is negotiated between the transit property and the supplier. Where internal personnel are used, the delivery cost will be the duration of the cost times the trainers hourly labor rate. In addition, the costs associated with the trainees will be the number of trainees times the course duration times their hourly labor rate.

Maintenance: As was introduced above, maintenance for a system can be provided by an outside organization or by internal personnel. In selecting the approach to be used, the complexity of the system must be considered. A simple system, such as one using a terminal integration approach featuring scanners interfaces through bar code wedges, will have very basic maintenance requirements. In this case, the relatively low cost of the system hardware may warrant a maintenance concept which replaces failed components with spares and discards the defective unit. In making this determination, the transit property can use the same unit cost criteria it applies to data processing equipment or vehicle components.

A more complex system such as one featuring real time portable terminals will have more extensive requirements. In this case, it will be most beneficial to obtain a maintenance contract with the subsystem supplier. A variety of arrangements are available including on-call maintenance with a specified response time. As an alternative, some suppliers offer plans with a pre-positioned pool of spares. Under this approach, the supplier will work with the transit property to identify the failed component which will be replaced with a spare. Generally this can be done remotely via phone conversations. The failed unit is then shipped back to the supplier who will repair the unit allowing it to be returned to the pre-positioned spares pool. It is possible for a transit property to perform maintenance of complex hardware of subsystems on its own, however the cost of developing this capability can be prohibitive. When evaluating this approach, issues such as spare parts, maintainer training, detailed maintenance documentation, and special tools and test equipment must be considered.

Installation: The cost of installation of the elements of a bar code system are often overlooked and, in many cases, exceed the cost of the hardware itself. As an example, bar code terminals such as those used for time and attendance systems are located far from the management information systems to which they provide data and a communications connection must be provided between the two. In addition, the terminals will also require power.

If there is no AC outlet nearby, a power circuit will need to be installed. Depending on local electrical codes and the practices employed by the transit property, these circuits are often required to be installed in conduit which can be costly. Accounting for the costs of the materials and the installation labor, it is conceivable that this could exceed the cost of the terminal itself. For this reason, caution should be exercised in planning equipment installation locations to avoid the installation of new power circuits unless absolutely unavoidable. Even if the system is simple and requires only scanners interfaced through wedges, the cost of having a person install and configure the devices should be considered.

Consumable Materials: The bar coded materials to be used with the system must be available and in place at the time the system is placed into service. This includes and bar code labels or documents which are integrated into the systems functionality. As an example, if material storage allocations are to be bar coded, labels must be obtained oriented, and installed at each storage location. As transit properties can have a few thousand storage locations, e cost of the labels and their installation can be significant. While these items are installed permanently, there will be cases where replacement will be required. A means of replacement and the cost of implementing this means must be considered. If the transit property plans to do this themselves, bar code printing software and an appropriate printer will be required.

Similarly, if bar coded documents such as work orders or defect cards are to be used, their design and printing costs must also be addressed. Items such as these are consumable and will need to be replenished periodically. The frequency and cost of replenishment will need to be incorporated into the system costs.

ECONOMIC BENEFITS ANALYSIS

Ultimately, the goal of any type of automation is to provide economic benefits. In commercial industries, it is culture to perform justifications of automation efforts in terms of their economic benefits before any capital expenditures are authorized.

In simplest terms, a system is economically justifiable if the cost savings it provides meets or exceeds the cost of system implementation.

It is difficult to make absolute determinations of how bar coding will produce savings for transit properties or any other type of organization. This is due to operational nuances and differences among organizations even for like applications. The best approach to evaluation of the savings is to examine problems and situations which gave rise to the bar code system in the first place. The most obvious of these is personnel dedicated to data collection and entry into management information systems. If information is collected using bar coding as a part of normal activities, these personnel become unnecessary and can be assigned to other tasks.

One of the benefits commonly associated with the use of bar coding is that it provides error free data. In the preceding section of this report entitled "Bar Coding Applicability," a scenario for a time and attendance system was described. In this description, an estimation of the costs associated with the rectification of errors induced by keyboard entry of information was described. Implementation of a bar code system would eliminate virtually all of these errors and the labor associated with the correction of the problems. While some errors may still occur, the frequency of occurrence will be magnitudes less where automation is employed.

Other savings are more difficult to quantify. In particular, the problems addressed by material management systems fall into this category. Generally, the intent of these systems is to reduce inventory variances and lost material. Most often, these problems arise due to lapses in discipline. As was described previously in this report, bar code systems help to breed and, in fact, require consistency and uniformity of operations. This uniformity will help to enforce discipline but it is not generally possible to quantify this benefit. For this reason, material management systems are best quantified in terms of general inventory level variances. Most properties are able to quantify their variances in terms of a percentage of the total inventory level. This can be converted to a dollar figure which can serve as the economic justification metric. As an example, a medium transit property with a total inventory value of $700,000 has an inventory variance of 2% or $14,000. This dollar figure then becomes the metric for performing economic justification analyses. Since a bar code system will not eliminate all errors, this dollar figure must be derated to some extent. To be conservative, it can be assumed that 90% of the errors will be eliminated so the target dollar figure becomes $12,600. When evaluating inventory variances, it is important to remember that this figure is not static. Generally, transit properties perform complete physical inventories each year and adjust balances to effectively eliminate the errors. As operations proceed from this point, new errors and lapses in discipline will result in the growth of a new variance. For this reason, a bar code system will provide continual benefits over its useful life and a payback period can be defined. As an example, if a system costing $25,000 is put in place under the scenario described above, it will pay for itself after two years. Beyond this period the benefits it provides will produce a net operational cost reduction. Economic factors such as the cost of capital funds constrain payback periods, however, it is reasonable to expect that a system which pay for itself in a period of three years will be economically justifiable.

It should also noted that the determination of economic benefits should not be a one-time occurrence. To benchmark the performance of the system on a continual basis, the system benefits and economic justification should be revisited on a periodic basis. This will help to identify any problems and resulting inefficiencies which arise due to changing procedures or circumstances. These problems can then be addressed and the system changed or procedures updated as necessary.

APPENDIX A

BAR CODING INFORMATION RESOURCES

There are many sources of information regarding bar coding including industry organizations, books and periodicals. The list which follows is designed to serve as a starting point for those wishing to collect further information on bar coding and its applications.

INDUSTRY ORGANIZATIONS

Automatic Identification Manufacturers (AIM USA)

AIM USA is a trade organization of bar code equipment and system suppliers. A significant portion of the mission of AIM USA is the dissemination of accurate, unbiased and up-to-date information. AIM USA is also the sponsor of SCAN-TECH which is the largest exposition and seminar for all aspects of Automated Data Collection which is normally held in the October/November time frame at varying locations in the continental United States. AIM USA can be contacted at:

AIM USA
634 Alpha Drive
Pittsburgh, PA 15238-2802
PH: (412) 963-8588
FAX: (412) 963-8753
Internet: adc@aimusa.org

AIM USA also publishes a book called *ADC Advantage*, *The Primer of Automatic Data Collection Technology* which they distribute at no cost. In addition, they publish a directory of their member companies including descriptions of their products and services and persons to contact for more information. As AIM USA members include all major manufacturers of bar coding hardware and software in North America, this directory will be highly useful to transit properties. AIM USA also produces and distributes documents detailing technical aspects of bar coding including copies of papers delivered during the SCAN TECH technical sessions.

PERIODICALS

The following periodicals are dedicated to all forms of automatic identification technology.

Automatic ID News
7500 Old Oak Blvd.
Cleveland, OH 44130
(216) 243-3343

ID Systems
174 Concord St.
Peterborough, NH 03458
(603) 924-9631

SCAN Newsletter
11 Middle Neck Road
Great Neck, NY 11021
(516) 487-6370

Automatic ID News and ID Systems both produce an annual directory issue which includes a comprehensive listing of bar coding equipment and service providers which is sorted according to the commodity that they provide. Additional application specific information on bar coding systems and applications is also provided in the following periodicals:

Material Handling Engineering
1100 Superior Avenue
Cleveland, Ohio 44114
(216) 696-7000

Modern Materials Handling
275 Washington Street
Newton, Massachusetts 02158
(617) 964-3030

Information obtained from these magazines will be most useful to properties implementing bar coding in material management system applications.

BOOKS

The following books provide information on all aspects of automatic identification technology including hardware and systems aspects.

Using Bar Code. Why It's Taking Over
David Jarrett Collins
Data Capture Institute, Duxbury, Massachusetts 1990
ISBN: 0-9627406-0-8

The Bar Code Book
Roger C. Palmer
Helmers Publishing, Peterborough, New Hampshire, 1989
ISBN: 0-1911261-05-2

Getting Started With Bar Codes: A Systematic Guide
Richard D. Bushnell, Jr. and Richard B. Meyers
Bushnell Consulting Group, 1993