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RETICLE MANAGEMENT ANALYSIS FOR THE PHOTOLITHOGRAPHY SECTOR OF A SEMICONDUCTOR FABRICATION FACILITY

by

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Reticle Management Study
for
MiCRUS, Inc.

Reticle Management Analysis for the Photolithography Sector of a Semiconductor Fabrication Facility

Abstract

The objective of this project is to analyze and recommend an appropriate system for reticle management in the photolithography area at MiCRUS.

The three proposed solutions are the Confined Positional System (CPS), Checkgate Tracking System (CTS), and the Bar Code Tracking System (BTS). In CPS, readers are located on the ceiling and can pick up radio frequency (RF) signals from a transmitting RFID tag clipped onto every pod. Reticle location has a precision level of ±10 feet. In CTS, readers are placed along the central aisle of the lithography area. As operators carry pods across the readers, they pick up RF signals bouncing off of RFID tags. Like the CPS, tags will also be clipped onto every pod.. BTS relies on scanning bar code labels affixed onto every pod. Racks with PC terminals and scanners are scattered throughout the lithography area. Operators must scan a pod when he or she retrieves or returns it to a rack to complete a simple check-in/checkout procedure. The system tracks ownership of reticles and depends more on cooperation from operators compared to CTS and CPS.

CPS offers the best performance, but all systems have acceptable performance. However the costs of the three systems differ dramatically. In increasing order of cost, they are BTS, CTS and CPS. The BTS requires a large degree of operator cooperation, whereas the other systems track reticales in a manner that is mostly independent of operator behavior. The BTS is clearly the preferred alternative, provided that the operators consistently conform to the BTS tracking requirments.

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EXECUTIVE SUMMARY

The objective for this project is to analyze and recommend an appropriate system for reticle management at MiCRUS. Our analysis will be limited to the photolithography area as that is the main location of all reticles.

MiCRUS currently has well over 5000 reticles in the lithography area. There are single and multi-pods (stores up to 6 reticles) for holding reticles, with single pods constituting 64% and multi-pods the other 36% of all outstanding pods.* All of the reticles are either located in the RMS (Reticle Management System), in or on an IPS tool, or on racks that are distributed throughout the floor. Operators currently have no fixed method of pinpointing the location of a reticle.

Knowing the exact location of a reticle at anytime is crucial to the operators and management. The motivation behind this is that, first, if an operator cannot find the needed reticle, he or she will tend to move on to the next job, one of a lower priority. Serviceability decreases, potentially increasing the number of hot jobs during subsequent shifts. Secondly, MiCRUS' collection of reticles is very sizable and will only continue to grow as new part numbers are introduced. Therefore, a good and reliable reticle management strategy is highly desirable to prepare the facility for future reticle expansion.

Prior to introducing our proposed solutions, we believe the following recommendations will benefit and enhance reticle tracking in general, as they apply to all three of our solutions. First, single pods are preferable to multi-pods. MiCRUS should work to gradually phase out multi-pods as more single pods are purchased. Secondly, license plates with a unique number should be placed on all pods and blue boxes. This number stays the same during the course of operation such that it eliminates the inconvenience of peeling off stickers with reticle numbers when the content of the pod is changed. This also helps to reduce contamination on the reticles caused by peeling the stickers off the pod. Finally, there should only be one person in charge of swapping reticles. This is to ensure that the database is updated correctly when reticles enter and leave the lithography area.

The three proposed solutions are the Confined Positional System (CPS), Checkgate Tracking System (CTS), and the Bar Code Tracking System (BTS). In CPS, readers are located on the ceiling and can pick up radio frequency (RF) signals from a transmitting RFID tag clipped onto every pod. Tracking is automated and reticle location has a precision level of ±10 feet. Operators will be able to see the needed reticle clearly marked on a map on the computer screen.

In CTS, readers are placed along the central aisle of the lithography area. As operators carry pods across the readers, they pick up RF signals bouncing off of RFID tags. Like the CPS, tags will also be clipped onto every pod. The system tracks movement of pods when operators cross from one designated section to the other. As the number of sections increases, the precision of the reticle location is also increased. BTS relies on scanning bar code labels affixed onto every pod. Racks with PC terminals and scanners are scattered throughout the lithography area. Operators must scan a pod when he or she retrieves or returns it to a rack to complete a simple check-in/checkout procedure. The system tracks ownership of reticles and depends more on cooperation from operators compared to CTS and CPS.

Performance measures were used to compare the different solutions. Below is a table detailing mean time to find a reticle, standard deviation of that mean time, and the probability that the reticle is found under five minutes. All values are normalized to BTS except system cost.*

Proposed Solutions	***Mean Time to Find Reticle (mins.)***	***Std. Dev. (mins)***	***P (find reticle < 1.02 mins)***	***Cost***
CPS	**0.91**	1.01	**69 %**	$282,566
CTS	1.24	**1.00**	34 %	$73,500
BTS	1.00	**1.00**	56 %	**$18,319**

Based on the table above, CPS offers the best performance. However, we **recommend BTS** because the cost is considerably lower and yet the performance is on par with CPS. Furthermore, system dependence of BTS on operator behavior is less than what we originally expected given the simplicity of the check-in/checkout procedure, as well as intrinsic discipline and motivation from the operators to follow the procedure to ease their frustration in spending unnecessarily long time locating a needed reticle. A sensitivity analysis on significant variables was performed and the results continue to favor BTS.

** MiCRUS confidential information; see Appendix 9.1 for unedited results.*

1 Introduction

1.1 MiCRUS, Inc.

Located at Hopewell Junction of Dutchess County, 70 miles north of New York City, MiCRUS was formed as a $800 million joint venture between International Business Machines Corporation (IBM) and Cirrus Logic Inc. in September 1994. The joint venture began operations January 1, 1995, occupying approximately 200,000 square feet of production space at the Hudson Valley Research Park. Headed by Chief Executive Officer Stanley J. Grubel, the company is now solely owned by IBM.

MiCRUS' mission is to provide IBM with world-class, sub-micron semiconductor products. The company is licensed to use the 0.25-micron Complementary Metal Oxide Semiconductor (CMOS) technology developed by IBM, with plans to implement extensions. MiCRUS manufactures these products to the finished wafer level, with IBM responsible for the post-wafer manufacturing process, and for sales and service. ISO-9002 Certification was awarded to MiCRUS in 1996.

1.2 Photolithography Sector

The fabrication facility is composed of several sectors responsible for the overall production line, its management, and maintenance. The photolithography sector stands out amongst others, as it is the most crucial step in manufacturing integrated circuits (IC). An integrated circuit is composed of multiple layers of circuitry patterns on a silicon wafer. Each finished wafer is the result of applying approximately 19 layers of resists and etching, along with careful quality control and inspection. The photolithography sector also houses the most expensive machines and tools that require extreme care and maintenance. Thus, maximizing the utilization of these tools and product throughput is a primary concern to the company.

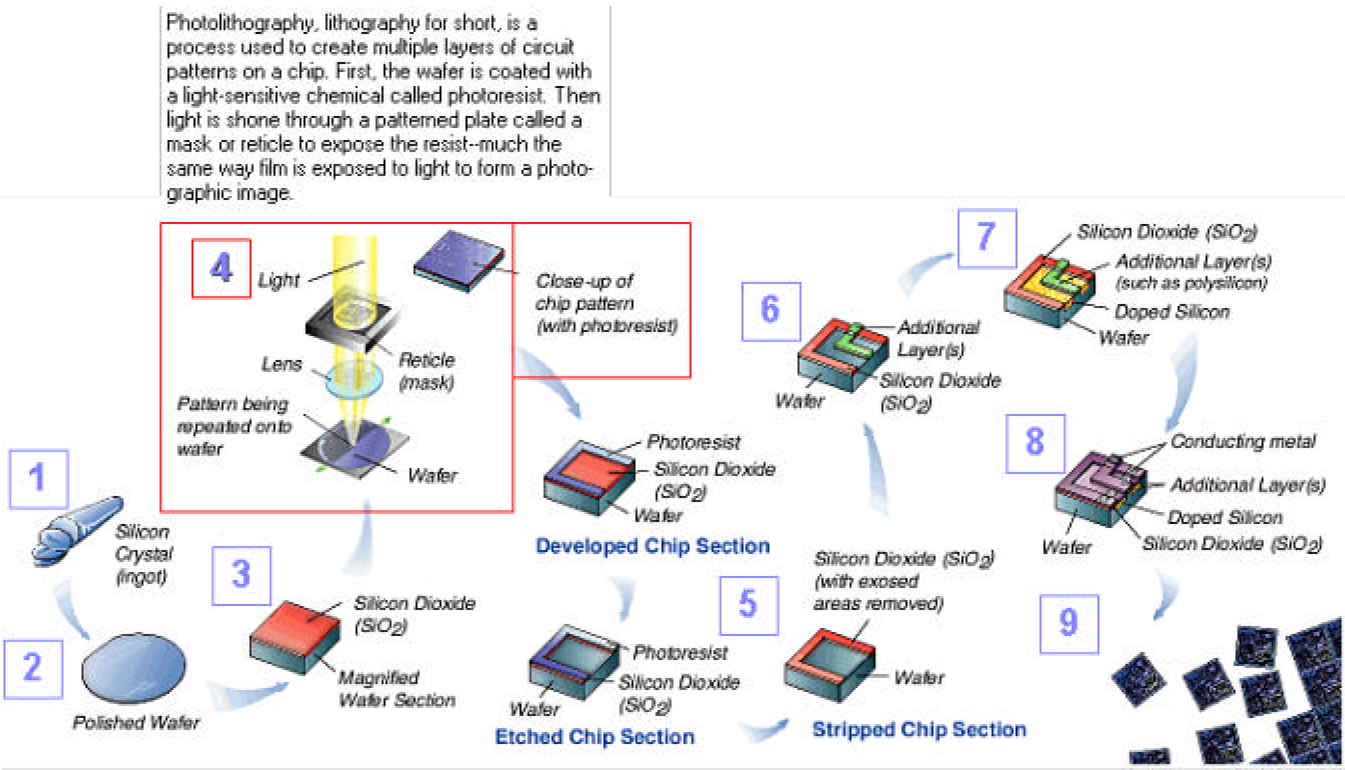

Figure 1-1 Integrated Circuit Development Cycle. (*International SEMATECH, www.sematech.org*)

The photolithography sector is a clean room with raised floors to provide a dust free environment for optimal wafer yields. It is divided into **Areas C, D,** and **E**, spreading over 300 feet lengthwise. The machines, termed **IPS tools**, consist of a **stepper** and a **track** machine.

Processing within the tool is completely automated. Silicon wafers travel in **wafer pods** that hold up to 25 wafers. A SMART-Tag by Asyst Technologies is attached onto the wafer pod to carry the job and part numbers for automatic identification. They are loaded into the IPS tool and each wafer enters the track portion sequentially. The wafer is placed on a spin tray where different types of photoresists are applied. After application of a resist layer, the wafer is then placed in a bake tray to solidify the resist. Automation and wafer transfer are done by a robotic arm, handling the wafers according to the pre-programmed routine. After the desired layers are laid, the wafer is then moved to the stepper where the actual lithography process takes place – it exposes the circuitry pattern from a mask called a **reticle** into the photoresist on the wafer. The reticle is a high precision quartz plate containing a circuitry pattern. Each finished wafer or part number normally employs a family of 19 reticles for circuit development and etching. After exposure, the wafer is sent back to the track for further photoresist development. It goes through another round of baking to maximize the resist-wafer adhesion. The finished wafer is now ready to be inspected. Before the finished wafers are packaged and shipped out, they are rigorously tested on several measures. If the wafers fail the tests, they are sent back to the photolithography sector to have the most recent resist layer stripped off. Then they must queue up again for processing later on the IPS tools.

Besides the IPS tools, reticles are the most significant tools and investment from the company's standpoint. Each piece of these quartz plates retails at several thousand dollars and proper management and care for these reticles are one of the highest priorities in MiCRUS. There are well over 5000 reticles on the floor (termed **active reticles**), with an additional of well over several thousand pieces (**inactive**) stored offline in another building for part number recall purpose. Each reticle is carried in a **reticle pod** to ensure cleanliness. Racks for storing reticle pods scatter across the entire lithography floor. A **Reticle Management System** machine (**RMS**), located in Area C, is used for large-volume reticle storage.

1.3 Purpose of Study

With the fabrication facility operating on a 24-hours, 7-days a week nonstop schedule, MiCRUS cannot afford to have any IPS tools idle because of missing reticles. Finding the appropriate reticle for a job in a short time is crucial for operators and management, as this ensures the highest prioritized jobs will get serviced first. Under the current reticle management system, to be described in detail next in Chapter 2, operators and floor managers spend precious and unnecessary time tracking down the appropriate reticles for jobs. At times these efforts turn out to be in vain as reticles are found to be missing due to mishandling. Serviceability decreases as tools are often working on jobs with lesser priority. The company believes that a revamp of the current reticle management would be beneficial to the well being of the facility in financial, managerial, and technological terms. This study thus outlines an effort from our team to utilize the knowledge of operations research and industrial engineering (OR&IE) to dissect and recommend viable solutions for improving MiCRUS' reticle management system. Three site visits have been made on November 23, 1999, January 17-18, 2000, and March 14, 2000 to gather data and facts pertaining to this study. A presentation has been made to MiCRUS on May 18, 2000 to summarize our analyses and recommendations for an improved system.

This project is made possible through the collaboration of MiCRUS and the School of OR&IE at Cornell University.

1.4 Structure of Report

In the rest of this report, we will first detail the existing reticle management on the floor. We shall point out how operators go about finding reticles under this system, as well as the system's weaknesses and opportunities for improvement.

In Chapter 3, we outline our three system recommendations – the **Bar Code Tracking System** (**BTS**), **Checkgate Tracking System** (**CTS**), and **Confined Positioning System** (**CPS**). Descriptions of each system's design, operational procedure, and specifications will be included. We will also discuss the differences in how operators go about finding reticles under each systems. Next, performance measures of these systems will be presented in Chapter 4 to reconcile the strengths and weaknesses of each solution.

Costing analysis in Chapter 5 calculates investments required to implement each solution. A summary of our recommendations for the reticle management study is given in Chapter 6. Finally, a sensitivity analysis is presented to determine the magnitude of impact of variations in certain parameters on the relative performance of the solutions. It attempts to estimate the degree of uncertainty in cost and performance, as well as to seek out the more significant factors and justify a suitable choice of solution based on these factors.

We shall also point out that material, discussions, and analyses pertaining to this study that are deemed confidential and proprietary by MiCRUS are extracted out of the report and will be found in Chapter 9 – *Proprietary Appendices*.

2 *Current Reticle Management System*

2.1 System Description

The lithography area at MiCRUS is composed of three areas: Areas C, D, and E (Figure 2-1). IPS tools are placed along the side of each area with a central aisle for operator movement. There are 11 tools in Area C, 14 in Area D, and 3 in Area E. Each IPS tool has slots for up to three reticle pods. The reticle pods can be either **singles** (holds one reticle) or **multi** (holds up to six reticles), giving each tool a capacity of 1 to 18 reticles. MiCRUS has three tools assigned to each operator. This gives MiCRUS about nine operators on the floor at any given time. Operators are divided into four shifts each consisting of 12-hour blocks so that the IPS tools are always in use (24 hours/day, 7 days/week). **Changeover meetings** occur at the end of each shift where information concerning job and tool status is related to the next shift. However, each operator works only ten hours once maintenance, setup/calibration, and lunch times are considered.

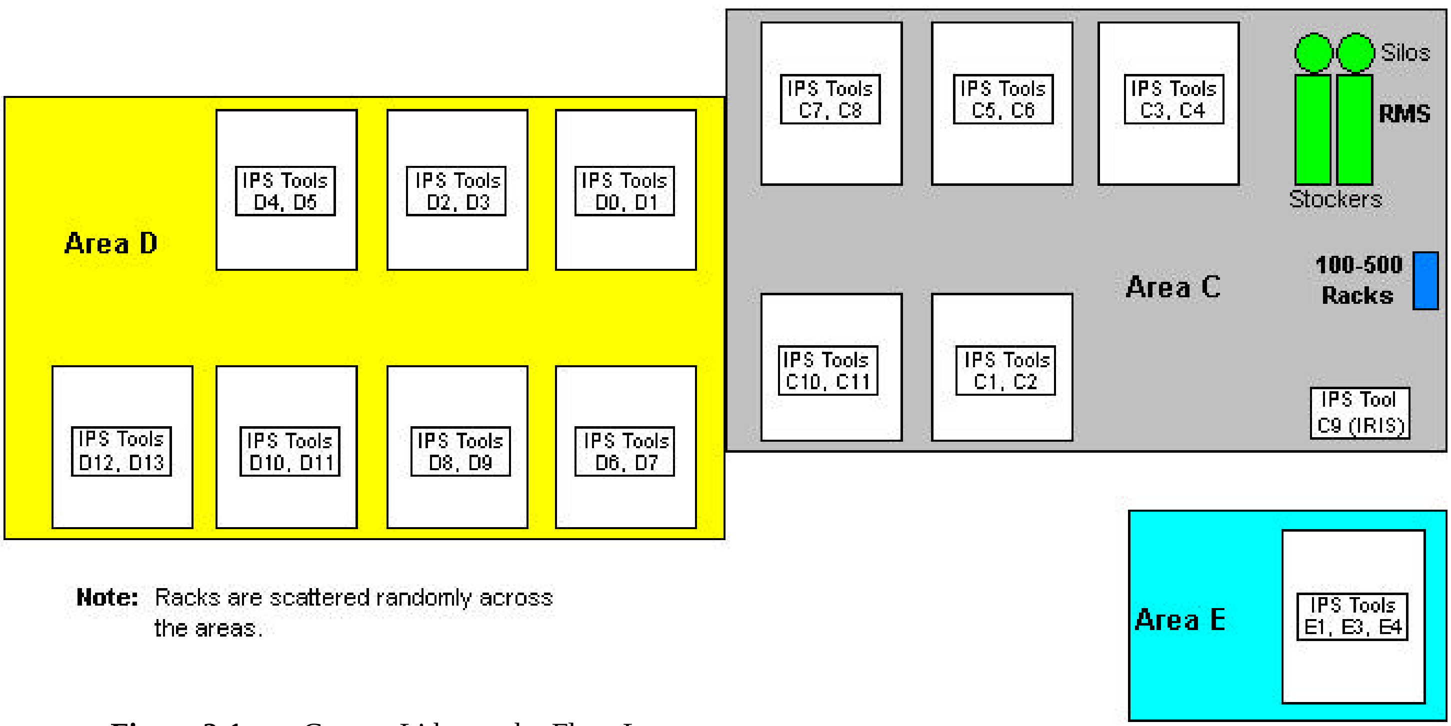

Figure 2-1 Current Lithography Floor Layout.

Besides the IPS tools, reticles are also stored in the **Reticle Management System (RMS)** in Area C. The RMS is composed of **two stockers** and **two silos**. Each stocker holds approximately 55 single and 210 multi-pods, with or without reticles inside them. The silos only hold bare reticles without any pods and have a capacity of approximately 1100 each. The stockers and silos actually have more capacity than the listed numbers, but the robotic arm that stores and retrieves the reticles have movement limitations and cannot reach portions of the stockers and silos. All multi-pods that MiCRUS currently possesses can all fit into the two stockers. Despite that the stockers have a capacity of 110 single pods, most of these single pods are distributed on racks throughout the lithography area. Operators search for reticles by browsing through the **stickers** affixed on the side of each pod. Each sticker is handwritten with a **reticle serial number** on it. When the content of the pod changes, operators have to peel off the old sticker and replace it with one having the new reticle number written on it. Each reticle contains a unique reticle serial number bar-coded on the top, even if the reticles are identical with the same circuitry patterns. They can be seen through the transparent reticle pod by operators to make sure the number matches with what is on the pod sticker.

Operators store reticle pods located on the floor on racks or on top of IPS tools (not the three slots mentioned above). Racks are disbursed throughout the floor. There are approximately four to five racks located in each of Areas C and D, and one rack in Area E. Area C also has special racks called **100-500 racks**. These racks are used to hold reticle pods for **first layer silicon jobs**. A first layer silicon job means that MiCRUS has never produced that part number before. Usually, first layer silicon jobs are for prototype parts, where only a few samples are needed to test quality and functionality before high volume production begins. The reticles for first layer silicon jobs are usually assigned to multi-pods. Since it is not as convenient to use multi-pods compared to single pods, low volume reticles are stored in there. Also, low volume reticles means that it is unlikely for more than one operator to look for the same set of reticles. However, this is not the case for the high volume reticles. To alleviate the problem of one operator waiting for another operator to finish with a needed reticle, MiCRUS may decide to purchase a duplicate set of reticles for a particular part number. This will allow an IPS tool to be in use at all times, working on a job at the top of the priority list.

Next to each IPS tool, an operator can use a computer terminal to find out what jobs are on the "***What's Next***" list, which shows the highest priority jobs on top. The "*What's Next*" list is part of the software system called **MiDAS** (**MiCRUS Access Delivery System**). It is a HTML-based web page that retrieves necessary information from a database engine. Currently, MiDAS only tells an operator what job he or she is supposed to do next, as well as the required reticles for the job. However, MiCRUS is currently trying to implement extra features into MiDAS. A *Location* Field is currently left blank next to all required reticles. In the future, MiDAS will be able to tell an operator if a desired reticle is in the RMS or what tool it was last used on, by linking the appropriate information from the RMS and IPS tools with the database. This will be a tremendous improvement for the operators to search reticles on the lithography floor.

Given that there are well over 5000 reticles on the floor, there are not enough space for the RMS or pods to hold all the reticles. The rest of the reticles are each stored in a **blue box**. The majority of the blue boxes contain reticles that have not been used for over 90 days and are thus recycled out of the lithography area and stored in **Building 320**. However, there are also blue boxes located on the floor containing reticles that have been used at least once within a 90-day period. When an operator needs a reticle from a blue box, he or she must use a pair of tongs to pick up the reticle and swap it with a reticle already in a pod or into an empty pod if one is available. From our third visit on March 14, we observed that most of the blue boxes are located on the racks near the **IRIS inspection tool**, with some scattered throughout the rest of the racks.

The final location for pods is on the racks next to the IRIS inspection station. The rack contains pods with reticles that need to be inspected for contamination before it can be loaded into an IPS tool for use. Proper cleaning will allow MiCRUS to produce IC's with higher quality and yield. There are several situations where a reticle requires cleaning:

1. Reticle is retrieved from the RMS.
2. Reticle from a blue box is swapped into a pod for use.
3. Reticle has had more than several hundred exposures in an IPS tool (ideal case is one-fourth of the current ratio).*
4. The top 20 volume reticles for the day.

The process of cleaning the reticle takes approximately seven minutes. If the reticle is clean, then the operator can proceed to use it. If not, the reticle is put through the process again. If the reticle is still not clean, then it is put through a process called **starlighting** (a more intense cleaning process) on a different tool.

** MiCRUS confidential information; see Appendix 9.2.*

2.2 Behavioral Analysis of Operators

Operators currently do not know the exact location of a particular reticle. Despite the absence of proper guidelines in retrieving reticles, operators have developed a behavioral pattern for searching reticles under current system. The steps taken by operators in searching for a reticle are detailed below:

Step 1 – *Operator queries MiDAS to find out what the next job and required reticle is*

If the operator does not already have that reticle, he or she must search the lithography area for it.

Step 2 – *Operator looks for reticle in the same area*

If the operator is in Area C (or D), he or she will look for the reticle in that area first. The operator searches for the reticle on the racks, in or on top of the IPS tools in the same area. It takes about 15 to 20 minutes to browse through all the pods in this area. If the operator does not find the reticle here, he or she will proceed on to Step 3.

Step 3 – *Operator inquires on the RMS*

If the operator does not find the reticle in his or her own area, then he or she will proceed to the RMS. If the reticle is not in the RMS, the operator will proceed to the other area.

Step 4 – *Operator looks for the reticle in the other area*

The other area is either Area C or D depending on the operator's original location. If the operator started his or her search in Area C, then the other area would be Area D, and vice versa. If the reticle is not here, then the operator proceeds to Area E.

Step 5 – *Operator looks for the reticle in Area E*

Area E is the smallest area of the three. Including walking time, it takes the operator three minutes to search Area E.

Step 6 – *Reticle is assumed to be misplaced*

If the operator could not find the reticle after going through Steps 1 to 5, then the operator will deem the reticle misplaced and request those in charge of IRIS tool to re-search for it when they are available to do so.

Step 7 – *Reticle is mislabeled*

The reticle is considered mislabeled if the IRIS operators could not locate it by the end of the shift. This means that the sticker on the outside of the pod does not match with the reticle serial number inside.

Currently, it takes an operator 15 to 20 minutes on average to find a desired reticle. However, operators frequently will not be able to find the needed reticles after going through the above steps a couple of times, thus causing tremendous frustrations among the operators as well as the floor managers. Since performance of operators is reviewed based on throughput, they must make sure that all of their tools are working on a job. If an operator cannot find a particular reticle, then he or she will work on a different job so that throughput is not affected. This is the most significant concern aside from reticle management for MiCRUS since now the operators are doing jobs that may not be on top of the "*What's Next*" list, which are the highest priority jobs that are due to customers very shortly.

We shall now proceed to propose our recommended solutions for improving MiCRUS' reticle management in Chapter 3.

3 *Viable Solutions and Analyses*

3.1 General System Recommendations

After reviewing the current state of reticle management, improvements on the following areas can largely enhance reticle tracking in general. The following general recommendations apply to all three solutions in our proposal – the Bar Code Tracking System (BTS), Checkgate Tracking System (CTS), and Confined Positioning System (CPS).

Treatment of Multi-Pods and Purchase of Single Pods

We recommend MiCRUS to keep the multi-pods in the RMS stocker and gradually phase them out of circulation on the floor. More single pods should be purchased in the future to facilitate reticle usage and tracking. We will now proceed with the reasons supporting this recommendation.

Current reticle capacity in multi-pods totals roughly 40 percent of all outstanding reticles, and most of them resides in the stocker portion of the RMS. The multi-pods are currently used for storing reticles of first layer silicon, which are used infrequently compared to other active reticles. Furthermore, the set of 19 mask reticles for a particular part number is usually grouped into the same pods. Thus, it is not a major concern in terms of swapping reticles often in and out of multi-pods. To save floor space and maximize the capacity of the stocker, the present treatment of migrating the multi-pods from the old 100-500 racks to the RMS stocker is recommended.

Most MiCRUS employees are fully aware of the problems associated with using multi-pods that can hold up to six reticles at a time. They are heavy and bulky, and the insertion and removal of reticles through the plastic slots create considerable friction, and in turn creates serious dust contamination on the surface of reticles. Furthermore, it is far less convenient and time-consuming to retrieve the desired reticle from multi-pods. A gradual phase-out should be implemented.

However, we will assume in the remaining report that there will still be multi-pods in circulation since they constitute a significant proportion of the active reticles on the floor as well as a large investment. As addressed in Section 2.1, each of the two stockers hold up to 213 multi-pods and 56 single pods, equivalent to a capacity of more than 2600 (a single pod can occupy a multi-pod slot but the stocker will then not be utilized at its maximum capacity). If we were to replace all the multi-pods with single ones, it would be impossible to come up with the necessary floor space to hold them. The cost to purchase all the single pods would also be prohibitively expensive.

Nevertheless, we recommend MiCRUS to increase the proportion of outstanding single pods by 40 percent.* Besides the benefits we gain from replacing a portion of multi-pods, this investment is also worthwhile since reticle retrieval from RMS is the bottleneck for minimizing overall retrieval time (minimum of seven minutes to retrieve from RMS). By having more single pods on the floor, operators will have less dependence on the RMS, and thus, retrieve the desired reticle faster.

** MiCRUS confidential information; see Appendix 9.3.*

Routine Reticle Pod Cleaning and IRIS Inspection

Since our site visit on January 17, MiCRUS has acted upon our concern with the lack of routine cleaning of reticle pods. While the wafer pods were being cleaned on a regular basis to ensure high chip yields, reticle pods, on the other hand, were not. MiCRUS' decision to begin routine cleaning on reticle pods will undoubtedly benefit its overall productivity. In addition to ensuring dust-free reticles, routine cleaning also decreases the frequency and necessity of IRIS inspection on reticles taken out from the RMS – assuming more single pods are available and the retrieval is made from the stocker and not the silo. By decreasing the load on the IRIS tool (plus an addition of a new tool in near future), MiCRUS can realistically follow the ideal ratio in terms of number of reticle exposures before necessary inspection (which runs at about four times higher at the moment). The minimum of seven minutes a reticle spends in IRIS coming out of the RMS can be saved, enabling faster access to reticles and decreasing the time required to retrieve them.

Routine Reticle Cycling

As we raise the number of single pods, new sets of reticles continue to arrive in a steady stream. Efforts must be maintained to cycle reticle storage so as to prevent overthrow of reticles and shortage of pods. Active reticles on the floor that are not used for more than 90 days are phased out into blue-boxed storage in Building 320. MiCRUS should strictly abide by the 90-day rule so as to maintain overall tracking system efficiency. At least one person should be dedicated to managing incoming reticles and storing outdated ones, so that the database reflects the appropriate locations for each reticle entry (see also *Handling of Blue-Boxed Storage, New and Repaired Reticles* below).

License Plates for Reticle Pods and Blue Boxes

Instead of using reticle numbers to identify pods for tracking purposes, we propose the idea of licensing all reticle pods and blue boxes with numbered plates. The major advantage of license-plating pods and blue boxes is to take advantage of the intrinsic property that the plate number will not change during the course of operation. Under the current system, operators attach reticle numbers onto the pod with removable labels. But since the content of the pod changes from time to time, operators must peel off the labels and replace them whenever the content is changed. Under this proposal, the responsibility of tracking the contents in pods and blue boxes is now delegated to the Database (see section *The Database, MiDAS Web, and Software Integration* below), with much higher efficiency and reliability than handwriting. By considering future expansion in single pod numbers, we propose license plate numbers *x* through *y* to be reserved for multi-pods, *y* to *z* for single pods, while license plate numbers *z* and thereafter are reserved for blue boxes.* Considering that pods are cleaned on a regular basis, the license plates should latch firmly onto the pod but also easily removable when needed, similar to the SMART-Tags by Asyst Technologies that were once deployed. The number should be clearly printed for quick sighting by the operators.

** MiCRUS confidential information; see Appendix 9.4.*

Handling of Blue-Boxed Storage, New, and Repaired Reticles

Over 2000 empty blue boxes are still available for permanent storage at this time; therefore shortage of these containers is not of short-term concern. However, blue boxes should only be allowed in Building 320 and not on the lithography floor to prevent buildup as floor space is tight and precious. Our tracking efforts will also be hindered if blue boxes are scattered on the floor.

As discussed above in *Routine Reticle Cycling*, there should be one person designated for continuously maintaining the most updated list of active reticles. Besides keeping track of which reticles have been inactive for more than 90 days, he or she should also be responsible for tasks such as updating the Database when new sets of reticles are put into circulation, damaged reticles taken out of circulation for repair, as well as handling retrieval and swapping of blue-boxed reticles. This person should be located near the 100-500 racks/IRIS tool as it is currently where some of these tasks take place.

When new or repaired reticles are put into circulation, empty pods must be available and the corresponding license plate numbers are input into the database. Conversely, when reticles are taken out of circulation for either inactivity or repair, the Database should also be updated appropriately (see section *The Database, MiDAS Web, and Software Integration* for details). When an operator needs a blue-boxed reticle, he or she will contact this person to retrieve it from Building 320. The reticle is swapped into an empty pod, and the database is again updated appropriately. Notice that this reticle will remain on the floor for at least 90 days before being blue-boxed again. Thus the operator need not worry about returning the reticle after he or she is done using it. Since each proposed solution handles blue-boxed storage, new, and repaired reticles slightly different, we shall explain such difference in detail in subsequent sections.

The Database, MiDAS Web, and Software Integration

The backbone to any of our solutions lies on the system's software development. We shall now propose and define the unique components necessary for our recommendations.

The illustration below shows each essential component of our generic tracking system, along with the data architecture interconnecting them. The major components are:

1. The Database
2. MiDAS Web
3. RMS and its software
4. IPS tools and its software
5. Devices of each solution on the floor
6. Coding that interfaces between the Database and MiDAS Web, RMS, IPS tools, and floor devices

The Database is the central storage for all types of tracking data – both reticle-related as well as job or part number- related. The contents for the Database should be refreshed on a real-time basis: changes made by operators and floor managers to the Database should be reflected on MiDAS Web instantaneously. To incorporate the license plate proposal into the Database, a new

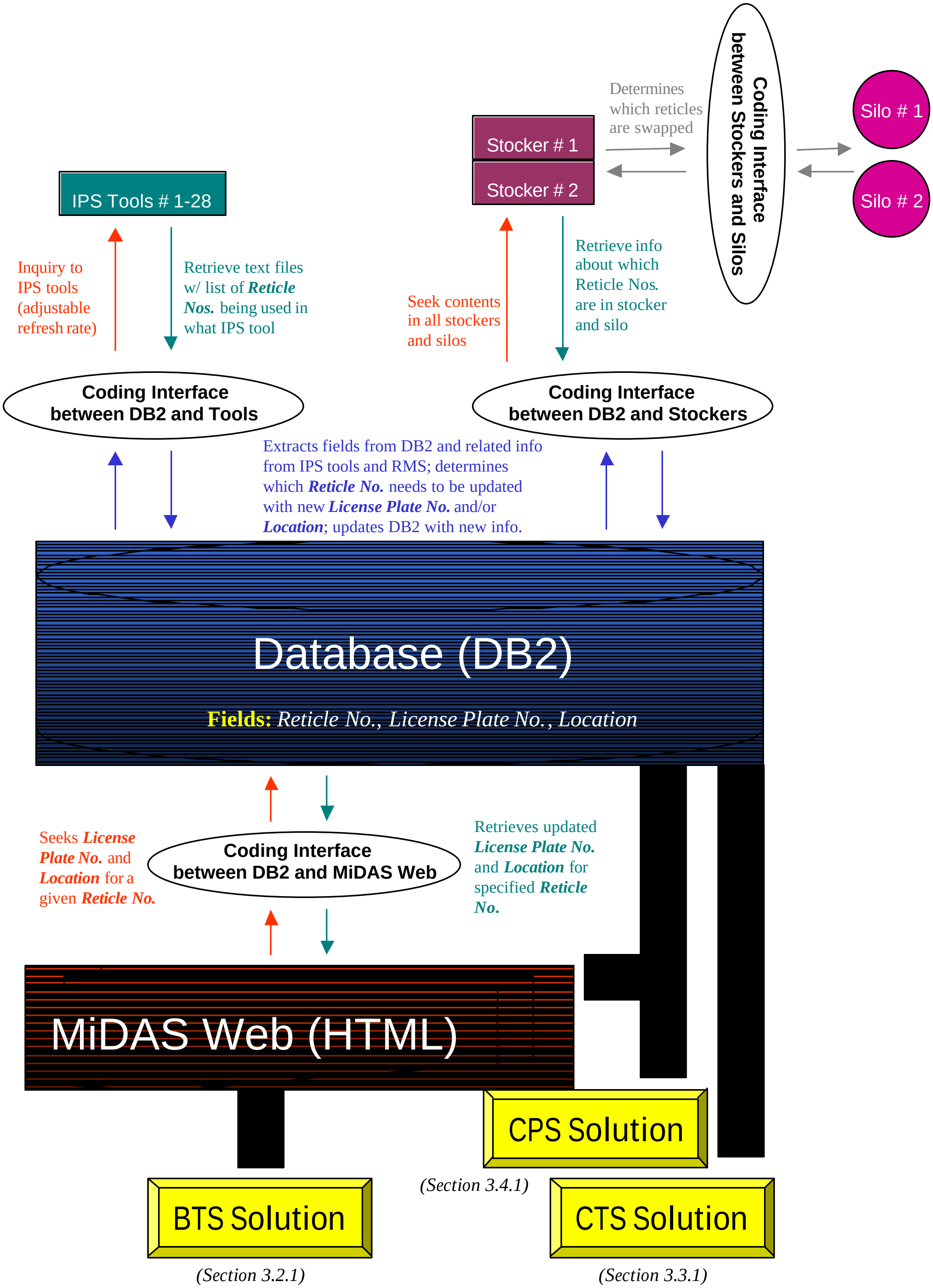

Figure 3-1 Data Architecture of MiDAS Web and Database Implementation.

field titled "License Plate Number" is added. The ongoing effort to link the RMS and information from IPS tools to the database will also add a *Location* field in the database and display the reticle's whereabouts, if it is inside the RMS or if it was last used in an IPS tool. We shall expand the use of this field to cover the location of reticles on the floor. The following table shows the proposed fields in the Database.

SCENARIOS		**DATABASE FIELDS**			
		(Existing)	*(New)*		
		Reticle Number	**License Plate Number***		**Location**
1.	Reticle in Building 320	XXXXXX	$\geq z$	B	Building 320
2.	Reticle sent out for repair	…	---	---	Repairing
3.	Reticle in silo of RMS	…	---	---	RMS Silo
4a.	Reticle in stocker of RMS (in single pod)	…	*y* to *z*	S	RMS Stocker
4b.	Reticle in stocker of RMS (in multi-pod)	…	*x* to *y*	M	RMS Stocker
5.	Reticle being used inside an IPS tool	…	*x* to *z*	M or S	IPS tool #C-1 to E-4
6.	Reticle is somewhere else on the floor…	…	*x* to *z*	M or S	Depends on solution

* *MiCRUS confidential information; see Appendix 9.5*
(S = single pod, M = multi-pod, B = blue box)

Figure 3-2 Database Fields with Possible Transaction Scenarios.

Each of our solutions utilizes the *Location* field differently when tracking reticle movements and locations on the floor. These differences will be addressed in Section 3.2, 3.3, 3.4. Notice that the license plate number stays with the reticle even when it is inside an IPS tool, since the reticle will almost always be placed back into the same pod that it came out of.

The MiDAS Web currently enables the operators to see, amongst other things, what job numbers they are responsible for. They can access the web pages through the existing PC terminals on the floor. With proper interfacing between the Database and the web pages, our recommendation will allow them to see locations of the reticles as well as their corresponding license plate numbers, if any. This interface should be simple and easy to use, and it applies to all three of our solutions.

Coding is required to successfully link reticle information from the IPS tools and the RMS to the Database. Based on the information regarding software development we have gathered at the time of writing, it is fairly reasonable to assume that the RMS will have the ability to track reticles both on the silo and stocker, and to update the Database accordingly. We have also confirmed that each reticle possesses a unique serial number including duplicates. This resolves our initial concern of whether RMS will be able to distinguish two identical reticles in order to update the Database appropriately.

Finally, on-the-floor tracking information is sent to modify the Database via different devices depending on the solution we propose. Under BTS, scanners and extra PC terminals are placed on the floor and equipped with a unique interface for operators to record movements. In CTS, the checkgates record times when a pod passes through and an algorithm calculates which region the pod belongs to. This information is then used to update the Database. In CPS, the pod locations are tracked automatically by the system and the attached software can then be configured to update the Database as well as MiDAS Web accordingly. Details will be discussed in Section 3.2, 3.3, and 3.4 respectively.

3.2 Bar Code Tracking System (BTS)

The Bar Code Tracking System (BTS) can be integrated with the existing software to keep track of which rack a pod is located as well as the reticle it contains by using bar code technology to update the Database whenever a reticle is retrieved from or returned to a rack. The system utilizes one of the most common inventory tracking technologies which is a fast, easy, cheap, and accurate data entry method. From the software implementation standpoint, this operation should be relatively easy to implement as the scanning can be treated as inputs from a second keyboard. The BTS is similar to the library check-in or checkout system, in which operator uses a PC terminal equipped with a bar code scanner next to the rack to record each transaction that in turn will update the Database accordingly. Details of how transactions are recorded are outlined in Section 3.2.1.

Before we proceed further, we shall define the place where reticles are stored as a "BTS Station." As we will discuss later in *System Design and Operations*, a BTS Station consists of a rack, a PC terminal, and a bar code scanner. The BTS Stations are spread across the lithography floor according to the grouping of IPS tools to allow operators to return pods conveniently to the nearest Station. Operators are given ID Badges to facilitate tracking of reticle ownership; and along with the license plate numbers discussed in Section 3.1, both will be bar-coded. A specially designed HTML interface on top of MiDAS Web helps in guiding operators to record each transaction. The BTS serves well to combat the current problem of mislabeling and misreading reticle numbers off of pods due to handwriting.

3.2.1 System Design and Operations

BTS Stations

BTS Stations are spread across the lithography floor, with approximately one Station for every four IPS tools which totals nine Stations. This system attempts to cut down average walking distance to retrieve a pod and thereby decrease time taken to look for reticles. As we mention in the chapter's introduction, a BTS Station consists of a rack together with a scanner and a PC terminal. Figure 3-3 shows our recommended configuration and gives a graphical representation for the location of the racks.

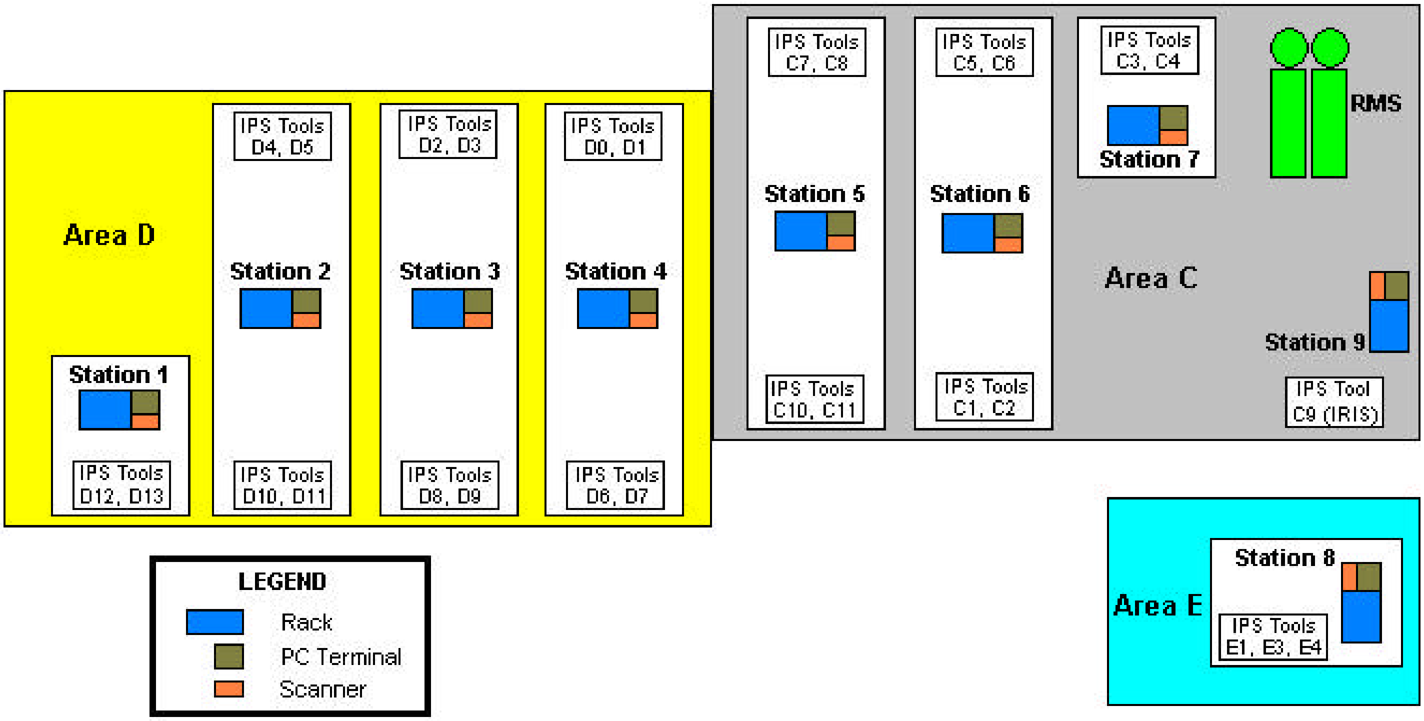

Figure 3-3 BTS Stations Configuration and Coverage.

Each rack should have a capacity of 50 to 100 pods so as to accommodate all the single pods on the floor, with some in the IPS tools and on the stocker of the RMS. Additional rack space should be reserved for future expansion in number of pods.

The old 100-500 racks near the IRIS tool can be reused in Station 9 so that extra racks need not be purchased. The issue of handling blue-boxed storage as well as new and repaired reticles under BTS will be addressed in next section.

The number of BTS Stations can be varied, and there is no absolute reason why we have selected the configuration of nine Stations. However, too few BTS Stations will in turn make the racks larger in order for them to hold more pods. Space limitation may be a problem if the dimensions of the rack exceed what is allowed. Operators will spend more time eyeballing each pod to find the desired one, and they have to walk longer on average to reach the Stations as they are more spread out. On the other hand, too many racks increase the cost as additional PC terminals and scanners must be purchased. Space limitation is again a problem here since the racks will then occupy more floor space due to the attached PC terminal and scanner. The configuration shown above serves as a good tradeoff between search time, cost, and floor space. More on this later in Chapter 6 *Recommendation and Sensitivity Analysis*.

Handling of Blue-Boxed Storage, New, and Repaired Reticles Under BTS

Besides serving as a rack, Station 9 is also responsible for dealing with blue boxes, new, and repaired reticles as prescribed in Section 3.1. The person will take charge of BTS Station 9, which is equipped with a similar HTML interface on top of MiDAS Web as in other Stations. However, it is also customized so that transactions regarding to blue boxes, reticle swapping, new, and repaired reticles, can be logged to update the Database.

Each time an operator needs a blue-boxed reticle from Building 320, he or she will contact this person in Station 9, whom in turn will make the retrieval from Building 320. According to MiCRUS, there are only about 2 to 3 retrievals of such kind per each week. Therefore, it is not of major time concern. The person in Station 9 will in turn swap the recalled reticle into an available empty pod, as well as recording such transaction through the customized interface (see section *BTS Software Interface and Specifications* for details) so that the Database will reflect the change. All swapping takes place in Station 9 so that the Database can be refreshed appropriately. When reticles are put into or taken out of circulation, such transactions are again recorded by this person via the HTML interface to ensure the correctness of the Database.

Extra Entries in the Database for Floor Tracking under BTS

To expand the Database entries in Section 3.1 under BTS, the following scenarios are added (Figure 3-4):

- ♦ If the pod is on a rack of any BTS Stations, the *Location* field will indicate which BTS Station it is on.
- ♦ If the pod is checked out by an operator, the operator's name will appear in the *Location* field to reflect proper ownership.

SCENARIOS	DATABASE FIELDS			
	(Existing)	*(New)*		
	Reticle Number	**License Plate Number***		**Location**
1 - 5. Inherit from Section 3.1	…	---	---	---
6. Reticle on rack of a BTS Station	…	*y* to *z*	S	Station 1 – 9
7. Reticle checked out by Operator Ken	…	*y* to *z*	S	Operator Ken

** MiCRUS confidential information; see Appendix 9.6.*

Figure 3-4 Database Fields Under BTS.

ID Badges for Operators

Each Operator is given a badge with a unique identification number that is bar-coded. We propose that in order for operators to retrieve or return pods, they must first scan their ID Badges. This is to maintain security and encourage responsible behavior, as the IDs allow the system to log the operator's activity for review and also acts as a security bridge to the database so that unauthorized personnel would not corrupt tracking information. Proper ownership of pods can be tracked with these ID Badges.

BTS Software Interface and Specifications

As discussed earlier, an extra HTML interface must be developed as an extension to the existing MiDAS Web to facilitate on-the-floor tracking under BTS. Figure 3-5 shows how BTS fits into the data architecture with MiDAS Web and the Database (extension to Figure 3-1). Figures 3-6 and 3-7 specify the components of this interface. In a nutshell, the operator is greeted with a password-protected screen that requires him or her to scan his or her ID Badge to log into the system. The next screen displays the possible options that the operator can do, such as retrieving and returning pods to the Station, transferring ownership of pods from one operator to the other especially during the changeovers, and inquiring current pods that the operator has checked out so far. In the case of Station 9, the person will also be able to view options pertaining to blue box swapping, new, and repaired reticles. The software interface is configured on each of the BTS Station's PC terminals so that it recognizes the Station number without asking operators for input when transactions are recorded.

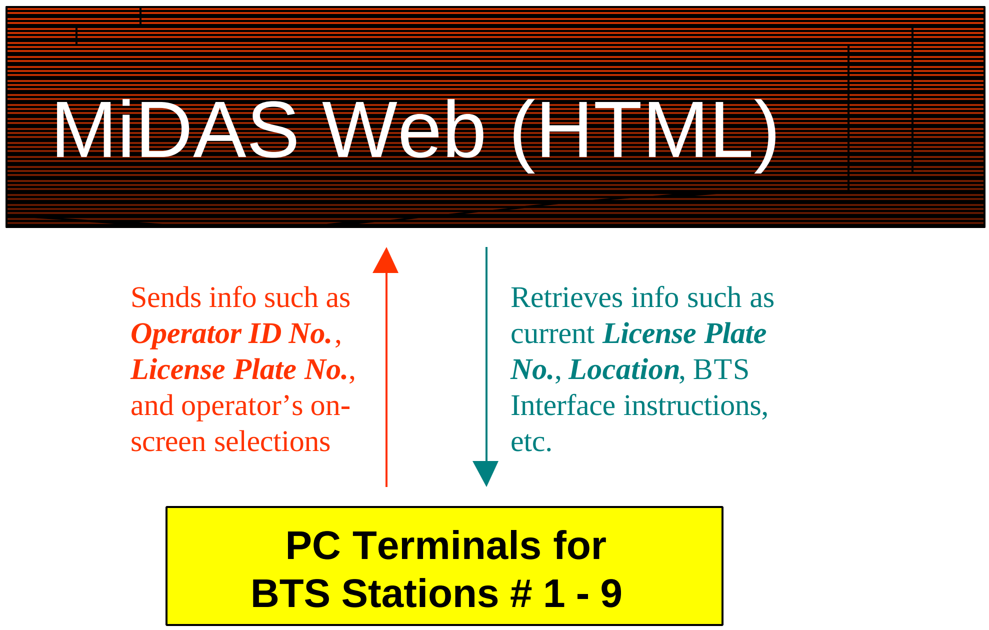

Figure 3-5 Explanation on Options of HTML Interface in Figure 3-6.

STATION 1 TO 8		
Option		***Function***
1.	**Retrieval**	To retrieval desired pod(s) from rack.
2.	**Return**	To return pod(s) to rack. Person returning pods do not have to be the person who checked out them.
3.	**Ownership Transfer**	To acquire pod(s) ownership from someone else. Operator can either designate reticle for transfer from the list of current owners or have the desired pod directly scanned. Useful when reticle is currently owned by someone else or during changeover in which subsequent operator inherits ownership from predecessor. Unnecessary reticles are removed from IPS tools and returned to racks at the end of shift to prevent build-up.
4.	**Inquiry**	To inquire about the list of pod(s) the operator has currently checked out. Any discrepancy between the Database and what the operator actually possesses should be rectified immediately, especially before changeovers.
STATION 9		
1-4.	**Same as above**	Same as above.
5.	**Swapping**	To update Database when swapping takes place amongst blue boxes, single, and multi-pods.
6.	**Reticle Repair**	To update Database which reticle is currently being sent out for repair.
7.	**Activation**	To notify and update Database with new reticle serial number and its corresponding license plate number when put into circulation on the floor.

Figure 3-6 Explanation on Options of HTML Interface in Figure 3-7.

Figure 3-7 HTML Interface Specifications for BTS.

To take advantage of simplicity and accuracy bar codes, the operator can scan his or her way through each screen instead of inputting via keyboard or mouse. A sheet of bar-coded labels with equivalent commands such as DONE and BACK is placed next to the PC terminal in each BTS Station. The complete list of the bar-coded commands are as follows:

LISTING OF BAR-CODED COMMANDS NEXT TO PC TERMINALS	
Command	***Functions***
1. A number pad from 0 – 9	To select appropriate option on screen
2. "Done"	To finish scanning pod numbers
3. "Back"	To delete an erroneous entry
4. "Home"	To go back to main the Home Screen

Figure 3-8 List of Bar-Coded Commands for BTS Interface.

System Scalability

With the proper software and bar codes in place, adding or removing BTS Stations is convenient. For instance, we can refine reticle locations further by using IPS tools as racks. Each tool knows what reticles are inside, but not the ones stacked on it. By adding a scanner to each tool, anyone can put a pod next to any machine and scan it into that station. This way, pods stacked on top of tools can be pinpointed with more accuracy. However, implementing this strategy will also cost a considerable amount of investment since all of the 28 IPS Tools will need a scanner next to it as well as a PC terminal if it does not already have one.

Behavioral Analysis of Operators under BTS

Combining the scenarios described in Figure 3-4 under Database entries, we can now formulate the behavior of operators in searching and returning reticles under BTS.

Step 1 – *Operator queries MiDAS Web*

The operator queries the MiDAS Web, which in turn retrieves the current status of the desired reticle from the Database. The *License Plate Number* field indicates which pod (or blue box) the reticle resides in. The *Location* field indicates where the reticle is.

Step 2 – *Operator proceeds to the designated location to search for reticle*

The location of the reticle falls under any of the scenarios 1 to 7 described by Figure 3-2 and 3-4. If the reticle is in Building 320 (Scenario 1), then he or she will follow the procedure described earlier in the section *Handling of Blue-Boxed Storage, New, and Repaired Reticles Under BTS.* The operator has to process other part numbers if the desired reticle is being repaired (Scenario 2). If the reticle is in either the silo or stocker of RMS (Scenario 3 and 4), then he or she will proceed to the RMS and take it out. The Database will be updated by the RMS software automatically. If the reticle is in an IPS tool (Scenario 5), the operator can either proceed to the tool and inquire from the other operator how long the job will take. He or she can either wait for the tool to finish or check back later once the processing is done. When the operator takes it from the original owner, he or she will proceed to any of the BTS Station and perform a transfer of reticle ownership on the PC terminal (Option 3 in Figure 3-7). If the reticle is on the rack of any BTS Station (Scenario 6), the operator will proceed to the appropriate Station, search for the correct pod, and perform a retrieval transaction on the PC terminal (Option 1 in Figure 3-7). Finally, if the reticle is currently owned by another operator, he or she can again perform a transfer of reticle ownership if the original owner approves.

Step 3 – *Operator gains ownership of reticle*

When the appropriate procedures have been taken as described previously, the operator now gains the ownership of the reticle and can use it to perform his or her jobs.

Step 4 – *Operator returns reticle to nearest BTS Station*

When the operator is done with using the reticle, he or she can perform a return transaction (Option 2 in Figure 3-7) on the PC terminal of the nearest BTS Station. Note that any operator can return any reticles to the racks – regardless of who checked it out in the first place.

Step 5 – *Operator returns all unused reticle to nearest BTS Station at end of shift*

At the end of the shift, the operator returns all his or her checked out reticles to the nearest BTS Station that are neither being used nor needed by the subsequent operator during next shift. The operator can use Option 4 in Figure 3-7 to verify if the list of checked-out reticles in the Database agrees with what he or she actually owns. Any discrepancies should be corrected before the operator can leave the shift.

Step 6 – *Operator transfer ownership from his/her counterpart during end/beginning of shift*

When the operator's counterpart takes charge of the same machines during shift change, the counterpart will transfer ownership of all reticles that the previous person has checked out (if any). This will ensure correct ownership tracking in the Database.

System Dependence on Cooperation from Operators

One tradeoff between BTS and other solutions is that the success of the BTS depends heavily on the operator's behavior and cooperation. Operators initiate updates for on-the-floor tracking whenever transactions take place. Based on the procedure outlined above, it is possible for operators not to scan and record the transactions. Simply put, there is no absolute way of tracking down all potential errors under BTS as an operator can just shuffle pods around on the floor without informing the Database. It is also a major concern of how other operators react when the Database becomes partially outdated due to one operator's uncooperativeness. Operators might lose motivation to follow the proper procedure after realizing that portion of the Database is erroneous. This will then revert back to our original problem of reticle tracking on the floor.

However, we are comfortably assured that the BTS will be successful based on a variety of reasons. First, pods that are not scanned for checkouts may still be accounted for by the system later as operators use them inside the IPS tools. Assuming that an operator retrieves a reticle with a strong intent of using it sometime during his or her shift, the Database will get updated at the moment of insertion into the IPS tools. The coding between the Database and IPS tools will restore proper ownership of the reticle during its usage (*Location* = IPS tool #) and *afterwards* as well (*Location* = Operator XYZ), since the system knows which operator is in charge of what tool. If the operator again forgets to scan when returning, floor managers can easily track down the operator who used it last as he or she will be held accountable for his or her actions. Similarly, operators should be compelled to follow the procedure during changeovers to make sure unused pods are returned and proper ownership transfer has taken place as their irresponsibility can be again easily tracked by the system. Cooperation from the person at BTS Station 9 can be readily assured as well as his or her sole responsibility is to update the Database with each transaction concerning blue boxes, new, and repaired reticles. In all, BTS enables management to track responsibilities and assess operator performance aside from measuring their throughput.

Most importantly, given the frustrations on the operators' part in spending unnecessarily long periods of time to track down reticles under the current system, we have every reason to believe that operators will cooperate with these simple check-in and checkout procedures to make their jobs easier. Therefore, we can conclude confidently that BTS is very implementable.

Perfect Operator Behavior Leads to Simpler System

In following up our previous discussion, there is also an extra incentive in which management and operators should strive for complete cooperation with the procedures. If we can demand full cooperation from the operators such that their behavior can be assumed perfect, BTS can be transformed into an even simpler system. Instead of tracking ownership of pods and require operators to scan their ID Badges during every check-in and checkout, we can simply implement a scanner and a PC terminal at every possible storage location on the floor and only require operators to scan at the newest location when pods are moved. This way, operators do not have the obligation to return pods (including changeovers) and they can move them anywhere they want as long as they scan in to let the Database know where the pod's newest location is.

3.2.2 Technical Specifications

Scanners and other Hardware

(Products and pricing from Worth Data Corporation of Santa Cruz, CA (www.barcodehq.com) are used in the remaining discussion. Other vendors of bar code products such as BarCode Discount Warehouse, Inc. (www.bcdw.com) are also suitable for implementing BTS. We shall leave the choice of the manufacturer at MiCRUS' discretion.)

Each BTS Station is equipped with a bar code scanner and a PC terminal. The following diagram shows a typical connection between the PC terminal, the bar code decoder, and the bar code scanner. A special "Y" cable is used to connect the computer to both the keyboard and scanner.

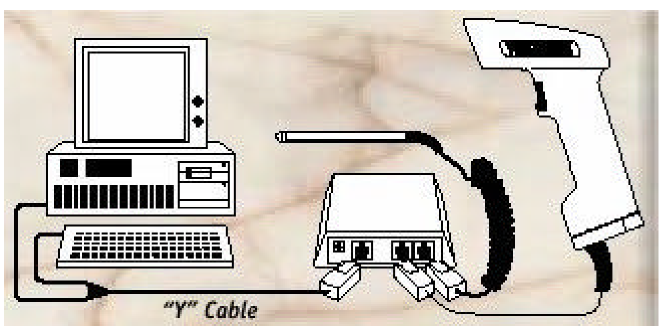

Figure 3-9 Connection Between PC Terminal, Bar Code Decoder and Scanner.

There are two ways of inputting data from the scanner to the computer: either through the serial port via the RS-232 protocol or through the keyboard PS/2 of an IBM PC or Macintosh. Serial port input is usually used for UNIX computers or "dumb" network terminals. For our purpose, the latter ("second keyboard bar code readers") would be appropriate. Any software that accepts keyboard input will accept bar code reader input. The computer and software simply see bar code data as coming from a fast keyboard operator.

For a computer to read the bar code, both decoder and scanner are necessary. To save equipment space, integrated laser scanners should be employed as it has the decoder built into the triggered laser gun. It is far more efficient than a wand, especially on large volume scanning. It is also more reliable than the CCD scanner (charge-coupled device) as laser reads bar codes, even poor quality ones, at a further distance. The following table summarizes the specifications for Worth Data's LZ100-WDP scanner model. For further information on scanner's operation and other specification details, refer to Worth Data's website and documentations. Other hardware necessary for BTS includes nine PC terminals in each Station, and a laser printer for printing out bar codes.

GENERAL INFORMATION	
Manufacturer	Worth Data Corporation 623 Swift St., Santa Cruz, CA 95060 1-800-345-4220 / *www.barcodehq.com*
Model No. and Name of Product	LZ100-WDP Integrated Laser Scanner
Decoder Built-in?	Yes
Mode of Connection	As second keyboard input; with optional USB support
Accessories Included	"Y" cable for connecting to keyboard and computer
Warranty	2 years with parts and labor; 30 day money back guarantee
Price	$659 per scanner (5% discount on order of 5; 10% discount on order of 10)
Maintenance Cost	Minimal
TECHNICAL INFORMATION	
Scan Engine	Symbol 1200 WA Scan Engine
Shock Resistance	2000 G's / Rugged design tested to withstand multiple 6 ft. drops to concrete
Scanning Rate	36 scans/sec. until a "good read" occurs
Cord Life	Rated 1,00,000 bends of life
Configuration	Wanding supplied menu stored in non-volatile EEPROM memory
Auto-discrimination of Bar Codes	Code 39, UPC/EAN, Codabar, Interleaved 2 of 5, 128, 2 of 5, Code 93, MSI, Plessey, Full ASCII Code 39, and Labelcode 4 and 5
Special Key Emulation	All Characters, Function Keys F1-F12, Ctrl, Alt, Shift, Home, End, PgUp, PgDn, Arrows
Preamble and Postamble	From 0-15 characters to be transmitted in front or at end of each bar code read
Terminator Characters	Select Enter, TAB, or nothing (for fill-the-field)
Check Digits	Optional transmission for all codes; optional checking for 128, 39, Interleaved 2 of 5, MSI
Operating Environment	32 – 120 °F

Figure 3-10 Specifications for the Integrated Laser Scanner *(LZ100-WDP).*

Bar Code Labeling Software

For bar code labeling, Worth Data also supplies software *LabelRIGHT* for Windows 3.1, 95, 98, or NT. Almost any kind of labeling configuration can be achieved through this software. Another popular bar code software is Rivers Edge Corporation's *LabelWorks* (*www.riversedge.com*). Similar to *LabelRIGHT*, *LabelWorks* provides sophisticated labeling features to create any kind of graphical label and includes a built-in bar code generator. Rivers Edge is also a vendor for bar code hardware.

INFORMATION ON *LabelRIGHT*	
General Features	Unlimited fields per label; Scalable fonts 3-375 points; True Type and Postscript; 14 bar code types and PDF 417
System Requirements	IBM PC compatible 80356 CPU or greater, 16 MB RAM, 6 MB of hard disk space, Windows 3.1, 95, 98, or NT.
Font Support	Dot matrix, deskjet, and laserjet (recommended for quality)
Price	$295 per copy

Figure 3-11 Specifications for the Labeling Software.

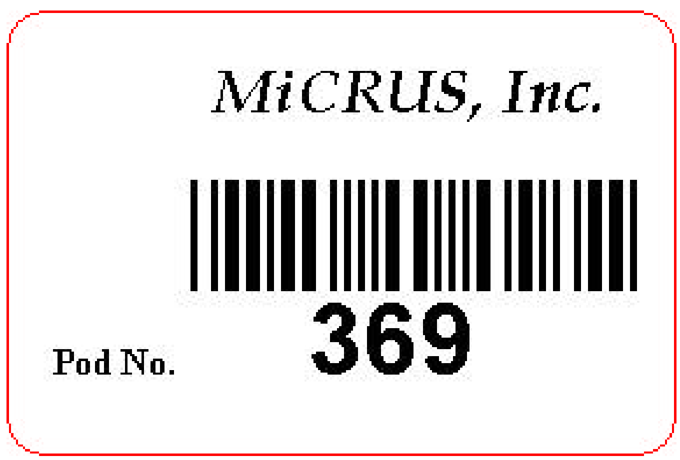

Figure 3-12 License Plate Example (using *LabelWorks* by Rivers Edge).

3.3 Checkgate Tracking System

The Checkgate Tracking System (CTS) is based on the technologies and products provided by Intermec Technologies Corporation (*www.intermec.com*), a subsidiary of UNOVA, Inc., an industrial automation system concern. CTS mimics the EZ-Pass system used by cars to pay tolls on a highway. It uses Intermec's *Intellitags*, which are RFID (radio-frequency) tags that clip onto all the reticle pods in the lithography area so that they can be tracked as operators carry them through the checkgates (Intellitag RFID readers). Another vendor with similar products is Checkpoint Systems, Inc. We shall leave the choice of vendors for implementing CTS at the discretion of MiCRUS. The rest of this discussion will be based on Intermec's Intellitags.

We recommend dividing the lithography floor into five areas. Checkgates will be placed at the boundary of each area to identify moving pods. Reticle racks (see Figure 3-13) will be spaced along the floor so that operators can have easy access to often-used reticles. Queries can be made to MiDAS Web to find the location of any reticle as CTS integrates with existing tracking capabilities of the RMS and IPS tools.

3.3.1 System Design and Operations

Subdivision of the Photolithography Area

Under CTS, the recommendation is to divide the lithography area into five smaller areas using a pair of checkgates at the boundary of each area (red rectangles in Figure 3-13). The reason why we are using a pair of two checkgates will be explained in the next section. The lithography area is comprised of Area C, D, and E. The locations for the checkgates are determined such that an operator will have to walk through the checkgates in order to get from one area to another. In the lithography area, the operator's paths are restricted to: C to D, D to C, or going into and out of E.

Area E currently consists of only three IPS tools, so a pair of checkgates at the entrance will suffice (see *How the System Works*). However, Areas C and D consist of 11 and 14 tools respectively and have the largest number of reticles on the racks and machines. Therefore, Areas C and D should be further subdivided. Area C is divided into Areas C1 and C2, and Area D is divided into D1 and D2. The areas have been divided in such a way that racks and hence reticles will be evenly spread out. The rack assignment is very similar to the grouping under BTS in which a total of nine racks are employed. As in the case with BTS, the number of racks can be varied. Our previous discussion of this issue in BTS applies here as well. However, we shall also be aware of the fact that checkgates can only inform us which section the pod belongs to. If we have a large number of racks in a subsection, operators have to search longer since he or she does not know which rack the desired pod is on within the given subsection.

In addition, the number of subdivisions can also be varied. Another possible configuration is to simply divide the floor into Area C, D, and E as it is labeled. The more subdivisions there are, the finer our tracking information becomes. However, the cost will also go up with each additional checkgate. We shall discuss this variability in Chapter 4 *Modeling Performance of Solutions*. The rest of this analysis assumes the configuration under Figure 3-13.

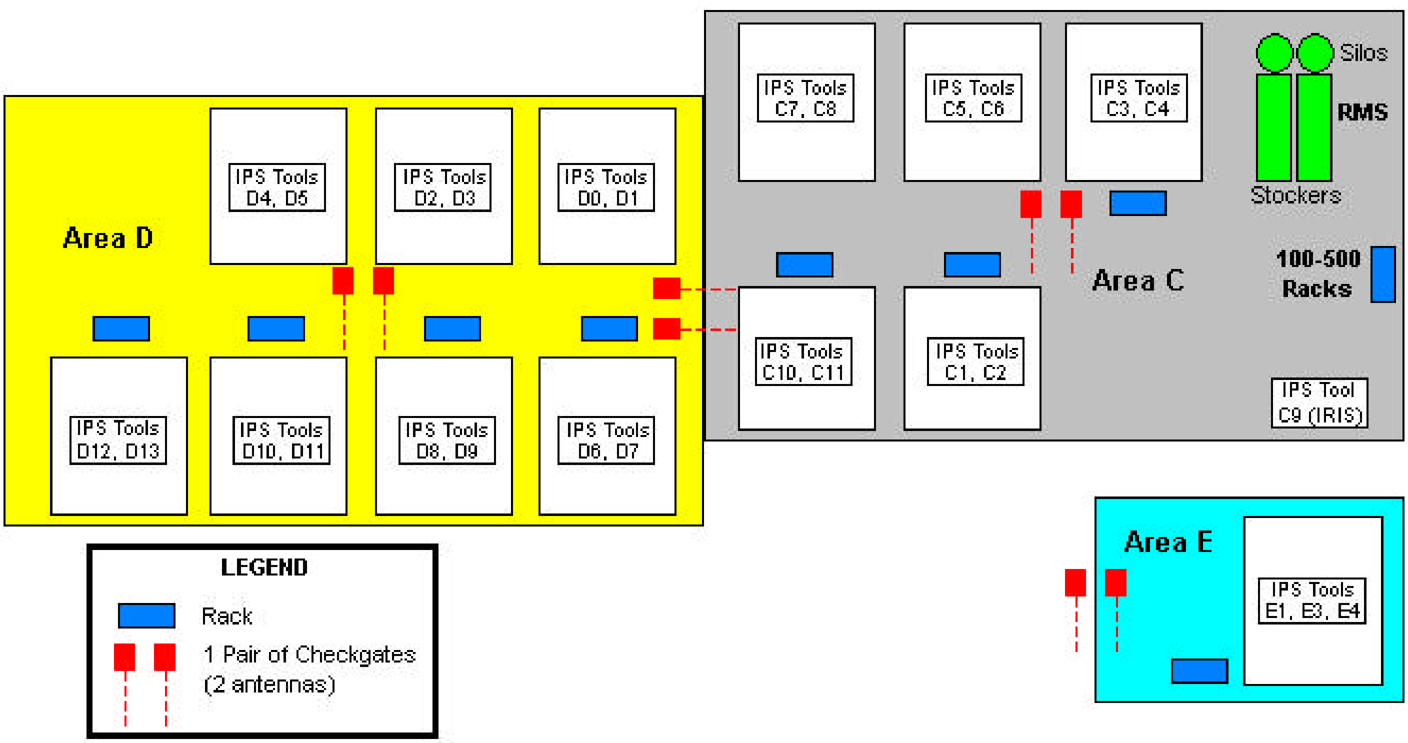

Figure 3-13 Configuration of Checkgates and Racks on Lithography Floor.

How the System Works

We recommend implementing the checkgates in pairs so that the system will not only be able to track the movement of the pods, but also the direction they are moving. Each pair of checkgates is composed of two antennas in parallel (see Section 3.3.2 for their technical specifications). Each antenna has a range of ten feet, enough to cover the width of the aisle that the operators will be walking through. The antennas are placed in parallel and are spaced apart by a minimum of four feet to avoid interference due to lateral dispersion. A time difference is created when an operator walks through the checkgates with a pod. For instance, when an operator moves from Area C1 to D2, the antenna closer to C1 will log a more recent time (see Figure 3-14). As the operator crosses the gates, the Database will be updated with the new area location of the reticle without regard to its previous location. The new area is specified to be the area with the latter time. This gives the system a tremendous advantage over just one antenna. With just one antenna, we would have to assume that the system was initialized correctly. When an operator walks through the antenna, the system simply switches the location field. However, if the system was initialized incorrectly, the pod's location will always be incorrect.

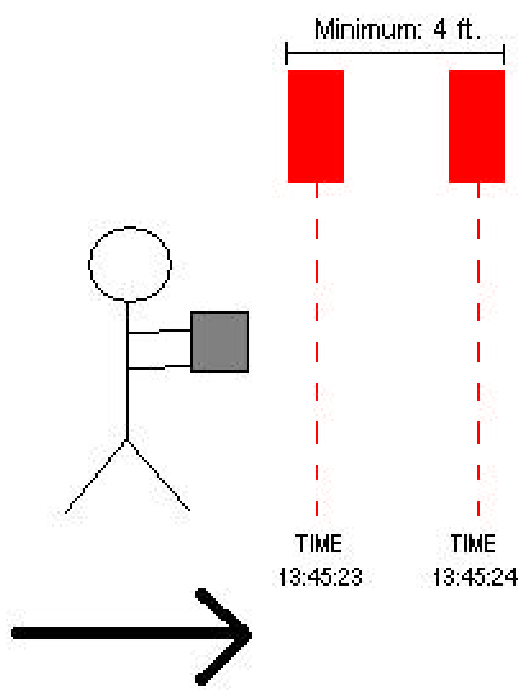

Figure 3-14 Time Difference between Two Checkgates to Determine Pod's Location.

Handling of Blue-Boxed Storage, New, and Repaired Reticles under CTS

Similar to BTS, the person responsible for handling blue boxes, new, and repaired reticles is stationed near the IRIS tool with a PC terminal equipped with a special interface to let him or her update the Database. The interface discussed in BTS is applicable here as well: Options 5 to 7 under BTS Station 9 can be implemented for CTS with the only difference that the inputs come from manual typing and mouse-clicking rather than scanning. Refer to Figure 3-7 for details.

Extra Entries in the Database for Floor Tracking under CTS

Besides the general locations mentioned in Section 3.1, reticles can also be in Area C1, Area C2, Area D1, Area D2, Area E. If the pod is not in one of these locations, then the tag may be broken or someone took the tag off the pod. Either way, the reticle will then be considered lost and operators proceed to request a search for it.

SCENARIOS	DATABASE FIELDS			
	(Existing)	*(New)*		
	Reticle Number	**License Plate Number***		**Location**
1 - 5. Inherit from Section 3.1	…	---	---	---
6. Reticle on rack in any subsections	…	*y* to *z*	S	C1, C2, D1, D2, or E

** MiCRUS confidential information; see Appendix 9.7.*

Figure 3-15 Database Fields under CTS.

Behavioral Analysis of Operators under CTS

The way in which an operator goes about finding a reticle is different under CTS than the current system or BTS. The operator first queries MiDAS Web to find out which reticle is required for the job, as well as its location. The operator proceeds to the indicated subsection and search for the reticle on the racks or on top of the IPS tools (if the *Location* is not IPS tools, RMS, or Building 320). When the reticle is found, the operator may proceed to use it on his or her tool and return it to a nearby rack or to the RMS when the job is completed. As the operator walks between the set of checkgates, the reader senses the tag on the pod and automatically tracks the movement of the reticle from one area to the next. Precautions must be taken to ensure that the checkgate is the only means by which the reticle may travel from one section to the other. Otherwise it would create great discrepancies in the Database.

Less System Dependence on Operators

The advantage of CTS compared to BTS is that it is less dependent on operator behavior and cooperation. Retrievals and returns require no scanning, which decreases reticle-seeking time. As long as the operators walk through the checkgates as they move from subsection to subsection, the system can update itself automatically based on which checkgates the operators crossed. The tradeoff in performance between the two systems lies on the fact that CTS provides a less precise location for the pod when compared to BTS. We will discuss this further in Chapter 4 *Modeling Performance of Solutions*.

One foreseeable problem that needs to be avoided is that tags on the pods can be accidentally dislodged or just swapped. If this happens without the operator's knowledge, then the checkgates will not be able to scan the pods as they pass through, and the Database will not be properly updated. Therefore, operators should be very careful to make sure that tags are clipped tightly onto each pod.

Software Development and Integration

CTS comes with the least amount of software of the three solutions. Intermec Technologies provides software to keep track of the times that a pod crosses the checkgates. The rest of the software must be developed by MiCRUS, which involves implementing an algorithm for detecting directions through the checkgates and determining the subsection in which the pod belongs to based on the time differences. However, Intermec does provide an optional three-day training program to get a software engineer acquainted with the API (Application Programming Interface) needed to interface with the Database. Figure 3-16 shows how CTS fits into the existing data architecture (extension of Figure 3-1).

System Testing, Installation, and Initialization

Intermec offers a site survey for the lithography area by sending an engineer to recommend which products would work best based on MiCRUS' layout and operations. Once the necessary software is complete, installation of hardware can begin. From previous clients of Intermec, the projected installation time would be approximately two days. However, since MiCRUS has more software needs, at least one week should be allocated. This does not include the time it takes to implement the Database as discussed in Section 3.1. When the system is up and running, it is easy to test and see whether it is working properly. Not all of the gates and tags need to be implemented at the same time.

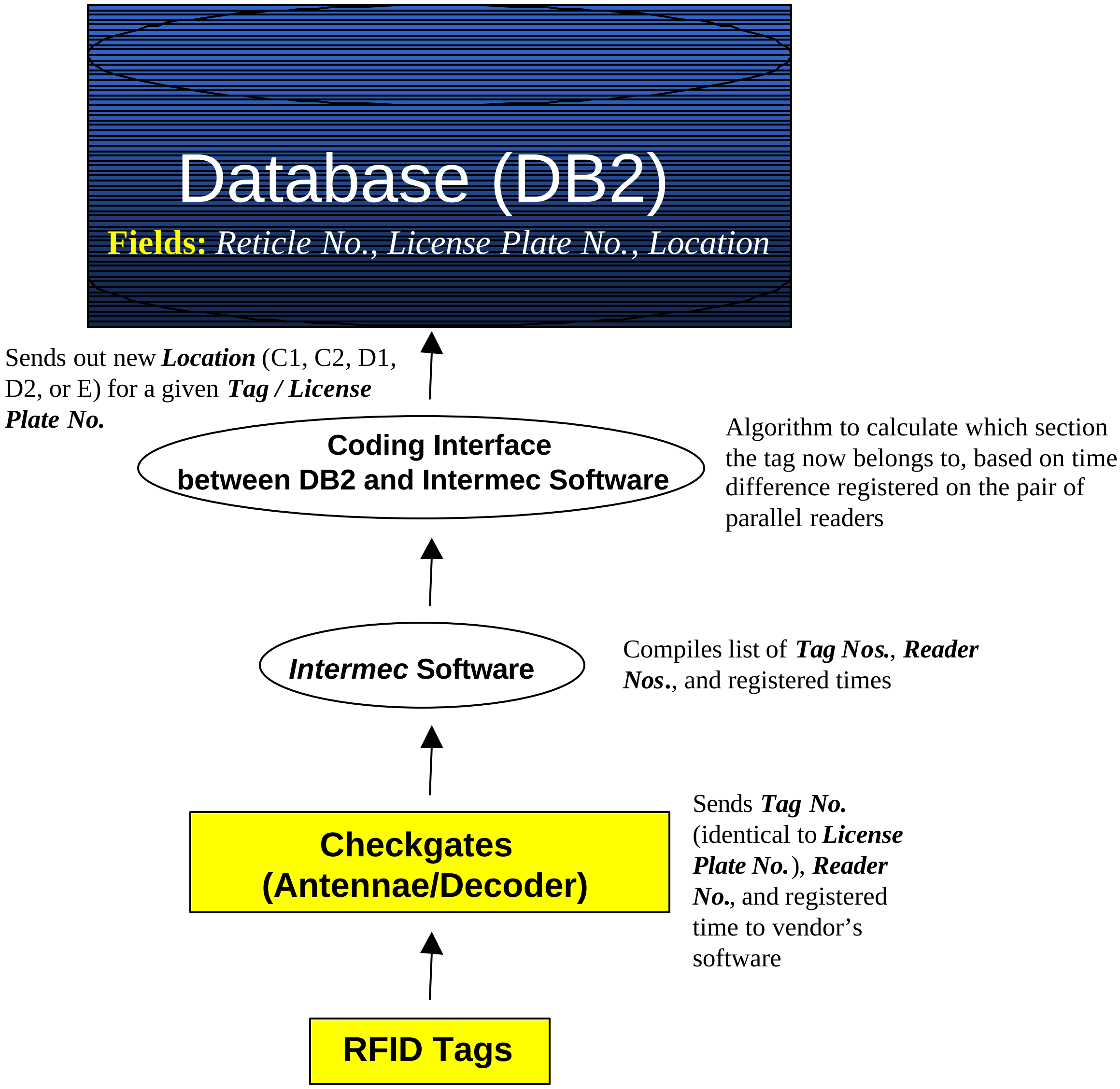

Figure 3-16 Integrating CTS into Current Data Architecture (see also Figure 3-1).

3.3.2 Technical Specifications

The basic components of the CTS are the checkgates (Intellitag RFID readers), tags, racks, PC terminals, appropriate software, and other miscellaneous items.

A checkgate is composed of a RF antenna used for detecting tags, as well as a box that interprets and decodes the signals from the antenna. The antenna operates at 915 MHz and can scan multiple pods as they pass through the checkgates.

Tags are clipped onto each reticle pod, which also operate at 915 MHz. These tags are passive in that they draw the needed power from the checkgates. The tags use a portion of the scanning signal to power themselves. The signal is then reflected back to the antenna with the correct tag information. We recommend using the passive tags over battery tags because passive tags are less costly and does not require monitoring the batter level for replacement.

It needs to be mentioned that these products from Intermec have not been implemented in semiconductor fabrication plants before. Therefore, MiCRUS will have to work with Intermec engineers during the site visit to make sure that the RF signals will not cause any interference with any tools in the facility.

GENERAL INFORMATION	
Manufacturer	Intermec Technologies Corporation 6001 36th Avenue West P.O. Box 4280 Everett, WA 98203-9280 (425) 348-2600 / *www.intermec.com*
Checkgates	Intellitag 500 Series UHF Reader Products
Tags	Passive (or Battery-operated)
Accessories Included	Antenna, power supply, software to log time for tags
Warranty	One year with parts and labor
Price	$4500 per reader (antenna); $5 per tag
Maintenance Cost	$500 per reader per year
TECHNICAL INFORMATION	
Operating Frequency	915 MHz
Memory	EEPROM, 1024 bits of total memory
Data Rate	Read 8 bytes of data from a tag in less than 12 ms
Developer's Kit	Includes tags, reader, antenna, power supply, documentation, PC-based software library, and test software
Anti-collision Protocol	Efficient, binary tree-type anti-collision algorithm; scan rate of 50 tags per second regardless of number of tags in the lithography region
Power Requirements	8 VDC
Reader Range	1.8 – 2.5 meters
Operating Environment	32 – 122 °F

Figure 3-17 Specifications for Intermec's Intellitags Products.

3.4 Confined Positioning System (CPS)

The Confined Positioning System (CPS) is similar to the Global Positioning System (GPS) used by cars and people to track their position on Earth. Readers will be installed on the ceiling (like satellites in GPS) that track RFID (radio-frequency) tags clipped onto each pod. Since the readers have an accuracy of locating a pod to within a ten feet radius, we recommend spacing the racks on the floor in increments of at least 20 feet. This system is the least dependent of the three solutions on operator behavior and cooperation. Queries can be made to MiDAS Web for finding the location of any reticle, as it is integrated with the Database, which also track pods in the RMS and IPS tools.

This recommendation utilizes a system package from WhereNet, Inc. (*www.wherenet.com*) called the *WhereNet Firefly System*. Located in Santa Clara, CA, WhereNet (former known as WiData) is a management systems concern that specializes in wireless real-time automated resource management. The cost of the Firefly System is the most expensive of the three solutions. However, the included software is very extensive as WhereNet will also be responsible for integrating their products with MiDAS Web and the Database. There will be a tradeoff in terms of cost versus ease of use by the operators.

3.4.1 System Design and Operations

How the System Works

For the CPS, our recommendation is to install four readers to cover Areas C, D, and E. Figure 3-18 shows the proposed locations for the readers (red rectangles labeled 1 to 4). In order for this system to work, the tag must be in sight of at least three readers to triangulate the signal back to the readers, so that the built-in algorithm can calculate the position of the tag based on the three signals/variables. In our recommendation, we need four readers because the pods in Area E will also need to be within the range of at least three readers. In this case, readers 1, 2, 4 are used to cover the pods in Area E. This configuration will allow the operator to ascertain the (X, Y) coordinates of a pod. Since the readers have an indoor range of 200 to 250 feet, we need not worry about the tags being out of range as long as they are somewhere in the lithography area.

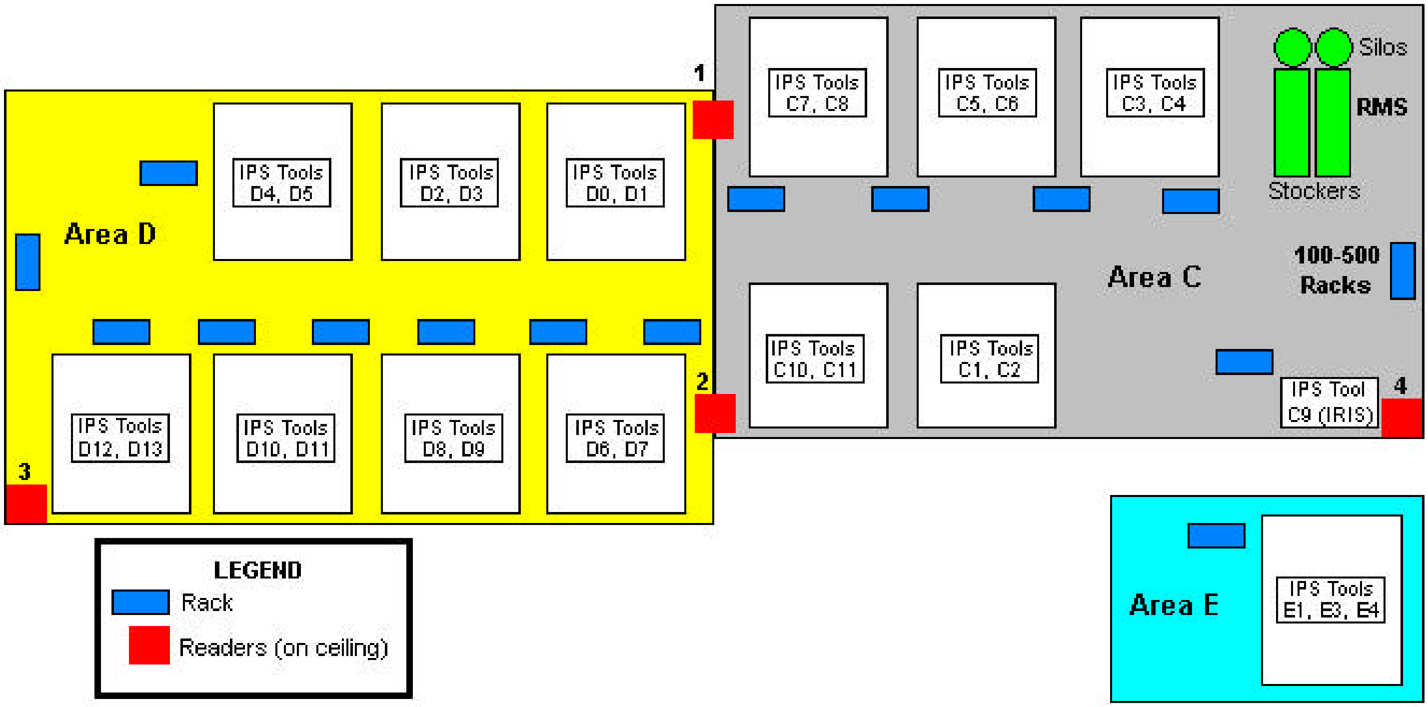

Figure 3-18 Configuration of Readers and Racks under CPS.

Our recommendation is to have 14 racks spread across Areas C and D (six in C and eight in D); each separated by at least 20 feet. Since Area E has only three machines, only one rack is needed there. This gives the proposed system a total of 15 racks. However, there could be any number of racks on the floor. As with the case of BTS and CTS, the purpose of having more rather than less racks is so that each rack will have fewer pods on it. This will allow an operator to browse through each rack faster since there will be fewer pods to eyeball. The number of racks that can be placed on the floor is limited by the fact that racks need to be spaced 20 ft apart. The more racks we have, the better the system's ability to pinpoint the exact location of a pod, and the less walking time is required of each operator on average to retrieve or return a pod. A sensitivity analysis on the mean time to find a reticle under CPS versus the number of racks on the floor will be presented in Chapter 6.

As discussed in section 3.1, license plating the pods is the only way this system will work properly. Due to the size of the tags (2 in x 2 in), it has to be clipped onto the side of each pod. Since the readers can only track the RFID tags, it is essentially "license plating" the pods. The label, with a printed pod number, should be adhered to the RFID tags so that operators can quickly browse through them as they search through racks. As the operators move around the lithography area with the pods, the tags will be transmitting a signal to the readers. The frequency of the signal emission can be set from once every few seconds to once every few minutes or hours. If the pod is not moved for a long period of time, the tag will automatically lower the frequency of emission to conserve on battery life. The information picked up by the readers will be used to update the Database via WhereNet's software with the current location of the pod.

Handling of Blue-Boxed Storage, New, and Repaired Reticles under CPS

The way in which CPS handles blue boxes, new, and repaired reticles is identical to CTS. Refer to Section 3.3.1 for details.

Extra Entries in the Database for Floor Tracking under CPS

WhereNet can configure the software of the CPS such that the MiDAS Web contains a graphical layout of the lithography area (similar to Figure 3-18 except to scale and displaying exact location of machines). When an operator queries MiDAS Web, he or she will see a link under the *Location* Field. By clicking on it, the operator can proceed to retrieve the pod from the location marked by an "X" on the map.

Behavioral Analysis of Operators under CPS

When an operator receives a new job, he or she will query MiDAS Web to find out which reticle is required for the job. MiDAS Web will inform the operator which reticle is needed, and display a layout of the lithography area with the reticle location. Since the system has an accuracy of 10 feet in radius, the operator will have to search within 10 feet of the specified location to find the reticle. The accuracy of the readers is not a problem because the 15 racks will be spaced at least 20 feet apart from each other.

We recommend that the operator take the pod back to a rack when he or she is done with the reticle. The system will be more accurate if pods are placed on racks. When the system displays a layout for the operator, he or she will always check the rack located closest to the marked "X" on the screen. The added advantage of CPS over BTS is that the system now knows where the pod is even if it is not returned to the racks or assigned to an operator.

Minimal System Dependence on Operators

The advantage of this solution is that it eliminates the majority of the system dependence on the cooperation from operators that is associated with BTS and the current system. Operators can move the pods anywhere around the floor without worrying to return it to a particular location. The intrinsic tracking capability of the system is robust enough to function well even if operators are careless in handling reticle pods. However, reticle-seeking time will even be lower if the operators are responsible enough to return most of the pods onto the racks instead of scattering them all over the floor.

The worst-case scenario occurs when the database entries are not correct. A reticle can be matched with an incorrect pod in the database. However, this happens with all the other solutions as well and is a part of the problem that cannot be completely solved, but can be minimized with careful operations.

Software Integration

The software that comes with this solution is the most complete of the three recommendations. All of the software needed for the proper functionality of the readers and their integration with the computers will be provided. The software for the PC is particularly impressive. As mentioned above, when an operator queries for a reticle, the computer will display a 2-D map of the lithography area with the pod's location clearly marked. The layout of the lithography area can be initialized at the time of installation and modified later if the locations of tools or racks are changed. Figure 3-19 shows how CPS fits into current data architecture (extension to Figure 3-1).

System Testing, Installation, Initialization, and Maintenance

From MiCRUS' standpoint, this solution appears to be the easiest to implement. Since most of the software is already included, it is only a matter of installation and testing to make sure it is working properly. WhereNet offers a site survey to help MiCRUS in determining the placement of the readers using a laser survey as well as measuring RF waves in the lithography area to make sure no interference occurs. WhereNet can also provide a team for installing and testing all of the software and hardware at an extra cost.

WhereNet's software comes with Hewlett Packard's *OpenView*, a customizable information technology package with system resource tracking capability. It is used to monitor the health of all the readers and tags. If a problem with a reader occurs, the software will pick up on it. If the battery in a tag is about to die out, the software will know which tag it is so that it can be removed and replaced with another one. WhereNet also provides technical support. An engineer can be staffed at MiCRUS to troubleshoot and maintain the system.

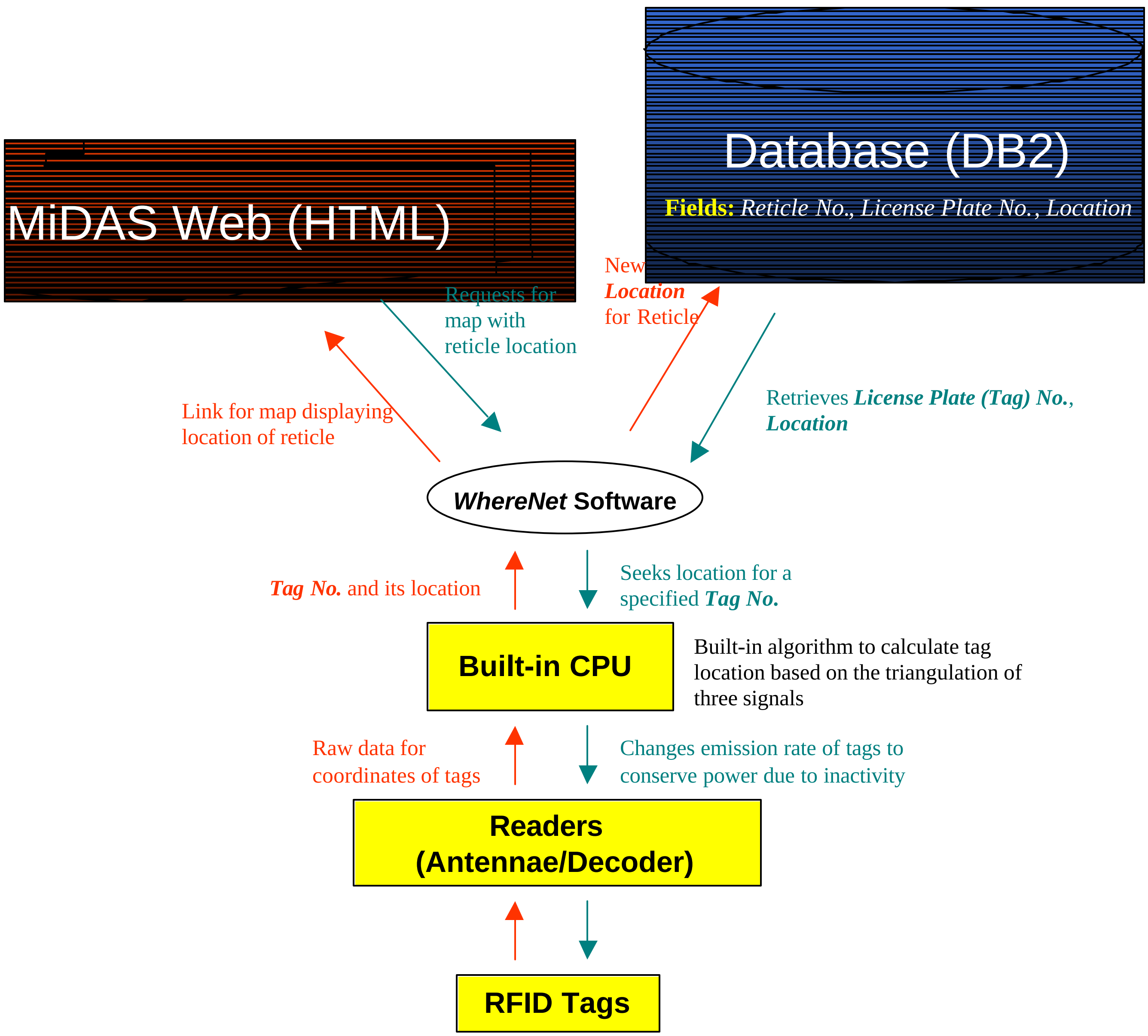

Figure 3-19 Integration of CPS into Current Data Architecture (see also Figure 3-1).

3.4.2 Technical Specifications

The basic components of the CPS are RF readers, RFID tags, reticle racks, computer terminals, appropriate software, and other miscellaneous items.

Besides WhereNet's Firefly System, there are other manufacturers such as Savi Technologies, Inc. (*www.savi.com*) who also specializes in delivering wireless tracking systems. However, we believe that WhereNet would be the primary candidate for this implementation not just because of the completeness that their solution provides, but also the comments we gathered as other manufacturers actually recommended WhereNet to us during our inquiry.

The readers and tags operate at 2.4 GHz. The tag uses a lithium battery that can be set to emit a signal at different time increments. To conserve battery life, we recommend setting it to every two minutes. This will give an approximate battery life of five years.

GENERAL INFORMATION	
Manufacturer	WhereNet, Inc. 2855 Bowers Avenue Santa Clara, CA 95051 (408) 845-8500/ *www.wherenet.com*
Readers	WhereNet Firefly Real-Time Location System
Tags	Battery-powered
Dimensions	Reader: 20 in. long, 4 in. wide, 4 in. deep Tag: 2 in. x 2 in.
Accessories Included	Extensive software for tracking tags
Warranty	90 days on-site for hardware; 1 year for software
Price	$6250 per reader $48,000 for first 1000 tags $45,000 for application software
Maintenance Cost	22% of total cost for 7 days/week assistance
TECHNICAL INFORMATION	
Operating Frequency	2.4 GHz RF for both reader and tag
Reader Range	200-250 ft. indoors, 800 ft. outdoors
Operating Environment	32 – 122 °F

Figure 3-20 Specifications for WhereNet's Firefly System.

4 Modeling Performance of Solutions

4.1 Performance Measures as Comparison Criteria

In this chapter, we present the methodology of the mathematical modeling on our proposed improvements over the current reticle management system. We have selected the following as our performance measures to compare and contrast the three proposed solutions:

1. **Mean time spent to find reticles**
   This performance measure is useful in comparing the overall speed of finding reticles for each system. It is the most important measure of the three.

2. **Standard deviation of mean time spent looking for reticles**
   This measure demonstrates the spread in varying our first measure.

3. **Proportion of time that reticle is found in less than *x* minutes**
   This measure gives us an idea of how frequently a reticle takes longer than *x* minutes to find.

We shall note again that the most significant aspect that MiCRUS management concerns about in operating the lithography area is serviceability. Serviceability will improve if operators are able to find the required reticles on their job list. The faster and the more certain they are in finding the reticle, the less chance that they will skip present jobs (high priority) and do the rest in queue; thus decreasing the frequency of hot jobs. We believe the above performance measures strongly correlate to the ease of which a reticle is found.

4.2 The Models

Mathematical Assumptions

The mathematical models are written in Microsoft Excel. They are stochastic models that have been broken down into the steps an operator would go through in looking for a reticle. We assume that all operators follow the logic as outlined in Chapter 3 when looking for reticles. The model contains two major parameters that are estimated:

1. **Relative frequency** (Probability) that the needed reticle is found in the given location.

2. The **lower** (***a***) and **upper limit** (***b***) of the uniform distribution.
   For each location, we estimate the total time required to find the reticle, under the assumption that the reticle is eventually found there, to follow a uniform distribution. If the reticle is found at a particular location, the operator is spending between a and b minutes, with equal probability, looking for the reticle.

Using these two components, we proceed to calculate the performance measures outlined in Section 4.1. Under uniform distribution, the mean is given by $(a + b) / 2$, while the variance is given by $(b - a)^2 / 12$. The standard deviation is simply the square root of the variance. The probability of locating a reticle in less than x minutes is given by the area of the uniform probability density function that is less than x. Figure 4-1 shows a sample of the model.

(The rest of the discussion will make reference to Appendix 9.8, which contains the entire set of modeling tables for all three of our solutions.)

SAMPLE OF MATHEMATICAL MODEL									
		Estimated Probability	*Time Spent Looking*		Statistics				
	Location	**Rel. Freq.**	***a***	***b***	**Mean**	**Variance**	**Std. Dev.**	**P(< 5 min.)**	**P(< 10 min.)**
1.	RMS								
2.	Tool								
3.	Same Area (C or D)								
4.	Other Area (C or D)								
5.	Area E								

Figure 4-1 Sample of Mathematical Model (written in Microsoft Excel).

Valuation of the Two Parameters

Each action that the operator performs takes a certain amount of time, governed by parameters *a* and *b*. This data was estimated from the interviews with operators and the floor managers. Let us look at an example to show how we derive values for *a* and *b*.

In the present system, an operator whose machine is in Area C will begin by looking for a needed reticle in Area C. If the reticle is not found within, for instance, 10 minutes, the operator will check the RMS and if it is still not found, he or she will proceed to Area D (the "other" area).

Let us say that the operator actually locates the reticle in the RMS. The lower bound, *a*, is the sum of the maximum amount of time spent looking through all the racks in Area C (10 minutes), the time taken to walk to the RMS (1 minute), the time required to query the RMS (2 minutes) and the time required to retrieve the reticle from the RMS (at least 2 minutes, assuming that a pod is available). Hence the lower bound *a* in this example is 15 minutes.

The upper bound is equal to the sum of the lower bound and the factors that might cause the operator to require more time to retrieve the reticle. For example, if there were no pods available, it would require an additional 4 minutes for the RMS to empty a pod and then store the needed reticle in the pod. Hence, the upper bound *b* in this example would then be 19 minutes.

The relative frequency with which an operator will eventually find a reticle in a certain location depends on the proportion of reticles that are stored there. For instance, under the current system the operator first searches for the reticle in Area C or D depending on where his or her IPS tools are located. Since he or she is likely to place frequently used reticles nearby for convenience, there is a high probability for the operator to actually find a needed reticle in the same area where he or she is. Forty percent of the reticles are stored in the RMS, but some of them are lower volume reticles, so the probability of finding a reticle in the RMS is less than 40 percent.

With the proposed solutions, more information is given to the operator about the location of the reticle, so there is a higher probability of finding the reticle in the places where he or she looks. Such distribution of the relative frequency with which the operator finds the reticle at each location is closer to the distribution of the physical location of the reticles because it is more probable that operators will be able to locate the reticle based on what each solution has to offer.

Sources of Data Used to Calculate Parameters

Two types of data were used during our analysis:

1. **Behavioral Data**
   Data in this category pertains to the decision process behind how an operator goes about looking for reticles, the time an operator would spend looking for a reticle in an area or the amount of time it takes to retrieve a reticle from the RMS.

2. **Physical Dimensions**
   Data in this category pertains to facts such as the length and width of the facility, the number of racks and pods on the floor, and the number of IPS tools.

Behavioral data was obtained through interviews with operators during our three site visits. The physical dimensions were obtained from the blueprint of the facility and observations on the lithography floor.

Calculating the Performance Measures for Proposed Solutions

For our first measure, the mean time spent looking for reticles, we first calculated the mean of the uniform distribution for each location where the operator searches. We then proceed to calculate the mean time by using a weighted average that multiplies the individual means by the relative frequencies that the operator is able to locate the reticle in the specified locale.

As for our second measure, the standard deviation of time spent looking for reticles, the following equation is used:

$$VarX = \sum_i p_i s_i^2 + \sum_i p_i m_i^2 - (\sum_i p_i m_i)^2$$

where s_i is the standard deviation of the individual location i,
p_i is the relative probability of the reticle being found in that location,
m_i is the mean of the uniform distribution of the individual location i.

For our third performance measure, the probability of locating the needed reticle in less than x minutes is again a weighted average between the individual probabilities as listed in Figure 4-1 and the relative frequencies for each locale.

4.3 Results of Solutions' Performance

From Figure 4-2* we can see that all the systems are vast improvements over the present system (as well as the present system with the *Location* fields in MiDAS implemented). CPS gives the lowest mean time for finding reticles followed by BTS and CTS. The same order is also true for the probability of finding the reticle within *x* minutes. The standard deviations between the three proposed systems are almost identical. It does not provide us with any useful information in terms of choosing which system to implement. However, the deviations of all three are significantly improved over the current system. The distributions of mean times for each solution can be found in Appendix 9.10.

The results imply that serviceability will increase as operators can locate a needed reticle faster. We shall now look at the costing analysis to see if it helps us to narrow down our choice to one system.

** MiCRUS confidential information; all values are normalized to BTS; see Appendix 9.9.*

SYSTEM	Mean Time (min.)	Std. Dev.	P(<1.02 min)	P(<2.04 min)	P(<4.08 min)
Current	3.71	1.64	0.07	0.23	0.48
Current w/ MiDAS	2.36	1.63	0.16	0.61	0.83
BTS (w/ 9 stations)	1.00	**1.00**	0.56	**0.99**	**0.99**
CTS (w/ 5 sections)	1.24	1.00	0.34	**0.99**	**0.99**
CPS (w/ 15 racks)	**0.91**	1.01	**0.69**	**0.99**	**0.99**

Figure 4-2 Results for the Performance Measures of Each Solution.

5

Costing Analysis

The purpose of this analysis is to estimate and compare the total cost of the investment for each solution. It is yet another performance measure that we can use to compare one system against another. The prices used in this analysis were obtained from manufacturers with no input from MiCRUS.

Constructing Costing Model

For all the systems, there is the fixed cost of integrating the MiDAS Web and the Database with the IPS tools and RMS. This cost is calculated based on the estimated number of man-months required to complete the project. For each of the solutions, the aggregate investment required derives from costs of hardware, software development, estimated repair and maintenance, site survey, installation, and initialization. The quotes we gathered for CTS and CPS are relatively complete and finalized. However, the cost of repair and maintenance for BTS is estimated. We will assume all systems carry a lifetime of five years in our modeling. *(For a complete listing of the costing model, please refer to Appendix 7.1 for details.)*

Confined Positioning System (CPS)

Prior to purchasing the product, there is a required site survey that costs $10,000. The hardware for the CPS consists of readers and tags for the pods that cost $6,250 and $48 each respectively. The cost of the complete software package is $45,000, and the cost of its integration is $1,500 a day for an estimated 3 days. Maintenance cost for hardware and software is 20 percent of the total purchase cost annually. The repair cost comes from failures in the tags. If a tag breaks down, a new tag must be purchased at $48. The lifetime of a tag is approximately 5 years if the emission rate is set to two minutes. Using this as the mean time to failure, we calculated the expected number of tags that would fail each year and the associated cost of purchasing new tags to replace them.

Checkgate Tracking System (CTS)

The cost of one pair of Checkgates is $9,000 and each tag costs $5 for a total of 1,000 tags. The on-site survey costs $1,500. An installation fee of $1,500 per day for an approximated total of two days also applies. The software starter kit costs $3,000. In addition, there might be a cost of software integration as this technology is not typically used for the purposes we propose. We estimated that it would take 0.25 man-months to integrate the software (or one man-week). The cost of maintaining the equipment is $500 per unit per year.

Bar Code Tracking System (BTS)

The hardware required for this solution consists of scanners and license plates for the pods. The costs are $659 per scanner and $5 per plate. With the popularity of bar codes, there are many different bar code vendors MiCRUS can choose from. We obtained prices for the hardware from several sources, and used the more conservative estimates for this analysis. Other hardware required for BTS include PC terminals next to racks where operators have to scan throughout the check-in/checkout procedure. Software and printers are also required to print out bar-coded labels. The software comes at a cost of $295 while we estimate the cost of acquiring printers and PCs to be $50 and $500 respectively. As we were unable to get estimates of the cost to repair and maintain the equipment, we estimated repair cost as 40% of the cost to purchase the equipment.

Costing Summary

Figure 5-1 shows the costs for all three solutions as it is evident to the reader that the CPS may very well be too expensive to implement. If the performance of the CPS is not substantially better than the other two by all of our measures, we would opt to consider an alternative solution that delivers both cost effectiveness and moderate system performance.

SYSTEM	COST
BTS (9 stations)	$18,319
CTS (5 sections)	$73,500
CPS (15 racks)	$282,566

Figure 5-1 Cost Summary for All Three Solutions.

6 Recommendation & Sensitivity Analysis

6.1 Recommendation

Based on the results obtained for our performance measures in Chapter 4 and cost analysis in Chapter 5, we **recommend** MiCRUS to implement the **Bar Code Tracking System** (**BTS**). With the designs proposed in Chapter 3, Figure 6-1, 6-2, and 6-3* display how the three solutions fare with each other as well as the current system with the inclusion of MiDAS (linked with RMS and IPS tools to utilize the *Location* field).

** MiCRUS confidential information; see Appendices 9.9, 9.11, 9.12.*

Mean Time Spent to Find Reticles

Under our most important performance measure, the mean time to locate a reticle, CPS is the leading candidate as it has the lowest mean time of all systems. However, BTS achieves a comparably low mean time to CPS and yet at a substantially reduced cost (more than ten-fold). BTS is a clear choice based on this performance measure.

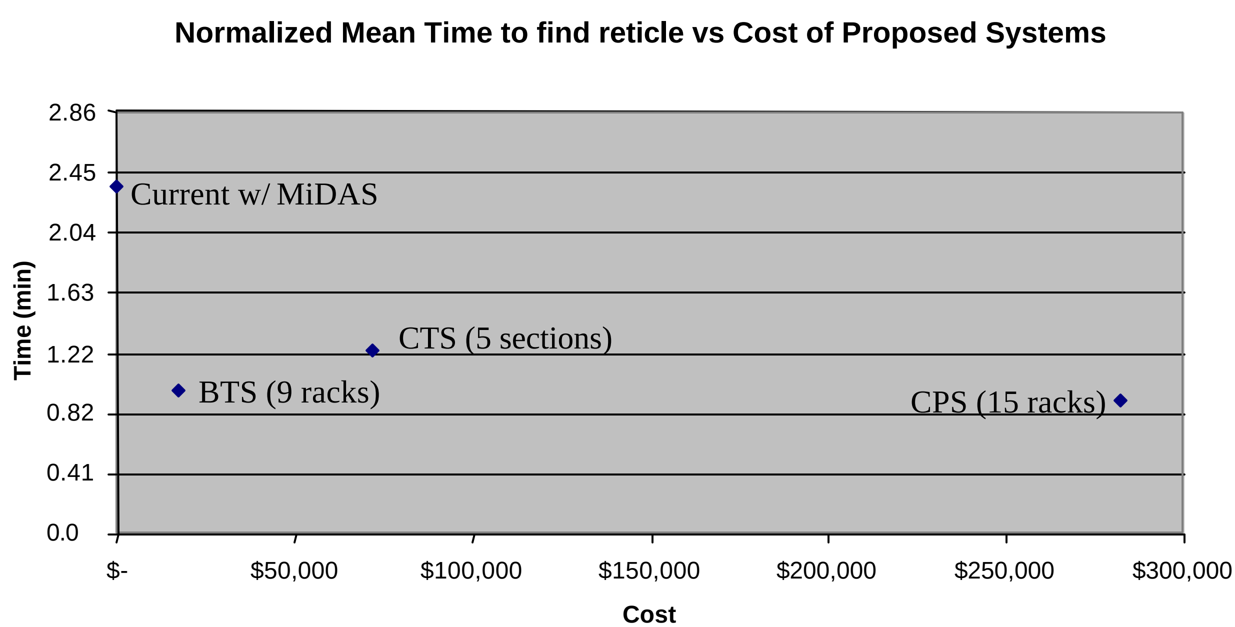

Figure 6-1 Mean Time *vs*. Cost for All Solutions.

Standard Deviation of the Mean Time Spent to Find Reticles

Our second performance measure calls for the standard deviation on the mean times found in the previous discussion. It shows the spread in the variations of the mean times and gives us an idea the ranges these mean times are likely to fall under. Figure 6-2 shows the normalized standard deviations for the three proposed systems as well as the current system in place.

The standard deviations for the proposed systems are fairly close to each other, and this relative closeness does not provide us with any significant information to help choosing the solutions. There is no apparent gain in choosing one system over another. The only important note here is that all three systems yields a better deviation spread than the current system. This derives from the fact that operators are now much more likely to actually find the reticle in the location designated by our solutions.

SYSTEM	Standard Deviation of Mean Time (mins.)
Current w/ MiDAS	1.63
BTS (9 racks)	1.00
CTS (5 sections)	1.00
CPS (15 racks)	1.01

Figure 6-2 Standard Deviations for the Mean Times Calculated.

Proportion of Time that Reticle is Found in Less Than x Minutes

The final performance criterion is the probability of finding a reticle in under *x* minutes. Figure 6-3 shows how this probability fare with the cost of the system. As with the case of mean time, CPS possesses the highest probability of all three. But again, the marginal gain we get from CPS does not justify with the ten-plus-fold increase in cost when compared to BTS. BTS is again the winner here.

As discussed in Chapter 3, the only downside for BTS is that the system is largely dependent on operators' behavior. Cooperation from the operators to follow the prescribed procedure is required for BTS to operate successfully. Minor training is necessary to have operators accustomed to the screens at the PC terminals and the check-in/checkout procedure. Nonetheless, we are reasonably assured that this will not prevent the system from functioning properly as we came to a general consensus with MiCRUS management that operators have incentives to cooperate with the procedure to reduce their current frustration of not being able to locate a reticle in reasonable time. If the system can make the operator's job on the lithography floor easier and more efficient, it is likely that he or she will abide by the set of rules imposed on them.

Finally, regardless of which proposed solution MiCRUS chooses to implement, the mean time to find a reticle will be reduced considerably. But given the costs of each solution, BTS offers the best tradeoff between cost and performance.

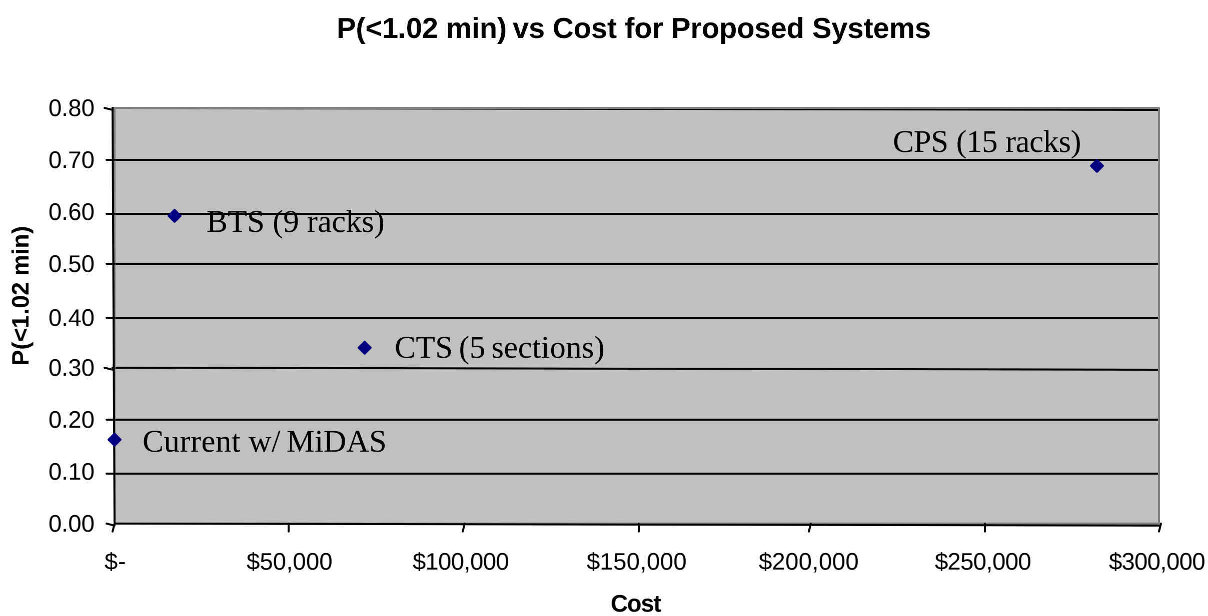

Figure 6-3 Probability to Find Reticle in Less Than *x* Minutes *vs*. Cost for All Solutions.

6.2 Sensitivity Analysis

Despite the recommendation we have given in the previous section, we are very interested in varying some of the estimated parameters in our system designs that might have a significant impact on our decision to recommend. The sensitivity analysis performed here will give us an idea on exactly how much influence these parameters will have on our decision. We shall revisit and re-evaluate our initial recommendation throughout this section based on the following results.

Methodology

As discussed in Chapter 3, the most crucial parameters in our system designs are those affecting the number of racks, floor divisions, and readers. We want to investigate whether our recommendation will change if these parameters are varied. Since these parameters directly affect the cost of the system, our fundamental concern lies on the degree of *diminishing marginal return* on system performance as investment increases. In other words, how much extra system performance do we get in return for a higher investment?

With BTS being our primary candidate, we also want to investigate how the cost of BTS varies depending on the hardware and software purchased, as well as our estimation on repair and maintenance costs.

Finally, we shall also address other interesting parameters that might affect system performance

Diminishing Marginal Return on Higher Investments

The meaning of cost increase is different in each of our solutions. Under BTS, higher cost signifies increase in the number of BTS Stations on the floor as each is equipped with a scanner and PC terminal. In CTS, higher cost means there are more checkgates installed, translating into more subdivisions on the lithography floor. We shall note that having more sections in CTS refines our *precision* for locating the reticle. However, the operator still does not know where exactly the reticle is located in a given section. On the other hand, having more stations in BTS refines our *accuracy* for locating the reticle as operators can pinpoint exactly what reticle is on which rack.

Cost for CPS is relatively fixed. However, the number of racks can be increased to improve our accuracy. But since the accuracy of the system is restricted to be ±10 feet due to limitation on the vendor's hardware, the number of racks we can place on the floor is bounded by this value as well. Figure 6-4 shows the comparison of normalized mean times between the three systems with the following variations (complete table can be found in Appendix 9.10):

1. The number of BTS Stations ranges from 5 to 20 (we propose 9 Stations in our design).
2. The number of sections in CTS ranges from 2 to 7 (we propose 5 sections in our design).
3. The number of racks under CPS ranges from 5 to 15 (we propose 15 racks in our design).

Similarly, the probability to find a reticle in less than five minutes is also plotted against the variation in costs on Figure 6-5.

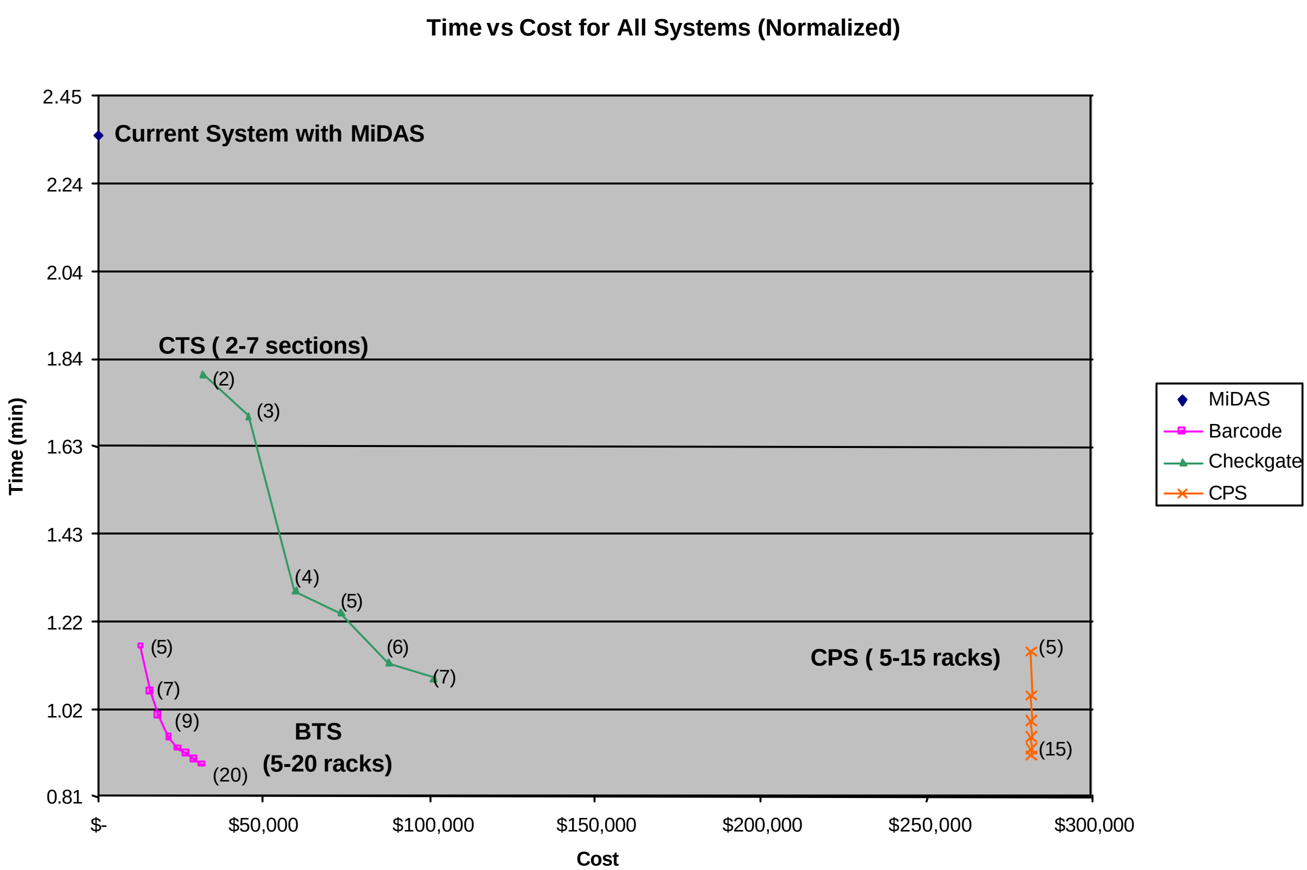

Figure 6-4 Normalized Mean Times *vs*. Cost for All Configurations of Solutions.

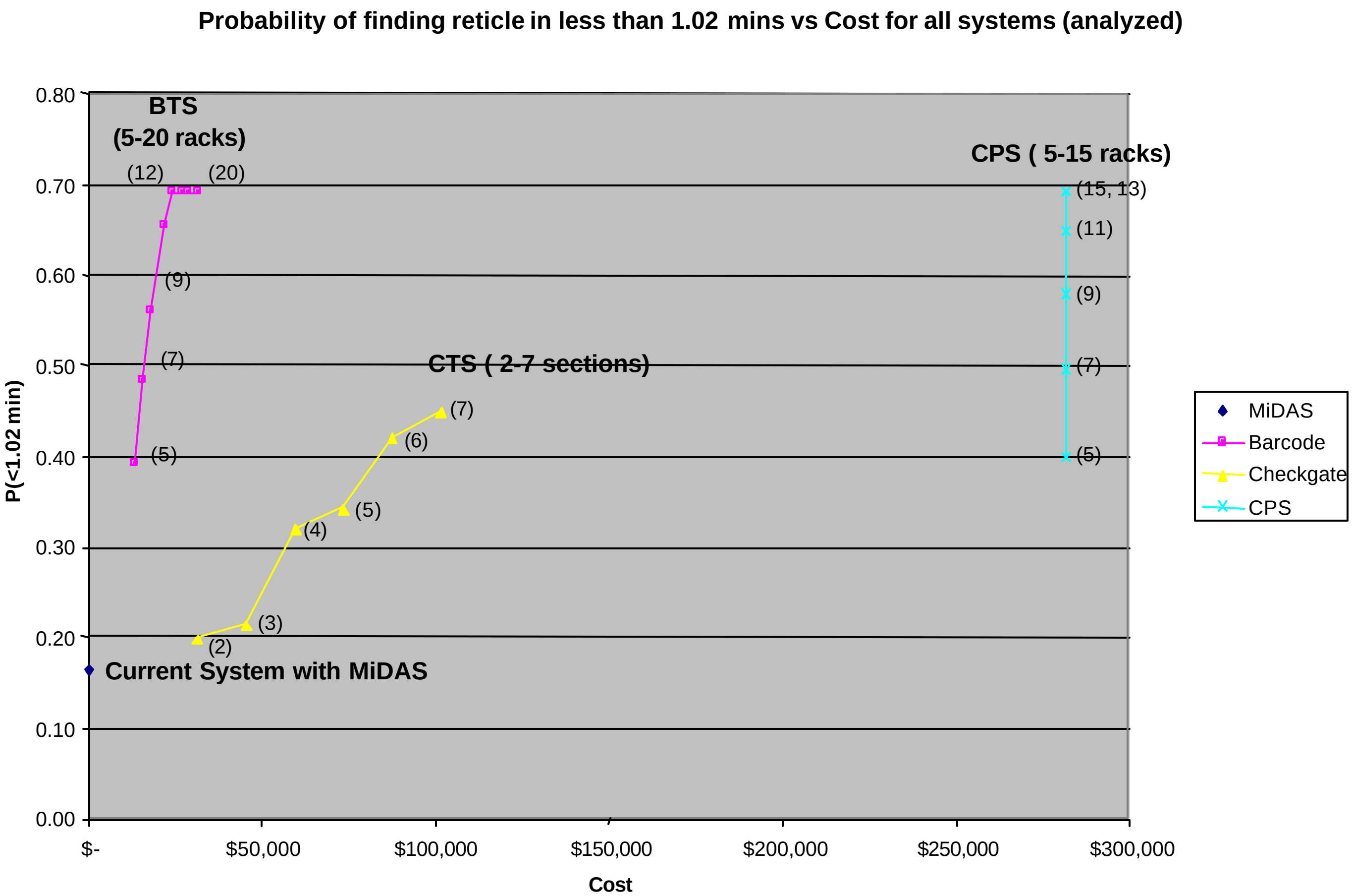

Figure 6-5 Normalized Probability *vs*. Cost for All Configurations of Solutions.

We can see from the graphs that the cost of CPS is still several times higher than BTS even if we vary the number of BTS Stations. Mean time for CTS is comparable to BTS when we have more subdivisions on the floor but with the cost being twice as much. The same can be said for the probabilities in finding a reticle in less than five minutes. By now, we are quite certain that BTS is superior to CTS.

Notice that the mean time and probability of BTS outperform CPS when the number of BTS Stations is increased dramatically. This is due to the fact that more racks are allowed on BTS as CPS requires racks to be spaced at a minimum of 20 feet. As the number of racks increase, there are less pods on each rack. Operators can browse through a rack quicker. If the cost increase for BTS were immaterial or reasonable for MiCRUS, we would certainly recommend increasing the number of scanners and racks to capitalize mean time and probability based on our analysis.

Variation in BTS Hardware, Software, Repair and Maintenance Cost

As discussed in our Costing Analysis, conservative costs are allocated for BTS hardware and software. Multiple price quotes for the bar code scanners and labeling software were gathered. The cost of PC terminals as well as repair and maintenance are estimated. Figure 6-6 shows the range of total BTS cost due to this variation in hardware and software. The total cost for BTS ranges from $12,022 to $21,443. Yet even at $21,443, BTS is still very attractive and costs significantly less compared to CTS and CPS.

BAR CODE SCANNER AND LABELING SOFTWARE COST	
High-End Estimate (Present Recommendation)	$659 per scanner; $295 for software
Low-End Estimate	$295 per scanner; $225 for software
PC TERMINAL COST	
High-End Estimate	$750 each (+50%)
Present Recommendation	$500 each
Low-End Estimate	$250 each (-50%)
REPAIR AND MAINTAINENCE COST	
High-End Estimate	70% of total cost
Present Recommendation	40% of total cost
Low-End Estimate	10% of total cost
TOTAL SYSTEM COST	
High-End Estimate	$ 21,443 (+ 17.1%)
Present Recommendation	$ 18,319
Low-End Estimate	$ 12,022 (- 34.4%)

Figure 6-6 Cost Variation in BTS.

Other Risks and Uncertainty

We have also considered other interesting parameters, especially those from our mathematical modeling, and see if their variations will have a substantial impact on our results and recommendation. We were not surprised to see that there is minimal absolute influence on our results after sensitivity analysis has been performed on these variables. This is due to the fact that all three solutions are subjected to the same set of assumptions. The relative impact on variations of these parameters is almost non-existent. Figure 6-7 shows the parameters that have been analyzed.

1.	Time to look in Area C or D under Current System
2.	Time to retrieve from RMS (empty pod available)
3.	Time to retrieve from RMS (no empty pod available)
4.	Time to query MiDAS
5.	Operators walking time
6.	Relative frequencies for operator to locate reticle in each location
7.	Frequency of operator looking for reticle
8.	Time accounted for locating reticle when Area E is merged under CTS

Figure 6-7 Other Parameters Subjected to Sensitivity Analysis.

7 Acknowledgements

We would like to express our sincere appreciation to all those who have assisted us in this project. This project would not be possible without the support from the people at MiCRUS. Specifically, we would like to thank Dean Kent for the opportunity of this project, Joe Hinderer, for his continuous support and effort in heading this joint initiative with Cornell, as well as John Murphy, Robert Marsin, Robert Oelsner, Joe Stavish, Bao Huang, Greg Divine, Bob Lamoree, Laura Ryan, Nancy McComb, and Nina Gemma for the time they spent in collecting data and explaining facility operations to us. Along with other operators and staff at MiCRUS, they had been patient, helpful, and very informative.

8 General Appendices

8.1 Cost Models

Fixed Costs

Implementation of reticle database software:

Salary (per month)	$ 10,000
Time (months)	0.25
# of people	1
Manpower Cost/Salary	$ 2,500

Barcode System

Item	Unit Cost	Quantity	Subtotal	Cost after discount	Total Cost
Scanners	$ 659	9	$ 5,931	$ 5,338	
Clamp	$ 5	1000	$ 5,000	$ 4,500	
Labelling Software	$ 295	1	$ 295	$ 266	
PCs	$ 500	9	$ 4,500	$ 4,500	
Printers	$ 50	1	$ 50	$ 50	
Repairs			$ 1,166	$ 1,166	
Fixed Cost			$ 2,500	$ 2,500	
Total					**$ 18,319**

Lifetime (years)	5
Mean time to breakdown	5
Warranty (years)	2
Discount	0.1
Repair/Replacement Cost (as % of p	$ 2,372
% of Purchase Cost	0.4

Checkgate System (3 Sections)

Item	Unit Cost	Quantity	Subtotal	Cost after custom.	Total Cost
Readers	$ 4,500	4	$ 18,000	$ 18,000	
Clamp/Tag	$ 5	1000	$ 5,000	$ 5,000	
Customization Software			$ 2,500	$ 2,500	
Installation Cost (day)	$ 1,500	2	$ 3,000	$ 3,000	
Site Survey	$ 1,500	1	$ 1,500	$ 1,500	
Maintenance (per unit per 5 years)	$ 2,500	4	$ 10,000	$ 10,000	
Starter Kit (software training)	$ 3,000	1	$ 3,000	$ 3,000	
Fixed Cost			$ 2,500	$ 2,500	
					$ 45,500

Custom. Cost of Software:

Salary (per month)	$ 10,000
Time (months)	0.25
# of people	1
Manpower Cost/Salary	$ 2,500
Maintenance Cost per Year per Unit	$ 500
Lifetime (years)	5

Checkgate System (5 Sections)

Item	Unit Cost	Quantity	Subtotal	Cost after custom.	Total Cost
Readers	$ 4,500	8	$ 36,000	$ 36,000	
Clamp/Tag	$ 5	1000	$ 5,000	$ 5,000	
Customization Software			$ 2,500	$ 2,500	
Installation Cost (day)	$ 1,500	2	$ 3,000	$ 3,000	
Site Survey	$ 1,500	1	$ 1,500	$ 1,500	
Maintenance (per unit)	$ 2,500	8	$ 20,000	$ 20,000	
Starter Kit (software training)	$ 3,000	1	$ 3,000	$ 3,000	
Fixed Cost			$ 2,500	$ 2,500	
					$ 73,500

Confined Positioning System

Item	Unit Cost	Quantity	Subtotal	Total Cost
Readers	$ 6,250	4	$ 25,000	
Clamp/Tag	$ 48	1000	$ 48,000	
Software Application			$ 45,000	
Repairs			$ 29,566	
Site Visit			$ 10,000	
Maintenance Cost			$ 118,000	
Software Integration	$ 1,500	3	$ 4,500	
Fixed Cost			$ 2,500	
Total Cost				**$ 282,566**

Lifetime (years)	5
Mean time to breakdown	5
Repair Cost	$ 48
Maintenance Cost	
% of Total Cost	20%

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