From Magnet Boards and Grease Pencils to Flat Panels and Overview Displays
TriMet Case Study

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The evolution of a light rail system from a simple single-line system to a multiple-line system with integrated bus operations is a complex process, requiring careful coordination by operations, information systems, and capital projects staff. The problems involved are complicated by the need to maintain service and cascading technology.

TriMet is now on its fifth phase of control center development. Each phase has been a learning process. Each phase has required increasing levels of involvement from all stakeholders. The evolution through each phase is described by providing the perspectives of each of the major stakeholders and the major lessons learned in each phase.

TriMet's experience is that the ongoing process of implementing technology and integrating operations has been workable and desirable. The current phase of development will bring the Interstate project on line in the joint bus and rail command center. The process of implementing new technology works best when all of the stakeholders are active participants, because all of the project goals are more clearly identified.

INTRODUCTION

Since TriMet began operating light rail in 1986 in Portland, Oregon, the systems used to manage the operation have been in almost constant evolution. The system is called MAX, for Metropolitan Area Express. The original system, about 15 mi in length with one service route was relatively easy to manage with flip charts, grease pencils, and magnet boards. Seventeen years later we are on the verge of opening our fourth line, comprising 45 mi and three main routes. Additionally, the bus dispatch and rail control centers have been located together. The operations management task has become increasingly complex, and many of the processes have been automated. Three points of view of TriMet's control center evolution are provided here: operations (the users), information systems [(IS) maintenance and development], and capital projects (design and procurement). Further, this paper describes the evolution in practices that has permitted these projects to be increasingly successful.

TriMet has gone through five phases of control center evolution so far:

- The Banfield era,
- The Westside years,
- Airport expansion,

- Bus dispatch relocation, and
- Interstate expansion.

Though some of the phases overlap in time, each marks a change in the way the control center has done business.

THE BANFIELD ERA

Description

In 1986, TriMet began operating a 15-mi light rail line. At that time the Control Center consisted of a 450 MHz desktop radio with 2 channels, a DOS computer system for logging events, a magnet board to track yard storage of 26 light rail vehicles, and a strip map of the alignment. Within a year an additional computer and radio system was installed to track alarms from ticket machines and traction power substations. Also, a flow chart was developed in-house as an aid to Controllers to graphically show scheduled train positions. This system was used with minor upgrades until 1998.

Figure 1 shows the Control Center during the Banfield Era. The layout was crowded and did not lend itself toward expansion of any sort.

Figure 2 shows the arrangement used to track yard storage. This arrangement was effective for handling 26 cars in one yard, but today's fleet of over 100 cars in two yards demands some sort of automated tracking.

FIGURE 1 Rail operations Control Center during the Banfield years.

**FIGURE 2 Essential tools for yard operations: magnet board,
telephone, two-way radio, and binoculars.**

Procurement

There was no formal procurement process for the Banfield Control Center. The basic structure was provided as part of the "turn-key" Banfield construction and was quite bare-bones, consisting of a small room in a corner of the Ruby Junction Maintenance Facility offices. The Control Center was handed over to operations as the contractors walked out the door. As new needs were discovered, the operations department did research to find the right solution, and worked with the purchasing department to put the solution in place. Generally, the solutions selected reflected what was available on the open market, for example, the radio-based Supervisory Control and Data Acquisition (SCADA) system was provided by a local two-way radio supplier. While functional, this approach did not produce the best solution, but produced solutions that could go into service expeditiously.

Control Center Staffing

The Control Center was staffed with one person at a time, 24 hours a day, 7 days a week, with employees who held the dual status of Rail Supervisor and Rail Controller. No additional support staff was assigned. When a technological problem arose, the two-way radio vendor or the IS department would send help.

Operations Limitations

The original Control Center was cobbled together, generally based on immediate needs rather than design. It grew as the controllers grew into their job. As the operating department discovered new requirements, attempts were made to expand the Control Center's capabilities. These ad hoc expansions were often rather awkward. The one-controller arrangement was adequate for most operations, but special events and emergencies often resulted in tense moments.

As the operation started, use of Standard Operating Procedures (SOPs) was limited. Gradually SOPs were developed to handle all sorts of operational conditions. At this stage of system development, SOPs were strictly on paper and not integrated with the control systems.

Information Systems Perspective

In 1986, at the dawn of light rail in Portland, the Banfield Line, TriMet's IS Department was in the middle of the mainframe computing era. Applications were one tier, systems were proprietary and not open, all resources were centrally managed, and user interfaces consisted of "dumb terminals." In the early 1980s, a state of the art IBM mainframe was installed for over $1 million with less computing power than today's personal computers. The department was focused on deploying large-scale mainframe systems such as Fleet Maintenance, Payroll, Accounting, and Driver Scheduling. Except for Fleet Maintenance and a simple DOS-based event logging application, the focus of the department was integrating the new Rail Division with existing, agency-wide, large-scale mainframe systems, not developing or maintaining systems directly related to the running of a railroad. The technology and focus of the department were soon to change.

Lessons Learned

The controllers need the proper tools to be able to handle extraordinary situations.

A lack of advance planning for operations will result in operations tools that poorly support operational requirements. In fairness to the builders of the system in 1986, at that time operations really did not know what tools were needed. Some neutral outside help was needed to moderate between the system builders and the eventual users. This is especially important for a starter system where the users may have little rail experience.

THE WESTSIDE YEARS

Description

In 1998, TriMet opened the Westside light rail extension. This expansion was 18 mi of alignment with a tripling of service. Included was the opening of a 3-mi long tunnel with a station 260 ft underground. A new yard and maintenance facility was opened. The size of this expansion along with the tunnel and expanded level of service required a proportional expansion of control capability. The 1986-era Control Center was replaced with a state of the art Central Control System (CCS), married to a SCADA system in the field. This system tracks trains in real time and monitors and controls most field equipment, including

- Ticket machines,
- Traction power substations,
- Communications equipment,
- Signal equipment,
- Elevators,
- Public address systems,
- Variable message signs,

- Ventilation equipment,
- Standpipe systems, and
- Intrusion detection.

When the Westside extension came on line, the MAX system expanded to 33 mi in length.

Procurement

TriMet's Capital Projects division hired a consultant staff to design all systems (traction power, signals, communications, and fare collection), integrate the systems with concurrent civil work, prepare specifications, and manage the procurements through to final acceptance. Procurement of the Westside CCS and SCADA was part of a system-wide communications contract. In addition to CCS and SCADA, the contractor installed a fiber optic backbone and SONET equipment, telephone systems, public address and variable message signs, and closed circuit television.

The central control design was prepared based on Westside project criteria, and it was prepared generally with input from the operations department, but there was little operations department hands-on involvement during the design stages. Operations did participate in design reviews after contract award, but these reviews were late in the process and did little to establish basic requirements for operational functionality.

The communications procurement was a two-step process: A request for proposals was sent out to likely bidders; then proposals were received and evaluated. Specifications were adjusted and sent out again to a short-list of bidders, and a best and final offer (BAFO) was requested. The low-bidder on the BAFO was awarded the contract.

One IS staffer was assigned to support the procurement on a part-time basis, but IS was not really integrated into the process.

Control Center Staffing

Staffing levels increased in 1998 when this system was brought on line, and the dual qualification was split so employees could specialize in Control or Supervision. The Control Center continued to be staffed 24 hours a day, seven days a week, and the number of controllers on duty at one time has increased. During day and swing shift there are three controllers on duty at one time. Two controllers are responsible for geographic segments of the mainline as well as yard operations within those areas; the third controller is responsible for administrative duties, communication with the maintenance departments, writing Train Orders, Special Instructions, and relieving the on-air controllers for breaks.

At the start of Westside operations, the IS department also assigned one full-time person to provide day-to-day system maintenance, in conjunction with the Control Center vendor's full time support. As the vendor's support was cut back, the IS department assigned another full-time staffer.

Operations Limitations

This system has worked well from an operational point of view, but shortly after the start-up we realized that the incident reporting function of this system did not meet our needs. The cost of a vendor upgrade was prohibitive, and overall the system was not as configurable as we desired.

Based on operations input, the IS department created an accident/incident database (ACID) to meet our current and future needs. This incident tracking system is maintained on our TriMet IS network, rather than on the CCS network. This makes it easier for our IS staff to maintain, and it does not clutter up the CCS screens. When the new incident tracking system came on line in 2000, we stopped using that function in the CCS.

Information Systems Perspective

By 1998, when the second light rail line (Westside) opened and the first Rail CCS went into operation, a lot had changed in TriMet's IS department. Applications were now two tiered, in some cases multi-tiered, and databases remained centrally managed, but system development, maintenance, and support were now shared with users, and PCs had proliferated to every corner of the agency. The mainframe computing era was dead. The era of client server computing was here.

The focus of the IS Department was evolving as well, from integrating users into existing agency wide mainframe applications, to understanding the client departments, business needs, and developing or maintaining systems that met those needs. This evolution was not yet complete in 1998 when the Rail CCS appeared.

The CCS system had been specified by an outside consultant and procured by the Capital Projects Division as a very small part of the much larger Westside Light Rail Communications Contract. At the time, IS had a Manager of Rail Information Systems, one programmer, and one analyst located at Ruby Junction, the main Rail Operations facility. While IS staff was located at the rail facility, they were not always dedicated to Rail or Operations only projects. The Manager of Rail Information Systems was the primary liaison between the IS department and the Capital Projects Division.

Unfortunately, during the Westside procurement, the interaction between the Capital Projects Division and the IS Manager and staff was primarily limited to information sharing. The Rail Operations Division participation, while greater than that of the IS Department, was also limited in scope. As a result of these limited relationships the IS Department had very little to do with the design and implementation of a large mission critical system that it was expected to maintain, and likewise, the Rail Operations Division had limited input into a system they were expected to use to perform their daily work. It was sheer luck that the vendor, Union Switch and Signal (US&S), chose Oracle as the relational database and Sun Solaris as the operating system, both TriMet IS standards.

The inadequacy of IS Department and Rail Operations participation in the procurement became obvious shortly after installation, and significant changes to the system were required. The most apparent shortcomings in the Westside specification, from the IS perspective, were in the database design, the accident and incident capture interface for controllers, and the scalability of the hardware and the software.

The database was designed for the day-to-day operation of the rail line only; that is to say, any data captured was considered "throw away" data, stored for a maximum of 48 h. Effective reporting or data analysis could not be accomplished against a database that held only 48 h of data. A replication scheme was developed and implemented by TriMet's IS Department and US&S, where the data stored in the US&S Oracle database would be replicated immediately to a second Oracle database on a separate machine, known as "Replica." Replica was designed to store the data for years, and it became the primary reporting and analysis database.

The accident and incident capture interface originally specified did not adequately meet the needs of the Rail Operations. This was not surprising considering the limited amount of input from Rail Operations during the specification phase of the contract. Coincidentally, the (completely separate) Bus Dispatch System also lacked an adequate accident and incident capture interface, so it was decided that the IS Department would develop a separate application for capturing incident information that Bus, Rail, and Accessible Transportation could use. The system, ACID, was developed using Sybase's Power Builder against an Oracle database. ACID uses data directly from the Replica database. This data included train, vehicle, operator, location, and route and schedule adherence.

The third shortcoming of the specification was the scalability and support of hardware and software. At the time the Westside contract was implemented, the hardware and software selected by the vendor was state of the art, but was designed to meet the current requirements only. Future rail lines and increased data requirements were not clearly defined, and so capacity for expansion was very limited. By the time the system was in service in 1998 the operating system software and hardware were fairly old by technology standards and were reaching their limits of scalability and vendor support. The specification did not call for scalable hardware and software, and the long time between specification (early 1990s) and implementation (late 1990s) resulted in shortened life cycles.

Lessons Learned

The main lesson learned from the procurement of the Westside Rail CCS was that inadequate stakeholder participation results in an end product that doesn't meet the stakeholder's needs. This sounds trite and in some ways is a replication of the lessons learned from Banfield. But it did turn out that way and the lesson deserves repetition. In the case of Westside, the technology was such an advance that TriMet just did not know how to get organized to identify stakeholder requirements. One thing was clear; the amount of IS staff support needed was severely underestimated at the beginning, leading to a second lesson: a dedicated IS staff is not a luxury but a necessity.

Systems integration was also critical in this project. The communications system is typically the "tail of the dog." All other civil and systems work is well on the way to completion before the communications work really begins. The CCS/SCADA system is the glue that holds together all the other systems and provides the Operations Department with the tools they need to do their work. Furthermore, because this part of the work is at the end of the project, there is often tremendous schedule pressure. On Westside, this situation was counter-productive. Schedule pressure and unclear requirements conspired to give Operations less of a system than they needed. Good advance planning and early buy-in by all concerned parties are mandatory.

In the technical details area, when choosing a central control system, the system standards should match those of the rest of the IS department—in this case, Oracle databases and Sun UNIX operating systems. This allows IS to leverage staff capabilities and provides an easier interface to related systems.

The CCS database needs to be designed to meet the agency's reporting needs. Even with the expansion of capabilities implemented after the system went on line in 1998, new and unforeseen requirements have developed. Since this time, database requirements have become more and more standardized at TriMet. The Control Center system must match up to these standards, so information can be shared among various applications. One of the main online data

users at TriMet is the Transit Tracker system, which provides real-time bus and train schedule information to the public. If the databases are not set up correctly, systems like this just will not work.

Alternatively, the incident tracking system is an example of the sort of information that you may not want to have married to a CCS. In an emergency situation, it might tend to clutter screens needed for immediate operational requirements.

Lastly, one must plan for system expansion. Clearly this is difficult to do when the likely system extensions are undefined. The capability for system expandability is needed.

AIRPORT EXPANSION

Description

In 2001, TriMet expanded the rail system again by opening a 5.5-mi extension to Portland International Airport. Airport MAX was TriMet's third light rail line, a unique public–private partnership. This line incorporated all of the systems elements seen on the Westside project, with the exception of the tunnel. When the Airport extension came on the line the MAX system was 38.5 mi in length.

Procurement

The Airport expansion was, from TriMet's perspective, a single design–build contract. US&S, the vendor of the 1998 CCS, provided the new software and hardware as a subcontractor to Bechtel, the primary contractor for the Airport Line expansion.

For the Airport expansion, the decision to add onto the existing CCS, as opposed to procuring a completely separate system, was made for several reasons. First and foremost, TriMet had learned from the experience of several other transit agencies, which had added separate vendors for each new rail expansion. This strategy has resulted in a duplication of support staff, higher support costs, and trouble with data integration. Additionally, US&S was able to provide the addition in the very short time frame demanded by the Airport expansion project. The disadvantages of this approach were that the issue of the system's age and scalability were not addressed with the expansion. These issues would soon rise to the forefront.

Staff Levels and Operational Issues

The staffing levels did not change for the Airport extension. Operationally, the major change was in relocating the geographic boundary for the responsible areas between the two on-air controllers.

Information Systems Perspective

By the time of the Airport extension, the IS department had taken over responsibility for administration of CCS and had two full time Unix administrators dedicated to the support of the rail control system. The administrators reported to a Manager of Operations (division) Information Systems. The Airport expansion was the first major upgrade since the implementation of the 1998 CCS and resulted in an addition to the current system of one additional server and new software.

Lessons Learned

The design–build approach presented a number of challenges for TriMet, primarily in the area of specifying systems designs. The approach taken was to use the Westside as-built documents as a baseline for the Airport extension. This approach did not permit for correction of Westside design problems. In the CCS area, the problems of system functionality and expandability were never addressed.

BUS DISPATCH RELOCATION

Brief Description

In late 2001 the Bus Dispatch Center was moved to Ruby Junction so it could be located with the Rail Control Center. This was done due to a change in philosophy within the agency; the idea is that the Bus and Rail divisions can work more closely together if they are coordinated under one management structure. An all-inclusive Field Operations Department was created to make this concept a reality. Rail Control is now part of the Operations Command Center where there are leads and a manager who directly oversee the operations of both Rail Control and Bus Dispatch. Relocation of the Bus Dispatch center was a homegrown project. The co-location and change in agency philosophy has worked well, and it has led to a closer working relationship between the Bus and Rail employees. This, in turn, has lead to better customer service.

Procurement

There were two phases to the relocation project.

First, a new home for Bus Dispatch was required, adjacent to the existing rail control center. This effort happened in conjunction with the construction of Ruby Junction's new South Shop building. Many rail maintenance staffers were moved from the Ruby Main building to the new South Shop building, leaving space for Bus Dispatch. The contractor for the Ruby Yard expansion, a part of the Interstate Project, prepared the physical space.

Second, the actual relocation of equipment and bus dispatch staff from TriMet's Center Street facility to the Ruby Main building required shifting of many communications circuits and a phased movement of workstations and related equipment. TriMet staff internally coordinated all the moves and equipment cutovers required. On-call contractors were used to shift communications circuits, provide power and network wiring, and move the furniture. This was successful because very little technology was changed. The Orbital Bus Dispatch System and radio equipment was relocated from TriMet's Center Street office to Ruby Junction one workstation at a time over a weekend, constantly maintaining service.

Figure 3 shows the post-relocation floor plan and several associated photographs.

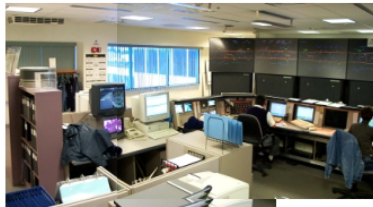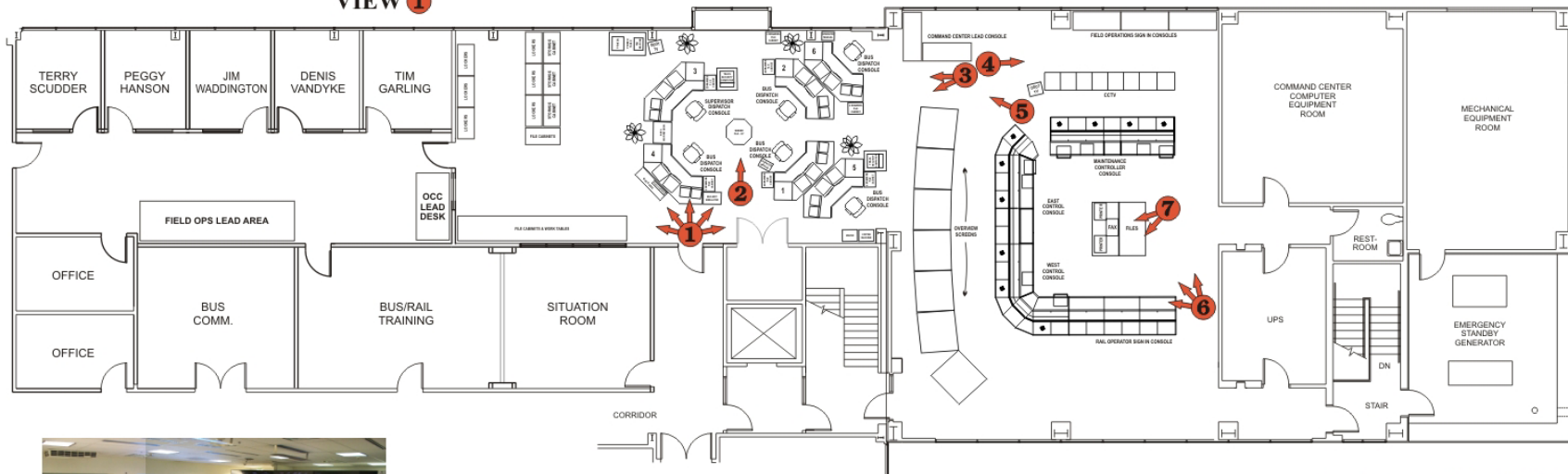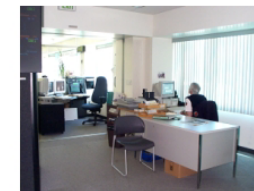# TRI-MET OPERATIONS COMMAND CENTER - *CURRENT CONFIGURATION*

FIGURE 3 Control Center floor plan, following integration of Bus Dispatch.

Staff Levels

Staff levels have not changed for rail controllers and bus dispatchers. The number of supervisors has changed, with one supervisor managing both bus and rail.

Lessons Learned

We learned that with teamwork and careful coordination, our internal staff could be successful in undertaking of a project of this type.

INTERSTATE EXPANSION

Description

While construction of the Airport expansion was underway, the design process was begun for the Interstate Avenue extension. The rail portion of the existing Operations Command Center will be refurbished in conjunction with the Interstate extension opening, planned for start-up in the spring of 2004. The MAX system will be a little over 44 mi in length when the new Interstate line is up and running.

A number of rail control changes will be taking place: 1) the layout of the Control Center will be changed dramatically because of a need to better align geographically in the room with the Bus Dispatchers and to accommodate the increased amount of equipment needed to handle the expansion of the rail system; 2) the number of workstations and the number of overview displays will be increased; and 3) the CCS software and hardware will be changed to a system that will accommodate the Interstate project as well as future requirements.

Figure 4 shows the Control Center arrangement following reorientation of the Control Center and full implementation of the new CCS.

Procurement

As planning began for the new line, the question of how to incorporate the new line into the existing Rail CCS became paramount. Three options were considered: add onto the existing system as was done with the Airport extension, procure a new and separate system for the Interstate MAX, or specify a completely new system for all four lines.

For option one, adding on to the existing CCS, the IS staff responsible for the maintenance of the CCS determined that to expand the Westside and Airport CCS system to accommodate Interstate Max, the hardware would have to be replaced, the operating system would have to upgraded to a version supported by the vendor (US&S), and the software code would have to be ported to a currently supported operating system (the existing operating system is obsolete and no longer supported). This task was beyond TriMet's in-house capability, but an outside vendor might wish to pursue the option.

The option of adding a new system solely for the Interstate Line was rejected for the same reasons that this option had been rejected for the Airport expansion. The added staff required to maintain two separate systems was not a viable option.
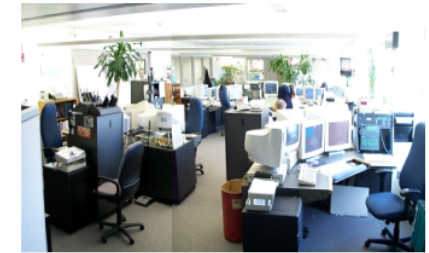
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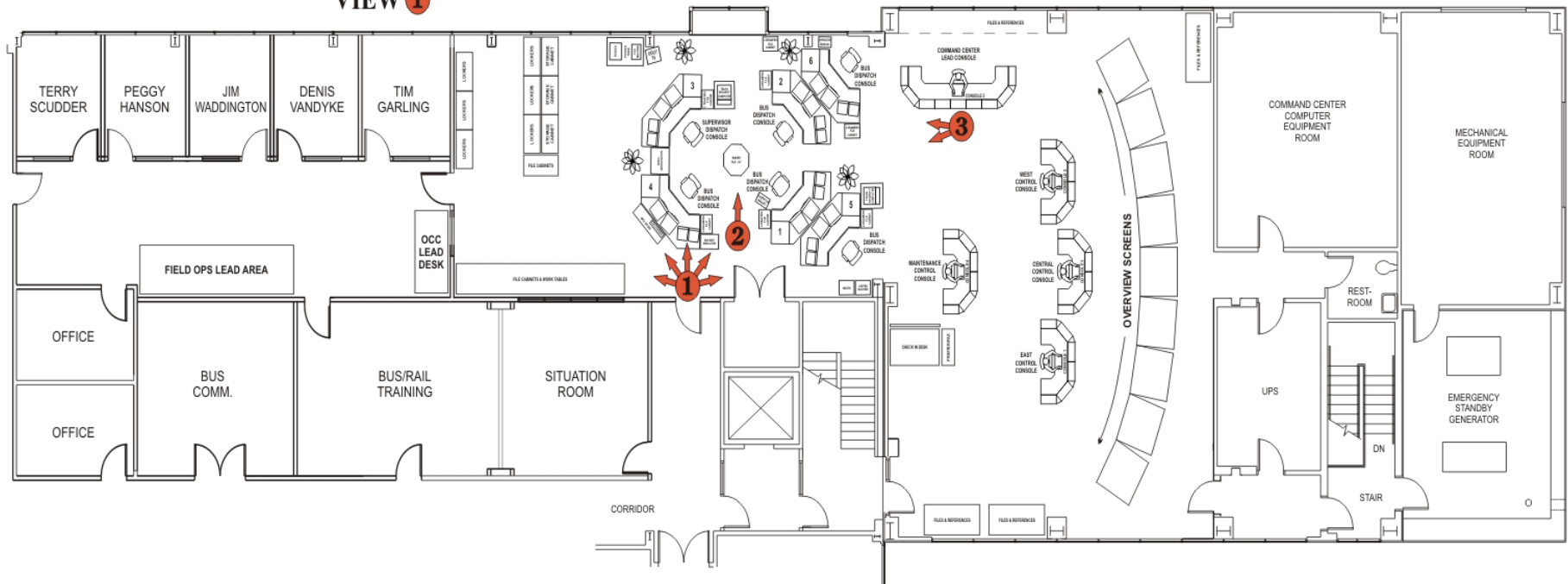

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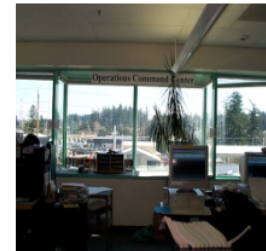
VIEW ②

VIEW ③

FIGURE 4 Control Center floor plan, following Interstate Line expansion.

To investigate the possibility of a wholesale replacement, TriMet staff contacted potential vendors for a whole new CCS and became educated with the marketplace. This research was a cooperative effort by operations, IS, and capital project staff. TriMet prepared a preliminary specification and requested budgetary quotes from all likely vendors. Based on the responses, TriMet decided to pursue replacing the entire existing CCS.

For this procurement, TriMet returned to the two-step procurement model, very similar to that used on the Westside project. The major difference between this procurement and the Westside procurement was the separation of the CCS procurement from the Interstate communication procurement. This was done to foster competition on both the Signals and Communication contract, and on the CCS contract. Our assessment was that marrying signals, communications, and CCS into one contract would have been very limiting. Potential suppliers for the CCS contract were given the option to either upgrade the existing CCS, or completely replace the CCS.

The follow-on task of replacing the CCS is currently under contract to ARINC, Inc. As of March 2003, final design for the new CCS was nearly complete.

To effectively support the new CCS, significant infrastructure changes were required. Additional workstations, additional overview displays, and reorientation of the room to better facilitate the Bus Dispatch area were all needed. The Control Center infrastructure is being reworked as a part of the Interstate Signals and Communications contract.

Staff Levels

The staffing of the Control Center will increase to allow for a third on-air controller position. This new position is needed to keep radio traffic at workable levels. At this time the amount of radio traffic is nearing maximum levels for the two controller positions. At peak hours, two on-air controllers would find the radio traffic to be unworkable. The use of three territories with three radio talk-groups will keep radio traffic to a workable level. Additionally, a Maintenance Controller position is planned.

Operations Limitations

One of the key goals of the new CCS is easier user-configurability, allowing TriMet staff to make minor changes and upgrades to the system without CCS vendor involvement. The new system, by design, will be more capable of expansion in the future. As is typical of many rail properties, field configuration changes to optimize operations occur on a regular basis. In the past, TriMet often was unable to make minor CCS changes due to budget constraints; CCS changes were expensive. TriMet now anticipates being able to make most CCS changes in-house as the field configuration changes.

Operations Perspective

While the Interstate line is in itself relatively simple to operate, the line's tie-in to the existing system at Rose Quarter will be the most complex interlocking in the system. The new on-air Controller will be responsible for the new alignment, the half-grand union interlocking, and the central business district areas of the alignment. The other on-air positions will have their geographic areas realigned to match up with the new position.

Information Systems Perspective

The Interstate MAX line was the first major expansion in TriMet's history where the IS Department was an equal participant in the specification, vendor selection, and creation of the new CCS. The IS Department was able to insure that all hardware, software, and software design met TriMet IS standards, which are designed to allow for scalability, reliability, and customer support.

Lessons Learned

Learning from the missteps in the procurement of the first CCS and the Westside system, a comprehensive selection team was formed. The team consisted of personnel from Rail Operations, Capital Projects, IS, Procurement, and one consultant who specialized in transit control systems. However, the team is larger than just those members, because the team members actively brought in staff from every group that might be affected to provide design input. Though this seems cumbersome at first, it works to get all the issues on the table and avoid expensive changes down the road. The most important lesson to learn is to allow enough time for this process.

In order to maximize competition for procurement of the Interstate field communications equipment (which was bundled with the signals system), the CCS procurement contract was separated from all other Interstate MAX contracts. There is a downside to this: the burden for integration falls on the agency. If the agency does not have the right staff available this can be very problematic.

OVERALL LESSONS LEARNED FROM TRIMET'S CONTROL CENTER EVOLUTION

First and foremost, an agency should take a strategic, holistic, organization-wide perspective when embarking on a brand new CCS, modifying an existing control system, or replacing your CCS. As you can see from TriMet's evolution, our perspective has broadened with each successive expansion. The Westside CCS was designed and implemented primarily by the capital projects division. At the end of the Westside project the CCS was handed over to the Operations Division. After a short time operating the system, the Operations Division asked the IS Department for assistance in the care and feeding of the system. Each group passed a baton of responsibility to the other group. Learn from our growing pains and involve all stakeholders at the beginning of the project, whatever the project scope may entail. Operating in departmental vacuums, turf wars, and silos of administration and responsibility do not work to create an efficient CCS that delivers effective service to customers. Cross-divisional teamwork, consensus decision making, and collaboration do make a CCS work.

Secondly, specifying, procuring, implementing, administering, and maintaining a CCS requires dedicated transit operations, IS, and engineering staff. Do not let vendors dictate your agency system requirements or how the system should be operated and maintained. A dedicated agency team will know what is best for your operating and information systems environments and your customers. The operation of the system should correspond to your standard operating procedures, and should fit with your agency's information systems standards. Do not allow a major system of the import of a CCS to drastically violate your standards, or be willing to change your standards to reflect the CCS. If a vendor says "It cannot be done," but the consensus is that it can be done, you probably do not want that vendor.