Realizing Benefits from ATCS Using a Motive Power Information and Management Support System

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The motive power management function at a railroad can be significantly improved thanks to more timely and accurate information. With earlier and more reliable knowledge of train and locomotive performance and demands for power, motive power managers can improve their forward planning, which leads to improved locomotive utilization and better on-time train performance. Advanced Train Control Systems (ATCS) can be an important source of information for motive power management. With their train location, locomotive health, and work order reporting systems, ATCS have the potential of increasing accuracy to near 100 percent and reducing to a matter of seconds the time lag between an event and when that event becomes known to motive power managers. For this more timely and accurate information to be exploited, it must be organized and presented to the motive power managers in an efficient manner. In addition, there must be established a mechanism for timely communication to field forces of the motive power managers' plans. To achieve this, a computerized motive power control system was designed and implemented at Canadian National Railways. It consists of graphic displays of current train and locomotive location and status, alerts that highlight critical new information, functions for motive power planning, and facilities for communicating plans to field forces. With the motive power system in place, and gathering its information from ATCS, managers know about and can respond immediately to changes in train and locomotive demand and performance. Although ATCS are not a prerequisite for achieving benefits from an improved management control system, an effective management control system for trains and locomotives *is* a prerequisite for achieving full benefits from ATCS.

Railroad motive power is an expensive asset that requires efficient management. Canadian National Railway (CN) operates a fleet of 2,000 diesel locomotives on a 50,000-km railroad that spans Canada from Halifax on the Atlantic coast to Vancouver on the Pacific coast.

Like many railroads, CN manages its motive power from one central control center. CN's motive power control center is responsible for monitoring and distributing locomotives, vans (cabooses), and end-of-train devices to meet the needs of more than 700 trains each day. It must operate these trains with as few locomotives as possible, but not delay any trains because of a lack of power. It must balance the flow of locomotives to take into account future demand and must meet locomotive maintenance requirements.

As of the mid-1980s, the center was principally a manual operation essentially unchanged since the conversion to diesel locomotives approximately 30 years before. Motive power assets were tracked using a large magnetic board covering one wall of the control center. The board contained a track schematic of the CN system. Each locomotive and van was represented by a moveable magnet. Reports of train and unit movements were received in the center via COMTEL (teletype) and telephone. The motive power distributors moved the appropriate magnets to correspond to a movement report. Colored tags were stuck on the magnets to indicate reports of abnormal condition, such as failures or inspections due.

Motive power control and CN's technological development department began looking at ways to modernize the operation center starting in 1985 and continued to do so off and on into 1987. Several studies were done during that time that highlighted the need for more timely and accurate reporting of events in the field. Coincident with CN's determination of this need, the railroad industry and its suppliers were investigating means for reliable automated tracking of trains as part of the effort to develop Advanced Train Control Systems (ATCS), and commercial demands were being made for automatic equipment identification systems to provide customers with more timely tracking of their shipments. As a consequence, CN committed to improvements by installing a railroad equipment identification system (REIS), on-board transponders, and wayside detectors at key locations to automate reporting (*1*, *2*). REIS would selectively replace reporting by field clerks in feeding CN's main computer system, TRACS. Field clerk reporting is typically hours behind reality, sometimes inaccurate, and therefore not relied upon by the motive power controllers. Obviously, the manual procedures in motive power control would have to be automated to take advantage of the improvement in timeliness and accuracy of reporting that ATCS technology would provide.

USER NEEDS

In the fall of 1987, a full-time user representative from motive power control joined with members of CN's technological development department to identify requirements for a new motive power control system. Questionnaires, studies, and in-depth discussions were used to produce an initial set of requirements. In April 1988, an outside consultant was retained to further refine the requirements and produce a system design.

CN's motive power is managed from a central control center, manned 24 hours daily, every day of the year. Normally

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four distributors are on duty at any one time, each of whom distributes power to a particular geographic region. On the weekday shift, a coordinator is on duty who exercises a supervisory role and ensures that the supply of power is properly balanced between regions. The system operations control officer handles these duties as necessary when the coordinator is not on duty.

The principal task of the motive power distributors is to plan upcoming locomotive assignments. For each train departing each major yard, the distributor must decide which locomotives to assign. The distributor works with yard personnel to determine this assignment. At minor yards, the yard personnel usually "turn around" or "send on" power to the next major yard, but the distributor may also need to specify plans at minor yards in certain circumstances. The distributor's work product is a list of locomotives, by serial number, to be assigned to each outbound train, from each major yard.

The distributor's work is complex because of the large number of variables that must be considered. The supply of locomotives is limited. Not all locomotives are suitable for every train. Certain trains require one or more locomotives with one or more special features. Trains should not be overpowered, lest locomotives and fuel be wasted. Trains should not be underpowered, lest they be unable to meet their scheduled transit times. Requirements for power are often unbalanced by direction, by day of the week, or by season, so locomotives must be "repositioned" to be where they are needed when they are needed. Locomotives must be cycled to a repair shop as close as possible to when they are due for maintenance. Locomotives fail en route and must be "rescued." There are also requirements for local and yard power that the distributor must meet.

A need was identified for both a broad-based view of power movements for purposes of achieving balance in power flows and a close-up view of individual trains and units for the distributors to use in determining which particular units should power which trains. It was important to the broad-based view that the trains and units appear in their proper geographical relationship. The existing magnet board was providing both views for the users in that they could step back and get the overall view or they could walk up close to the board to see detail in a particular area. The controllers and coordinator wanted to have both these views in any automated system.

Another need was for the system to remind power controllers of work to be done. Placing paper stickers on unit and train magnets, placing magnets at odd angles (such as upside down or sideways), placing blank train racks on the magnet board, and piles of paper notes and COMTELs were all being used by the controllers to note work to be done. The controllers hoped that the automated system would organize work to be done in a helpful way and provide automatic reminders of things that needed attention. Certainly, the system could not rely on the controllers hunting and searching through a computer system for things that needed attention.

The users also pointed out a shortcoming in the visual symbology of the current board. Color coding was being wasted on static attributes such as builder class, number of axles, and so forth. After a short time working in the center, all of the controllers had these static attributes memorized based on ranges of serial numbers. The colorful symbology of the magnets was unnecessarily obscuring important information on temporary conditions. This information was being noted on small stickers stuck to the magnets and by placing magnets sideways or upside down. The new system should focus on highlighting temporary conditions and not be made busy with unnecessary static information. It should not be what Tufte (*3*) calls a "graphic duck."

It was desirable that a new system automatically detect problems with field-reported data or controller instructions. For example, if a controller tried to power a train with too few locomotives for its tonnage and train profile, the system should alert the controller and require confirmation before issuing the power consist instructions to the field. Similarly, if an impossible or contradictory locomotive reporting was received from the field, the controller should be automatically alerted to solicit a correction on the reporting.

Finally, the system should be expandable to take advantage of advances in expert system, optimization, and other technologies. CN was interested in the expert system and optimization logic of ALK Associates' Locomotive Distribution System (*4*). CN and its consultant agreed that it was essential to automate both inbound reporting and outbound instructions as a prerequisite to considering expert system or optimization technology.

SYSTEMS AT OTHER RAILROADS

Simultaneous with surveying user needs, other railroads were canvassed to see what solutions they had undertaken to automate motive power control.

The largest group of railroads had nonautomated systems similar to CN's then-current system. Canadian Pacific Railroad (CP), CN's principal competitor, has its control center a few blocks from CN's in Montreal, Canada, and the two centers appeared to operate nearly identically. CP's center did seem to rely more on the telephone than on COMTELs relative to CN's. The CP power controllers wore headsets so they could stand at the magnetic board and move magnets while listening to reportings on the telephone. Like CN, the CP controllers made limited use of mainframe computer terminals to perform enquiries.

Several railroads (Union Pacific, Conrail, and CSX) had recently replaced their magnet boards with nongraphic terminals linked to their mainframe systems. Motive power managers at all three railroads were relatively unhappy with this. The mainframe systems forced the controllers to do a lot of hunting through the system for locomotives, there was no queuing of reminders of work to do, no way to see power in its geographic perspective, and no way to get a broad view of how power was doing. In addition, the amount of typing involved was extensive and introduced numerous errors. (CSX has recently begun to address these shortcomings (*5*).)

Two of these railroads (Union Pacific and CSX) were in the process of installing large "cyclorama" dispatch centers, containing enormous (hundreds of projectors) computer-driven wall displays for dispatching the entire railroad system from one large room. To improve communications between controllers and dispatchers, the motive power controllers were to be relocated to these dispatch centers. Management at both railroads thought the controllers would obtain some value from the large wall displays. However, the displays were designed for the dispatching function and are of little use to motive power control. Only trains, not locomotives, are shown on the wall displays. In any event, the displays are too dim and the controllers' desks are too far away for the displays to be readable.

The most extensive attempt found to automate motive power control was Burlington Northern's CAPMAC system. This system features an array of 42 CRT screens that contain a schematic of Burlington Northern's system and the trains on it. Like the dispatch centers, the schematic is in the form of straight lines and does not show the rail lines connecting in the proper geographic context. However, it is oriented to motive power control in that individual locomotives are shown, and the controllers can easily read the displays from their desks. A very complicated visual symbology is used to convey both static and transient locomotive attributes. Like the mainframe systems, however, there are no automatic reminders of work to do, no checking of work, and the system requires a lot of typing, making it prone to human error. Another disadvantage was that CAPMAC runs on a type of computer that has been discontinued and it would be expensive to port CAPMAC to more modern equipment.

Two railroads (Burlington Northern and Union Pacific) were beginning to install expert system and optimization technologies for distributing locomotives (*4*). Both railroads were reporting efficiencies from using these systems (*6*; Hornung, unpublished data), although acceptance was being hampered by problems in the timeliness and quality of data reporting. Like CN, as part of a broader effort to implement ATCS, both railroads are moving to automated reporting technology similar to REIS, which, by improving data reporting, will make such systems more useful (*7*).

DESIRED SYSTEM FEATURES

It was clear from the user interviews, and from the evaluation of other railroads' systems, that the magnet board had a number of attractive attributes that should be incorporated into an automated system. The system must be designed to meet the needs of motive power controllers, not dispatchers. It must support views for both broad-based power flow and detailed power consisting. It must show power in its proper geographic perspective. It should be as easy to use as moving magnets on a wall. It should not require lengthy typing of locomotive numbers or train identifiers.

To improve upon the manual system, the automated system should also contain a number of new features. It must update itself automatically without human intervention at any point in the process. It must automatically remind the controllers of work to be done, and it must check the integrity of both inbound reportings and outbound controller orders. It should be expandable to include expert system and optimization logic. Finally, it should use a widely accepted computer architecture so as to prevent unnecessary dependence on any one vendor and should use current technology to minimize the chance of early obsolescence.

HARDWARE SELECTION

To meet the desired system attributes and avoid the shortcomings of other railways' systems, a graphic user interface was deemed essential. This eliminated nongraphic and noninteractive graphics systems from consideration. The intensive graphics, size of data files, and desire for expansion ruled out low-end systems such as personal computers. It appeared that what are commonly referred to as "graphic work stations" would be the most appropriate platform. These are single-user microcomputers, usually connected in networks, that are more powerful than personal computers. Further, to support a large "system" view, high-resolution, wall-mounted projection screens were selected.

USER INTERFACE

System and Detailed Views

The completed motive power system (MPS) has one system view and a number of detailed views. An artist's rendering of approximately one-twelfth of the system view is shown in Figure 1. The system view is a schematic of the mainline trackage of the CN railroad system, shown as solid lines connecting major yards. Each train is shown, at its last reported location, as a sequence of small rectangles representing the train itself and the units on it. The complete system-level view is projected on a wall of the control center. The user can change which portion of the view is shown on a work station by clicking on the relevant area on the scrolling strip (bottom of Figure 1), which is a condensed version of the entire system display.

There are also four detailed views in MPS: yard-, outpost-, branchline-, and link-level displays. These can be invoked from the system-level display by clicking on the appropriate yard, link, etc. An artist's rendering of a yard-level view is shown in Figure 2. The name of the yard (Gordon in Figure 2) and various statistics are shown at the top of the view. There are areas in the view for outbound trains in two directions (top left and top right in Figure 2) and for inbound trains from two directions (bottom left and bottom right in Figure 2). The center of the screen shows units that are not on trains but that are at the yard. These are shown according to what facility they are at in the yard; for example, at a shop (in a repair facility) or on the ladder track (serviced and ready to go).

Unit and Train Symbology

On all MPS views, trains and units are represented by icons using consistent symbology. Unit icons are rectangles with a pointed end, which show the direction the cab on the unit is facing (the icon for cab-less units is pointed at both ends). The unit number is shown inside the icon. The color of the unit icon corresponds to its current condition, and the color of the icon tip indicates ownership and/or lease status. A unit icon may also have a white border indicating that the unit is preassigned to a train. Such a unit is displayed at its preassigned location with a solid border and at its actual location with a dashed border.

The MPS train icon is a rectangle containing the train's identifier (train I.D.), together with a small square that contains a one-letter status code. The color of the train icon indicates the train's on-time or lateness status. The unit icons for each unit on the train, in order, follow the train icon.

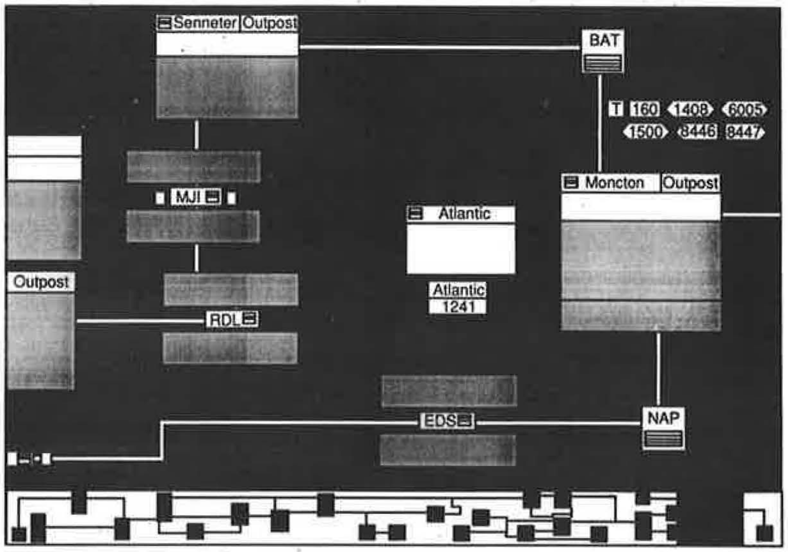

FIGURE 1 One section of the MPS system-level display.

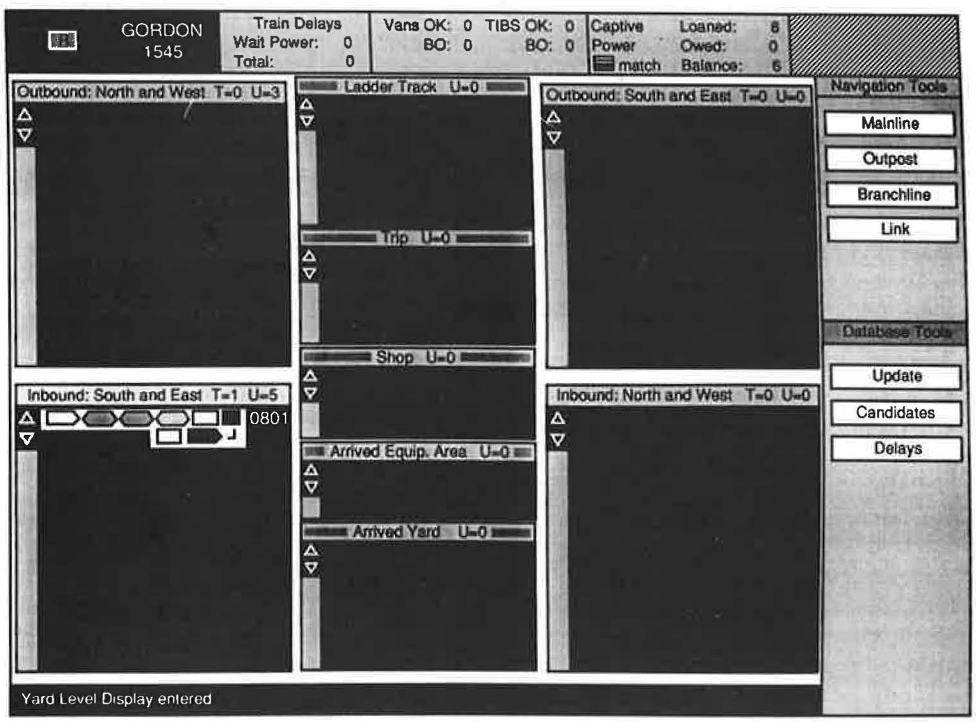

FIGURE 2 MPS yard-level display.

After the last unit icon is a rectangle listing the number of vans (cabooses) and/or TIBS (brake-sense units) on the train.

The symbology chosen is simple, yet communicates all the transient information necessary for the motive power controllers to make their decisions. To make the transient information more prominent, the displays are not overly burdened with static information (such as locomotive characteristics). A new controller can show the static information by making an object-sensitive query.

Alerts and Highlights

Alerts, in the form of blinking icons that look like flags, are used to draw the controller's attention to work to be done. For example, when a unit's status changes from noncritical to critical, the controller is alerted so action can be taken. Similarly, when a new lineup of outbound trains is issued by a yard, the controller is alerted so that a power supply plan will be prepared. A blinking border is used to highlight trains or units at the direction of the motive power controller.

Object-Sensitive Menus and User Dialogue

The MPS user interface is object-oriented. The user chooses the object of interest using a desktop "mouse" that controls the movement of an on-screen pointer. The user points at the object of interest and presses a button on the mouse to "pop up" a menu of functions pertinent to that object.

Many functions in MPS can be completed just by pointing at the object and selecting the function from the menu if the MPS needs no additional information from the user to complete the function. Other functions need more information than just the identity of an object and the function to be performed. For example, to move a unit or train, one needs to know two things: what to move and where to move it to. In MPS, a user can move a unit or train by pointing at it, then—while keeping a button on the mouse pressed—dragging the unit or train across the screen and releasing the mouse button at the location it is to move to. In MPS, objects are moved on the screen to indicate position in the same way that magnets were moved on a board in the system MPS is replacing.

MPS uses dialogue boxes for those functions that require a more in-depth dialogue with the user. The dialogue box is drawn in a "window" on top of the display from which it was invoked. For example, suppose the user pointed at train A216 and chose the "change train confirmation status" function. A dialogue box for this function would appear (Figure 3) drawn on top of the display with current information for train A216 displayed. Within the dialogue box, one or more items of information are displayed that the user can type over, as well as buttons to click on to perform certain functions.

PROTOTYPING EXPERIENCE

The design of MPS was derived not only from conceptual thinking but also from prototyping experiments. Screen layouts were initially sketched on paper, then refined using a computerized drawing program, and finally mocked up on the UNIX work station. The work station was attached to a projector to show the result projected onto the wall display. Often, a result that looked good on the work station screen did not look good on the projector and vice versa.

Prototyping was used to determine the size of the wall display, icon size, lettering fonts, colors, suitability of blinking, and so on. The concept that was subjected to the experiment usually worked in principle but was refined by prototyping. For example, the number of screens for the system-level view was increased from 10 to 12 to accommodate a larger, more readable lettering font. Alert flags were made to blink to make them more visually prominent. Additional timing, fuel, crew change, and power control points were added that were important to the controllers but had never been on the magnet board and were not identified by conceptual thinking.

A color editor provided by the manufacturer of the UNIX work stations proved to be of enormous benefit in selecting colors for each type of object. The prototype system was organized so that each type of object was assigned its own color index. Using the color editor, the designer pointed to an object, then used the mouse to slide on-screen bars corresponding to each of the three primary colors (red, blue, green) until the best color was found. The intensities of red, blue, and green for that object type were then noted for inclusion in the permanent data base.

Prototyping was also used to refine the interaction of the dialogue boxes. For example, MPS dialogue boxes provide the ability to "undo" the last action at two levels. At the broadest level, the user can cancel everything he has done since invoking the dialogue box by pressing the "abort" button in the dialogue box (such as in the center right of Figure 3). At a narrower level, the user can cancel entries for a particular object (such as a unit or train) by not pressing the "save" button (also see Figure 3) before moving on to the next object. Implicitly, then, while in a dialogue box there are two states: saved and not saved. The initial prototype did not visually indicate the state of the object being displayed, whether it was saved or not saved. Users who were interrupted by the telephone while using the dialogue boxes forgot what state they were in. It became obvious that a visual indication was necessary, and this was added (see the upper right corner of the dialogue box in Figure 3).

IMPLEMENTATION EXPERIENCE

MPS was installed and tested at CN during the winter of 1990–1991. One component of the testing was to compare the timeliness and accuracy of MPS information with that of the manual system, which continued to operate throughout the testing period.

Train and unit information was expected to become more timely due to the elimination of two existing time lags. First, there was a delay in the field between the actual time of an event and the time a clerk reported the event. This delay, which averaged several hours, would be eliminated at locations where REIS interrogators were installed. Second, there was a delay in the motive power center between the time information was received via COMTEL or telephone and the time the magnet board was updated to reflect this information. This delay, which also averaged several hours, would be eliminated entirely with MPS, regardless of how extensively REIS interrogators were installed in the field.

During the testing time period, only a handful of REIS interrogators were operational, so a significant impact from this improvement has yet to be measured. However, the improvement from eliminating the delay in posting information was immediate and dramatic. Motive power controllers who assisted in the testing were impressed with the improved timeliness of MPS, even though only one of the two sources of delay had been eliminated. The testing also revealed instances of trains and units that were missing from or incorrectly displayed on the magnet board, but were shown correctly in MPS.

A further test was conducted in which MPS was used manually, without benefit of its automatic information link to the field, to "shadow" the activities of a power controller. This test was conducted for two reasons: to make sure that all the functionality a power controller needed had been included in MPS, and to make sure that a power controller could keep up operation of the railroad in the event of a failure in MPS data links to the field. The test was successful in both cases. With the benefit of the field data links eliminating the work of updating the magnet board and the system of alerts to draw the controller's attention to work needing to be done, the controller's productivity is certain to increase over that of the manual system. The increased productivity can be used to reduce the number of simultaneous power controllers re-

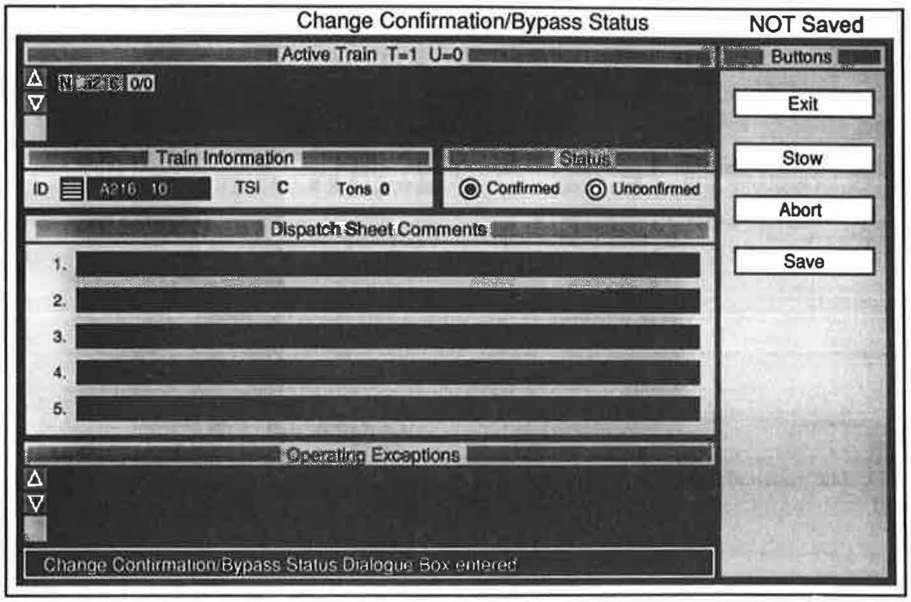

FIGURE 3 MPS dialogue box.

quired, to increase the amount of time and attention paid to motive power planning, or a combination of both.

CONCLUSIONS

The MPS testing period is just concluding as this is being written, so it is as yet impossible to measure quantitative improvements in locomotive utilization or one-time performance. However, based on what has been learned in design, development, and testing, the following conclusions can be drawn:

- Information on train and unit location and status is available several hours earlier in MPS than on the magnet board, even without benefit of automatic reporting technology.
- Automatic reporting technology results in information being made available a further several hours earlier, to the point where the motive power controllers know what happens in the field within a matter of seconds. This has been measured by CN at less than 1 min for those sites that were measured.
- The elimination of manual update tasks and use of MPS alerts to items needing attention will likely increase the productivity of the power controllers.

The new CN control center, including the MPS software, was dedicated on March 14, 1991, and is now operational.

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