Communications-Based Signaling (CBS) – Vital PTC
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Abstract: This paper describes a Positive Train Control system based on using new technologies to evolve proven signaling principles and safety-critical architectures to achieve the safety, cost and performance benefits of positive train control systems. In addition, it describes the process for developing interoperability manual parts through AREMA Committee 37.

There has been substantial interest in developing an interoperable communication-based train control system for decades. The initial effort started almost 25 years ago with the Advanced Train Control System (ATCS) efforts. Since then, these systems for freight railroads have been generally called Positive Train Control (PTC) systems. For clarity's sake, the Federal Railroad Administration (FRA) has defined PTC systems to include the following major characteristics:

- Prevent train-to-train collisions.

- Enforce speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders.

- Provide protection for roadway workers and their equipment operating under specific authorities

Various architectures have been suggested for Positive Train Control systems, from extremely large, complicated centralized systems to overlay systems used only to enforce the existing method of operation, such as verbally transmitted train orders. Most of these systems have focused on transmitting and enforcing train orders as generated by a dispatcher (manually or by use of a Computer-Aided Dispatch system) rather than looking at how existing signaling principles can be used to improve safety and efficiency.

CBS BEGINNINGS

The process of defining the CBS system began at the 2005 AREMA C&S show. During the roundtable discussions, a request was made by the railroads to define an interoperable radio-based cab signal system. This in turn was assigned to AREMA Committee 37 (Signal and Train Control systems). In order to proceed with this task, members of the committee who have existing processor-based signaling equipment in revenue service, and had expressed an interest in communication-based signaling concepts previously, met separately to determine if there was any hope in coming to an agreement on an

interoperable system based on the systems they currently have in the field or the drawing board.   The companies participating were Alstom Signaling (Atlas), General Electric Transportation Systems Global Signaling (ITCS - Incremental Train Control System), Safetran Systems (vTc -virtual Traffic control) and Union Switch and Signal (CAS - Collision Avoidance System). Somewhat surprisingly, all of the companies quickly agreed that it was in the best interests of the industry to develop interoperability standards based on the common system architecture we had independently arrived at.

Of the companies participating in the original meeting, GETS, Safetran and US&S agreed to proceed with the development of draft manual parts. These draft manual parts have now been presented to the full AREMA committee 37 membership for comment; and eventual approval.

CBS SYSTEM OPERATION

Before getting into the specific manual parts, it is useful to understand the system architecture and philosophy used in developing this system. In principle, a CBS system operates the same as a conventional cab signal system except for the following:

- Physical blocks (as determined by track circuits in conventional systems) are replaced with virtual blocks that are generally equivalent in length to track circuits in cTc territory.

- Communications via the rails is replaced with a digital data link

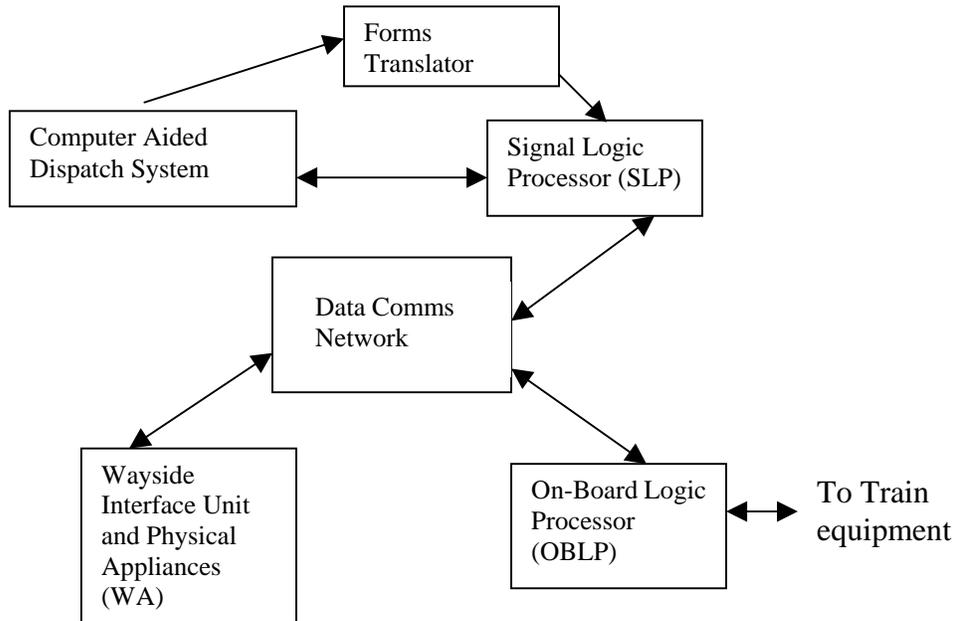- Train location is determined as an on-board function.

In a CBS system, instead of transmitting vital cab signal information through the rails, an RF communications data link is employed for this function.

The location of the locomotive is determined via the on-board location determination equipment. This location data is transmitted (in terms of a unique block identification ID and indicating either occupancy or un-occupancy of that unique track section) to a Signaling Logic Processor (SLP). The SLP determines the appropriate governing signal aspect for the track section the train is approaching and the 'cab signal, aspect for the track section currently occupied by the train's head-end; and transmits them to the appropriate locomotive. The SLP determines signal aspect information using the signaling principles defined elsewhere in the AREMA Manual. Switch positions (and other necessary wayside information) are also transmitted via the data communications network from the wayside to the Signaling Logic Processor. The onboard logic processor (OBLP) determines the limiting speed for the train based on the 'cab signal' aspect received from the SLP and the civil speed limits from the onboard database. Temporary speed restriction information is handled similarly to civil speeds. Wayside Interlocking control logic may be replaced with a Signaling Logic Processor located at a central location (or elsewhere if desired).

Since the number of possible signal aspects is not limited by the physical characteristics

of the track, it is possible to define a larger number of available aspects so that additional information can be conveyed to the engineman. This allows more flexibility in operation and better system throughput.

The following diagram shows the basics of a Communication Based Signaling System.

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                    ┌──────────────┐
                    │ Forms        │
          ┌────────▶│ Translator   │──────┐
          │         └──────────────┘      │
          │                               ▼
┌──────────────────┐           ┌──────────────────┐
│ Computer Aided   │◀─────────▶│ Signal Logic     │
│ Dispatch System  │           │ Processor (SLP)  │
└──────────────────┘           └──────────────────┘
                                         ▲
                    ┌──────────────┐     │
                    │ Data Comms   │◀────┘
              ┌────▶│ Network      │◀────┐
              │     └──────────────┘     │
              ▼                          │
┌──────────────────┐          ┌──────────────────┐
│ Wayside          │          │ On-Board Logic   │        To Train
│ Interface Unit   │          │ Processor        │◀──────▶ equipment
│ and Physical     │          │ (OBLP)           │
│ Appliances       │          └──────────────────┘
│ (WA)             │
└──────────────────┘
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In the communication-based system the dispatcher sends requests, via the computer-aided dispatch office system, to the SLP in order to control switches and set routes just as would be done in conventional cTc operation. The SLP acts on these requests if it is safe to do so, and sends indications to the Computer Aided Dispatch office system. These control and indication messages will be the same as existing control and indication messages used for conventional signal systems. The SLP sends control commands to the WA to position and lock switches and/or receives switch position information. The OBLP reports the train's location in terms of the blocks it is occupying. The SLP determines the governing signal aspect based on block occupancies, temporary speed restrictions, switch positions, other set routes and transmits it to the OBLP.   The OBLP determines the governing aspect for the block based on the data received via the data link and the civil speed data contained in the onboard database and displays the appropriate signal aspect and/or speed limit to the operator, who in turn controls the train appropriately and/or the OBLP determines overspeed and requests brakes when required. When actual wayside signals are present the SLP will provide the OBLP with the address of the signal in place of the signal aspect. The OBLP will then request the signal status directly from the signal and use the received signal to determine the limiting aspect/speed for the upcoming block.

The communication-based system can also allow the office dispatcher to install temporary speed limits that are then used to determine the appropriate signal aspects

CBS Subsystems

The following subsystems make up the CBS system. Each subsystem is responsible for the functions identified within its subsection.

1) Computer Aided Dispatch System

The office is the same as the cTc or Dispatcher office system currently in use providing a central command and control facility for management of traffic and work crews within the controlled territory. Specific functions and operations are railroad dependent. This allows current dark territory to be dispatched just as if it was cTc territory with the obvious safety and efficiency benefits (e.g following moves through a DTC or TWC block).

2) Form Translator

The Forms Translator converts specific railroad Forms data for functions such as temporary speed restrictions into commands that can be used by the SLP.

3) Signaling Logic Processor (SLP)

The signaling logic processor is responsible for the implementation of signaling principles. It calculates the appropriate signal aspect and/or speed limit for each virtual block, based on train position and travel direction, the position and travel direction of other trains, the defined authority limits, the position, status and location of switches, and any temporary speed restrictions.

The SLP is responsible for the following functions.

- Convert incoming messages (via the data communications network) from locomotives into appropriate block occupancy information within the SLP.

- Convert incoming messages (via the data communications network) from wayside interface units into appropriate switch position information within the SLP.

    - o   Note: Interim systems may have alternative methods of entering switch position (e.g. dispatcher input based on voice radio from locomotive).

- Execute Signal Logic Equations to determine governing signal aspects for all blocks within the territory.

- Convert signal aspect information into serial messages for transmission to appropriate locomotives for display.

  - o Note: Signal aspects are vitally associated with specific blocks. Since the Locomotive also vitally knows which block it is occupying, it is not a vital function to send the proper aspect to the proper locomotive.

- Respond to non-vital controls and provide non-vital indications to CAD system.

- Verifying locomotive contains the latest version of all critical databases.

- Interface to Forms Translator

Note: The SLP may be constructed from a group of local or remote processor units, each responsible for a geographic section of railroad. Each processor unit within the SLP will be responsible for data exchanges with its 'geographic' neighbors.

4) Wayside Appliances (WA)

The wayside appliances include signals, switches, track circuits, highway crossing controllers, defect detectors, and the equipment necessary to allow the appliances to interface to the communications links. The WA may include a wayside interface unit (WIU), which contains both the necessary control equipment and the necessary interface equipment for linking traditional signaling appliances to the communication-based system. The WA is responsible for the control of switches, and determining the status of switches, track circuits and actual signals

5) On Board Logic Processor (OBLP)

The on board logic processor is responsible for determining the train's current location, current speed, train integrity (if installed as a part of the system), direction of travel, and the train's allowed speed as defined by the civil speed limit contained in the onboard database, the aspect or speed limit received from the SLP or from local devices as instructed by the SLP. The OBLP also determines train overspeed, warns the operator and provides enforcement.

The OBLP is responsible for the following functions.

- o Maintain a topographical representation (infrastructure database) of all blocks in the territory, using the virtual blocks as the fundamental track elements.

o   Using information from a Location Determination System (LDS), identify block ID(s) of block currently occupied by train.

   ▪   LDS may be GPS based, transponder based or other. (Note: if based on transponders or other wayside equipment not supported by foreign roads, the locomotive may be required to operate as "Unequipped" on the foreign roads.)

o   Transmit Block Occupancy information to SLP.

o   Determine signal aspect and/or speed limit information received from SLP (after verifying that the received aspect is for the occupied block).

o   Determine the maximum allowed civil speed for the block being occupied by the lead end of the train and any civil speed restrictions ('look back') for any block occupied by the train.

o   Display the correct signal aspect and/or speed limit based on the civil restrictions and the signal aspect/speed information received from the SLP.

o   Provide overspeed protection, via request of brake application, of most restrictive speed limit.

o   Provide overrun protection for exceeding allowable signal aspect authority via request of brake application.

o   Provide self-testing function with an indication that self-testing has been successfully accomplished.

6) **Communication Links**

The CBS system may use any physical communications infrastructure that is suitable. Message protocol and structure are as defined in Manual Part CBS.4. The physical communication links are not vital. Vitality is maintained within the data messages.

For CBS, a decision was made to continue the use of ATCS addressing and protocols. The ATCS addressing perfectly fits the desired operation along with capitalizing on the existing ATCS addresses widely used in the industry today. The ATCS datagram was chosen as it supports the performance and safety needs of the system. The use of ATCS addressing and datagrams does not mandate the use of ATCS frequencies and radios. The datagrams can easily be sent as a payload through any type of system (e.g. IP based systems) that supports the needed system performance.

7) **Infrastructure Database**

The database defines the railroad infrastructure including; track circuits (actual or virtual), signal locations (actual or virtual), and switch locations. The database defines the linkages between the track circuits, signals and switches. It defines grades, civil speed limits, signal aspects, defect detector locations, highway crossing locations, etc. The database defines everything the CBS system needs to know about the fixed infrastructure

CBS MANUAL PARTS

The following manual parts have been drafted and are currently being reviewed by the full membership of committee 37. These manual parts will be assigned a new section within the AREMA C&S manual (probably section 23 although they are labeled as section "CBS" for now).

Section CBS.2

CBS.2.1 Recommended Functional Requirements of a CBS System.

This section defines the functional requirements for a Communication-Based Signaling (CBS) system, including safety-critical train protection functions and train operation functions. Systems may vary widely in complexity and not all functions are required for all systems.

CBS.2.2 Recommended RAMS, Environmental and Other Requirements for Signaling Systems Using CBS Architecture.

This manual part defines the recommended reliability, availability, maintainability, safety, environmental, electromagnetic compatibility, and quality assurance requirements for the CBS system.

For the CBS system, there is no difference recognized between a safety-critical system and a vital system as others attempt to do. In both cases, you have to analyze the functions and make sure that any credible failures (and secondary failures) maintain a safe state. Basic subsystems will be built on platforms already in use to accomplish vital functions (e.g. interlocking controllers, onboard controllers, etc.). Use of signaling philosophy and existing platforms provide a substantial advantage in verifying the safety of the system.

Section CBS.3

CBS.3.1 Recommended Design Guidelines for a CBS System

This manual part defines the system architecture and the interfaces for a system design based on conventional signaling principles as needed to meet the functional requirements specified in Section CBS.2.1

Section CBS.4

CBS.4.1 Recommended Communications Protocols for a CBS system

This manual part defines the recommended system communication protocols (i.e. what language you use to speak to each other). As noted earlier, use of ATCS protocols and addressing is recommended to meet the safety and performance requirements, as well as to leverage the large amount of existing addressing schemes currently in use and the ATCS protocol expertise. These addresses and protocols can be used over any type of communication systems, not necessarily an ATCS radio system. Given the rate of change in communication technology, this approach allows use of any desired communication framework, while maintaining the interoperability and safety requirements.

CBS.4.2 Recommended Communications Messages for a CBS System

This manual part defines the recommended system messages (i.e. what information are you communicating between users) used between subsystems of the CBS system. Detailed message contents are included within the manual part. Samples of the messages defined include

- Train Location / Database Revision / Temporary Speed Restriction Information

- Governing Aspect / Switch Position

- Temporary Speed Restriction List

- Switch Position

Section CBS.5

CBS.5.1 Recommended Onboard Database Guidelines for a CBS system

This manual part defines the structure and content of the onboard database to facilitate interoperability. It includes the naming structure for each track section, switch, signal, etc based upon ATCS addressing techniques.

BENEFITS OF CBS

The following points address many of the benefits of CBS and should be self-evident. Among the benefits, some of the major ones to keep in mind are

1. Use of signaling principles allows each railroad to control their own operations according to their own desires, as the application logic is programmed by the railroad over which the train is operating. There is no need for all railroads throughout the country to maintain common operating rules (other than clear definitions of what the signal aspects transmitted by the CBS system mean).

2. Use of signaling principles and currently accepted safety-critical (vital) processing techniques should improve the ability for regulatory acceptance of the system.

3. Use of signaling principles and accepted vital processing techniques allows the underlying method of operation to be changed, thus reducing the cost of maintaining both current and overlay systems. As the system becomes accepted, it should be possible to remove much of existing signal equipment as it becomes life-expired.

4. Use of signaling principles and current (conventional) cTc dispatching techniques allows common train control operations across each railroad's entire territory, regardless of train operating density.

5. Costs of the CBS system will be comparable to other overlay systems, even with the additional benefits provided

With the above major features in mind, the following is a checklist of general benefits that are provided by a CBS system.

Enhanced Safety Features

- Continuous overspeed protection
- Safe movement of trains throughout the territory
- Route protection based on signaling principles
- Vital monitoring of all wayside appliances
- In-cab display reduces wayside signal reliance due to weather, etc
- Secure communication between different subsystems
- Reduced train collisions
- Protection of roadway workers
- Reduces human error from movement authorities / train orders / track warrants
- Incorporate other wayside elements into signal protection system

Reduced System Costs

- Cost-effective upgrade of currently non-signaled territory to radio-based cTc operation.
- Cost-effective upgrade of wayside signal systems to onboard displays with enforcement.

Reduce Labor to Operate

- In-cab display of aspect-based authority reduces crew workload
- cTc type dispatching techniques used everywhere reduce dispatcher workload
- Consistent method of train operation consistent across all territories reduces training requirements

Reduced Labor to Maintain and Test

- Reduced wayside equipment as compared to conventional cTc territory.
- Improved reliability and availability
- Ability to make changes and simulate/test from central location
- Remote monitoring and testing easier to incorporate within communication-based system.
- Deterministic Testing (predictable, consistent responses to inputs)
- Use of existing concepts reduces training for troubleshooting and maintenance.

Reduced Installation cost

- Less wayside equipment as opposed to conventional cTc

- Can be installed incrementally
  - Operational enhancements easily added to safety-critical protection system
- Use of existing signaling principles reduces rule changes and training impact

Interoperability
- Industry association defined and maintained
- Defines interfaces between equipment and basic system architecture, not form or fit.
- Developed jointly by multiple suppliers, consultants, users and regulatory representatives through Industry committee
- Availability from multiple suppliers
- Open Interface – no barriers to entry
- Based on existing open ATCS protocols (upper layers, not physical or network specific)
- Open system with multiple users leads to stable operation and increased functionality
- Maintains cost competition from multiple suppliers
- EACH RR MAINTAINS THEIR OWN OPERATING PRINCIPLES THROUGH APPLICATION LOGIC DESIGN

Regulatory Acceptance

- Ability to qualify under 49CFR part 236, including subpart H
  - Based on proven and accepted signaling principles
  - Based on proven and accepted safety-critical platforms
  - Use of existing principles reduces human factor issues
- Builds on existing knowledge base of S&C employees
- Familiarity of concepts

Integration with Existing Systems

- Use of existing principles allows easier integration
- Simplifies overlay on signaled systems
- Easily interfaces with existing control offices through conventional controls / indications
- ATCS protocols simplify integration with existing communication systems.
- Interoperability AREMA manual parts simplify integration with multiple suppliers components.

Growth Path for Added Functionality

- Initially provide protection system, add operational enhancements as needed.
- Add blocks, signals and number of aspects as needed for increased capacity without adding infrastructure
- Add wayside elements (e.g. slide fences, portals) into signal system.

Migration path
- Convert dark territory to cTc operation
- Convert wayside signals to virtual signals
- Use of existing proven techniques may allow eventual replacement of existing signaling when life expired
    - Assumes any potential rail integrity issues solved or addressed with other techniques

Applicable over a variety of rail transportation modes
- Can be used for freight, commuter, passenger, light rail
- Supports mixed traffic at varying speeds (e.g. high speed passenger and lower-speed freight)
- Larger base leads to lower equipment costs for customers

NEXT STEPS

Independent of AREMA, funding is being sought from the Federal Railroad Administration through the Railroad Research Fund (administered by the AAR) for a lab demonstration. This demonstration will verify the interoperability manual parts (and any recommendations will be fed back through AREMA committee 37 for inclusion in the manual parts) as well as demonstrate system operation so that the benefits discussed above can be clearly seen.