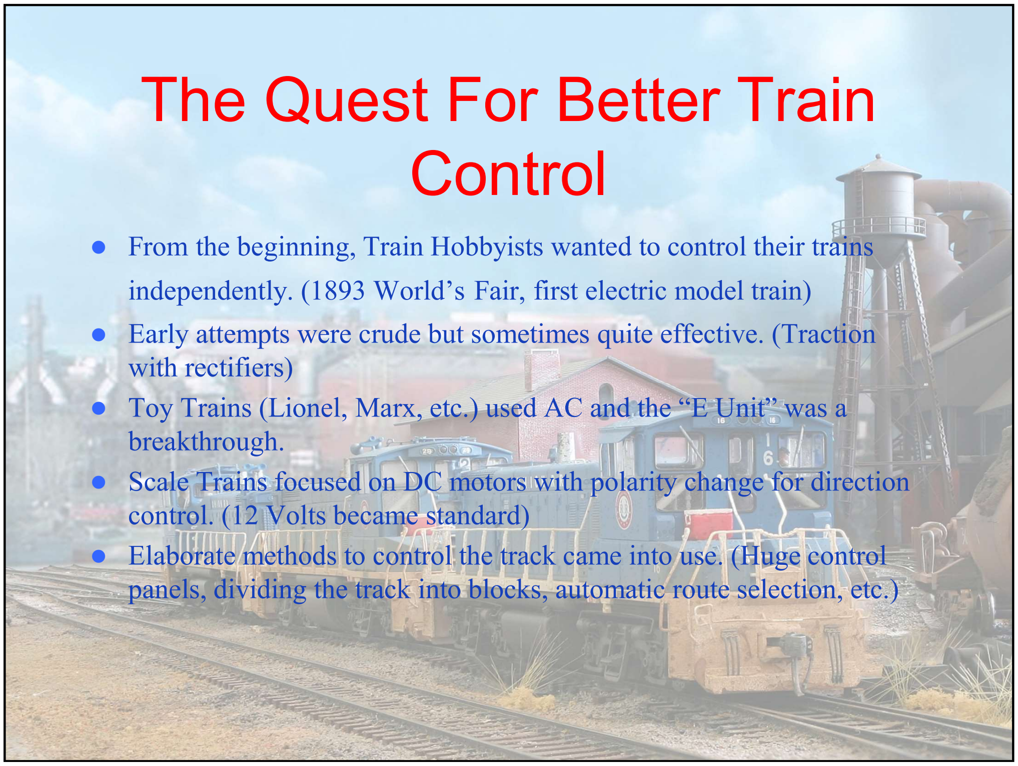
From the earliest days of model railroading, hobbyists have sought methods to improve the operation and control of their trains. Much of what we take for granted today was the work of many dedicated individuals who sought to develop common methodologies which would allow reliable operation of multiple trains from a variety of manufacturers.

Decisions had to be made regarding subjects that we now consider trivial: What voltage should we use? Should the motors be AC or DC? Should we use three rails or two rails? How do you control a reverse loop? Without the early work to get agreement (eg. Standards) the ability to intermix equipment from a variety of manufacturers might never have occurred.

Today we are fortunate to have an NMRA standard for control that continues to improve and evolve. Take a moment to thank the dedicated people at the NMRA that make this happen.

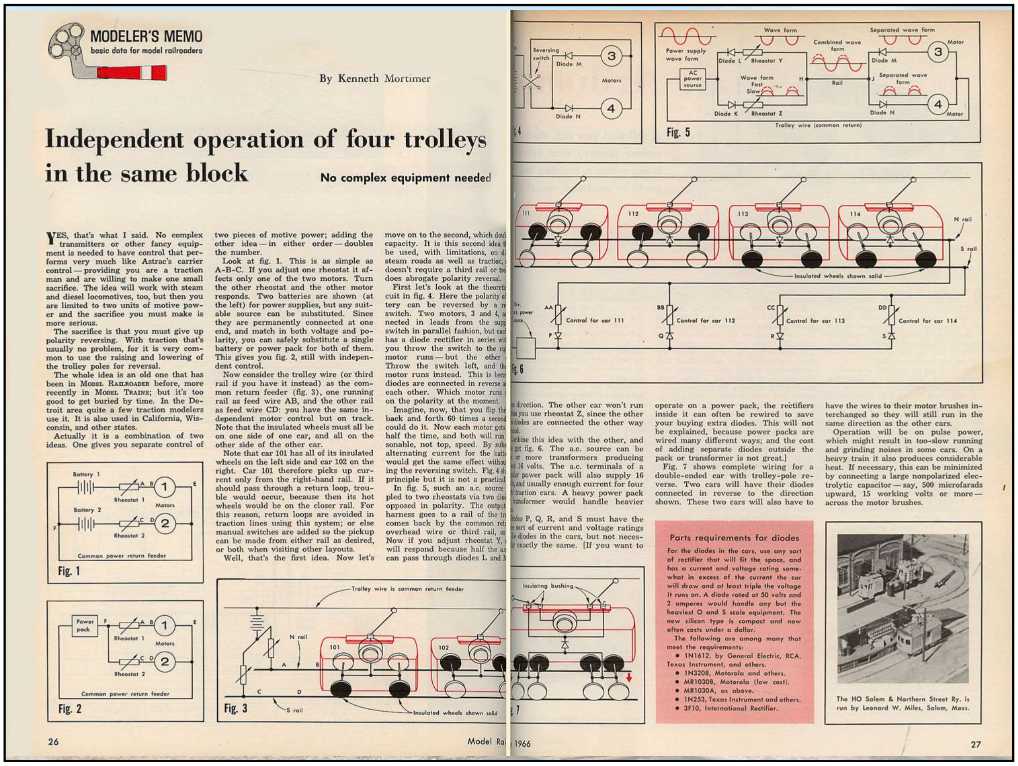


In 1893 an electric train model was demonstrated the World's Fair. This was intended to thrill and impress the attendees, with the hope that they would see the possibilities of full size electric trains. Little did they know that at the same time they were promoting electric railways they were sowing the seeds for a new hobby1

Some of the earliest attempts to independently control were surprisingly effective. Traction modelers used small Selenium rectifiers and the overhead wire (3^{rd} rail) to control up to four trolleys independently.

Early toy trains incorporated a little lever protruding through the top of the model which could be used to switch the field winding therefore allowing direction control. Awkward at best, this manual operation was replaced with the invention of the "E Unit". This was an electromechanical sequencer that allowed the operator to change direction remotely by going through a sequence of forward-stop-reverse-stop-forward. This was a breakthrough!

The Scale train enthusiasts opted for DC control. This eliminated the need for the third rail, but added to the control complexity of the railroad., eg. most notably reverse loops.



MODELER'S MEMO
basic data for model railroaders

By Kenneth Mortimer

Independent operation of four trolleys in the same block

No complex equipment needed

YES, that's what I said. No complex transmitters or other fancy equipment is needed to have control that performs very much like Astrac's carrier control — providing you are a traction man and are willing to make one small sacrifice. The idea will work with steam and diesel locomotives, too, but then you are limited to two units of motive power and the sacrifice you must make is more serious.

The sacrifice is that you must give up polarity reversing. With traction that's usually no problem, for it is very common to use the raising and lowering of the trolley poles for reversal.

The whole idea is an old one that has been in MODEL RAILROADER before, more recently in MODEL TRAINS; but it's too good to get buried by time. In the Detroit area quite a few traction modelers use it. It is also used in California, Wisconsin, and other states.

Actually it is a combination of two ideas. One gives you separate control of two pieces of motive power; adding the other idea — in either order — doubles the number.

Look at fig. 1. This is as simple as A-B-C. If you adjust one rheostat it affects only one of the two motors. Turn the other rheostat and the other motor responds. Two batteries are shown (at the left) for power supplies, but any suitable source can be substituted. Since they are permanently connected at one end, and match in both voltage and polarity, you can safely substitute a single battery or power pack for both of them. This gives you fig. 2, still with independent control.

Now consider the trolley wire (or third rail if you have it instead) as the common return feeder (fig. 3), one running rail as feed wire AB, and the other rail as feed wire CD: you have the same independent motor control but on track. Note that the insulated wheels must all be on one side of one car, and all on the other side of the other car.

Note that car 101 has all of its insulated wheels on the left side and car 102 on the right. Car 101 therefore picks up current only from the right-hand rail. If it should pass through a return loop, trouble would occur, because then its hot wheels would be on the closer rail. For this reason, return loops are avoided in traction lines using this system; or else manual switches are added so the pickup can be made from either rail as desired, or both when visiting other layouts.

Well, that's the first idea. Now let's move on to the second, which dou[...] capacity. It is this second idea t[...] be used, with limitations, on di[...] steam roads as well as traction, [...] doesn't require a third rail or tro[...] does abrogate polarity reversal.

First let's look at the theoreti[...] cuit in fig. 4. Here the polarity of [...] tery can be reversed by a re[...] switch. Two motors, 3 and 4, ar[...] nected in leads from the supp[...] switch in parallel fashion, but eac[...] has a diode rectifier in series wi[...] you throw the switch to the rig[...] motor runs — but the other [...] Throw the switch left, and th[...] motor runs instead. This is beca[...] diodes are connected in reverse a[...] each other. Which motor runs [...] on the polarity at the moment.

Imagine, now, that you flip the [...] back and forth 60 times a second [...] could do it. Now each motor gets [...] half the time, and both will run [...] sonable, not top, speed. By subs[...] alternating current for the batt[...] would get the same effect withou[...] ing the reversing switch. Fig. 4 sh[...] principle but it is not a practical [...]

In fig. 5, such an a.c. source [...] pled to two rheostats via two dio[...] opposed in polarity. The output [...] harness goes to a rail of the tra[...] comes back by the common ret[...] overhead wire or third rail, as [...] Now if you adjust rheostat Y, [...] will respond because half the a.c. [...] can pass through diodes L and M [...] direction. The other car won't run [...] you use rheostat Z, since the other [...] diodes are connected the other way [...]

[...]ombine this idea with the other, and [...] get fig. 6. The a.c. source can be [...] or more transformers producing [...] 16 volts. The a.c. terminals of a [...] power pack will also supply 16 [...] and usually enough current for four [...] traction cars. A heavy power pack [...] transformer would handle heavier [...]

[...]iodes P, Q, R, and S must have the [...] sort of current and voltage ratings [...] diodes in the cars, but not neces[...] exactly the same. [If you want to operate on a power pack, the rectifiers inside it can often be rewired to save your buying extra diodes. This will not be explained, because power packs are wired many different ways; and the cost of adding separate diodes outside the pack or transformer is not great.]

Fig. 7 shows complete wiring for a double-ended car with trolley-pole reverse. Two cars will have their diodes connected in reverse to the direction shown. These two cars will also have to have the wires to their motor brushes interchanged so they will still run in the same direction as the other cars.

Operation will be on pulse power, which might result in too-slow running and grinding noises in some cars. On a heavy train it also produces considerable heat. If necessary, this can be minimized by connecting a large nonpolarized electrolytic capacitor — say, 500 microfarads upward, 15 working volts or more — across the motor brushes.

Parts requirements for diodes

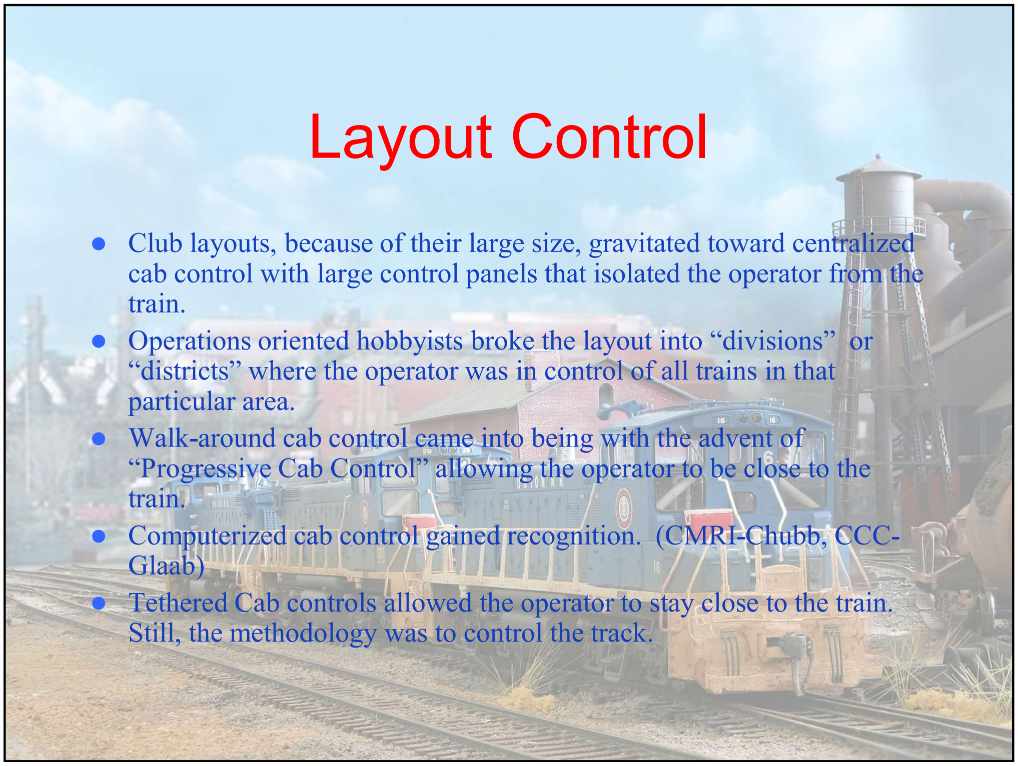
For the diodes in the cars, use any sort of rectifier that will fit the space, and has a current and voltage rating somewhat in excess of the current the car will draw and at least triple the voltage it runs on. A diode rated at 50 volts and 2 amperes would handle any but the heaviest O and S scale equipment. The new silicon type is compact and now often costs under a dollar.

The following are among many that meet the requirements:

- 1N1612, by General Electric, RCA, Texas Instrument, and others.
- 1N3208, Motorola and others.
- MR1030B, Motorola (low cost).
- MR1030A, as above.
- 1N253, Texas Instrument and others.
- 3F10, International Rectifier.

The HO Salem & Northern Street Ry. is run by Leonard W. Miles, Salem, Mass.

Various methods were devised to allow multiple engines or trolleys to be controlled independently on the same track, using analog signals. This article from 1966 describes such a scheme.



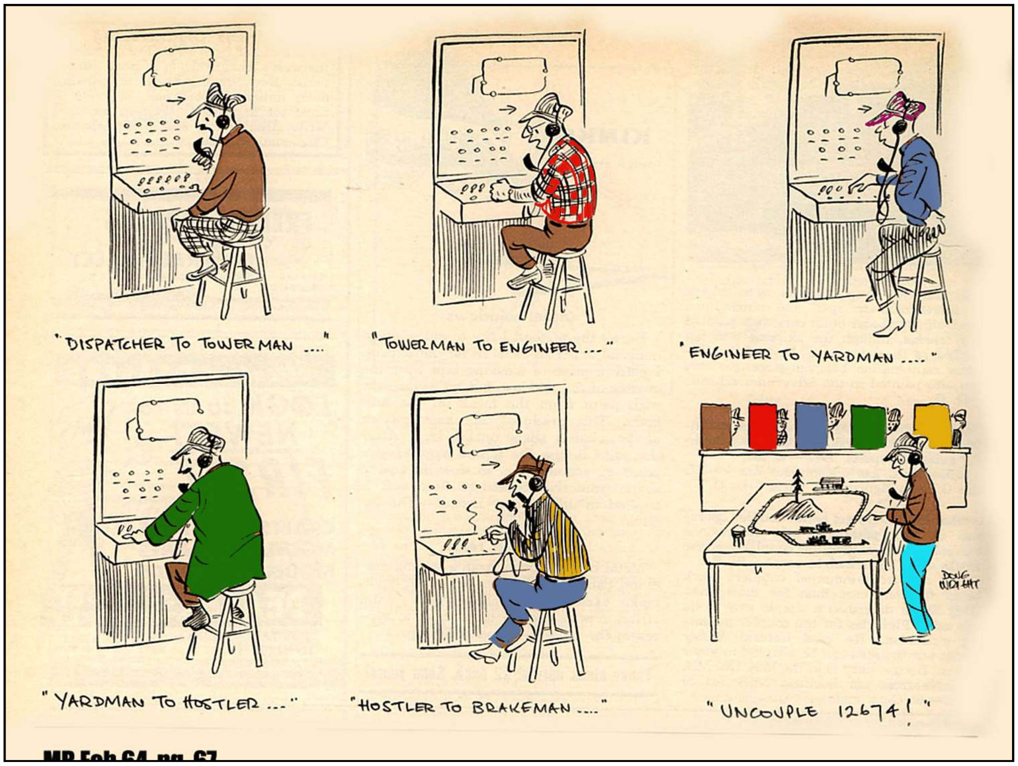
As layouts grew in size the problems with controlling multiple trains also grew. Club layouts, traditionally large, posed some of the greatest control problems and offered challenges to a larger number of hobbyists who could solve these problems working together.

The “Control Panel Era” was upon us! Several different concepts emerged. Some layouts gave control of all trains to an operator of a “district”. Other concepts duplicated the entire railroad schematically for every operator, with controls for turnouts and block power duplicated on every panel. Other concepts were hybrids of these methodologies ultimately evolving into dispatcher control which is still quite popular today.

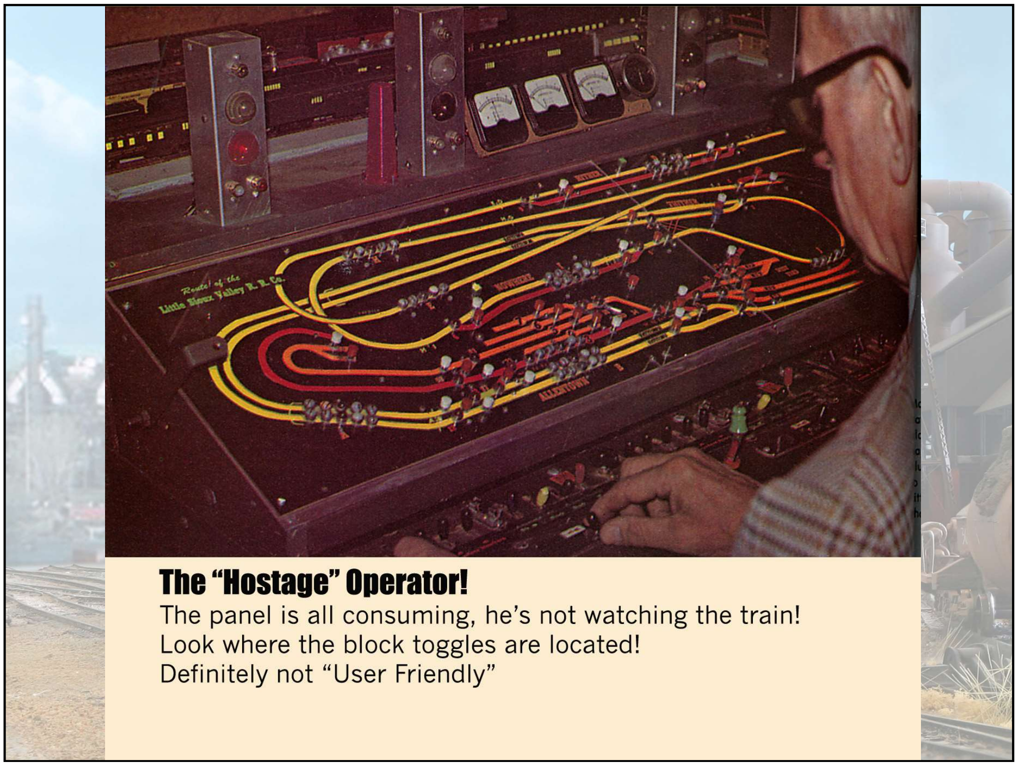
With the advent of semiconductor technology being applied, “Walk-Around” control came into popular use which allowed operators to stay close to their trains.

For a short while there were forays into “Compute Cab Control” which relieved the operator from the task of throwing electrical switches to route power. Better described as “Computer Power Routing”, this concept was short lived as the technology for independent train control began to emerge.

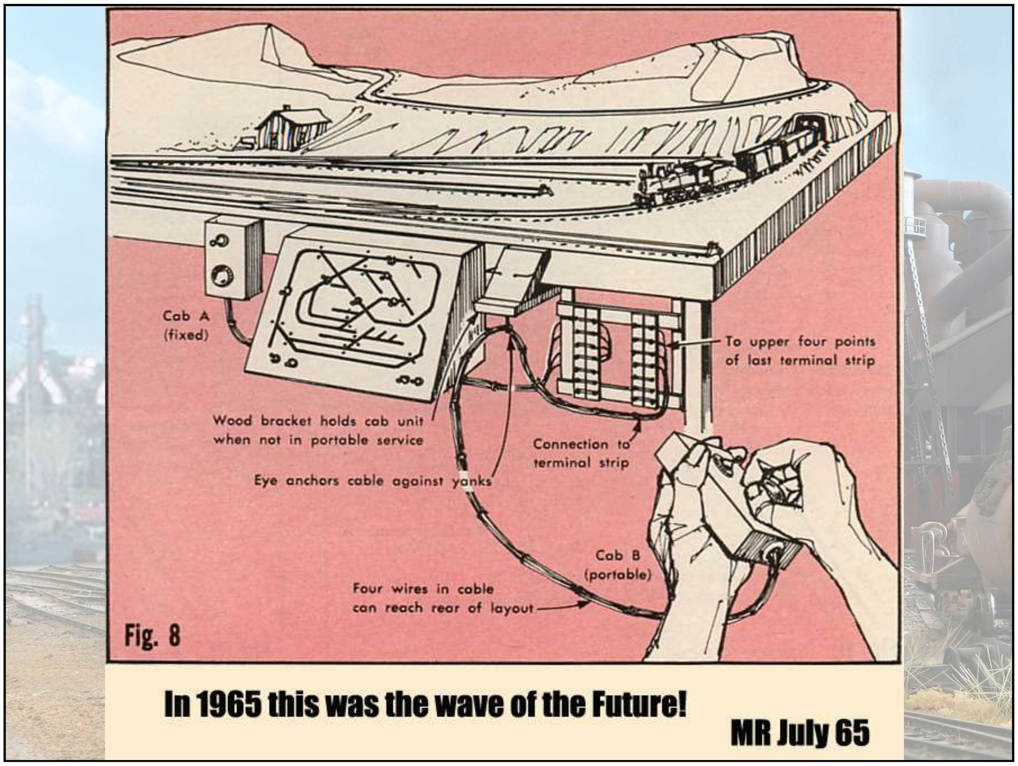
Elaborate panels located far from the actual model train became the norm for large layouts. Although experienced operators could operate the trains smoothly and realistically, the operator was far removed from the action.



Although highly satirical, this cartoon illustrates that in some cases, the control system was more important that the train layout!

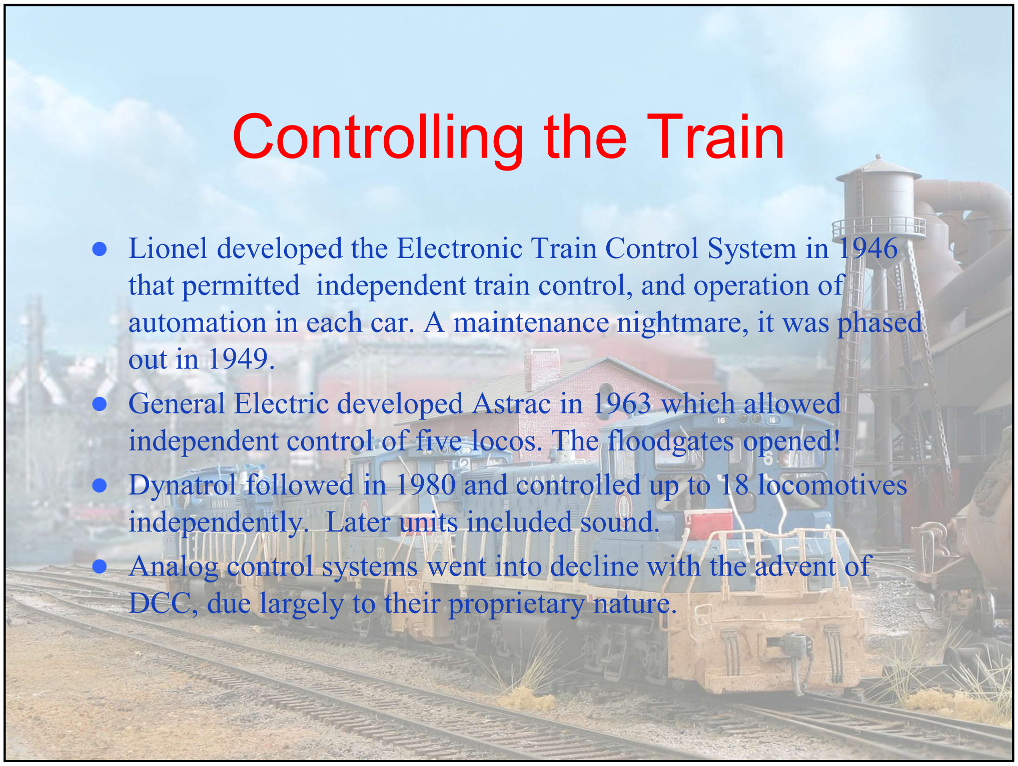


The ultimate evolution of the "Control Panel Era" is achieved when the operator spends so much energy and time operating the control panel that he no longer actually sees the train!



By 1965 , train control concepts were “beginning” to change from the traditional central panel oriented control to the walkaround throttle oriented operation. Note that only one throttle is tethered, the other was still firmly fixed next to the control panel.

This introduced a fundamental conceptual change in the way trains were operated – the operator no longer was in charge of the entire layout or all the trains running in a specific district – rather he/she was assigned to a particular train. This approach became popular in the United States, while the more traditional central panel control remains popular in other parts of the world.



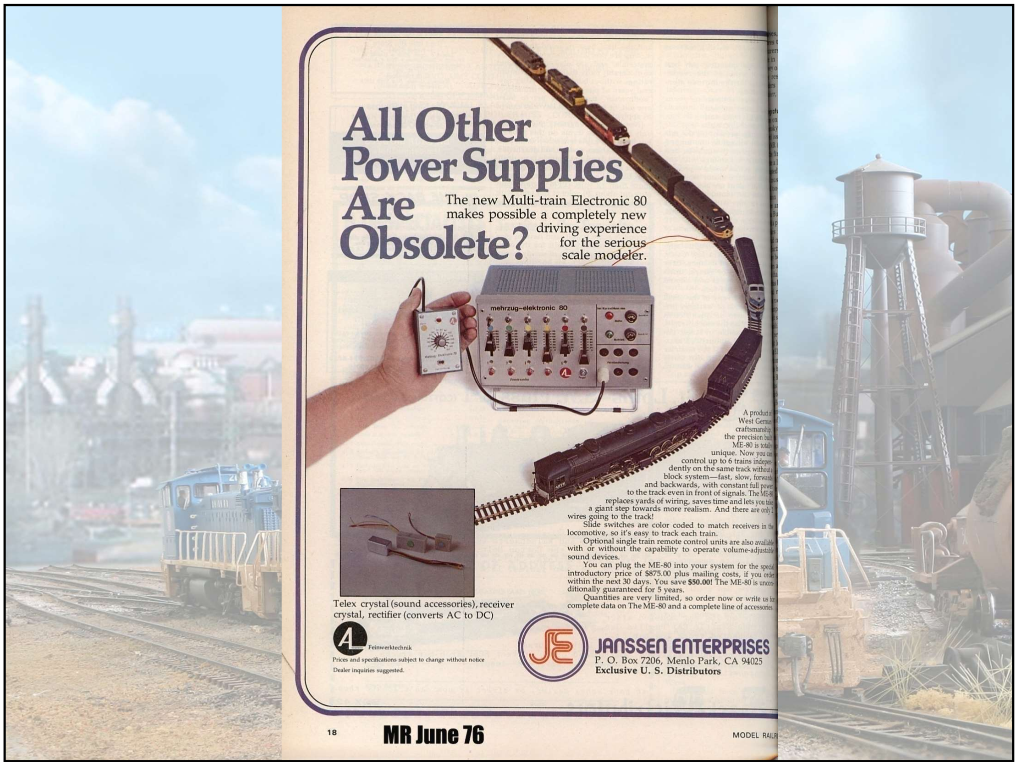
In 1946 Lionel pioneered independent train control. What in theory, appeared to be a real leap forward, was a disaster. Promoted as allowing the operator to independently control his train and uncouple each car independently proved to be impractical.

Lionel's methodology was basically a "tone-control" system which used electron tubes and frequency filters. The problem was that it was unstable.

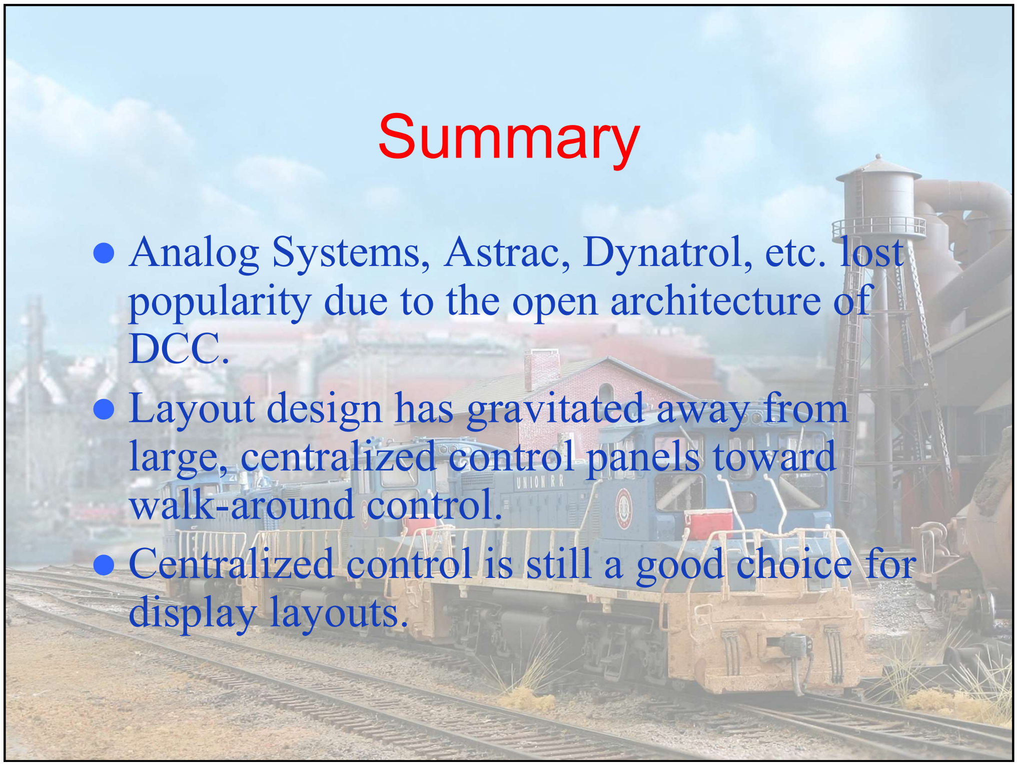
The oscillators generating the tones shifted with heat, and crosstalk caused serious frustration.

GE's Astrac (Automatic Simultaneous Train Control) was introduced in1963 and could independently control up to five trains simultaneously. This system demonstrated that independent control of each train was possible and affordable.

Dynatrol and other Analog systems improved and expanded the capabilities of analog control but were limited by their proprietary nature and were soon to be surpassed by a variety of digital systems which ultimately let to the open source DCC system.



In spite of advertising and promotion some systems failed to gain acceptance. Have you ever seen or used one of these systems? It is an example of a "future product" ad that never made it to become a viable commercial product.



Some analog systems are still supported by their manufacturers, but virtually all are out of production.

The large centralized control panel has largely given way to walk around control. No longer is the engineer removed from his train. By being close to the train switching operations are easier, and the engineer can actually see the scenery up close. (This may be good or bad.)

For some systems, primarily layouts used as commercial displays, analog still has advantages. The Pacific Fast Mail sound system is still the best sounding train control system. No DCC whistle can compare to it.

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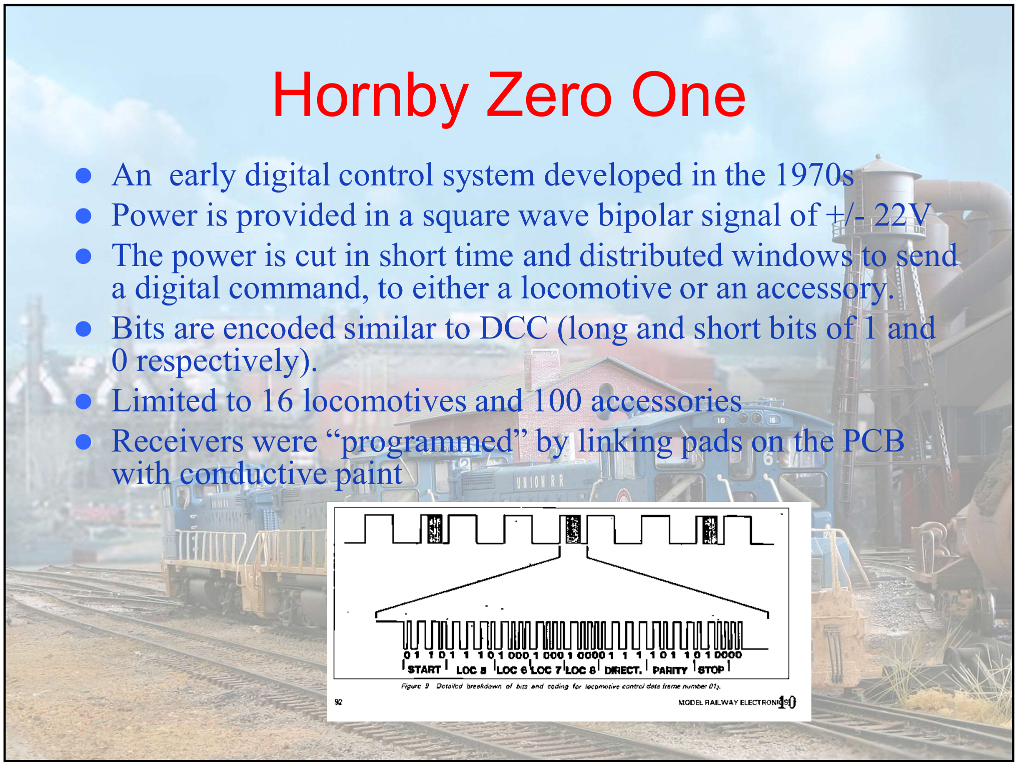
The second part of the clinic “The Quest for Better Train Control” discusses the history and evolution of Digital Train Control.

Digital train control evolved along with developments in the electronics industry and the adoption of digital systems, computers and microcontrollers. The ultimate goal was to improve the control experience, simplify system design, improve supportability and maintainability of the products, and make the system more robust.

Early attempts of digital train control started appearing in the early 1970s, following the evolution of digital systems. Early systems were based on discrete components and “glue logic” rather than microprocessors, microcontrollers or computers. As a result, the design flexibility of these systems was limited by what the electronics industry had to offer.

In reviewing the progression of digital train control systems, it is noticeable that early systems were partially analog in nature. Analog elements such as pulse width and amplitude were used in those systems for lack of a better control mechanism, and due to performance limitations. As digital technology sophistication increased, with higher available transmission rates, train control systems became fully digital.

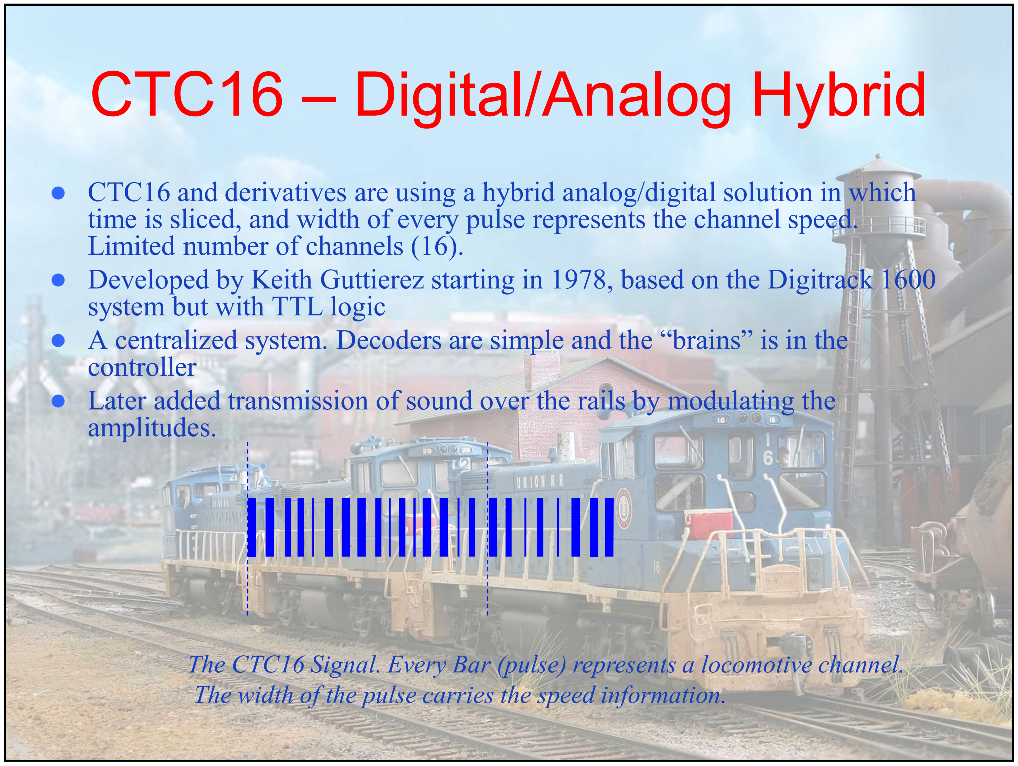
The proliferation of systems and protocols, while creating customer “forced loyalty” and binding them to a single manufacturer, created an interoperability problem. It was virtually impossible to operate one manufacturer’s equipment along with another’s on the same layout. A major milestone in the development of digital train control systems was the introduction and acceptance of NMRA DCC as a set of standards and recommended practices in 1993. While a few major manufacturers continued to develop their proprietary protocols, DCC took its place as an industry standard with the majority of manufacturers adopting it.



One of the early adopters of digital technology was Hornby of the UK, with the Zero One system. This system was developed in the early 1970s and was an early attempt to combine a power signal with a digital transmission. In order to achieve that, the command station cuts power to the rails at a predefined short time window, used to transmit a short burst of data.

Power was delivered as a square 22V bipolar signal, to allow travel in both directions. As control data transmission was confined to a short window, the bandwidth was limited to controlling 16 locomotives. The limit on accessories was more lenient – 100, as they typically do not require frequent command repetitions to be sent. It is interesting to notice that the NMRA DCC bidirectional specification uses a similar technique of cutting power to the rails for a window that allows locomotives to transmit data back to the command station. Time synchronization with the locomotives is more complicated in DCC than in the Zero One protocol.

Technology limitations did not allow a sophisticated receiver programming and configuration mechanism, similar to the one offered by DCC. Receivers were configured by soldering links to pads or conductive paint links on the PCB.



Another example of an early digital control system is CTC16 which was developed by Keith Guttierez starting in 1978. Keith is a former engineer of Texas Instruments and now owns CVP industries, a manufacturer of DCC systems. Several versions of CTC16 were introduced and gained wide popularity among modelers – especially following 2 series of articles in “Model Railroader” magazine that described the construction of the system as a DIY project.

CTC16 is based on an earlier system, “Digitrack 1600”, that was developed using discrete components. CTC16 is more compact as it was developed using digital integrated circuits (“glue logic”).

As one of the early systems, CTC16 is a good example of a hybrid analog/digital solution. It uses time slices to control up to 16 locomotives. The 16 channels are controlled by a series of 16 pulses – pulse width conveys the locomotive speed. Most of the smarts are located in the controller and receivers are simple and relatively small. In later versions of CTC16, sound transmission was added by modulating the amplitude of the pulses.

Selectrix was developed in 1982 in Europe by Döhler and Haas for TRIX (the DC branch of Märklin). In 1999 it was adopted as a NEM standard by MOROP, and became publicly known.

Although a relatively old system, it is still popular primarily in Europe. Selectrix uses proprietary hardware and this allows integration of most desired functions into a single IC, keeping decoder sizes (in general) smaller than DCC decoders. The transmission rate is higher than DCC as well. Due to the small number of implementation and dedicated hardware, compatibility and interoperability of Selectrix components is guaranteed. Despite the above, components are relatively expensive as royalties have to be paid to producers of the specialized hardware, and product selection is limited to a small subset of German manufacturers.

The German train manufacturer Märklin has introduced its digital track protocol in 1983. Based on a set of integrated circuits from Motorola, that were designed for remote control applications (ex. TV remote control) these gave reasonable performance for the early days of train control.

In order to support accessory control using the same IC base, the developers halved the transmission rate, thereby creating two independent channels. The Märklin – Motorola system could control up to 80 locomotives. Decoders had to be rated for high voltage to be compatible with pulses of >30V used in Märklin's AC analog system to change the direction of travel.

The protocol used “trinary logic” in which every pair of bits represented a value of 0 (00), 1 (11) or 2 (10) and where a (01) sequence indicated an error. This trinary system was used for addressing locomotives. The command bit pairs (speed or function control) were always binary (00 or 11). For additional reliability every message was repeated twice. Effectively on the wire a message would always consist of 18 binary pulses, and polarity was significant for correct detection. This represented no problem with Märklin’s 3-rail track, but was not very suitable for 2-rail operation.

Decoder size was dictated by the space reserved for the direction control relay in analog Märklin engines, which was guaranteed to be available. Several systems spawned off of the Märklin system by the company itself (Delta for starter systems, Motorola ver. 2 and later mfx). Other compatible systems evolved as DIY projects, such as the EDITS system by “Elektor” magazine.

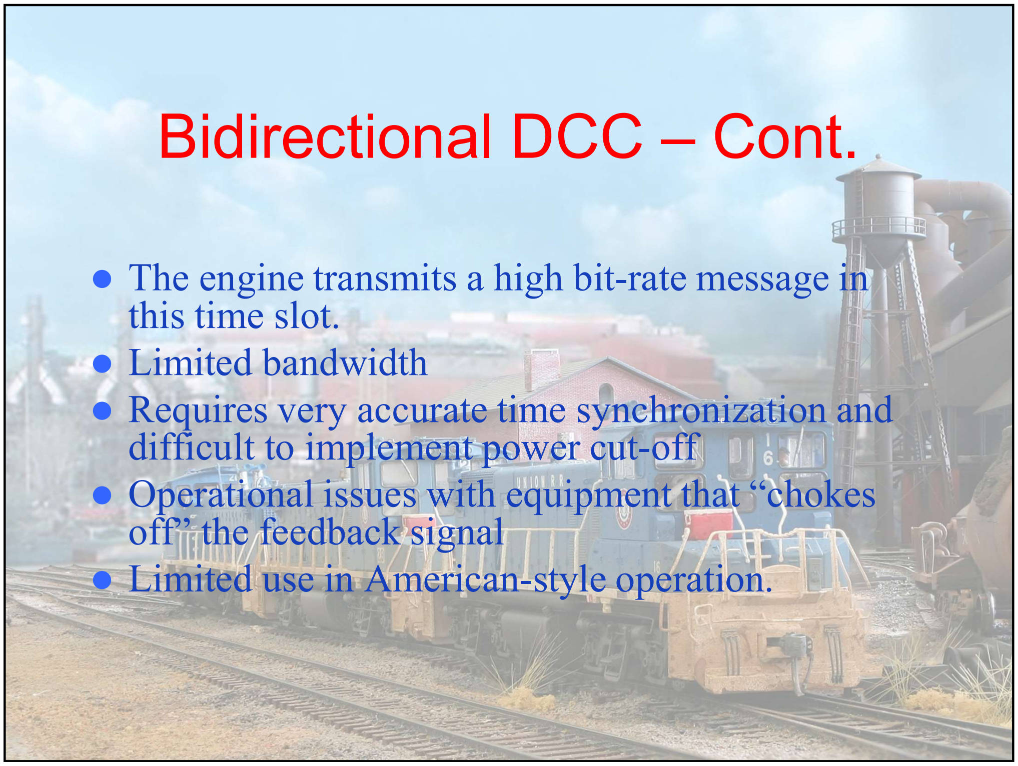
Bernd Lenz, whose company “Lenz GMBH” formerly designed for Märklin, developed around 1988 a protocol suitable for 2-rail systems that was polarity-independent and noise immune. Initially targeted for Arnold N-scale systems,The protocol was proposed as an NMRA standard free of any patent claims, accepted and ratified in 1993. The S9 standard and RP9x include the specifications for this protocol, known as NMRA DCC.

DCC is the most widely accepted world-wide standard for train control. Apart from technical innovations that were introduced with DCC, such as the ability to program decoder configurations, it is not controlled by any specific manufacturer and is accepted as a baseline standard.

DCC is accompanied by conformance tests, providing the modeler a level of assurance that conformant products can interoperate with other DCC conformant products, regardless of the producer. As a result of its wide acceptance modelers can enjoy a large number of product offerings, from stand alone decoders and those embedded in engines, to command stations, power boosters, accessory control units and occupancy detectors. In recent years sound decoders have been proliferating, adding to the experience and enjoyment of their owners. As more and more features are introduced to the market, more problems are found – including incompatibilities and ambiguities in the standards which are continuously worked on by NMRA and participating manufacturers.

NMRA DCC was originally designed as a one-way power and control protocol where the command station sends packets over the rails to engines and accessory controllers, and simultaneously powers the rails. In the European market, there was a demand to add the capability for an engine to transmit data back to the command station and further to other attached control systems.

The European style of operation, unlike the style mostly used in the USA, is based on central control of multiple trains – either of the entire layout or in a district. Every operator is responsible for multiple trains and passes them through the districts. Signaling systems are used with strict regulations, and it is vital that a train can be stopped directly in front of a red signal. In order to accurately locate the train, the engine can transmit some data back to the command station between every pair of regular DCC packets in a well defined time "window". An added benefit is that engines can be immediately identified when they are set on the rails.



Considering DCC is a power bus as well as a data bus, in order to allow the decoder to generate a signal on the rails, power from the command station has to be cut off for a brief period. Very accurate synchronization of the cut-off window and the transmission by the decoder is required for this to work. This system was patented and named "RailCom" by Lenz and Zimo, and supported by a few manufacturers. Other methods that were investigated were modulation of high frequency signals over DCC.

Every method proposed so far has introduced some problems, and comes with its own set of restrictions. RailCom requires that no rolling stock or accessories connected to the rails load the rails with current during the BiDirectional transmission, power-off window. Frequency modulation requires that no high capacitance load is connected to the rails, since such capacitance dampens the signal and interferes with its detection. Unfortunately, old MR equipment, not designed for BiDirectional DCC operation, tends to cause more interference (examples are locomotives with open frame motors, presenting high power load and generating high electromagnetic noise). In order for Bidirectional DCC to work, such equipment should be either modified or removed from the rails.

The evolution of digital train control systems is closely tied to advances in microelectronics and the proliferation of microcontrolles (single chip computers).

Early systems were hybrid, a combination of analog and digital components and were constructed from dedicated ICs and “glue logic” componenets. Later systems utilized programmable devices, primarily microcontrollers.

Design approaches included centralized systems in which most of the “brains” and logic was concentrated in the “master” control unit. This lead to high load of these units and limited bandwidth for operation – a limited number of engines could be controlled. Decentralized design mandated more sophisticated receivers (decoders) which used microcontroller technology, but performed better.

A major step in the evolution of Digital Train Control was the endorsement of DCC as an NMRA standard and its wide acceptance in the market. Modelers were finally assured to a reasonable degree that products from different manufacturers can interoperate in the same layout. While there is always room for improvement, a unified protocol brings value to the consumers and promotes innovation. Emerging enhancements to DCC include bidirectional transmission which can potentially simplify the user experience and allow for more features in operation. It requires more R&D in order to increase its reliability and viability as a widely accepted technology.

The DCC developer community continues to propose enhancements and improvements to the standard. Several initiatives are attempts to standardize the control bus protocol – which is used to connect throttles, panels, sensors and signals - in a similar way to the track protocol. A major obstacle here is the competition among vendors and market presence of their proprietary solutions.

Decoders are enhanced with more features and reduced size, one key feature being improved sound capabilities. Sound decoders are becoming a de-facto standard and expected by many modelers.

Command stations are beginning to embed PC technology (PDA or single board PCs) and full operating systems such as Windows and Linux. This allows modelers a rich experience in controlling trains, including GUI displays, touchpad controls and interfaces to the network and the Internet.

Improved protocols for train location and signaling continue to be developed.

All the above initiatives are driven by market demand for improved standardization and interoperability of products – and this boils down to each and every consumer. The more demand there is for products to be conformant to the standard, the more manufacturers would be driven to follow the standards and make the extra investments necessary in testing and correction of problems. This is especially important during difficult economic times.

please support the DCC standard by asking for conformant DCC products!

Thank You!