NMRA Standard	
Layout Command Control™ (LCC) **Train Control Protocol**	
July 22, 2024	**S-9.7.4.6**

Adopted as a NMRA Standard

The OpenLCB Standard document appended to this cover sheet has been formally adopted as a NMRA Standard by the NMRA Board of Directors on the date shown in the *Adopted* column in the *Version History* table below.

Version History

Date	Adopted	Summary of Changes
July 22, 2024		Initial version submitted for public comment

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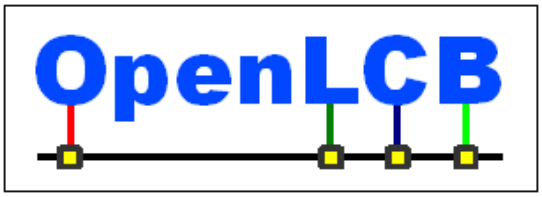

OpenLCB Standard	
Train Control protocol	
July 22, 2024	Adopted

1 Introduction (Informative)

This Standard covers the Train Control protocol, the way that OpenLCB handles moving objects such as locomotives, engines, and other rolling stock.

2 Intended Use (Informative)

The Train Control protocol covers the interaction between one (or more) Throttles and one or more Trains, as this interaction is represented on the OpenLCB bus. There can be more than one Throttles controlling a single Train, and more than one Trains being controlled by a single Throttle (also called consisting). The Throttle, as a Node on the OpenLCB bus, may be either a physical throttle, or a Gateway converting messages of a different throttle protocol to OpenLCB. The Train is also represented as a Node on the OpenLCB bus; this may be a physical decoder present in a locomotive and capable of participating in the OpenLCB network (presumably via wireless communication), or it may be a Gateway device translating the OpenLCB Train Control protocol to some other method of controlling trains. The most important example of such other method is the DCC track protocol, in which case the Gateway device is commonly referred to as a DCC Command Station.

3 References and Context (Normative)

For more information on format and presentation, see:

- OpenLCB Common Information Technical Note.

For information on OpenLCB message transport and OpenLCB communications, see:

- OpenLCB Message Network Standard.

A Node implementing the Train Control protocol must implement:

- OpenLCB Event Transport Standard;
- OpenLCB Simple Node Information Protocol Standard.

The following protocols are strongly recommended to be implemented by any Train node:

- OpenLCB Memory Configuration Standard and Datagram Protocol it depends on;
- OpenLCB Configuration Description Information Standard;
- OpenLCB Function Description Information Standard;
- OpenLCB Train Search Protocol.

Float-16 is the half-precision numeric format defined by IEEE 754-2008. This is the format that the GNU toolchain's -mfp16-format=ieee flag and __fp16 type makes available on some CPU types.

3.1 Terminology

The following Nodes participate in the interactions presented in this Standard:

- **Train Node**: A Train is represented by a single, specific Node. To control that specific Train, OpenLCB messages are sent addressed to that Node. It is not a requirement that the hardware operating the given Train Node be mechanically installed in the specific Train.
- **Throttle Node**: An OpenLCB Node controlling one or more Train Nodes using the Train Control protocol. It is not a requirement that the hardware operating the Throttle Node be mechanically installed into the physical throttle that the operator is using. A single OpenLCB Node may have independent interactions with multiple Train Nodes, and thus represent more than one physical throttle.

The following additional concepts are used:

- **Train Control Operation:** The set of commands Set Speed, Emergency Stop and Set Function.
- **Controller**: A Train Node has zero or one Throttle Node assigned as the Controller. There is no requirement that the Train Node should accept Train Control Operations from the Controller only. A Throttle Node set as the Controller has to stay alive and connected to the OpenLCB bus, and the Train Node may periodically verify this as a safety check.
- **Listener**: A Throttle Node may be interested in receiving a copy of all state changing messages from a given Train Node. Since Throttle-to-Train configuration is addressed, there is no network-level mechanism to guarantee that messages destined to the Train Node can be intercepted by the interested third party. The Train Node therefore has a feature that allows other nodes to be registered, and the Train shall forward the speed (and optionally function) setting messages to the registered Listener nodes. A way to achieve consisting is to specify the consist members as listeners on the lead engine's train node, or to allocate a virtual node and specify all engines as listeners to that virtual node.

4 Message Formats (Normative)

4.1 Defined Event IDs

Is Train: 01.01.00.00.00.00.03.03

Emergency Stop All: 01.00.00.00.00.00.FF.FD

Clear Emergency Stop All: 01.00.00.00.00.00.FF.FC

Emergency Off All: 01.00.00.00.00.00.FF.FF

Clear Emergency Off All: 01.00.00.00.00.00.FF.FE

4.2 Defined Error Codes

Permanent error – source not permitted – not a controller: 0x1021.

Permanent error – not found: 0x1030.

Permanent error – already exists: 0x1032.

4.3 Train Control Command Message

MTI: Priority 1, index 15, modifier 3, addressed => MTI 0x05EB, CAN frame [195EBsss] fd dd

This message type and MTI is specific to train control. Bits 0-6 of the first byte of the content codes an instruction, which defines the rest of the format. See below for the definition of bit 7.

Instruction	Byte 0		Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8
	Bit 7	Bits 6-0								
Set Speed/Direction	P	0x00	Speed and direction as signed float16							
Set Function	P	0x01	Address			Value				
Emergency Stop	P	0x02								
Query Speeds	0	0x10								
Query Function	0	0x11	Address							
Controller Configuration	0	0x20	Assign Controller 0x01	Flags (Reserved)	Controller Node ID					
			Release Controller 0x02	Flags (Reserved)	Controller Node ID					
			Query Controller 0x03							
			Controller Changing Notify 0x04	Flags (Reserved)	New Requesting Controller Node ID					
Listener Configuration	0	0x30	Attach Node or Update Flags 0x01	Flags 0x01=Resv'd 0x02=Rev direction 0x04=Link F0 0x08=Link Fn 0x80=Hide	Listener Node ID					
			Detach Node 0x02	Flags (Reserved)	Listener Node ID					
			Query Nodes 0x03	Listener index {optional}						

Instruction	Byte 0		Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8
Train Control Management	0	0x40	Reserve 0x01							
			Release 0x02							
			No-op 0x03							

The Set Function instruction uses a three-byte address for brevity; it's to be interpreted with a high byte of zero to make a four byte address in the function memory space (0xF9).

The P bit shall be set to 0 when a Throttle Node sends a command to a Train Node, and set to 1 when a Train Node is sending a forwarded command to a Listener Node.

4.4 Train Control Reply Message

MTI: Priority 0, index 15, modifier 1, addressed => MTI 0x01E9, CAN frame [191E9sss] fd dd

Instruction	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8	Byte 9	Byte 10
Query Speeds Reply	0x10	Set Speed		Status Bit 0: 1=E-Stop.	Commanded Speed		Actual Speed				
Query Function Reply	0x11	Address			Value						
Controller Configuration Reply	0x20	Assign Controller Reply 0x01	Result: 0 == OK Non-zero == Failed Fail Code: Bit 0=Assigned Controller Refused Connection Bit 1 = Train Refused Connection								
		Query Controller Reply 0x03	Flags 0x01=Resv'd	Active Controller (0.0.0.0.0.0 if no controller active)							
		Controller Changed Notify Reply 0x04	Result: 0 == OK Non-zero == Reject								
Listener Configuration Reply	0x30	Attach Node Reply 0x01	Node ID						Reply Code		
		Detach Node Reply 0x02	Node ID						Reply Code		
		Query Node Reply 0x03	Node count	Node index {opt}	Flags {opt}	Node ID {optional}					

Instruction	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8	Byte 9	Byte 10
Train Control Management Reply	0x40	Reserve Reply 0x01	Result: 0 == OK Non-zero == Failed								
		Heartbeat Request 0x03	Timeout in seconds								

The Query Speed/Direction reply is almost in the Set Speed/Direction format, with the addition of the two additional speeds. If a node cannot provide any of those three speeds, it shall use float16 NaN (not a number) 0xFFFF. “Set Speed” is the most recent speed received in a Set Speed/Direction instruction, or ±0 if an E-Stop command was received after the last Set Speed/Direction command. The E-Stop bit in the Flags byte represents whether the Train Node is in Emergency Stop state. “Commanded Speed” is the speed that the train is currently attempting to move, taking into account momentum and any other control modifiers. “Actual Speed” is the current measured speed of the locomotive. There is no accuracy guarantee for Actual Speed.

5 States (Normative)

OpenLCB Train Nodes have the following states:

Related to Speed:

- *Set Speed* – The speed set by a throttle, the content of the most recent “set speed” instruction
- *Commanded Speed* – the current speed that is intended by the control algorithm of the Train Node. Optional (assumed to match the Set Speed when not implemented).
- *Current Speed* – a physical state, the speed at which the object is currently moving. Optional (assumed to match the Commanded Speed when not implemented).

Related to Emergency Stop:

- A Train Node enters *Emergency Stop* state upon receiving a Train Control Command message with Emergency Stop command. A Train Node leaves Emergency Stop state upon receiving a Train Control Command message with a Set Speed command (for any speed, including ±0).
- A Train Node enters *Global Emergency Stop* state upon receiving an Event Report message with the Emergency Stop All event. A Train Node leaves Global Emergency Stop state upon receiving an Event Report message with the Clear Emergency Stop All event.
- A Train Node enters *Global Emergency Off* state upon receiving an Event Report message with the Emergency Off All event. A Train Node leaves Global Emergency Off state upon receiving an Event Report message with the Clear Emergency Off All event.

Related to Functions:

- It is not specified, which Function numbers are part of the state of the Train Node, and for those that are, what resolution the value needs to be represented.

Related to Listeners:

- The state consists of which Listeners are currently attached (their Node ID), the Flag byte with which they were last attached, and the order in which they were attached. Updating the flags shall not change the order.
- It is strongly recommended to store the Listener configuration in persistent state.

Related to Controller:

- The state consists of a single Node ID, which may be unset.

6 Interactions (Normative)

6.1 Controller

A Train Node maintains a single Node ID in its state as the Controller. A Throttle Node, before attempting any Train Control Operation, shall assign its own Node ID as the Train Node's Controller. A Throttle Node which is the current Controller, before intentionally powering down, shall attempt to release itself from the Train Node.

A Train Node may, but is not required to, reject all Train Control Operations from an OpenLCB Node that is not the current Controller. In such a case the Terminate Due To Error message shall be used with the error code "source not permitted – not a controller". Messages arriving from an attached Listener with the P bit set to 1 shall never be rejected.

A Train Node may, but is not required to, use heartbeats (see Section Heartbeat) to ensure that the Controller is continuously present on the network and is intending to keep the control of the locomotive.

A Throttle Node, to assign itself as the Controller of a Train Node, sends a Train Control Command message to the Train Node, with the Controller Configuration – Assign Controller command and its own Node ID. To accept the request, the Train Node shall set the Controller to the provided Node ID and reply with a Train Control Reply with a Controller Configuration – Assign Controller Reply with a Result of 0. A result of non-zero rejects the request. If there was a previous Controller, the Train Node sends a Controller Changing Notify Request to the previous Controller. The Train Node may, but is not required to wait for the reply of the previous Controller and factor in its reply to the decision. The Train Node shall reply to the Assign Controller message within 3 seconds.

A Node may query the active Controller from a Train Node. If no Controller is assigned the Train Node returns a Node ID of 0.0.0.0.0.0.

A Throttle Node assigned as a Controller of a Train Node, to release itself as the active Controller, sends a Controller Configuration – Release Controller request with its own Node ID to the Train Node. The Train Node shall verify that the Node ID matches the current Controller before setting the Controller to empty.

6.2 Emergency Stop

Receipt of the Emergency Stop instruction stops the locomotive as fast as possible. This sets the Set Speed to zero (preserving existing direction) and the Commanded Speed to zero (preserving existing direction) regardless of any momentum, BEMF or other operations with the train node.

Entering the Global Emergency Stop or Global Emergency Off state also stops the locomotive as fast as possible, but does not change the Set Speed. The train shall remain stopped while it is in any of the Emergency Stop, Global Emergency Stop or Global Emergency Off states. Upon exiting all Emergency Stop states, the locomotive shall accelerate to the currently valid Set Speed, if that is not zero, according to its settings.

In addition to stopping movement, the Global Emergency Off state shall de-energize all other outputs of the Train Node if possible. Upon exiting Global Emergency Off, these shall then be restored to their commanded state, which may have changed during the period of the Global Emergency Off state.

6.3 Function Operation

Function values are stored in the 0xF9 memory space. They are written using the memory configuration protocol or using the Set Function instruction.

For a binary function the Throttle Node shall write the value ‘0’ to turn the function off, and ‘1’ to turn the function on.

6.4 Train Identification

Train Nodes shall be producers of the well-known reserved event ‘Is Train’ according to the OpenLCB Event Transport Standard.

6.5 Listeners

When listeners are configured on a Train Node, the incoming Train Control Operations are forwarded by the Train Node to all the Listener nodes. The forwarded message shall be a Train Control Request message with the bit P set to 1.

Even if the source node of the incoming message is on the listener list, the message is not forwarded to the source node to avoid message loops.

The listener flags define which messages shall be forwarded:

- Set speed message is always forwarded. If the flag “Rev direction” is set for the listener, the direction of the forwarded speed is flipped.
- Set function message with function number = 0 shall be forwarded if and only if the “Link F0” flag is set on the listener configuration.
- Set function message for any other function number shall be forwarded if and only if the “Link Fn” flag is set on the listener configuration.

To add or remove a listener, the Attach Node or Detach Node message shall be sent to the target Train Node. The response shall contain the same node ID and a 2-byte OpenLCB Error Code. The following error codes may be helpful:

- 0x0000: Success.
- Permanent error, Not found. Useful if the caller tried to remove a node that is not attached as a Listener.
- Permanent error, Already Exists. Useful if the caller tried to add a node as a Listener to itself.

If a caller wants to update the flags of a specific listener, the Attach Node message shall be sent with the same node ID and the new flags.

To query the listeners from a train node, a Listener configuration Query Nodes message shall be sent to the train node. The response message contains the number of listeners currently configured. Listeners are indexed from 0 to count-1. Sending the Query Nodes message with the index specified, the train node will return the information for that specific listener, including Node ID and the flags specifying the forwarding options. If the requested index is out of bounds, or no index is requested, then the response will be short (no node information).

User interfaces that show the listeners shall not show listener nodes that are marked with the flag “Hide”. This flag is intended to be set for controlling throttles and train automation systems.

A Train Node may, but is not required to change its state upon a received Set Function message with P=1. Whether or not it changes state, the forwarding of the message to other Listeners is required as specified above.

6.6 Heartbeat

The Heartbeat Request may be sent by a Train Node to the currently active Controller node at the discretion of the Train Node. The argument is a deadline in seconds for the Controller node to reply. The Controller node may reply with any control or query command, or a No-op command.

Trains shall not initiate a Heartbeat Request if the last Set Speed is zero (including when the Train Node is in Emergency Stop state).

Trains shall accept any command or query sent from the Controller node to the Train Node to clear the Heartbeat Request. If the Controller node does not have anything to command or query, the Train Control Management No-op request may be used to clear the Heartbeat.

If a Train Node does not receive any command or query from the Controller node within the deadline presented in the Heartbeat Request, the Train Node shall interpret that as a Set Speed 0 command. This command shall be forwarded to all registered Listeners at the same time, including the Controller node, if it is registered as a Listener.

In case there is no assigned Controller node, the Train Node shall continue operating as last commanded.

7 Memory Spaces (Normative)

7.1 Function Information 0xF9

Functions, such as lights and sounds, can be operated by the Train Control Set Function instruction, and their current value can be retrieved via the Train Control Query Function instruction. The values

are also available for reading and writing in the Function Information memory space, so long as the value of a given function does not exceed 255.

The NMRA S-9.2.1 Standard describes four separate DCC packets controlling sets of “functions”. The OpenLCB 0xF9 space is allocated to cover all these by using the third byte of the address as a selector.

Type	Low Address	High Address	Values
F0-F68	0x0 00 00	0x0 00 44	A non-zero value indicates "ON", a zero value is "OFF".
Binary State Controls (full space)	0x1 00 00	0x1 7F FF	"
Binary State Controls (short space, if separate)	0x2 00 00	0x2 00 7F	"
Analog Outputs	0x3 00 00	0x3 00 FF	

A Train Node representing a DCC locomotive may, but is not required to provide support for all of the above features, and it may, but is not required to provide the last written data upon a read command.

7.2 Function Definition Information (FDI) 0xFA

0xFA is a read-only memory space which provides information for Throttle Nodes on how to present a user interface to control the specific functions that are available on this particular Train Node.

The format and semantics of this data is specified by the OpenLCB Function Definition Information Standard.

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