Planning

LCC Fusion Project

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Contents

Planner's Guides

Welcome to the Planner's Guides — your starting point for designing an LCC-enabled layout. Whether you're planning detection zones, signal logic, card deployments, or power distribution, this section helps you design with intention and clarity before you build.

Ready to build? Once your layout plan is in place, head over to our **Builder's Hardware Assembly Guides** for:

- **Step-by-step build instructions** for every LCC Fusion card (Node, BOD, Button, PWM, Power-CAN, etc.)
- **Solution-based hardware selections** and recommended parts lists for common layout tasks (block detection, turnout control, signaling, power distribution)
- **Complete BOMs** and alternative component options to fit different budgets or power requirements
- **Best-practice tips** for cabling, mounting, and integrating each card into your accessory bus

Use the guides below to understand key layout planning strategies and how to best utilize the LCC Fusion system components.

System-Level Planning

- Node Power Planning Guide
  Understand how to power your nodes safely and efficiently.
- Pod Build-Out Planning Guide
  Strategies for scaling a multi-node layout.
- Wireless Node-to-Node Planning Guide
  Design considerations for wireless communication between LCC Nodes.
- Terminology
  Definitions and common language used across LCC Fusion documentation.

Detection & Input Planning

- Sensor Planning Guide
  Choosing and placing sensors (analog/digital) for occupancy and triggering.
- BOD Card Planning Guide
  Design blocks with detection using the BOD Card.
- Button Card Planning Guide
  Planning control points for pushbuttons, toggles, and panel input.

Output & Accessory Planning

- LED Card Planning Guide
  Design layout lighting and LED-based indications.
- Sound Card Planning Guide
  Placement and event planning for audio outputs.
- Servo Motor Card Planning Guide
  Integrate servos for semaphores or other mechanical devices.
- Turnout Card Planning Guide
  Plan switch machine control and frog polarity handling.

Signal Planning

- Signal Planning Guide
  Basics of signal system design.
- Signal Aspects Planning Guide
  Choose which aspects (e.g., Stop, Clear, Approach) to use.
- Signal Complex Planning Guide
  Advanced signal logic for interlockings and multi-block lookaheads.
- Signal Types & Deployments
  Real-world signal examples and where to deploy them.

BOD Card Planning Guide

Introduction

Block Occupancy Detection (BOD) on a model train layout provides real-time awareness of train presence, enabling automation, safety features, and responsive layout behavior.

In the LCC Fusion Project, BOD is implemented using the **BOD Card**, which senses track occupancy and generates LCC events that drive logic, signaling, and automation.

> Block Occupancy Detection defines *where* trains are detected; logic, signaling, and automation define *how* that information is used. The BOD Card reports presence state via events only and never encodes behavior.

Planning Context

BOD is introduced during layout planning when you decide **where trains need to be detected and why**. Each detected block exists for a purpose, such as enforcing safety, driving signals, triggering automation, or providing operator feedback.

The BOD Card supports **up to eight track blocks**, so planning begins by identifying block boundaries and grouping related blocks that can be served by a single card.

Physical Planning Considerations

A BOD Card is installed in a **Node Bus Hub** and connects via cable to one or more **Block Breakout Boards**. **Block Breakout Boards** are typically positioned close to the track blocks they serve to simplify wiring and reduce cable runs.

When planning block occupancy detection: - Group nearby blocks so they can be served by the same BOD Card - Consider physical distance from the Node Bus Hub to the track - Plan block boundaries based on detection needs, not just rail length - Ensure blocks are electrically isolated according to the chosen detection method

Uses

Each use case below represents a **reason to create one or more track blocks**. During planning, you should be able to point to a specific operational goal for every block you define.

While block occupancy detection is commonly associated with signaling systems, it is equally useful for automation, safety, and operator feedback on layouts without signals.

Below is an assortment of ways the BOD Card can be utilized:

Block Detection Use	Description
Detect Train Presence	The card senses when a train enters a block, allowing the system to update signal aspects and turnout positions accordingly.
Occupancy-Based Signaling	Triggers signals to display a ‘stop’ aspect when a train is detected, ensuring other trains do not enter the occupied block.
Route Setting Based on Occupancy	Automatically adjusts turnouts to route trains correctly based on block occupancy to prevent collisions.
Support for Automated Train Operation	Facilitates automatic train control by providing real-time occupancy status to the system, which can be used to start, stop, and control train speeds without manual intervention.
Emergency Brake Trigger	In case of a detected issue, such as unexpected occupancy, the system can trigger an emergency stop to prevent accidents.
Aid in Traffic Management	Helps manage train traffic by allowing more sophisticated logic for track reservations and train scheduling based on block occupancy.
Prevent Dispatcher Errors	Provides an additional layer of safety by confirming the status of track occupancy to prevent dispatcher errors in manual control systems.

Block Detection Use	Description
Enhance Layout Realism	Contributes to the realism of the layout by automating train movements and interactions just like in the real world.
Diagnostics and Maintenance	Block detection cards can log occupancy data for diagnostics, helping to identify potential issues with train detection or track integrity.
Multi-train Coordination	Allows multiple trains to be coordinated smoothly by providing essential data for synchronization and timing of train movements.

References

- Planner's Guides
- Getting Started
- Scaling With PODs
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- Power-CAN Card Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media**

  – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Button Card Planning Guide

Introduction

Buttons on a model railroad layout provide **direct, intentional operator input**, enabling manual control, overrides, and interaction with automated systems.

In the LCC Fusion Project, button inputs are implemented using the **Button Card**, which detects button presses and releases and generates LCC events. These events are consumed by other nodes to control turnouts, signals, lighting, sound, automation sequences, or safety functions.

> Buttons define *when an operator intervenes*; logic, signaling, and automation define *how the system responds*. The Button Card reports button state changes via events only and never encodes behavior.

Planning Context

Button planning begins when you decide **where human interaction is required and why**. Each button should exist for a clear operational purpose, such as initiating an action, overriding automation, acknowledging a condition, or triggering a predefined sequence.

Planning involves determining: - Which actions should be manual versus automated - Where operators naturally expect controls to be located - How buttons interact with existing logic and automation - How many buttons are needed and how they are grouped per card

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Uses

The table below lists common planning use cases that drive the need for this card. Each entry represents a reason to introduce this capability into a layout design.

Button Use	Description
Start/Stop Trains	Use buttons to manually start or stop trains on various tracks.
Change Train Directions	Allow operators to change the direction of a train's travel.
Activate Sound Effects	Trigger sound effects like train whistles, station announcements, or ambient noises.
Control Lighting Effects	Turn on or off specific lighting elements, or change lighting scenarios (e.g., day to night).
Operate Turnouts	Switch rail turnouts to direct trains to different tracks
Animate Scenery	Activate moving parts in the scenery, such as opening bridge, rotating windmill, or animated figures.
Control Level Crossings	Operate gates and signals at level crossings manually.
Activate Special Effects	Trigger special effects like smoke from chimneys, fire scenes, or water effects.
Emergency Stop	A safety feature to immediately stop all trains and moving parts in case of an issue.
Cycle Through Scenes	Change between different scenes or layouts, for modular train setups.
Activate Display Lights	Control additional lighting for display purposes, not part of the layout's operational lighting.
Launch Automated Sequences	Start a sequence of events, like a complete train journey with multiple actions.

References

- Planner's Guides
- Getting Started
- Scaling With PODs
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
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Complex Signals Planning Guide

Introduction

Complex signaling is used on layouts where a single downstream condition is insufficient to safely or realistically convey operating instructions to train crews. These situations arise when multiple routes, graduated speed restrictions, overlapping blocks, or special operating conditions must be considered simultaneously.

In the LCC Fusion Project, complex signaling is a **planning decision**, not a hardware feature. It determines *how many downstream conditions must be evaluated* before setting the aspect of a signal mast and *how signal logic must be structured* to support safe and predictable operation.

> Complex signaling defines *how far ahead the system must reason*. Logic, aspects, and configuration define *how that reasoning is implemented*.

Planning Context

Complex signaling is introduced during signal planning when simpler models - such as evaluating a single downstream block or mast—are no longer sufficient.

You should consider complex signaling when: - Train speeds change gradually rather than abruptly - Multiple downstream routes affect current movement authority - Signal blocks overlap to provide additional safety margin - Route-dependent speed profiles exist - Advance warning is required beyond the next signal

This guide focuses on **planning the logic structure** required to support these scenarios. It does not prescribe hardware choices, wiring, or CDI configuration.

Only after determining that complex signaling is required should you proceed to: - Define the number of downstream masts or blocks involved - Select signal aspects - Implement logic groups and statements

Check for Multiple Downstream Masts

In complex rail networks, it may be necessary to evaluate the speeds of two or more **downstream masts** before setting the aspect of the current mast. This approach ensures safety and operational efficiency in scenarios with high train density, intricate track layouts, or varying speed requirements. > **Downstream signals** are ahead of the train in its direction of travel, while **upstream signals** are behind it.

Complex Signaling Examples

Here are a few situations where such an approach would be necessary:

1. Approaching Junctions or Interlockings

When a train approaches a junction or an interlocking area with multiple possible routes, it may be necessary to consider the speeds allowed on the routes beyond the immediate next signal. This ensures that the train can safely proceed through the junction and continue at an appropriate speed for the conditions that will be encountered further ahead.

2. Graduated Speed Reduction

In situations where there's a need for a graduated speed reduction—perhaps due to a gradient, curve, or approaching a congested station area—checking two downstream masts allows for a smoother transition. The current mast can display an aspect that prepares the train for the speed restrictions that will come into effect not just at the next signal but the one after that, facilitating a gradual deceleration.

3. Overlapping Signal Blocks for Added Safety

In dense rail corridors or high-speed sections, there might be overlapping signal blocks where the conditions of two downstream blocks affect the current signal aspect. This is to provide an additional safety margin by ensuring that a train has sufficient warning and space to stop or slow down, even if a problem is detected two blocks ahead.

4. Divergent Routes with Different Speed Profiles

When divergent routes from a signal have significantly different speed profiles—such as one route leading to a high-speed line and another leading to a slow-speed yard—checking two downstream masts helps in setting the current aspect. This approach ensures that the train is not only warned about the immediate next signal but also about the speed expectations of the route it will be taking thereafter.

5. Pre-emptive Signaling for Special Operations

In cases where special operations are in effect, such as track maintenance, construction work, or emergency situations, the signaling system may need to incorporate conditions from further down the line to preemptively adjust train speeds. This can involve taking into account the aspects of two downstream masts to set the current mast's aspect accordingly, ensuring trains are at the correct speed for upcoming restrictions.

Complex Signaling Planning

Once it's determined a complex signaling configuration involving aspects of 2 (or more) downstream masts need to be checked before setting the aspect of a current mast, the process revolves around a common set of logics and checks. These foundational principles ensure the system's consistency, safety, and efficiency. Let's outline how this typically works in practice:

1. **Identify Primary Conditions**: The first step involves identifying the key conditions that influence the current signal aspect. This includes the statuses (aspects) of the two downstream masts and may also involve track occupancy, switch positions, and any special operational conditions.
2. **Define Conditional Hierarchy**: Given multiple inputs, it's crucial to define the hierarchy of conditions. This often starts with the most restrictive condition to ensure safety. For instance, if either downstream mast shows a 'Stop' aspect, this might override other less restrictive conditions.
3. **Implement *If-Then-Else* Logic**: The core logic is implemented using 'if-then-else' statements. For example:
   - **If** the first downstream mast is at 'Stop', **then** set the current mast to 'Approach' or another appropriate restrictive aspect.
   - **Else if** the second downstream mast is at 'Stop' and the first is at 'Clear', **then** consider setting the current mast to 'Approach Medium' or a similarly moderated aspect, reflecting the need to slow down but not stop immediately.
   - **Else**, if both downstream masts are 'Clear', set the current mast to 'Clear' under conditions that all other safety checks (track occupancy, etc.) are satisfied.
4. **Incorporate Exit and Continue Logic**: Within each logic group, decisions on whether to exit the logic chain or continue to the next check are made. This ensures that once a determinative condition is met, the system either sets the aspect accordingly or continues to evaluate further conditions if no definitive action is determined.
5. **Speed Gradation Logic**: Based on the downstream conditions, the logic may need to apply speed gradation, gradually reducing speed based on the distance and expected stopping or slowing points.
6. **Divergence and Convergence Logic**: Special considerations are made where tracks diverge or converge, checking the aspects of signals that govern entry into and exit from these track configurations.
7. **Emergency and Special Operation Conditions**: Incorporate logic to handle emergency conditions or special operational states, such as maintenance work, which may override standard signaling logic.
8. **Feedback Loops**: Implement feedback loops for dynamic adjustment. For example, if a train's speed or the status of a downstream mast changes, the system can adjust the current mast's aspect in real-time or near-real-time to reflect new conditions.

Setting Aspects Using Block Status

For users configuring signals without track circuits, signal aspects are determined by evaluating the occupancy status of at least two downstream blocks. This ensures the upstream mast aspect reflects the safest and most appropriate condition for train operations.

Key Characteristics:

1. Block Occupancy-Based:
    - The upstream mast aspect is set based on whether the first and second downstream blocks are occupied or clear.
2. Progressive Restriction:
    - Aspects become progressively less restrictive as downstream blocks clear.
3. Applicability:
    - This approach is suitable for systems where speed reporting is unavailable or unnecessary.

3-Aspect "Block Signaling" Configuration Using Block Occupancy Detection

A **3-Aspect signal** using block status can be managed by checking two downstream blocks. Use a **single logic group** with **2 logic statements**, where the last statement determines one of two possible aspects (`Advance` or `Clear`).

Logic Statement	**Downstream Block 1**	**Downstream Block 2**	**Upstream Mast Aspect**	**Logic Statement**
1	Occupied	-	**Stop**	1. **If** `Downstream Block 1` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Stop` and **Exit**. **Else** `Continue`.
2	Clear	Occupied	**Approach** or **Clear**	2. **If** `Downstream Block 2` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Approach` and **Exit**. **Else** Set `Upstream Mast Aspect` to `Clear` and **Exit**.

5-Aspect "Gradient Speed Reduction" Configuration Using Blocks Occupancy Detection

A **5-Aspect signal** using block status refines this logic further by differentiating additional aspects such as **Approach Medium** and **Advance Clear**. Use a **single logic group** with **4 logic statements**, where the last statement determines one of two possible aspects (`Advance Clear` or `Clear`).

Logic Statement	**Downstream Block 1**	**Downstream Block 2**	**Downstream Block 3**	**Upstream Mast Aspect**	**Logic Statement**
1	Occupied	-	-	**Stop**	**If** `Downstream Block 1` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Stop` and **Exit**. **Else** `Continue`.
2	Clear	Occupied	-	**Approach**	**If** `Downstream Block 2` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Approach` and **Exit**. **Else** `Continue`.
3	Clear	Clear	Occupied	**Approach Medium**	**If** `Downstream Block 3` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Approach Medium` and **Exit**. **Else** `Continue`.
4	Clear	Clear	Clear	**Advance Clear** or **Clear**	**If** `Downstream Block 3` is `Clear`, **Then** Set `Upstream Mast Aspect` to `Advance Clear` and **Exit**. **Else** Set `Upstream Mast Aspect` to `Clear` and **Exit**.

3-Aspect Configuration for Using Block Occupancy And Point Status

This configuration uses block status and turnout points to determine the aspects of the signal mast for both the **mainline** and the **divergent route**. The turnout determines which route is active, and the corresponding signal head governs train movement.

In the following example, the Mast before the turnout has 2 heads, one the mainline route and one for the divergent route. This can be configured using 2 separate logic blocks, one for each head.

Mainline Route: 3-Aspect Signal Head

Logic State-ment	Turnout Block	Point Position	Mainline Block 1	Mainline Block 2	Mainline Head Aspect	Logic Statement
1	Occupied	Open/Thrown	-	-	**Stop**	**If** `Points` are `Open/Thrown` **Or** `Turnout Block` is `Occupied`, **Then** Set `Mainline Head` to `Stop` and **Exit**. **Else** `Continue`.
2	Clear	Closed	Occupied	-	**Stop**	**If** `Mainline Block 1` is `Occupied`, **Then** Set `Mainline Head` to `Stop` and **Exit**. **Else** `Continue`.
3	Clear	Closed	Clear	Occupied / Clear	**Approach** / **Clear**	**If** `Mainline Block 2` is `Occupied`, **Then** Set `Mainline Head` to `Approach` and **Exit**. **Else** Set `Mainline Head` to `Clear` and **Exit**.

Divergent Route: 3-Aspect Signal Head

Logic State-ment	Turnout Block	Point Position	Divergent Block 1	Divergent Block 2	Divergent Head Aspect	Logic Statement
1	Occupied	Closed	-	-	**Stop**	**If** `Points` are `Closed` **Or** `Turnout Block` is `Occupied`, **Then** Set `Divergent Head` to `Stop` and **Exit**. **Else** `Continue`.
2	Clear	Open/Thrown	Occupied	-	**Stop**	**If** `Divergent Block 1` is `Occupied`, **Then** Set `Divergent Head` to `Stop` and **Exit**. **Else** `Continue`.
3	Clear	Open/Thrown	Clear	Occupied / Clear	**Approach** / **Clear**	**If** `Divergent Block 2` is `Occupied`, **Then** Set `Divergent Head` to `Approach` and **Exit**. **Else** Set `Divergent Head` to `Clear` and **Exit**.

Setting Aspects Using Track Circuits

Signal aspects are critical for ensuring safe train operations by providing advanced warnings to train crews about track conditions. The logic for setting signal aspects leverages track circuits, which report the aspect (speed) of the downstream mast. This information determines how the current signal should behave.

- **1 downstream mast** is sufficient for **3-aspect signals** (e.g., **Stop**, **Approach**, **Clear**) because the downstream mast conveys speed restrictions for the block beyond it.

- **1 downstream mast** is also sufficient for **5-aspect signals** (e.g., **Stop**, **Approach**, **Approach Medium**, **Advance Clear**, **Clear**) when track circuits are used. The downstream mast reports speeds for multiple blocks, allowing the current signal to adjust based on the most restrictive condition downstream. The upstream mast's block speed is simply set to a lower speed than the next downstream block as reported by the downstream mast.

By utilizing track circuits, the signaling system simplifies decision-making, ensuring that upstream signals dynamically respond to downstream conditions for both safety and operational efficiency.

3-Aspect "Block Signaling" Configuration** Using Track Circuits

A 3-Aspect signal** can be managed by checking 1 downstream block and mast. Use a **single logic group** with **2 logic statements**, where the last statement determines one of two possible aspects (`Approach` or `Clear`).

Logic Statement	Downstream Block	**Downstream Mast Aspect**	**Upstream Mast Aspect**	**Logic Statement**
1	Occupied	-	**Stop**	**If** `Downstream Block` is `Occupied`, **Then** Set `Upstream Mast Aspect` aspect to `Stop` and `Exit`, **Else** `Continue`
2	Clear	Stop or Approach	**Approach** or **Clear**	**If** `Downstream Mast Aspect` is `Stop`, **Then** `Upstream Mast Aspect` aspect to `Approach`, and `Exit`. **Else** Set to `Upstream Mast Aspect` to `Clear` and `Exit`

5-Aspect "Gradient Speed Reduction" Configuration Using Track Circuits

A **5-Aspect signal** can be managed by checking the **Downstream Block** and a single **Downstream Mast**. Use a **single logic group** with **4 logic statements**, where the last statement determines one of two possible aspects (`Advance Clear` or `Clear`).

Logic Statement	**Downstream Block**	**Downstream Mast Aspect**	**Upstream Mast Aspect**	**Logic Statement**
1	Occupied	-	**Stop**	1. **If** `Downstream Block` is `Occupied`, **Then** Set `Upstream Mast Aspect` to `Stop` and **Exit**. **Else** `Continue`.
2	Clear	Stop	**Approach**	2. **If** `Downstream Mast Aspect` is `Stop`, **Then** Set `Upstream Mast Aspect` to `Approach` and **Exit**.
3	Clear	Approach	**Approach Medium**	3. **If** `Downstream Mast Aspect` is `Approach`, **Then** Set `Upstream Mast Aspect` to `Approach Medium` and **Exit**.
4	Clear	Approach Medium or Clear	**Advance-Clear** or **Clear**	4. **If** `Downstream Mast Aspect` is `Approach Medium`, **Then** Set `Upstream Mast Aspect` to `Advance-Clear` and **Exit**. **Else** Set `Upstream Mast Aspect` to `Clear` and **Exit**.

General Recommendations

- When configuring aspects, always ensure the **Track Circuit Link Event ID** is correctly associated with downstream masts.
- For complex logic involving more than five aspects, consider using additional downstream masts or refining conditions to handle unique scenarios.

After thoroughly examining the table of logic statements and their corresponding conditionals and actions, we now present a comprehensive flow diagram. This diagram serves as a visual representation of the logic flow dictated by the conditions and actions detailed in the preceding table. Each conditional check and subsequent action, as described in our logic statements, is illustrated to provide a clearer understanding of how each signal aspect is determined based on the states of two downstream masts.

The flow diagram is structured to mirror the sequential processing of the logic statements, beginning with the initial condition check of Mast 1's aspect and progressing through the various potential outcomes and actions. By following the diagram, readers can visually trace the decision-making path for setting the current signal mast's aspect, offering an intuitive grasp of the process that complements the tabular data.

Key Features of the Diagram:

- **Conditional Decision Points**: Illustrated as branching paths, these points reflect the 'if-then-else' structure of our logic statements, guiding the flow based on the conditions met.
- **Action Nodes**: Represent the actions taken when specific conditions are satisfied, such as setting the signal aspect to 'Approach', 'Approach Medium', or 'Clear'.
- **Flow Direction**: Indicates the sequential order of logic evaluation, demonstrating how an initial condition can lead to various outcomes based on the downstream mast aspects.
- **Highlighting Key Transitions**: Through the use of color or other visual markers, key transitions and critical decision points are emphasized to aid in navigation and understanding.

This diagram not only aids in visualizing the operational logic behind signal aspect setting but also serves as a practical reference for those configuring or troubleshooting signal systems. By aligning the visual flow with the logic statements covered earlier, we aim to provide a dual-perspective understanding—both textual and visual—of the intricate decision-making process involved in railway signaling."

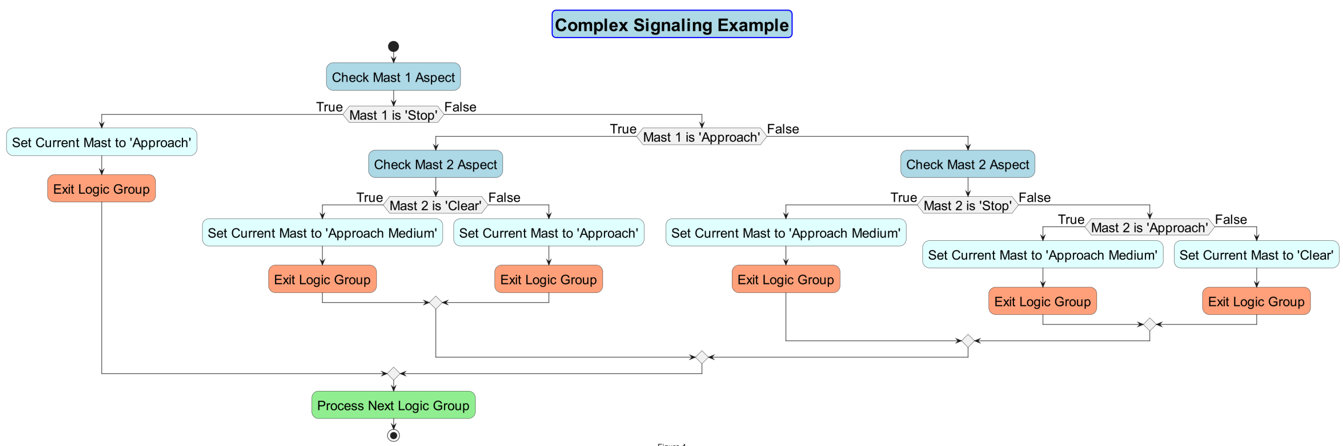

Figure 1: Image

References

- Planner's Guides
- Getting Started
- Signal Planning Guide
- Signal Aspects Planning Guide
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- Wireless Node-to-Node Planning Guide
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PWM Card Planning Guide

Introduction

Lighting on a model railroad layout provides **visual feedback, realism, and atmosphere**, helping convey layout state, time of day, and operational intent.

In the LCC Fusion Project, LED lighting is implemented using the **PWM Card**, which generates variable-duty PWM outputs in response to LCC events. These outputs are used to control brightness, fading, flashing, and sequencing of LEDs and other low-power loads.

> Lighting defines *what is shown* on the layout; logic, signaling, and automation define *when and why it changes*. The PWM Card controls output intensity only and never encodes behavior.

Planning Context

PWM planning begins when you decide **which visual elements on the layout need dynamic control and why**. Each lighting output should exist for a clear purpose, such as conveying status, enhancing realism, or responding to operator or sensor input.

Planning involves determining: - Which scene elements require controllable lighting - Whether lighting is static, animated, or event-driven - How many independent lighting channels are needed - How lighting integrates with signals, sensors, buttons, and automation

The PWM Card supports multiple independently controlled outputs, so planning focuses on grouping related lighting elements that can share a card.

Physical Planning Considerations

A PWM Card is installed in a **Node Bus Hub** and connects via cable to one or more **Digital I/O Breakout Boards** or **Signal Breakout Boards**. Breakout boards are typically placed close to the LEDs they serve to minimize wiring complexity and voltage drop.

When planning PWM-controlled lighting:

- Group nearby LEDs so they can be served by the same PWM Card
- Separate logic-level wiring from higher-current lighting circuits
- Consider brightness and duty-cycle requirements rather than raw voltage
- Plan spare outputs for future scene expansion

Uses

Each use case below represents a **reason to introduce PWM-controlled lighting** into a layout design. You do not need to implement every item; each entry reflects a potential planning motivation rather than a required feature.

Light Use	Description
Train Headlights and Taillights	Install LEDs as realistic headlights and taillights on locomotives and cabooses.
Interior Car Lighting	Illuminate passenger cars, freight cars, or other rolling stock interiors with small LEDs.
Street Lights	Use LEDs to create street lamps that add life and realism to your towns and cities.
Building Lighting	Light up windows in houses, office buildings, and other structures to create a lived-in look.
Signal Lights	Implement LEDs in railway signals to control train movements, just like in real-world railroading.
Level Crossing Lights	Equip level crossings with flashing red LEDs to indicate when trains are passing.
Platform and Station Lighting	Illuminate station platforms and buildings for a realistic night-time scene.
Scenery Accent Lighting	Use LEDs to highlight landscape features like rivers, cliffs, or trees.
Emergency Vehicle Lights	Create realistic emergency scenes with flashing LEDs on police cars, fire trucks, or ambulances.
Vehicle Headlights and Taillights	Add headlights and taillights to cars and trucks on roads and highways.
Airport Runway Lights	If your layout includes an airport, use LEDs for runway and taxiway lighting.
Dock and Ship Lighting	Illuminate docks and ships in maritime-themed areas.
Amusement Park Lighting	Create a vibrant and colorful amusement park with LEDs on rides and attractions.
Industrial Area Lighting	Light up factories, warehouses, and other industrial structures for a working environment look.
Fire and Explosion Effects	Simulate fires or explosions in dynamic scenes using flickering red and orange LEDs.

References

- Planner’s Guides
- Getting Started
- Node Clusters
- Multi-Node Planning Guide
- Node Power Planning Guide
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Signal Aspects Planning Guide

Introduction

Signal aspects define the **meaning conveyed to a train operator** by one or more signal heads acting together. An aspect represents a single instruction - such as stop, proceed, or proceed with restriction - regardless of how many lamps or heads are used to display it.

In the LCC Fusion Project, signal aspects are **planning constructs**, not hardware features. An aspect describes *what information must be conveyed*; the physical signal heads and lamps describe *how that information is shown*.

> Signal aspects define *what the operator must know*; signal hardware defines *how that information is displayed*. Aspect planning always precedes hardware selection.

Signal aspect planning occurs early, alongside track and route planning, when you decide **what instructions trains must receive at specific locations** and **how much information must be conveyed**.

Planning signal aspects involves determining: - How many distinct instructions are required at a location - Whether a single route or multiple routes must be indicated - How much visual complexity is appropriate for the layout - How closely the model should follow prototype signaling practices

Only after aspects are defined should you decide: - How many signal heads are needed - How many lamps per head are required - Whether multiple heads work together to display a single aspect

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Relationship Between Aspects, Heads, and Lamps

An aspect may be displayed using: - A single multi-lamp head - Multiple heads acting together - Different lamp counts depending on route complexity

The number of heads or lamps does **not** determine the number of aspects. An aspect is defined by the **instruction conveyed**, not the physical implementation.

# Aspects Shown (Per Mast)	# Heads	# Lamps (Per Head)	Usage	Comments
1	1	3	Used for simple track layouts where a single head can convey clear, caution, or stop for a single route.	A single head with a red, yellow, and green lamp used to indicate stop, caution, and go on a main line.
1	2	2	Utilized in scenarios where two heads work together to show a single aspect across both heads for enhanced visibility or redundancy.	Two heads, each with a green and red lamp. Both display green to indicate a clear route ahead.
2	2	3	Suitable for junctions or diverging tracks where each head can independently signal the status of the main route and a diverging route.	Upper head shows green for a clear main route, lower head shows yellow to indicate caution on a diverging route.
Multiple	Multiple	Varied	Used in complex rail network sections with multiple potential routes, each requiring its own signal indication.	Several heads, each potentially with a different number of lamps, to manage complex junctions with multiple diverging paths.

Signal Aspects: One or Two Multi-Lamp Heads

The decision to use a single 3-lamp head to show both main and divergent route aspects versus using two separate heads, one for each route, on a signal mast in a real-world railway system depends on several factors including operational requirements, space constraints, clarity of signaling to the train operator, and historical practices of the railway.

Operational Requirements

- **Complexity of the Junction**: If a junction or track section has multiple possible routes with varying levels of priority or speed restrictions, using separate heads for main and divergent routes can provide clearer instructions to the train operator.
- **Frequency of Divergent Movements**: Railroads with frequent divergent movements might prefer separate heads to clearly indicate when a divergent route is set, as opposed to a single head that might be less clear in complex operational scenarios.

Space Constraints

- **Physical Space Available**: In areas where space is limited, such as in urban environments or in tunnels, it might be preferable to use a single head due to physical constraints.
- **Mast and Signal Placement**: The placement of signals along the track and the practicality of installing additional masts or heads can influence the choice. A single 3-lamp head might be used on a simpler layout to save space and reduce infrastructure costs.

Clarity of Signaling

- **Ease of Interpretation**: Two separate heads might be used to provide unambiguous instructions for each route, improving safety and operational efficiency. This is particularly important in high-speed areas where clarity and advance notice are critical.
- **Simplification**: Conversely, in less complex areas or on railways with less variation in route settings, a single head might suffice for clarity and simplicity, especially if the signaling system is designed to be intuitive with the use of color and flash codes.

Historical Practices and Regulations

- **Railway Signaling Standards**: Different railways have their own standards and practices, which can be influenced by historical developments, regulatory requirements, and safety studies.
- **Legacy Systems**: The existing infrastructure and the need to maintain consistency with legacy signaling systems can also dictate the choice. Upgrading or changing to a different signaling system can be costly and complex.

In model railroading and simulation projects like the LCC Fusion Project, these considerations can be simplified, but understanding the logic behind real-world practices can help in creating realistic and functional model systems. When documenting or configuring signals within the LCC Fusion framework, consider how these factors translate into the scale and objectives of your model railway system, especially in terms of signaling complexity and the desired level of realism. When documenting or configuring signals within the LCC Fusion Framework, consider how these factors translate into the scale and objectives of your model railway system, especially in terms of signaling complexity and the desired level of realism.

References

- Planner's Guides
- Getting Started
- Node Clusters
- Scaling with PODs
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide

- **Educational Media** – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Signal Planning Guide

Introduction

Signals on a model railroad convey operational instructions to train operators by presenting specific **signal aspects** at defined locations on the layout. Effective signal planning focuses on *what information must be conveyed* and *under what conditions*, rather than on the physical construction of signal masts or lamps.

In the LCC Fusion Project, signal planning is centered on: - Defining the signal aspects required at each location - Determining the downstream conditions that influence those aspects - Structuring logic statements that evaluate conditions and set aspects accordingly

This guide focuses on **planning signal behavior** using logic statements and signal groups. Physical implementation details - such as mast wiring, lamp connections, and PWM channel assignment - are intentionally out of scope.

> Signal planning defines *what instructions are shown* and *when they change*. Hardware and configuration define *how those instructions are displayed*.

Planning Context

Signal planning occurs after track, turnout, and block planning, when you understand: - Where trains may travel - Where routes diverge or converge - Which blocks must be protected - Which downstream conditions influence train movement

Planning signal behavior involves deciding: - Which aspects are required at each mast - How many downstream elements influence each signal - How logic statements should be ordered to enforce safe operation - When logic processing should stop or continue within a signal group

Only after signal behavior is planned should physical signal hardware and lamp layouts be selected.

Relationship to Logic and Configuration

Signals in LCC Fusion are controlled by **logic groups**, each consisting of one or more logic statements. During planning, logic is expressed using an *if-then-else* structure to clearly describe behavior without committing to configuration details.

This planning approach allows: - Complex signal behavior to be reasoned about before configuration - Incremental refinement of logic without hardware changes - Consistent behavior across different signal hardware types

Terminology

Below is a set of terms used in both planning and configuring of signal aspects:

- **Logic Statement**: for planning purposes, a logic statement is in the form of a typical *if-then-else* statement as shown here:

  IF `conditional` **THEN** `action(s) for true conditions` **ELSE** `actions for false conditions`

  Example: 1. **If** Block is Occupied, **Then** Set aspect to `Stop` and `Exit` **Else** Set aspect to `Clear` and `Continue`.

  Explanation:

```
- `1.`: indicates this is the first logic statement in the group.
- `Block is Occupied`: is the conditional, consisting of a single variable to be checked for true or f
- `Set aspect to Stop`  is the action that to be performed when the conditional is true.
- `Continue` determines that the processing of additional logic statements should continue. If this is
- `Set aspect to Clear` is the action to be performed when the conditional is false.
```

- **Conditionals**: condition(s) to be evaluated, resulting in either true or false. Conditionals contain either one or two variables. When two variables are define, a logic operator is used; `V1 and V2`, `V1 OR V2`, `V1 Only`, etc.
- **Actions**: is what happens when the conditional is *true* or *false*. Typically the action *sets the aspect* or does nothing.
- **Logic Group**: represents a collection of logic configurations accessible via the CDI tool in the **Logics and Conditionals** section.
  - Planning example:
    1. **If** Block is Occupied, **Then** Set aspect to `Stop` and `Exit` **Else** `Continue`.
    2. **If** Downstream Mast's Track Circuit indicates `Stop`, **Then** Set aspect to `Approach` and `Continue` **Else** Set aspect to `Clear` and `Continue`.
- **Logic Processing** determines what happens after the a logic statement is processed, `Exit` to stop processing the logic statements in the group, or `Continue` to continue with the next logic statement (e.g. additional conditions need to be evaluated and aspects set). Note that processing the last logic statement in the group will automatically exit the group upon completion.
- **Track Circuit**: Track Circuits report the downstream track speed as shown by a mast linked to the track, simplifying the number of conditions that need checking and are particularly useful when dealing with downstream masts. During configuration, a track circuit is used as a variable in the conditions. For example, when the downstream signal aspect is reporting a stop speed, the current mast typically would show an approach speed.
  - Planning example: **If** Downstream Mast's Track Circuit indicates `Stop`, **Then** Set aspect to `Approach` and `Continue` **Else** Set aspect to `Clear`and `Continue`.

Signal Mast Aspect Usage Examples

Aspects	Mast Name	Signal Type	Purpose/Use	Example Triggers
Caution, Clear	Mainline Distance Signal	Two-Aspect Signal	Provide advance warning of mainline signal status.	Next Block Occupied or Clear
Stop	Yard Entry Mast	Single-Aspect Signal	Signal yard entry restrictions.	Yard Block Occupied
Stop, Approach, Clear	Crossover Signal Mast 3	Three-Aspect Signal	Indicate safe crossover alignment.	Turnout Aligned or Block Status
Stop, Clear	Mainline Signal Mast 1	Two-Aspect Signal	Control train movement on a mainline.	Block Occupied or Turnout Misaligned
Stop, Clear	Yard Exit Mast 6	Two-Aspect Signal	Signal safe yard exit onto mainline.	Mainline Block Status
Stop, Diverging Clear, Clear	Junction Mast A	Three-Aspect Signal	Control train movement at a turnout junction.	Turnout Alignment and Block Status
Stop, Restrict, Clear	Siding Signal Mast 2	Three-Aspect Signal	Indicate siding availability.	Siding and Mainline Block Status

Aspects	Mast Name	Signal Type	Purpose/Use	Example Triggers
Stop, Restrict, Approach, Advance Approach, Clear	Mainline Mast 4	Multi-Aspect Signal	Provide multiple aspects for mainline operations.	Turnout and Block Status

Signal Mast Aspect Configuration Summary

The following table is provided to assist in simplifying the configuration of signal mast aspects. The configurations are listed based on the number of signal aspects to be set (heads and lamps) and what is influences the aspect downstream of the signal (blocks, turnouts, masts).

To further simplify the planning:

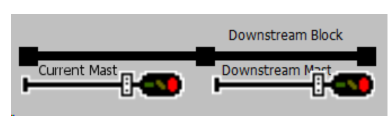
1. only three aspects are define; `Stop`, `Approach`, and `Clear`.

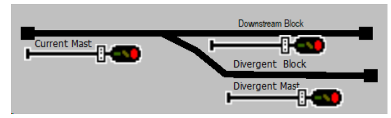
2. check for all conditions that set the aspect to `Stop`, followed by conditions for `Approach`, and finally `Clear`.
3. even thought configuring aspects requires configuring the indications, the setting of the lamps is not defined below since that varies by the aspect rules and signal head type.
4. utilize the minimum necessary number of logic statements.
5. track circuits are used to check for downstream track speeds

Note that up to 4 actions can be executed for true and false conditions, allowing for a **tumble-down** to be configured for setting up to 4 aspects. For example, when configuring the first signal located at the beginning of a set of blocks between sidings (headblock), configure multiple actions for this signal where each action sets the same aspect downstream signals, thus creating a tumple-down of the signals being set (all appear the same).

The use of `Exit` and `Continue` within the logic statements' actions signals whether the logic processing for that group should cease ('Exit') or proceed to evaluate the next logic statement ('Continue'). Generally, once the appropriate aspect is displayed based on the evaluated conditions, the logic processing for that group concludes.

> **Ordering Conditionals**: When crafting a logic statement for a signal, it is standard practice to first assess conditions that necessitate the most restrictive track speed (e.g., Stop), followed by conditions for intermediate speeds (e.g., Approach), and lastly, conditions allowing the least restrictive speeds (e.g., Clear).

Signal Mast Configuration	Downstream Elements	Logic Group (one or more logic statements)	Visual
Single 2-Lamp Head	1 Block, 1 Masts, 0 Turnouts	1. **If** Block is Occupied, **Then** Set aspect to `Stop` and `Continue` **Else** Set aspect to `Clear` and `Continue`.	
Single 3-Lamp Head	1 Block, 2 Mast, 0 Turnouts	1. **If** Block is Occupied, **Then** Set aspect to `Stop` and `Exit`**Else** `Continue`. 2. **If** Downstream Mast shows `Stop`, **Then** Set aspect to `Approach` and `Continue` **Else** Set aspect to `Clear`and `Continue`.	

Signal Mast Configuration	Downstream Elements	Logic Group (one or more logic statements)	Visual
3-Lamp Head over 2-Lamp Head	3 Blocks, 3 Masts, 1 Turnout	1. **If** Turnout Block is Occupied, **Then** Set Upper Head aspect to `Stop`, Lower Head aspect to `Stop`, and `Exit` **Else** `Continue`.2. **If** Turnout is `Thrown`, **Then** Set Upper Head to `Stop` and `Continue` **Else** `Continue`3. **If** Downstream Mast shows NOT`Clear` **Then** Set Upper Head aspect to `Approach` and `Continue` **Else** Set Upper Head aspect to `Clear` and `Continue`.4. **If** Turnout is `Closed` OR Divergent Mast shows NOT `Clear`, **Then** Set Lower Head aspect to `Stop` and `Continue` **Else** Set Lower Head aspect to `Clear` and `Continue`	
3-Lamp Head over 3-Lamp Head	2 Blocks, 2 Masts, 1 Turnout	1. **If** Turnout is Diverging, **Then** Upper Head Red, Lower Head Green for Diverging Route;2. **If** First Block is Occupied, **Then** Upper Head Red, Lower Head Yellow;3. **Else** Upper Head Green, Lower Head Green;	
2-Lamp Head over 2-Lamp Head	1 Block, 1 Mast, 1 Turnout (Diverging)	1. **If** Turnout is Diverging, **Then** Upper Head Red, Lower Head Green;2. **If** Block is Occupied, **Then** Both Heads Red;3. **Else** Both Heads Green;	
Twin 3-Lamp Heads (Side by Side)	2 Blocks, 2 Masts, 2 Turnouts	1. **If** Either Turnout is Diverging, **Then** Corresponding Head Shows Yellow;2. **If** Either Block is Occupied, **Then** Corresponding Head Shows Red;3. **Else** Both Heads Show Green;	
2-Lamp Head over 3-Lamp Head	1 Block, 2 Masts, 1 Turnout	1. **If** Turnout is Diverging, **Then** Upper Head Green, Lower Head Yellow;2. **If** Block is Occupied, **Then** Upper Head Red, Lower Head Red;3. **Else** Upper Head Green, Lower Head Green;	
Dwarf Signal, 3-Lamp	1 Block, 0 Masts, 1 Turnout (Diverging)	1. **If** Turnout is Diverging **And** Block is Occupied, **Then** Display Red;2. **If** Turnout is Diverging, **Then** Display Yellow;3. **Else** Display Green;	
Vertical Stack of 3-Lamp Heads	3 Blocks, 3 Masts, Multiple Turnouts	1. **If** Any Turnout is Diverging, **Then** Corresponding Head Red;2. **If** Any Block is Occupied, **Then** Corresponding Head Yellow;3. **Else** All Heads Green;	

Signal Mast Configuration	Downstream Elements	Logic Group (one or more logic statements)	Visual
4-Lamp Head (Single or Multiple)	Specialty areas like speed-controlled zones	1. **If** Speed Restriction in Place, **Then** Display Aspect According to Restriction;2. **If** Block Ahead is Occupied, **Then** Display Yellow;3. **Else** Display Green;	

References

- Planner's Guides
- Getting Started
- Node Clusters
- Scaling with PODs
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
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Signal Types and Deployments

Introduction

Railroad signal systems use different signal types to convey specific operational instructions to train crews. Each signal type exists to answer a particular question, such as whether a block is occupied, whether a route is set, or whether a speed restriction applies.

In the LCC Fusion Project, **signal types and deployments are planning concepts**, not hardware requirements. They help determine: - What information must be conveyed to operators - Where signals are needed on the layout - How signal behavior should be structured before hardware or configuration decisions are made

This guide provides a **conceptual catalog of common railroad signal types** and describes where they are typically deployed. It is intended to support **early signaling design decisions**, not to prescribe how signals are wired, configured, or implemented.

> Signal types define *why a signal exists* and *what role it plays*. Signal aspects, hardware, and logic define *how that role is implemented*.

Planning Context

Signal type selection occurs after basic track and route planning but before signal hardware or logic configuration.

During planning, signal types help answer questions such as: - Where must train movement be protected or restricted? - Where advance warning is required before a condition changes - Which locations require operator-facing instructions versus automation-only control - Whether a location requires simple stop/go indication or richer information

A single physical signal mast may serve multiple signal roles depending on layout complexity and operating goals.

How to Use This Table

The table below lists common signal types, their operational role, and typical deployment locations. Each entry represents a **reason to introduce signaling at a location**, not a required feature or a mandatory hardware choice.

You do not need to implement every signal type shown. Instead, use this table to identify which roles apply to your layout and which can be omitted.

Signal Type	Role Description	Typical Deployment Location
Block Signals	Indicate the status of a block section to ensure only one train occupies a block.	Deployed along the mainline to indicate block occupancy and maintain safe spacing between trains.
Speed Signals	Warn of upcoming conditions that require speed reduction or stopping.	Placed before areas where speed reductions are required, such as stations or junctions.
Diverging Signals	Indicate a diverging route and the speed at which a train should proceed.	Positioned at junctions or where tracks diverge to indicate route selection and speed.
Crossover Signals	Control train movements over crossovers between parallel tracks.	At crossovers between parallel tracks to manage train movements across these tracks.
Interlocking Signals	Govern entry into and exit from interlocking limits, controlling movements through junctions.	At the entrance and exit of interlocking areas to control movements through complex track layouts.
Distant Signals	Act as a preliminary warning to an upcoming stop signal or condition.	Before stop signals or significant track conditions to provide advance warning to train crews.
Shunting Signals	Permit trains to move into or out of sidings or perform shunting movements.	In yards, sidings, or where trains or cars are assembled or disassembled.
Stop Signals	Require trains to come to a complete stop.	At points where trains must stop for operational reasons, such as station platforms or block endpoints.
Aspect Signals	Convey how a train should proceed using defined visual indications.	Used wherever detailed operator-facing instructions are required.
Cab Signals	Provide track condition information directly within the train cab.	Used in conjunction with trackside signals or as a primary signaling system within the train cab.
Automatic Block Signals	Operate automatically based on track conditions and train presence.	Used along mainlines where signaling responds directly to train movement.
Temporary Speed Restriction Signals	Indicate a temporary reduction in speed due to track work, obstructions, or other conditions.	At locations where temporary conditions necessitate a reduction in speed.

This list covers the most common types of signals based on their roles in railroad operations. The specific implementation and appearance of these signals can vary by country and rail system, but their fundamental purposes are generally consistent worldwide.

References

- Planner's Guides
- Getting Started
- Signal Planning Guide
- Signal Aspects Planning Guide
- Node Clusters
- Scaling with PODs
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Configurator's Guides
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Sound Card Planning Guide

Introduction

Sound on a model railroad layout provides **auditory feedback, atmosphere, and narrative context**, enhancing realism and helping convey what is happening on the layout beyond what can be seen.

In the LCC Fusion Project, sound playback is implemented using the **Sound Card**, which plays preloaded audio in response to LCC events. These events may originate from sensors, buttons, logic rules, automation sequences, or other nodes on the network.

> Sound defines *what is heard* on the layout; logic, signaling, and automation define *when and why it plays*.
> The Sound Card executes audio playback only and never encodes behavior.

Planning Context

Sound planning begins when you decide **which moments, locations, or conditions on the layout should produce audible feedback and why**. Each sound should serve a purpose, such as providing operator confirmation, enhancing immersion, guiding visitor attention, or explaining scene context.

Planning involves determining: - Where sound adds meaningful value versus distraction - Whether sounds are ambient, event-driven, or instructional - How many independent audio zones are needed - Physical placement of speakers relative to the scene elements they support

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Physical Planning Considerations

A Sound Card is installed in a **Node Bus Hub** and connects to one or more speakers either directly or via a **Digital I/O Breakout Board**. Speakers are typically placed close to the scene they represent to maintain spatial realism and reduce wiring complexity.

When planning sound integration: - Group related sounds so they can be served by the same Sound Card - Consider speaker placement, enclosure, and sound direction - Plan for accessibility to adjust or replace speakers if needed - Allow for expansion if additional scenes or narration are added later

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Uses

The table below lists common planning use cases that drive the need for sound playback on a layout. Each entry represents a potential reason to include sound, not a required feature.

Sound Category	Description
Locomotive Engine Sounds	Recreate the sounds of steam, diesel, or electric engines, including startup, running, and shutdown noises.
Train Whistles and Horns	Different types of whistles and horns for various locomotives, signaling arrivals, departures, and crossings.
Rail Clack and Wheel Sounds	The rhythmic sound of train wheels rolling over track joints, creating the classic 'clickety-clack' noise.
Station Announcements	Automated announcements for arrivals, departures, and other station information.
Ambient Station Sounds	Background noise found in stations, like crowd chatter, footsteps, and luggage movement.
Level Crossing Bells and Warnings	The sound of bells or alarms at crossings as trains approach.
Industrial Sounds	For industrial areas, include sounds like machinery, factory whistles, or trucks loading and unloading.
Scenic Nature Sounds	Birdsong, water flowing, wind, and other nature sounds for rural or wilderness areas.
City and Urban Sounds	Traffic noise, car horns, sirens, and general city bustle for urban landscapes.
Emergency Vehicle Sirens	Police, ambulance, and fire engine sirens for emergency scene recreations.
Airplane or Airport Sounds	If your layout includes an airport, sounds of airplanes taking off and landing add realism.
Harbor and Maritime Sounds	Sounds of boats, foghorns, and seagulls for layouts with water features or docks.
Amusement Park or Carnival Sounds	Music, laughter, and ride sounds for layouts featuring a fairground or amusement park.
Weather Effects	Thunderstorms, rain, or wind sounds to simulate weather conditions.
Animal Sounds	Farm animal noises or wildlife sounds for rural areas.

References

- Planner's Guides
- Getting Started
- Node Clusters
- Multi-Node Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide

- Configurator's Guides
- CDI Configuration Tool Installation Guide
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Turnout Card Planning Guide

Introduction

Turnouts define how trains move through a layout by determining which routes are available at any given time. In the LCC Fusion Project, turnout control is implemented using the **Turnout Card**, which drives turnout motors and generates events reflecting turnout state.

The Turnout Card does not decide *when* a turnout should move; it executes movement in response to LCC events generated by buttons, logic, schedules, or other automation.

> Turnouts define *where trains can go*; logic, signaling, and automation define *when and why routes change*. The Turnout Card performs motion only and never encodes behavior.

Planning Context

Turnout planning begins during layout design when you decide **where routes diverge and how those routes should be controlled**. Each turnout exists for a reason, such as enabling alternate paths, supporting operational flexibility, or enforcing safe train movement.

Planning involves determining: - Which turnouts are required for the intended operating scheme - How turnouts are grouped by location and function - Whether control is manual, automated, or a combination - How turnout state interacts with signals, detection, and routing logic

The Turnout Card supports multiple turnout outputs, so planning focuses on grouping related turnouts that can be served by the same card.

Physical Planning Considerations

A Turnout Card is installed in a **Node Bus Hub** and connects via cable to one or more **Turnout Breakout Boards**, or directly to turnout machines depending on the installation approach.

When planning turnout control: - Group nearby turnouts to minimize wiring runs - Consider the type of turnout motor being used (stall, servo, coil) - Plan for frog polarity control if required - Allow spare capacity for future track expansion

Breakout boards are typically placed near turnout machines to simplify wiring and improve serviceability.

Uses

Each use case below represents a **reason to include automated turnout control** in a layout design. You do not need to implement every item; each entry reflects a planning motivation rather than a required feature.

Category	Turnout control use	Description
Operations	Managing turnout positions	Control the precise position of each turnout, switching between "thrown" and "closed".

Category	Turnout control use	Description
Operations	Automating route selection	Automatically select routes for trains to ensure smooth transitions at junctions.
Operations	Creating complex track layouts	Operate layouts with multiple junctions and crossover points.
Operations	Reducing manual intervention	Minimize manual turnout operation during exhibitions or automated running.
Automation	Sequencing turnout movements	Execute predefined sequences of turnout movements for scenarios or displays.
Signaling	Integrating with signal systems	Synchronize turnout positions with signals for safe and realistic operation.
Coordination	Coordinating with train schedules	Align turnout movements with scheduled train movements.
Safety	Implementing fail-safe operations	Automatically set turnouts to a safe position during faults or emergencies.
Interaction	Enhancing layout interactivity	Allow operators to manually command turnout positions when desired.

References

- Planner’s Guides
- Getting Started
- Node Clusters
- Multi-Node Planning Guide
- Node Power Planning Guide
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Wired Node-to-Node Planning Guide

Introduction

In the LCC Fusion Project, reliable **wired communication** between nodes is achieved using the **CAN Bus** standard. CAN (Controller Area Network) provides robust, differential signaling that is ideal for noisy environments and long cable runs.

In addition to wireless options such as Wi-Fi and ESP-NOW (which are optional and not required to understand this guide), LCC Fusion supports wired node-to-node connections using a wired CAN Bus.

Configuring Wired Node-to-Node Communication

1. **Identify the Bus Ends**
   - CAN requires a linear bus with two ends.
   - Termination resistors (120 Ω across CAN_H and CAN_L) must only be present at the two endpoints.

   In the LCC Fusion Project:

   - The **Node Card**, **Quad-Node Card**, and **Node Bus Hub** all include **automatic termination circuits**.

     Automatic CAN termination applies when using LCC Fusion hardware exclusively; manual termination is only required when integrating non-Fusion CAN devices at the ends of the bus.

   - Termination is engaged only when the device is physically at the end of the bus.
   - No jumpers, switches, or manual configuration are required.

   When sharing the CAN Bus with other LCC devices (non-Fusion):

   - External devices generally **do not provide automatic termination**.
   - If such a device is at the end of the bus, its termination must be **enabled manually** or added with an external resistor.
   - Across the entire network—Fusion and non-Fusion combined—there must always be **exactly two terminations**, one at each end of the bus.

2. **Select Cabling**
   - Within the **LCC Fusion Project**, the CAN Bus is carried using standard **network cables (CAT5 or CAT6)**.
   - Standard network cables are used only as convenient twisted-pair wiring; Ethernet signaling or networking concepts do not apply.
   - These cables provide twisted pairs, which are ideal for differential signaling (CAN_H and CAN_L).
   - Using network cables ensures consistency, easy availability, and compatibility with Node Cards and Node Bus Hubs.

3. **Chain Hubs if Needed**
   - Multiple **LCC Fusion Project Node Bus Hubs (PCB boards)** can be interconnected to expand the system.
   - Each hub provides both **multiple 8-pin headers** (for direct board-to-board connections) and a **pair of RJ45 sockets** (for remote connections using standard CAT5/6 network cables).
   - Node Bus Hubs may be chained together as a **planning option** when layouts expand beyond a single physical hub.
   - This flexibility allows hubs to be chained together locally or over longer distances while maintaining proper signal integrity on the CAN backbone.
   - Automatic termination still ensures that only the physical endpoints of the combined chain are terminated.

     The diagram below is a conceptual illustration of CAN topology and hub relationships; it is not intended to represent exact wiring or physical placement.

```
flowchart LR;
nonFusionNode["Non-LCC Fusion<br>Node/Device<br>(CAN Bus Termination)"]
can(("CAN Bus"));
hub[["LCC Fusion<br>Node Bus Hub"]];
hub2[["LCC Fusion<br>Node Bus Hub"]];
n1[["LCC Fusion<br>Node Card<br>(CAN Bus Auto-termination)"]];
n2[["LCC Fusion<br>Node Card<br>(CAN Bus Auto-termination)"]];
pc[["LCC Fusion<br>Power-CAN Card"]];
iocards[["LCC Fusion<br>I/O Cards"]];
iocards2[["LCC Fusion<br>I/O Cards"]];
bb1[["LCC Fusion<br>Breakout Boards"]];
bb2[["LCC Fusion<br>Breakout Boards"]];
```

```
subgraph layout ["Train Layout"];
direction LR;
nonFusionNode --> can;
can --> n1;
can --> pc;
subgraph Installation ["LCC Fusion<br>Installation"]
n1 <--> |"CAN"|hub;
pc --> hub;
hub <--> |"CAN"|hub2;
hub --> |"Network Cable, or <br/> Direct Connection"| hub2;
hub --> iocards;
hub2 --> iocards2;
n2 <--> |"CAN"|hub2;
end;
iocards <--> bb1 <--> devices((Devices));
iocards2 <--> bb2 <--> devices2((Devices));
end;

classDef lSalmonStyle fill:#FFA07A,stroke:#333,stroke-width:2px,font-size:24px;
class hub,hub2 lSalmonStyle;
classDef lightGrayStyle fill:#d3d3d3,stroke:#333,stroke-width:2px,font-size:24px;
class layout lightGrayStyle;
```

Common Planning Notes

- CAN uses electrical bus wiring, not Ethernet networking.
- Automatic termination is handled by LCC Fusion hardware when used exclusively.
- Manual termination is only required when integrating non-Fusion CAN devices.
- Multiple Node Bus Hubs may be chained together to extend the bus.

For general questions about CAN wiring and behavior, see the main FAQ.

Benefits of Wired CAN in LCC Fusion

- **Reliable** – CAN is robust against electrical noise and long distances.
- **Modular** – Node Bus Hubs allow plug-and-play expansion.
- **Error-Proof** – Automatic termination prevents configuration mistakes.
- **Scalable** – Multiple hubs and nodes can be chained together as one continuous bus.

References

- Planner’s Guides
- Getting Started
- Scaling With PODs
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wireless Node-to-Node Planning Guide

- Node Bus Hub Installation Guide
- Power-CAN Card Installation Guide
- Configurator's Guides
- **Educational Media**
- – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Wireless Node-to-Node Planning Guide

Overview

Wireless node-to-node communication is an optional planning tool in LCC Fusion. It supplements wired CAN Bus in cases where cabling is impractical, temporary, or mobile.

Relationship to Wired CAN Bus

- Wired CAN Bus remains the primary transport for LCC Fusion
- Wireless does not replace CAN Bus
- Wireless links carry LCC traffic between nodes that are already part of the CAN Bus

When Wireless Makes Sense

- Hard-to-wire locations
- Temporary or portable modules
- Demonstrations and test setups
- Transitional layouts

What Wireless Is (and Is Not)

- IS: a transport mechanism between nodes
- IS NOT: a replacement for hubs, power planning, or clusters
- IS NOT: a hierarchy or control plane

Wireless Transport Options

LCC Fusion supports two wireless transport mechanisms, each with different planning implications:

- **ESP-NOW**
  - Peer-to-peer communication between ESP32 nodes
  - No SSID, password, or access point required
  - Lowest setup overhead; well-suited for quick deployment, portable layouts, and temporary installations
- **Wi-Fi**
  - Nodes communicate over a standard Wi-Fi network
  - Requires an access point and SSID/password configuration
  - Better suited when integrating with external systems, dashboards, or infrastructure networks

Pods and Wireless Connectivity

Wireless connectivity extends **CAN communications** between nodes without changing how hardware is physically organized.

In a wireless configuration:

- Nodes may communicate across **pods**

- Pods remain the physical build-out unit
- Power planning remains local to each pod or hub
- Nodes continue to operate as peers on the CAN network

Wireless links do not create a new grouping type and do not replace hubs, pods, or power planning. They provide an alternative transport mechanism for CAN participation when physical wiring is impractical or undesirable.

Tradeoffs and Constraints

- Range and interference
- Reliability vs wired CAN Bus
- Planning expectations

References

- Planner's Guides
- Getting Started
- Scaling With PODs
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- Power-CAN Card Installation Guide
- Configurator's Guides
- **Educational Media** – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Historic Circuits → Fusion Solutions (Planner)

[TOC]

Introduction

This planner page helps you translate **classic model railroad electronics** (as seen in magazines/books) into **modern LCC Fusion** solutions. Instead of building one-off relay/timer boards, you can select a Fusion **card + breakout** and drive it with **CDI-configured events**. The comparison table below shows the legacy function, the recommended Fusion hardware, and a short note on how it's implemented.

Scope: This project focuses on **DCC and automation**. Legacy DC-throttle "momentum/brake" add-ons are out of scope.

How to use this page - Find the legacy function you want (e.g., "grade crossing flashers").
- Use the **Fusion Card(s)** and **Breakout** listed to plan your build.
- Copy the suggested **implementation notes** into your wiring/config plan, then add CDI rules to generate/consume the needed events.

> Tip: Pair this planner with the individual Card Assembly Guides (e.g., Node Card) for wiring, addresses, and CDI examples.

Fusion Coverage: Historic Circuits → Fusion Solutions

Model Train Electronics Circuitry	Typical Usage	LCC Fusion Card(s)	Associated LCC Fusion Breakout Board	How it's implemented
Detecting Trains via Track Current	ABS / CTC signaling	**BOD/BSD Cards** (train detection)**PWM Card** (LED control)**Node Card** (Rules & Conditional Statements)	**Block Breakout Board** (block wiring)**Signals Breakout Board** (masts/lamps)	Train (current) occupancy events provide events for rule conditions to compute aspects; PWM drives mast LEDs (dimming, fades, warm-up).
Grade Crossing Controller	Flashers, gates, bell	**BOD/BSD Cards** / **POD Card** (train detection)**PWM Card** (LED control)**Servo Card** (Crossing arm movement)**Sound Card/Audio Card**(Crossing bells)	**Block Breakout Board** (block wiring)**Signals Breakout Board** (masts/lamps)**Servo Motor Driver Breakout Board**(servo wiring)	Train detection(current or position) ap-proach/occupy/clear events trigger flash patterns, gate motion, and bell/announcement audio.
Relay Based Controllers	Signal aspects & approach lightingcrossing flashers/gate sequencingroute locking (prevent conflicting moves)delayed on/off switching	**Node Card I/O**, **Digital I/O Card**, **Output Card** (switch relay on/off**Node Card** (Rules & Conditional Statements)**PWM Card / Servo Card / Turnout Card** (as targets)	**Relay Breakout Board** (only when switching track/power/AC loads)**Signals Breakout Board** (masts/lamps)**Servo Motor Driver Breakout Board**(servo wiring) **Turnout xx Breakout Board** (turnout wiring)	Replace ladder/relay logic with LCC rules and conditions that process events (BOD/POD/UOD/buttons) and emit actions (signals, turnout throws, DCC commands). Use **Relay Breakout** for high-power/AC switching; otherwise drive LEDs/servos directly via PWM/Servo/Turnout.
ATC / Cab Signaling (event → DCC)	Enforce stop/slow/go	**POD Card** (position/speed)**DCC Card** (commands)**Node Card** (Rules & Conditional Statements)	**POD Breakout Board**	Two train position timings are used to produce speed related events. Events are used by rule conditions to compute drive DCC speed/stop commands.
Station Stop / Dwell Timer	Auto stop/restart	**Node Card** (timers/rules)**POD Card** (position detection)**DCC Card** (Cab stop/start/delay)	**POD Breakout Board**	Train detection (position) events trigger cab events for stop and delay start.

Model Train Electronics Circuitry	Typical Usage	LCC Fusion Card(s)	Associated LCC Fusion Breakout Board	How it's implemented
Speed Trap / Scale Speed	Over-speed alerts, logging	**POD CardAudio CardNode Card** (speed zone firmware)	**POD Breakout Board**	Two sensors compute excessive scale speed within a speed zone triggering events for audio or output messages
Lighting Effects	Flicker, neon, warm-up	**PWM Card** (LED control)**Node Card** ()	**Signals Breakout Board**	CDI-selectable patterns on PWM outputs (flicker, fade, incandescent warm-up).
Sequential / Chase Lighting	Marquee / tower banks	**PWM Card**	**NeoPixel Breakout Board** (+ pixel string)	Event-triggered RGB patterns (chaser, marquee, fades) on addressable LEDs.
Sound Effects / Announcements	Bells, horns, TTS	**Sound Card** (MP3)**Audio Card** (.wav + TTS)	—	LCC events map to playlists or speech; volume/track selection via CDI.
Animations (general)	Gates, semaphores, cranes	**Servo Card** (servos)**PWM Card** (DC motors)	**Servo Breakout BoardTurnout Stall Switch Machine Breakout Board**	CDI motion profiles (travel, speed, easing); events start/stop sequences.
Auto-Reverser (loop)	Reverse polarity on short	**BRD Card**	**Block Breakout Board**	Short detection drives latching relay to flip polarity; emits LCC status events.
Frog Polarity Switching	Reliable turnout routing	**Turnout Card**	**Turnout Stall Switch Machine Breakout Board**	TQ relay follows turnout state to set frog polarity; sense lines can confirm position.
Short Detect → District Disconnect	Protect power district	**BLVD CardRelay Breakout Board**	**Relay Breakout Board**	BLVD event trips relay to open the district; CDI policy controls auto-restore.
Object / Presence Detection (optical/ultrasonic)	Triggers for logic	**POD Card**, **UOD Card**, **Sensor Card**	**POD Breakout BoardUOD Breakout BoardDigital Sensor Breakout Board**	Sensors generate enter/exit/threshold events for use by CDI rules.
Twin-Coil Turnout (CDU)	Snap-action machines	**Turnout Controller (CDU variant)**	—	Controlled capacitor-discharge pulses with interlock timing; event-driven.
Tortoise Slow-Motion Turnout	Stall motor control	**Turnout Card**	**Turnout Stall Switch Machine Breakout Board**	Direction/power handled on card; feedback lines generate LCC events when settled.

Model Train Electronics Circuitry	Typical Usage	LCC Fusion Card(s)	Associated LCC Fusion Breakout Board	How it's implemented
Turntable / Traverser Indexing	Indexed positions	**PWM Card** (step/dir)**Node Card** (rules)	**Stepper Motor Breakout Board** (A4988/TMC)	Homing + indexed stops; CDI "Go to track N"; optional accel/decel ramps.
Voice Control (Alexa → Events)	Dispatcher/ops voice	**Node Card** (Alexa mapping)**DCC Card**	—	Alexa intents defined in CDI → LCC Events; events drive DCC and Node actions.
Power Meter / Logger (bench/fascia)	Live VDC/I/alerts	**Node Card** (serial monitor)	*(Optional)* I^2C Display	Live telemetry via serial; optional LCD for quick viewing during tests.
Isolated Hub Linking / Bus Extension	Long-run reliability	**Node Bus Repeater Board**	—	Placed between Node Bus Hubs; extends/cleans segments; preserves auto-termination behavior.

References

- Planner's Guides
- Getting Started
- Node Clusters
- Multi-Node Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- Power-CAN Card Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media** – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Diorama Planning Example

Introduction

This example illustrates how LCC Fusion can be used to build an **interactive, self-contained diorama** that demonstrates automation, sensing, sound, lighting, and optional train interaction.

Unlike operational track scenarios, a diorama emphasizes **experience and interaction**:

- Visitors approaching the display
- Buttons triggering actions or narration
- Sound and lighting responding dynamically
- Optional rolling stock added later without redesign

This guide focuses on **planning decisions**, not installation or configuration.

Example Scope (Diorama)

The diorama includes:

- A static or lightly animated scene
- One or more interactive buttons
- Scene lighting
- Audio playback, including optional text-to-speech narration
- Optional proximity detection when a person approaches
- Optional short track section for a locomotive
- Optional reversing section for unattended operation

All components are contained within a **single Pod**, with breakout boards placed near scene elements.

Hardware Planning Summary (Diorama)

The table below identifies **required hardware** and **optional capabilities** commonly planned for an interactive diorama.

LCC Fusion Hardware	Quantity	Purpose
Node Bus Hub	1	**Required.** Distributes power and communication to all cards
Node Card	1	**Required.** Hosts the diorama logic, events, and configuration
Digital I/O Breakout Board	1	**Optional.** Connects buttons and diorama lighting
Button Card	1	**Required.** Handles visitor interaction via push buttons
Button Breakout Board	1	**Required.** Connects physical buttons to the Button Card
Sensor Card	1	**Optional.** Supports proximity or presence detection (e.g., visitor approaches)
Sensor Breakout Board	1	**Optional.** Connects IR, ultrasonic, or other sensors
Audio Card	1	**Optional.** Provides sound effects or narration to a diorama speaker
PWM Card	1	**Optional.** Controls scene lighting or simple signal lamps
Signal Breakout Board	1	**Optional.** Connects to LEDs and lighting circuits
UOD Card	1	**Optional.** Detects a person approaching the diorama
UOD Breakout Board	1	**Optional.** Connects ultrasonic or proximity sensors
BOD Card	1	**Optional.** Detects occupancy if a locomotive is added
Block Breakout Board	1	**Optional.** Connects to track feeders
DCC Card	1	**Optional.** Provides DCC power for a short track section
BSD Card (Block Reversing Detection)	1	**Optional.** Enables unattended or reversing track operation
BRD Breakout Board	1	**Optional.** Connects to mainline and reversing loop blocks

Key planning takeaway: A compelling diorama can be built with **just a Node Card, Node Bus Hub, and Button Card**, with all other hardware added incrementally to enhance interaction and realism.

Hardware Placement Strategy

Centralized Pod Components

All logic and control cards are typically centralized in a compact Pod:

- Node Card
- Node Bus Hub
- Button Card
- *(Optional)* Sensor, Audio, PWM, BOD, UOD, or DCC Cards

This simplifies:

- Maintenance
- Demonstration
- Transport of the diorama

Distributed Breakout Boards

Breakout boards are placed near scene elements:

- Buttons at visitor-accessible locations
- Speakers hidden within the scene
- Sensors aimed toward the viewer
- Lighting breakout near LED clusters
- Track breakout near rails *(if used)*

This keeps wiring short and unobtrusive.

Interaction Planning Examples

Visitor Interaction (Buttons)

Buttons may be planned to:

- Start or stop a scene animation
- Trigger sound effects
- Initiate narration
- Override automatic behavior
- Reset the diorama to an idle state

Buttons define **intentional interaction**, distinct from automated sensing.

Proximity and Presence Detection (Optional)

Using a Sensor Card or UOD Card, the diorama can respond when a person approaches:

- Wake the scene from idle
- Fade lighting up
- Play introductory audio
- Enable buttons only when someone is present

This supports hands-off operation in public settings.

Audio and Narration Planning

Audio can be planned for:

- Ambient background sound
- Discrete sound effects
- Spoken narration explaining the scene
- Text-to-speech playback for accessibility

Audio playback is **event-driven** and can be triggered by:

- Buttons
- Sensors
- Occupancy detection
- Timed automation

Lighting and Visual Feedback

Using a PWM Card, lighting may include:

- Scene illumination
- Indicator lights
- Status LEDs
- A simple two- or three-lamp signal

Lighting reinforces interaction and provides immediate visual feedback.

Optional Track and Train Integration

If a locomotive is added later:

- A **short block** can be defined using a BOD Card
- A **simple signal** can indicate block occupancy
- A **DCC Card** can power the track
- An **auto-reverse solution** can support continuous unattended operation

Planning for this early avoids redesign but does not require immediate implementation.

Power Planning Overview

- All cards receive power via the Node Bus Hub
- Breakout boards connect to the layout accessory bus
- Higher-current loads (lighting, motors, track) are isolated from logic electronics

This separation is especially important in compact diorama builds.

Why This Diorama Example Matters

This example demonstrates that LCC Fusion supports:

- Non-operational displays
- Educational and outreach projects
- Museum or club exhibits
- Incremental growth from static to interactive
- Adding trains *after* the scene is complete

It reinforces that LCC Fusion is not limited to track-centric automation.

References

- Planner's Guides
- Getting Started
- Node Clusters
- Multi-Node Planning Guide
- Node Power Planning Guide
- Sensor Card Planning Guide
- Button Card Planning Guide
- BOD Card Planning Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media**

  – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Half-Siding Planning Guide

Introduction

This guide defines the **minimum LCC Fusion hardware** required to implement a simple half-siding within a single Pod.
It is intended as a **planning reference**, not an installation or configuration guide.

The half-siding example represents a common real-world scenario: - A turnout branching from a mainline - A siding track protected by signals - Occupancy detection used to influence signaling and turnout behavior

This guide focuses on **what hardware is required**, **where it is physically placed**, and **how capacity is planned**.

> This example assumes familiarity with earlier planning guides and focuses on applying those concepts to a concrete layout scenario.

Example Scope

The half-siding includes:

- One turnout controlling access to a siding
- Signals governing movement into and through the siding
- Occupancy detection for mainline and siding blocks
- All components contained within a single LCC Fusion pod

No node-to-node networking is assumed.

Hardware Planning Summary

LCC Fusion Hardware	Quantity	Purpose
Node Card	1	Hosts firmware, logic execution, and LCC event handling for the half-siding
Node Bus Hub	1	Interconnects all cards in the pod and distributes power and communication
Turnout Card	1	Controls the turnout motor and reports turnout position
Turnout Breakout Board	1	Connects the Turnout Card to the physical turnout machine
PWM Card	1	Drives signal LEDs with controlled brightness and aspect control
Signal Breakout Board	1	Connects signal heads to PWM outputs
BOD Card	1	Detects block occupancy for the siding and mainline
Block Breakout Board	1	Interfaces between track wiring and the BOD Card inputs

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Hardware Placement Strategy

Centralized Pod Components

The following components are typically **centralized** in one physical location, such as under the layout or inside a control enclosure:

- Node Card
- Node Bus Hub
- Turnout Card
- PWM Card
- BOD Card

These cards: - Share power and communication via the Node Bus - Benefit from short, clean interconnections - Are easier to service and expand when grouped together

This centralized arrangement forms the **pod core**.

Distributed Breakout Boards

Breakout boards are placed **near the physical devices they serve**:

- Turnout Breakout Board near the turnout machine
- Signal Breakout Board near the signal mast(s)

- Block Breakout Board near track feeder connections

This placement: - Minimizes long runs of device wiring - Keeps high-current or layout-voltage wiring off the pod - Simplifies troubleshooting and future changes

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Block Planning Example

A typical half-siding may be divided into the following occupancy blocks:

- **2 blocks before the turnout** (approach / mainline)
- **1 block through the turnout**
- **1 block in the siding**
- **2 blocks after the turnout** (departure / continuation)

This results in **6 blocks total**, well within the capacity of a single BOD Card.

> A single BOD Card supports up to **8 blocks**, allowing headroom for expansion or refinement.

Signal and Lamp Planning Example

Signal planning directly affects PWM and Signal Breakout Board requirements.

Example signal usage for a half-siding:

- **Approach signal (mainline)** – 3 lamps

- **Turnout-protecting signal** – 3 lamps

- **Siding exit or clearance signal** – 2 lamps

- **Optional downstream signal(s)** – 2 lamps each

This example might include: - **5 × 3-lamp signals** - **8 × 2-lamp signals**

A single Signal Breakout Board supports up to: - **16 individual lamps** - Or combinations such as: - Five 3-lamp signals (15 lamps total) - Eight 2-lamp signals (16 lamps total)

Proper lamp counting during planning ensures: - Correct selection of PWM Cards - Correct number of Signal Breakout Boards - No redesign later due to capacity limits

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Power Planning Overview

Pod Power Distribution

- All LCC Fusion cards within the pod receive power via the **Node Bus Hub**
- Power and communication are distributed using **standard network cables**
- No point-to-point power wiring is required between cards

This keeps the pod compact and modular.

Layout Accessory Bus

Breakout boards connect to the **layout accessory bus**, not the Node Bus.

Typical uses include: - Turnout motor power - Signal LED power - Track connections for occupancy detection

This separation ensures: - High-current or layout-voltage wiring stays off the pod - Logic electronics remain isolated - Cleaner wiring and safer expansion

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Planning Notes

When planning a half-siding, consider:

- How many blocks are truly needed versus desired
- Whether signals protect individual blocks or grouped movements
- The number of lamps per signal mast
- Future expansion beyond the initial siding

These decisions influence **capacity planning**, not basic hardware selection.

Why This Example Matters

This half-siding example serves as:

- The first **multi-card planning reference** in the LCC Fusion documentation
- A realistic, compact operating scenario
- A reusable planning pattern for other scenes
- A bridge between dioramas and full layout planning

References

- Planner's Guides
- Getting Started
- Node Power Planning Guide
- Multi-Node Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Clusters
- Node Bus Hub Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media**

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Node Power Planning Guide

Introduction

When setting up your LCC Fusion Node Cluster(s) for model railroad automation, a crucial consideration is the choice of power supply configuration. Efficient power management ensures stable operations, longevity of the components, and safety. It is essential to understand the power requirements of each component within the cluster to ensure that your chosen power supply can adequately support the entire system without risk of overload or insufficient power delivery.

Below are options for powering the LCC Fusion Node Cluster using one or more power supplies and various connection option. Select a method that works best based on planned usage.

> **Note:** This document specifically addresses DC power supply configurations, as the LCC Fusion Node Cluster is designed to operate exclusively with DC power supplies. AC power configurations are not supported and are not covered here.

General Safety Recommendations:

- Always select a DC power supply rated above your calculated maximum load to ensure safety margins.
- Include fuses or circuit breakers appropriate for your setup to protect against shorts and overloads.
- Regularly inspect wiring for signs of damage or overheating.

Common Ground

A **Common Ground** is the shared **0 VDC reference** that ties together all logic, power, and devices in an LCC Fusion system. Without a common ground, signals between cards and breakout boards cannot be interpreted reliably, and current may return through unsafe or undefined paths.

How a Common Ground is Created

- The **Node Card** and **CAN-Power Card** establish the primary ground plane for the system.
- This ground is automatically distributed to all other cards through the **Node Bus Hub**.
- Breakout boards may connect to this same ground using the card's **LINE 8 selector**, which can be set to GND when a return path is needed.

Options for Connecting to the Common Ground

- **Line 8 GND (Card → Breakout)**
  - Required when the breakout board has no other valid ground reference.
  - Optional when the breakout board is powered from a **DC accessory bus** that already shares the same supply as the Node Card.
- **Layout DC Bus**
  - If the layout's DC accessory bus also powers the Node Card, its **negative rail (DC−)** is already common and can be used directly by breakouts.
  - If the Node Card and layout bus are powered by **different DC supplies**, their **DC− outputs must be bonded together** so they share the same reference.
- **AC or DCC Bus**
  - After rectification, the resulting DC− is floating until it is tied to the Node's GND.
  - In these cases, **Line 8 must be configured as GND** to provide a common return path.

Rule of Thumb

> All signals and devices must share one common ground for reliable operation. Tie all DC− rails to the Node's ground plane at a single point, and never attempt to bond power supplies at the AC input side.

LCC Node Cluster Power Consumption Guide

Power consumption can often be misunderstood when looking at individual component current ratings. At first glance, it may seem like an ESP32 drawing 200 mA could quickly consume available power in a 3A system. However, real-world power distribution accounts for **voltage levels, regulator efficiency, and actual current needs at different supply voltages**.

Higher input voltages reduce current draw at the source while allowing efficient conversion to lower voltages using switching regulators. This means that a **65W power supply is more than sufficient** to support an LCC Node Cluster with multiple I/O cards, breakout boards, and ESP32-based components.

This guide provides **realistic power consumption estimates** to help users select an appropriate DC power supply based on actual energy needs, rather than just summing up component current ratings.

LCC Fusion Cards/Boards	12 VDC Load (mA)	5 VDC Load (mA)	3.3 VDC Load (mA)	Power (W)	16 VDC Input (mA)	24 VDC Input (mA)	35 VDC Input (mA)	Notes
LCC Node Card (no I/O, WiFi, or Bluetooth)	5	80	2	**0.48W**	30	20	14	80 mA for ESP32 and manages Node Bus communication without Bluetooth and WiFi enabled. 7mA for idle regulators.
BOD Card (1 detection)	0	0	20	**0.16W**	10	7	5	27 mA for IC + 3mA for 1 LED on.
PWM Card (16 lamps @ 15%)	0	16×3	0	**0.32W**	20	13	9	3mA per LED.
Turnout Card (1 Tortoise)	20+20	0	1	**0.48W**	46	32	22	21 mA for Turnout Card components + 20 mA Tortoise
Output Card (8 LEDs @ 15%)	0	8×3	0	**0.16W**	10	7	5	7mA for ICs, 3mA per LED at 15% brightness with 1K resistor.

Network Power Considerations

The estimated power consumption for a basic signaling configuration (Node Card with 5 I/O cards and breakout boards) is **only ~2.6W** as shown below. This is significantly lower than the typical computer laptop **65W power supply capacity**, indicating **plenty of available power** for expansion.

Additionally, the **maximum current capacity of the Node Card power traces and regulators is 3A**, which is well above the estimated current draw in typical configurations. This means that **a single LCC Node Cluster can support a large number of hardware devices** within the network without exceeding power limitations.

Use Case	Card / Breakout Board	Power Supply @ 24 VDC (mA)
Detection, turnout, signaling for track spur	1x LCC Node Card1x BOD Card /w 4 detections1x PWM Card /w 16x LEDs on 1x Turnout Card /w 1x Tortoise	20071332Total 72 mA (1.7W)
Detection, turnouts, signaling for track siding	1x LCC Node Card2x BOD Card /w 8 detections2x PWM Card ea/w 16x LEDs 1x Turnout Card /w 2x Tortoise	20142648Total 108 mA (2.6W)

Power Sources for LCC Fusion Components

Component/Board	Power Supply (DC)	Node Bus Hub (DC)	Layout Power Bus (AC/DC/DCC	Notes	Ground Reference Requirements
LCC Node Card	Yes	No	No	Main processing and network hub.	Provides the system ground plane.

Component/Board	Power Supply (DC)	Node Bus Hub (DC)	Layout Power Bus (AC/DC/DCC	Notes	Ground Reference Requirements
All I/O cards	No	Yes	No		Automatically share ground via Node Bus Hub.
Block Breakout BoardBLVD Breakout BoardBRD Breakout Board	No	No	DCC	Routes Track Bus and Track Rails to attached card.	**N/A – Wiring-only breakout board.** Ground not used.
DC Motor Driver Breakout Board	No	No	ACDCDCC	Layout Power Bus AC, DC, and DCC supported via bridge rectifier	Either:1) **Line 8 of PWM Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.
Digital I/O Breakout Board	No	Yes	ACDCDCC5V	Layout Power Bus AC, DC, and DCC supported via bridge rectifier.<5V from Node Card I/O, Digital I/O Card, or Output Card (requires LINE 8 configuration)	Either:1) **Line 8 of PWM Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.
Digital Sensor Breakout Board	No	Yes	No	Uses Node Card (or Sensor Card) 5V/GND, converted to 3V3 and 5V for sensors (requires LINES 7/8 configuration for 5V/GND)	**Line 8 of Sensor Card is used.** No configuration required.
NeoPixel Breakout Board	No	Yes	ACDCDCC	Layout Power Bus AC, DC, and DCC supported via bridge rectifier.<5V from Node Card I/O or PWM Card (requires LINE 8 configuration for GND)	Either:1) **Line 8 of PWM Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.
Node Analog Sensor Breakout Board	No	Yes	No	Uses Node Card 5V/GND, converted to 3V3 for 3-wire sensors.	**Always uses Node GND via Line 8 (required).**
NFC Tag Reader Breakout Board	No	Yes	No		**Always uses Node GND via Line 8 (required).**
POD Breakout Board	No	Yes	No		Comparator outputs must be tied to Node GND.
Relay Breakout Board	No	Yes	ACDCDCC5V	Layout Power Bus AC, DC, and DCC supported via bridge rectifier.5V from attached card (requires LINE 8 configuration for GND)	Either:1) **Line 8 of Node Card I/O, Digital I/O Card, or Output Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.

Component/Board	Power Supply (DC)	Node Bus Hub (DC)	Layout Power Bus (AC/DC/DCC	Notes	Ground Reference Requirements
Servo Motor Breakout Board	No	Yes	ACDCDCC	Uses either:Layout Power Bus (AC, DC, and DCC) supported via bridge rectifier.12V from PWM Card (requires LINES 7/8 configuration for 12V/GND)	Either:1) **Line 8 of PWM Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.
Signal Masts Breakout Board	No	Yes	ACDCDCC	Uses either:Layout Power Bus (AC, DC, and DCC) supported via bridge rectifier.5V/12V from PWM Card (requires LINES 7/8, 15/16 configuration for VDC+/GND)	Either:1) **Lines 8/16 of PWM Card configured for GND**2) DC Layout Power bus shared with the Node Card's power supply.
Stepper Motor Breakout Board	No	No	ACDCDCC	AC, DC, and DCC supported via bridge rectifier.	Motor supply DC− must be bonded to Node GND for control signals.
Test Breakout Board	No	No	ACDCDCC	AC, DC, and DCC supported via bridge rectifier.	Rectifier DC− must be tied to Node GND.
Turnout - Twin-Coils Switch Machine Breakout Board	No	No	ACDCDCC	AC, DC, and DCC supported via bridge rectifier.	Coil supply DC− must be tied to Node GND.
Turnout - Servo Switch Machine Breakout Board	No	No	ACDCDCC	AC, DC, and DCC supported via bridge rectifier.	Servo supply DC− must be tied to Node GND.
UOD Breakout Board	No	Yes	No		Comparator outputs must be tied to Node GND.

Component/Board	Power Supply (DC)	Node Bus Hub (DC)	ACC BUS (DC)	Track Bus (DCC)	ACC BUS (AC)	Notes
LCC Node Card	Yes	No	No	No	No	Main processing and network hub.
All I/O cards	No	Yes	No	No	No	
Audio Breakout Board	No	Yes	No	No	No	
Block Breakout Board	No	No	No	Yes	No	
DC Motor Driver Breakout Board	No	No	Yes	Yes	Yes	Required 5V or 12 VDC from a power bus. AC, DC, and DCC supported via bridge rectifier.
Digital I/O Breakout Board	No	Yes	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier, or 5V via attached card (lines 7/8)
Digital Sensor Breakout Board	No	Yes	No	No	No	Uses Node Card (or Sensor Card) 5V/GND, converted to 3V3 and 5V for sensors.

Component/Board	Power Supply (DC)	Node Bus Hub (DC)	ACC BUS (DC)	Track Bus (DCC)	ACC BUS (AC)	Notes
NeoPixel Breakout Board	No	No	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier.
Node Analog Sensor Breakout Board	No	Yes	No	No	No	Uses Node Card 5V/GND, converted to 3V3 for 3-wire sensors.
NFC Tag Reader Breakout Board	No	Yes	No	No	No	
POD Breakout Board	No	Yes	No	No	No	
Relay Breakout Board	No	Yes	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier, or 5V via attached card (lines 7/8)
Servo Motor Breakout Board	No	Yes	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier. 12 VDC from Node Bus Hub via PWM Card
Signal Masts Breakout Board	No	Yes	Yes	No	No	Use of ACC BUS is optional
Stepper Motor Breakout Board	No	No	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier.
Test Breakout Board	No	No	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier.
Turnout - Twin-Coils Switch Machine Breakout Board	No	No	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier.
Turnout - Servo Switch Machine Breakout Board	No	No	Yes	Yes	Yes	AC, DC, and DCC supported via bridge rectifier.
UOD Breakout Board	No	Yes	No	No	No	

Note: While the Node Card itself usually receives its power from the accessory bus (if not from a dedicated power supply), many breakout boards will also draw some current from the same accessory bus. In several cases this is not just for the board's logic, but also to power attached I/O devices such as LEDs, relays, servos, or motors. When planning total accessory bus capacity, be sure to account for both the Node Cards and the cumulative loads from all connected breakout boards.

Power Supply Options for LCC Node Clusters

There are two main approaches to powering your LCC Node I/O cards and the attached LEDs, each with its benefits and considerations.

Option 1: Single Power Supply Configuration

The simplest method is to employ a single power supply to power both the LCC Fusion Node Cluster(s) and the layout accessories. In this configuration, all LCC Fusion Project components, including layout accessories like LEDs attached to the I/O cards, share a common ground. This approach minimizes complexity and reduces the number of components required. It's ideal for setups where all of the power requirements of the layout accessories and the LCC Fusion Node Cluster are within the capacity of a single power supply, ensuring a streamlined and efficient power management system.

Advantages of the single power supply configuration include:

- **Simplicity:** Easier setup with fewer components to manage.
- **Cost-Effectiveness:** Reduces the need for multiple power supplies, saving on costs.

- **Unified Grounding:** With a shared common ground, there's a reduced risk of ground loop issues, which can be crucial in sensitive electronic environments.

Option 2: Dual Power Supply Configuration

For more extensive setups or where the power demands exceed the capacity of a single supply, a dual power supply configuration can be used. In this scenario, one power supply is dedicated to the LCC Fusion Node Cluster and its I/O cards, while a second, separate power supply is responsible for providing power to layout accessory devices (i.e. LEDs, etc.). Importantly, these devices will ground through a layout accessory bus's common ground back to the second power supply. Despite using two power sources, both power supplies share the same ground—this can be achieved through a common power strip or connected to the layout room ground to ensure stability and prevent potential electrical interference.

The dual power supply configuration offers several benefits:

- **Flexibility:** Allows for greater power distribution thru segmentation, especially useful in larger or more power-intensive setups.
- **Stability:** By dividing the power load, each supply can operate within its optimal capacity, potentially increasing the lifespan of the components.
- **Safety:** Separating the power sources can enhance safety, as it allows for more controlled management of power flows and reduces the chances of overloading a single supply.

In summary, the choice between a single or dual power supply configuration depends on your specific needs, including the scale of your LCC Fusion Node Cluster, power requirements, and considerations for cost, complexity, and safety. It's essential to carefully plan your power supply strategy to ensure a stable and efficient operation of your model railroad automation system.

Use Cases

The LCC Fusion Project provides several methods of power a LCC Fusion Node Cluster, a single LCC Card, or just I/O cards. This can be useful while testing new hardware, configuring an LCC Node, or for distributing multiple LCC Node Clusters or I/O cards around an under your layout. These options can be use for both convience and simplifying layout wiring while providing optins for integration with a layout power grid.

Below is a table summarizing the use cases for each type of power input connector available with the LCC Fusion Project hardware. This table is designed to help planners choose the most appropriate connector based on their requirements, including the number of secondary LCC Nodes, LCC Node Clusters, LCC Node Bus Hub(s), and I/O cards to connect and their preferred power sources.

> Refer to Terminology for an explanation of terms used below

Connector Location	Power Input Connector	Power Module	Max Current / Voltage	Use Cases	Why Choose This?	Considerations
DevKit-C Module on LCC Fusion Node Card	USB Connector	No	2A / 5V	Use while testing a LCC Fusion Node Cluster and using the computer's serial monitor.	LCC Node has an integrated management system for bench testing hardware. Don't use for non-testing to prevent damage to the DevKit-C Module circuitry.	Use computer based serial monitors such as Arduino IDE, PuTTY, RealTerm,Tera Term, CoolTerm, and YAT.

Connector Location	Power Input Connector	Power Module	Max Current / Voltage	Use Cases	Why Choose This?	Considerations
LCC Node Bus Hub	USB-C Connector	No	3A / 5V	Use while testing or temporarily powering a small LCC Fusion Node Cluster.	Simplifies adding power from any location using a USB cable. When using a LCC Fusion Node Card, consider using a Power Module for more robust power supply and protection.	Use temporarily when 12 VDC+ is not required and working with a small LCC configuration. Computer power adapters can provide up to 3A with a USB-C plug.
LCC Node Bus Hub	1) Network Cable Sockets (RJ45)2) 8-Pin Female Pin Headers	No	600 mA / 3V3, 5V, 12 VDC+	Use when expanding the LCC LCC Fusion Node Bus with additional LCC Node Bus Hubs without a Primary LCC Fusion Node Card.	Required for expansion (secondary) LCC Node Bus Hub to receive power and communications from another LCC Node Bus Hub.Useful when powering additional Node Bus Hubs with centralized locations around the layout.	Use CAT6 network cable to carry more current. Secondary Node Bus Hub can be daisy chained together.
LCC Fusion Node Card	CAN Bus Network Cable Sockets (RJ45)	Yes	600 mA / 12-35 VDC	Smaller networks with a focus on simplicity and integration of power and communication in one cable. Ideal for scenarios where the layout is compact or the number of secondary LCC Nodes is limited.	Simplifies cabling by integrating power and communications. Less clutter and easier to manage in smaller setups.	Limited to 3-5 secondary LCC Nodes. Requires network cable between LCC Nodes.

Connector Location	Power Input Connector	Power Module	Max Current / Voltage	Use Cases	Why Choose This?	Considerations
Power-CAN Card	USB-C or DC-005 (barrel connector)	Yes	2A / 12-35 VDC	Medium-sized networks requiring more secondary LCC Nodes. Suitable for users with readily available USB-C power supplies (e.g., laptop chargers). Good balance between power capacity and convenience.	Easy connect/disconnect of power. Utilizes common, modern power supplies. Offers a good mix of power capacity and ease of use.	Suitable for a moderate number of secondary LCC Nodes.
Power CAN-Card	Spring/Screw Terminal, or ATX 5557 Connector	Yes	3A / 12-35 VDC	Larger networks with a higher number of secondary LCC Nodes. Ideal for users who prefer to use their layout accessory power supply, providing the highest power capacity.	Maximizes the number of secondary LCC Nodes that can be connected. Best for extensive layouts requiring significant power distribution.	Leverages existing layout accessory power supply.Supports max number of LCC Nodes.LCC Fusion Node Cluster can be serially connected using both input and output ATX connectors.

This table offers a straightforward comparison to help planners make informed decisions based on their specific needs and preferences for their model railroad automation projects. Each connector option caters to different scales and complexities of layout setups, ensuring flexibility and adaptability in planning and implementation.

References

- Planner's Guides
- Getting Started
- Multi-Node Planning Guide
- Node Clusters
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- Power-CAN Card Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media** – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

Pod Build-Out Planning Guide

Introduction

This guide focuses on **build-out options** for multi-node LCC Fusion systems.
Rather than describing individual cards in isolation, it explains how **multiple nodes, hubs, and power sources** are combined in real layouts.

The key architectural idea introduced here is the **pod**.

A pod is a **physical grouping of one or more Node Bus Hubs**, populated with Node Cards and I/O cards, and connected to the rest of the layout through the CAN network. Pods are the primary unit used when scaling a layout horizontally.

This document explains: - how multiple nodes coexist as peers, - how hubs are added to expand I/O capacity, - how power can be introduced at multiple points, - and why these configurations are **supported and safe by design**.

Nodes Are Peers

All LCC Fusion Node Cards are **peers** on the CAN network.

- No node is a master
- No node is designated "primary"
- Any node may generate or consume LCC Events
- Nodes may be added or removed without re-architecting the system

This peer model applies whether nodes are located: - on the same hub, - on different hubs within a pod, - or across multiple pods.

What a Pod Is (and Is Not)

A **pod** is a *physical planning concept*.

A pod: - contains one or more Node Bus Hubs, - may contain multiple Node Cards and I/O cards, - may have multiple power entry points, - shares CAN communications across all contained hubs.

A pod **is not**: - a logical hierarchy, - a single power domain, - or a control boundary.

Nodes inside a pod remain peers on the CAN network regardless of how power is distributed.

Expanding a Pod with Multiple Hubs

Why Multiple Hubs Exist

Each Node Bus Hub provides: - a fixed number of card slots, - local power distribution, - short, controlled signal paths.

As layouts grow, it is common to: - exceed the slot count of a single hub, - physically spread hardware across a layout, - or group I/O near the devices it controls.

Adding hubs is the intended expansion mechanism.

Power Distribution Philosophy

Power distribution in LCC Fusion is **intentionally flexible**.

Key design principles: - Power may be introduced at **multiple points** - Each hub may have its **own power source** - Built-in diodes prevent harmful back-feeding - Fusing protects against over-current conditions - Power sharing is allowed and expected

This allows real-world build-outs without artificial constraints.

Power Zones (Conceptual)

For planning purposes, it is useful to think in terms of **power zones**.

A power zone typically aligns with: - one Node Bus Hub, - its installed cards, - and its local power entry.

Power zones help reason about current consumption, but they do **not** imply strict electrical isolation unless explicitly designed that way.

Hub-to-Hub Connectivity Options

Node Bus Hubs can be connected in two common ways. Both are supported.

1. Board-to-Board (Pin) Connections

Used when hubs are: - physically adjacent, - acting as a local expansion.

Characteristics: - Power rails pass between hubs - CAN and I^2C are shared - The hubs behave as a unified local assembly

This is ideal for dense installations where hubs form a compact pod.

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2. Network Cable (RJ45) Connections

Used when hubs are: - physically separated, - located across a layout, - or expanded remotely.

Characteristics: - CAN communications are carried - Power *may* be carried depending on configuration - Each hub may have its own power source

This method is commonly used when hubs are mounted near the devices they serve.

Multiple Power Entry Points (Supported)

It is **fully supported** to power a pod using **multiple power sources**, for example:

- Hub A receives modest power via a network cable (e.g., under 1A)
- Hub B receives higher current from a local computer power supply (e.g., ~3A)
- The hubs are connected and share CAN communications
- Some power may naturally flow between hubs as loads demand

This is normal behavior.

Built-in diodes ensure: - current flows in safe directions, - supplies do not drive into each other, - and no damage occurs due to imbalance.

No special configuration is required.

Why This Is Useful

This flexibility allows builders to:

- inject power close to high-current I/O devices,
- reduce long power cable runs,
- reuse available supplies,
- scale systems incrementally,
- and avoid artificial “single supply” limits.

Rather than forcing rigid rules, the system supports practical layouts.

What Users Do *Not* Need to Manage

Because protection is built in: - users do not need to match supplies precisely, - do not need to balance loads manually, - do not need to configure jumpers, - and do not need to worry about harming hardware.

The system is designed to tolerate real-world variations.

Typical Pod Build-Out Examples

- One hub with multiple Node Cards and light I/O
- Two hubs sharing local power via pins
- Two hubs connected by network cable, each with its own supply
- One hub powered over network cable, another powered locally
- Multiple hubs spread across a layout, all within one CAN domain

All of these are valid.

Summary

This guide is about **build-out choices**, not restrictions.

Key takeaways:

- Pods are physical groupings of hubs
- Nodes are always peers
- Hubs are added to expand I/O
- Power may be injected at multiple hubs
- Mixed power sources are supported and safe
- CAN communications remain unified across the pod

By design, LCC Fusion supports growth without forcing rigid power or topology rules.

References

- Planner’s Guides
- Getting Started
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide

- Power-CAN Card Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
- **Educational Media**

  – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Scaling With PODs

Purpose

This guide explains how **LCC Fusion systems scale over time** using **PODs** as the primary physical build-out unit.

Rather than focusing on individual cards, this document describes: - when to add more hardware, - how expansion is structured, - and how power and communication scale together.

This is a **planning guide**, not an assembly or configuration reference.

Scaling Philosophy

LCC Fusion is designed for **incremental growth**.

Systems typically start small: - one Node Card, - one Node Bus Hub, - one power source.

As layouts evolve, capacity is increased by: - adding Node Cards, - adding Node Bus Hubs, - adding additional power entry points, - and organizing hardware into PODs.

Scaling does not require redesigning existing installations.

What a POD Represents

A **POD** is a **physical grouping of one or more Node Bus Hubs** installed near the devices they serve.

A POD may include: - multiple Node Bus Hubs, - multiple Node Cards and I/O cards, - one or more power sources, - wired and/or wireless CAN connectivity.

A POD is used to describe **physical build-out**, not logical control.

When to Add Another Hub

Adding a Node Bus Hub is appropriate when:

- available card slots are exhausted,
- I/O devices are spread across a larger area,
- it is convenient to place hardware closer to field devices,
- or additional local power capacity is needed.

Multiple hubs may exist within a single POD or across multiple PODs.

Power Scaling With PODs

Power scaling is achieved by **adding power where it is needed**, not by increasing a single centralized supply.

Common patterns include: - one power source per Node Bus Hub, - multiple power entry points within a POD, - mixed power sources (e.g., network cable power and local supplies).

Built-in protection allows multiple power sources to coexist safely without manual configuration.

Power Zones (Planning Concept)

For planning purposes, each Node Bus Hub can be considered a **power zone**.

A power zone: - defines a local current envelope, - simplifies reasoning about load placement, - does not require strict electrical isolation.

Power zones are a planning aid, not a rigid rule.

Scaling Across a Layout

As layouts grow, PODs are commonly:

- placed near groups of turnouts, signals, or detectors,
- connected via wired CAN or wireless links,
- powered locally to reduce long power runs.

This approach improves: - fault isolation, - wiring simplicity, - and long-term maintainability.

Wired and Wireless Expansion

PODs may be connected using: - wired CAN connections, or - wireless CAN connectivity (such as ESP-NOW).

Wireless links are used when: - wiring is impractical, - distance is significant, - or modules must be movable.

Wireless communication extends CAN participation but does not change POD structure.

What Scaling Does *Not* Require

Scaling with PODs does **not** require: - designating primary or secondary nodes, - centralized power supplies, - reconfiguring existing nodes, - or restructuring the CAN network.

Nodes always operate as peers.

Typical Scaling Examples

- One POD with multiple hubs serving a dense yard
- Multiple PODs distributed around a layout
- A POD powered locally with an additional POD powered remotely
- Mixed wired and wireless POD connections
- Incremental expansion as new layout sections are added

All are supported configurations.

Summary

Scaling with PODs provides a clear, repeatable way to grow LCC Fusion systems:

- PODs organize physical hardware
- Hubs expand I/O capacity
- Power is introduced locally and incrementally
- Nodes remain peers on the CAN network
- Expansion is additive, not disruptive

This model supports layouts ranging from small test setups to large, distributed installations.

References

- Planner's Guides
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- **Educational Media** – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics

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Servo Card Planning Guide

Introduction

Servo motors on a model railroad layout provide **controlled, repeatable mechanical movement**, enabling realistic animation and precise positioning of layout elements.

In the LCC Fusion Project, servo-driven devices are implemented using the **Servo Card**, which generates controlled PWM signals in response to LCC events. These events originate from buttons, sensors, logic rules, or automation sequences elsewhere in the system.

> Servos define *how something moves*; logic, signaling, and automation define *when and why it moves*. The Servo Card executes movement commands only and never encodes behavior.

Category	Servo Use	Description
Turnouts	Turnout control	Use servos to control turnouts (switches), enabling smooth and reliable route changes.
Signaling	Signal operation	Operate semaphore or mechanically driven signal aspects using servos.
Signaling	Level crossing gates	Open and close crossing gates in coordination with train movement.
Operations	Coupler operation	Automate coupling and uncoupling of rolling stock.
Operations	Transfer tables	Move transfer tables to align tracks in engine or service facilities.
Operations	Turntables	Rotate turntables for directing locomotives.
Operations	Cargo and crane operations	Drive cranes, loaders, or hoists for industrial scenes.
Structures	Drawbridge movement	Raise and lower drawbridges or lift bridges.
Structures	Engine house doors	Open and close engine house or workshop doors.
Structures	Station platform doors	Simulate platform doors synchronized with train arrivals.
Scenery	Animated scenery elements	Animate windmills, water wheels, cable cars, or similar features.
Scenery	Pop-up scenery	Trigger pop-up figures, animals, or scenic elements.
Scenery	Variable terrain	Adjust terrain elements such as mine elevators or water levels.

Category	Servo Use	Description
Scenery	Scenic effects	Create dynamic scenic motion effects.
Scenery	Diorama movements	Add motion to diorama scenes for enhanced realism.
Vehicles	Moving vehicles	Control steering or motion of road vehicles.
Facilities	Load/unload mechanisms	Automate loading and unloading of cargo.
Facilities	Track cleaning	Operate track-cleaning mechanisms.
Information	Station announcement boards	Animate mechanical or visual announcement boards.
Infrastructure	Rotating antennas or dishes	Rotate radar dishes or antennas for industrial or military scenes.

Planning Context

Servo planning begins when you decide **what elements of the layout should move and why**. Each servo-controlled device should exist for a clear operational or scenic purpose, such as controlling turnouts, operating signals, animating scenery, or enabling interactive features.

Planning involves determining: - Which layout elements require precise or repeatable motion - Whether movement is operator-driven, automated, or both - How many servos are needed and how they are grouped per card - Physical placement of servos relative to the mechanisms they drive

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Uses

The table below lists common planning use cases that drive the need for this card. Each entry represents a reason to introduce this capability into a layout design.

References

- Planner's Guides
- Getting Started
- Scaling With PODs
- Pod Build-Out Planning Guide
- Node Power Planning Guide
- Wired Node-to-Node Planning Guide
- Wireless Node-to-Node Planning Guide
- Node Bus Hub Installation Guide
- Configurator's Guides
- CDI Configuration Tool Installation Guide
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- – Understanding LCC Fusion – A Clear On-Ramp into LCC-Based Layout Automation – LCC Fusion Podcast – Fusion Hardware Architecture Overview – LCC Fusion Podcast – Cards & Node Basics