Building and Deploying Enterprise-Wide Design and Drafting Tools for Hybrid Fiber Coaxial Networks

A technical paper prepared for SCTE TechExpo24 by

Kathy Binns
Program Delivery Director
Comcast Cable
Kathy_Binns@cable.comcast.com

John Schlack
Distinguished Architect
Comcast Cable
john_schlack2@comcast.com

Rina Hayashi
Senior Director, Product Management
Comcast Cable
Rina_Hayashi@comcast.com

List of Figures

1. Introduction

Network design tools have struggled to keep pace with the ever-evolving demands of the cable industry. The need for frequent updates due to new construction, technologies and network expansion has highlighted the limitation of existing design tools. An access network design tool that is tailored to address the unique challenges of the cable industry was needed.

The program focuses on incorporating innovative technologies and setting up the product to leverage artificial intelligence and machine learning easily. This will improve the access network design operations. By leveraging agile development processes and working closely with network design stakeholders, our new access network design tool aims to alleviate the inefficiency and restrictive tendencies of existing tools. Through painstaking design and development, we worked to create a seamless user experience that would be least disruptive to our user community.

This document outlines the challenges of existing tools, along with designing, developing, and deploying a tool specific to access network design. We highlight the key milestones and challenges faced along the way of working on this five-year journey.

2. Challenges in Existing Tools

Companies may be using multiple access network design tools across their footprint. However, many access network design tools were stagnant in innovation, cumbersome to use, slow in performance and offered few integration opportunities. To meet business needs, additional tools and processes may need to be created to circumvent these challenges.

3. Development of a New Access Network Design Tool

Access plant design is a complicated and highly specialized aspect of the cable industry. Not everyone working in the cable industry is familiar with its complexities and underlying technology. Conversely, not all access plant designers are versed in product development and best practices. Most of the product development team are from different organizations who were not specialized in access plant design. This presented a significant challenge in developing a tool for a user group the team had limited knowledge about. The team needed to be creative in overcoming this gap.

To supplement the development team with plant design knowledge, we entered into a Joint Development Agreement (JDA) with an access network design firm. The firm brought design knowledge that helped guide the discussions around what would be a minimally viable product. In parallel, learning about cable operations, engaging directly with stakeholders, and learning to ask the right questions were integral parts of our journey. The product development team worked strategically to expedite the development and adoption of our access plant design tool. The team identified that instead of working with a large pool of people, it was more effective to collaborate with identified leads from each division. The leads from each division brought valuable access network design knowledge that the product development team lacked. This helped create a collaborative team that grew trust with the division leads, as it allowed them to know we were building a tool for them and that we understood their business needs.

As we overcame these challenges and refined our approach, we developed a comprehensive deployment strategy critical to our success. The next section will discuss this strategy, focusing on the successful integration of existing workflows and downstream tools that are heavily used by our network technicians. By leveraging our stakeholders' expertise and employing agile principles, we identified problem areas ahead of time and mitigated them so that we had a smooth deployment process and enabled adoption.

4. Deployment Strategy

When landing on a deployment strategy, we knew that the best, but also the most challenging, method would be a hard cutover. The deployment process would be without rollback options, and we would need to do it right the first time. There were technical hurdles to overcome and notable change management opportunities.

4.1. Extract, Transform & Load

The team developed an Extract, Transform, and Load (ETL) process that would extract data from a relational database and load it into a distributed systems architecture, while transforming the data model in a way that would bring us flexibility and growth capabilities. We knew that we would need to phase the deployments to allow for the transition to have the least amount of impact. By breaking the rollout into regional areas, we were able to accommodate the uniqueness of each region when moving over tens of millions of data points each time. We built a timeline that would let us complete a full rollout over 12 months, giving each regional area time to prepare their legacy data before extracting it into the new data model.

The deployment team stepped through multiple dry-runs for each transition and built the muscle-memory needed to seamlessly move the data from one system to another. After several single-region updates, the team stretched that muscle-memory and created a launch-stacking process that allowed them to do two regional areas at the same time. This improvement had the potential to cut our overall rollout timeline significantly and created exciting momentum for the team.

4.2. Change Management

Implementing a change management process was challenging since we had already been partnering with leaders in access network design for four years. Building this partnership meant that many of our users were as invested in the success of the deployment as we were.

We built our deployment schedules in such a way that we could mitigate unique regional risks. As an example, some areas of the country were heavily impacted by collegiate activity and needed to have their launch on the calendar months before, or after, the end of the summer to accommodate their business needs.

Our guiding principles during the change process were transparency and communication. By keeping these at the forefront of our planning, implementation of our change management plan, as shown in Figure 1, was very well-received. We were able to show our users that we were making the change with them, not to them.

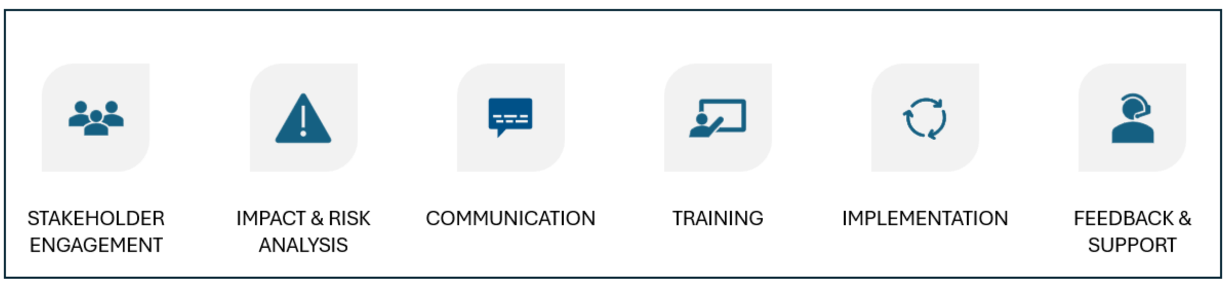

Figure 1: Change Management Milestones

4.3. Integration with Downstream Tools

Our legacy design tool provided a data source that had been integrated into over 100 custom tools and reports over the last decade. Many of these tools integrated with the raw data, while others were one degree removed, levering a comprehensive collection of Geographic Information System (GIS) layer services as shown in Figure 2

The deployment team implemented a company-wide audit of our outside-plant tools with the goal of identifying as many of the tool owners possible. We reviewed requirements with the users and owners and winnowed the list to a much smaller subset of tools supported by the GIS layer services.

We then had a new challenge: Do we build a set of GIS layers for our new tool while maintaining the existing layer services during our 12-month rollout process? Surprisingly, the answer was no. Instead, our team developed a hybrid data model that would ETL data from both sources into a single set of GIS layer services. Another benefit to this solution was that the team maintained the same endpoints for all existing layer services. This meant that those downstream tool owners did not have to make a single change to seamlessly incorporate design information from the new tool.

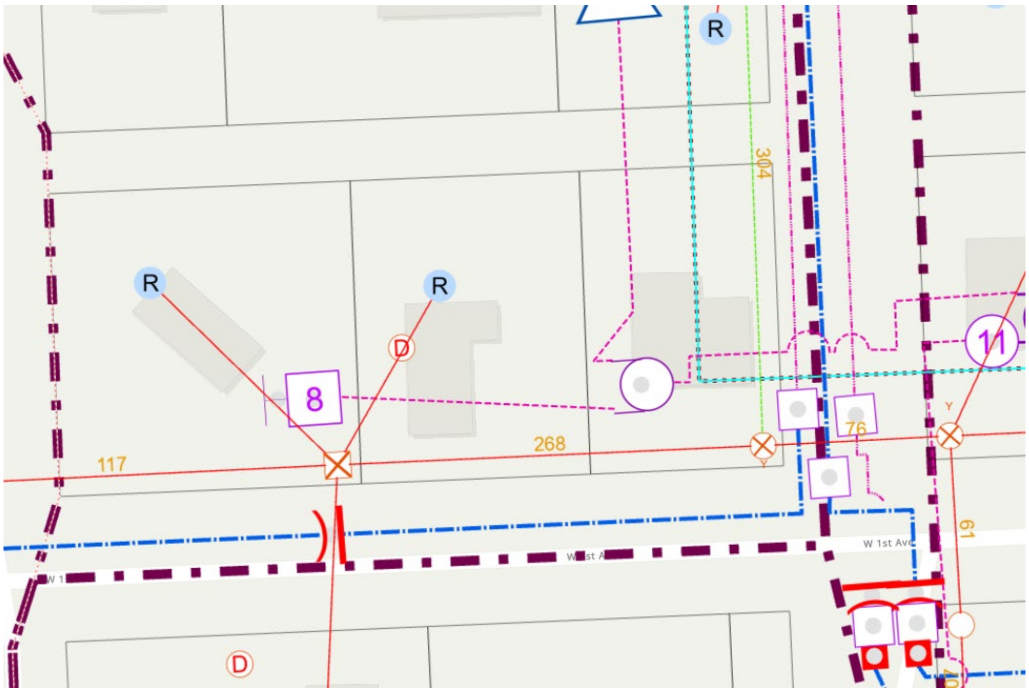

Figure 2: GIS layer services map rendering

4.4. Training

A key component to our change management plan is a successful training strategy. In addition to providing extensive training classes, videos, and user manuals, the team conceptualized building a group of subject matter experts from our user base in each regional area. These experts would receive first access to the design tool and training videos and function as the first line of support for their colleagues.

This strategy provided the extra benefit of having a new set of champions for the change. As our experts began to learn how to use the new tool, they could experience the features and improvements firsthand. They shared their experience with their teams and the deployment process shifted from a push to a pull as the anticipation of using the new tool started to grow. The two-day training course held during the launch process was extremely well attended in every region, due in no small part to the excitement that our experts, aka champions, built for us.

5. Features of the Design & Drafting Tool

5.1. Speed

The first thing users will notice about our new design and drafting tool is the ability to launch map-based navigation and display plant data in a matter of seconds. Time efficiency is always an opportunity, and this tool delivers a lightning-fast first impression.

5.2. Integration

After launching the application, the design tool offers a workflow that integrates with other internal services, ensuring that each designer's work ties back to our business requirements. In addition to a formal design workflow, there is a quick editing function that can be used to update our record of the production network based on feedback from our field operations teams.

5.3. HFC Node / EPON / rOLT

Placing a hybrid fiber coaxial (HFC) Node in a design is as simple as locating a support structure and selecting the node attribute details as shown in Figures 3-5. The node is placed on the map with the fiber and coax port internals already built, and the only remaining steps are to configure the ports and select the splice connections. Similar to building a HFC Node, ethernet passive optical network (EPON)/remote optical line terminal (rOLT) drafting could not be easier with our new design tool.

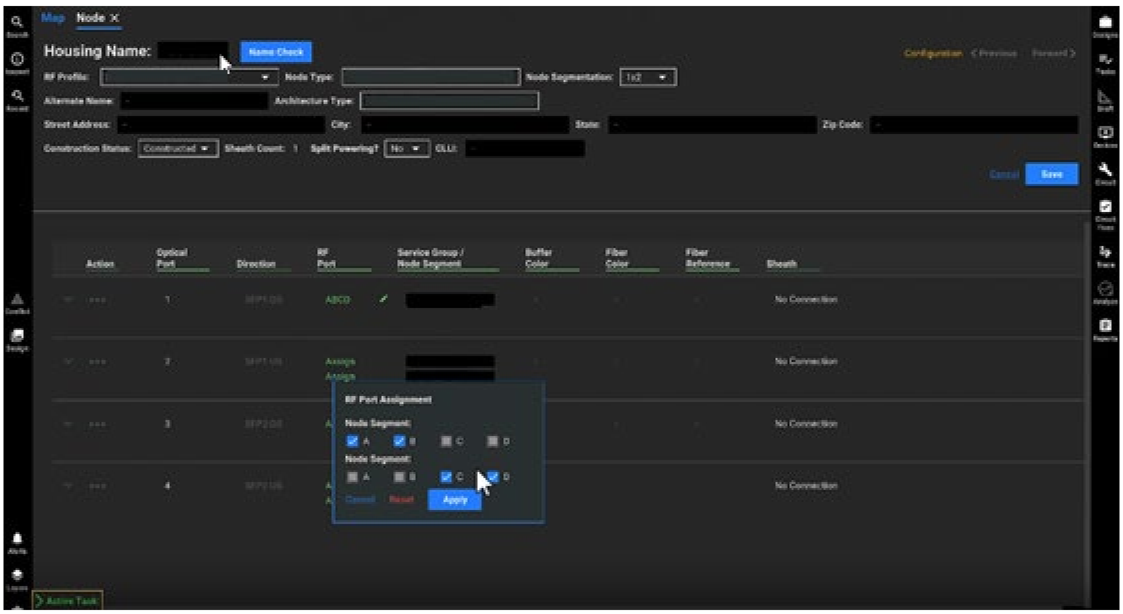

Figure 3: Design tool HFC node configuration

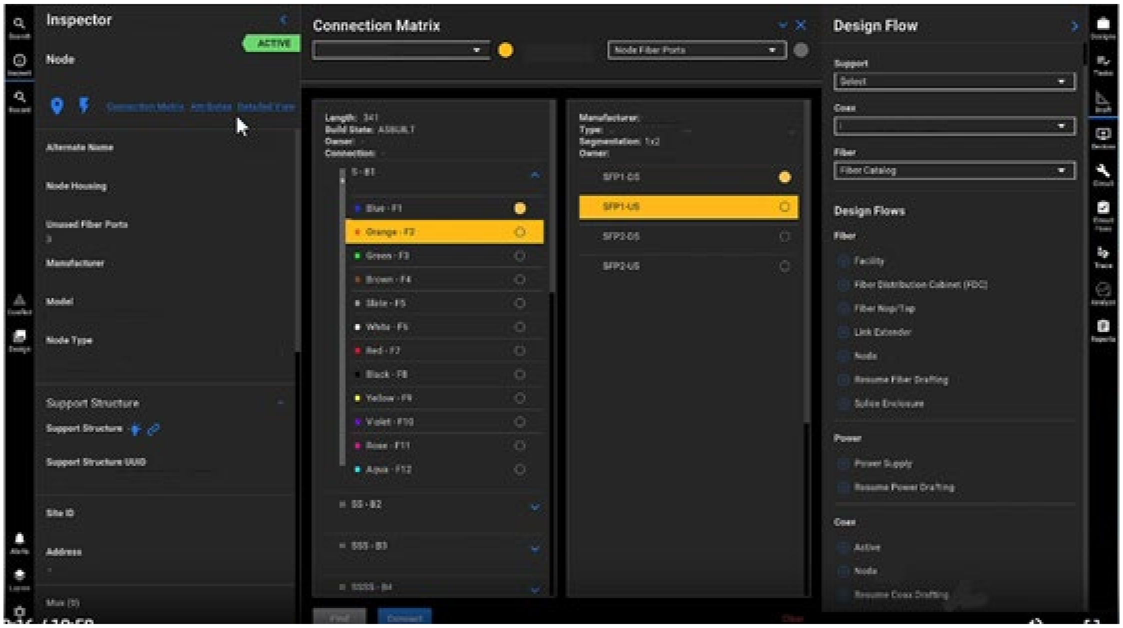

Figure 4: Design tool HFC node connection matrix

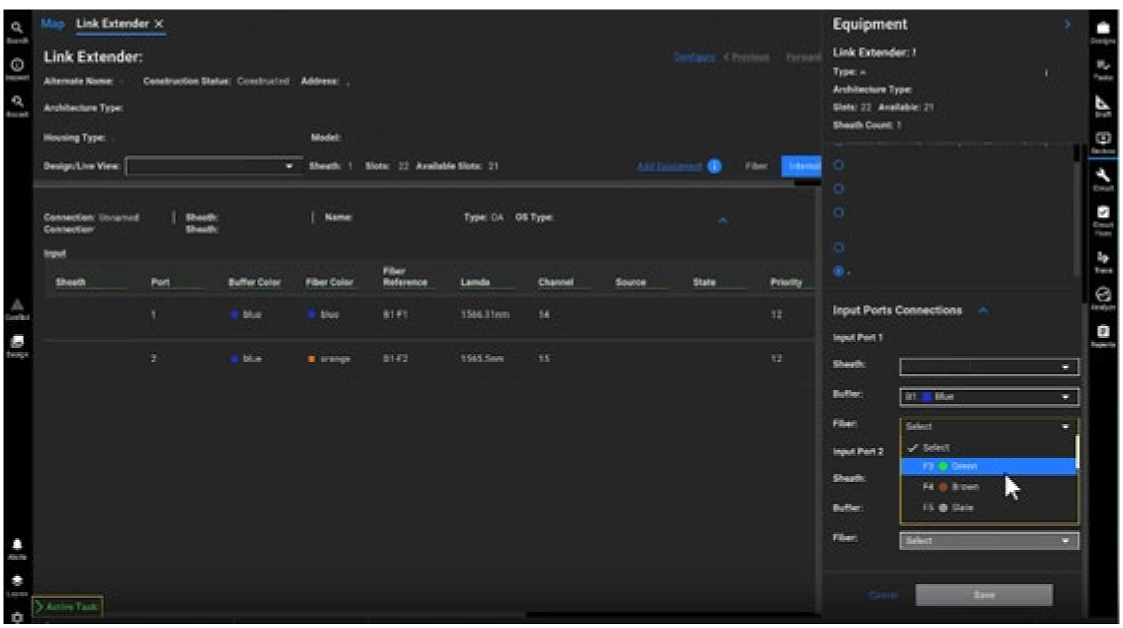

Figure 5: Design tool link extender port configuration

5.4. Fiber Tracing

Single, bi-directional, and optical time domain reflectometer (OTDR) fiber tracing is easily performed starting at the design map and navigating into the detailed view of any fiber housing. Trace results are quickly viewable on a map and in stepwise fashion in a separate panel. These results can be exported and are saved for the user in a history view. Future integration of OTDR capabilities with a proprietary fiber monitoring system will enable us to validate and monitor fiber installations real-time and pinpoint issue locations within seconds.

5.5. Web Viewer

Many, if not most, users of design data want easy access to live data without having to install a client application. For those users, we launched a companion web-based viewer that provides instant access to live data and lets the user perform detailed lookups as well as fiber tracing and reporting. The web viewer provides potential for significant expansion opportunities in the future. One such opportunity is design automation.

6. Design Automation

Creating and deploying our own Design and Drafting application provides us with the ability to add new and innovative features to the drafting process. One such innovative feature is design automation.

6.1. What is Design Automation?

Design automation is the process of automatically generating all or part of the drafted design for a construction job. Design automation executes against the "AS BUILT" network to create a design layer containing the proposed design applicable to that construction job type.

Benefits of design automation include reducing manual efforts, producing consistent designs regardless of the experience of the designer, improving analytics, and reducing time to deliver designs. Improvements in quality enable better troubleshooting during network impairments. Improved design delivery times mean that new technologies can be scaled out into the network faster.

The HFC capacity upgrade job type makes for an ideal initial design automation candidate. Operators of HFC Networks continue to deliver advancements in speed, capacity, and performance. Also, HFC capacity upgrades have well-documented design steps consistent across several types of capacity upgrades, including mid-split and data over cable service interface specification (DOCSIS®) 4.0 versions.

The figure below shows the revised design process when incorporating Design Automation for HFC node upgrades. HFC nodes are identified for upgrade based on capacity requirements and operator plans. Design Automation automatically examines all construction jobs in the "Design" state and determines if the construction job is eligible for automation. Design automation executes for the designated construction job types, creating a design layer with the proposed design changes for the HFC node upgrade. A designer reviews the proposed design and optionally makes any necessary adjustments. The designer submits the design when it is complete to advance the construction process.

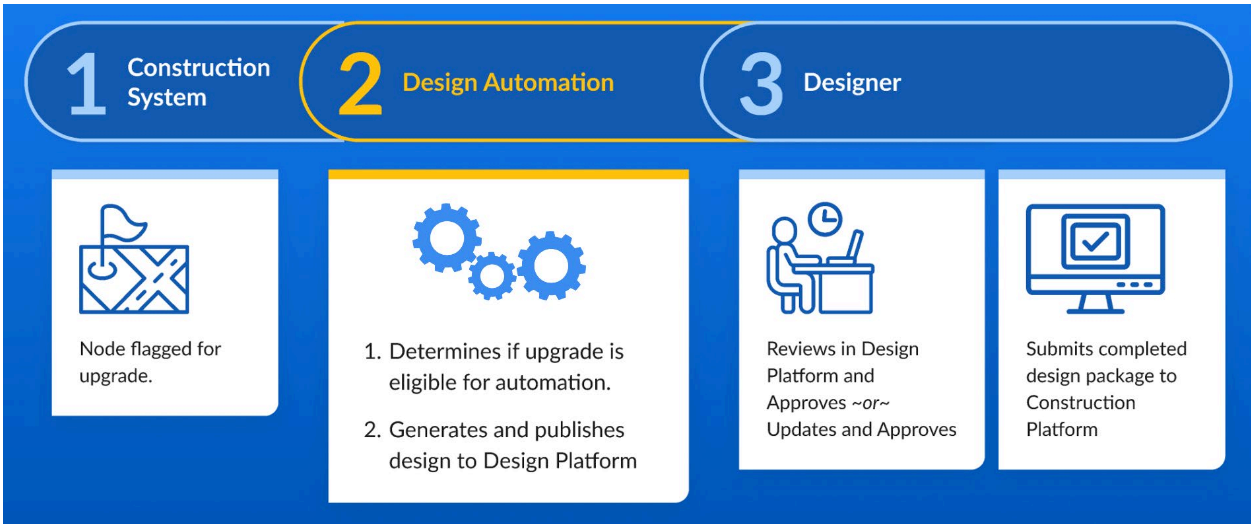

Figure 6: Design Automation Flow

Design automation uses a combination of algorithms, rules-based processing, machine learning, and generative design. Generative design is a set of optimization algorithms that use various inputs and constraints to iteratively process and improve upon a design until a "best fit" solution is found.

The sections below introduce the design automation concepts for the specific case of DOCSIS 4.0 node upgrade. They discuss some of the challenges that are encountered and places where generative design are applied. Details for addressing these challenges and methods of implementing these algorithms will be provided in future papers.

6.2. DOCSIS 4.0 Node Upgrade

The figure below enumerates the DOCSIS 4.0 node upgrade steps. Additional details appear in the following sections.

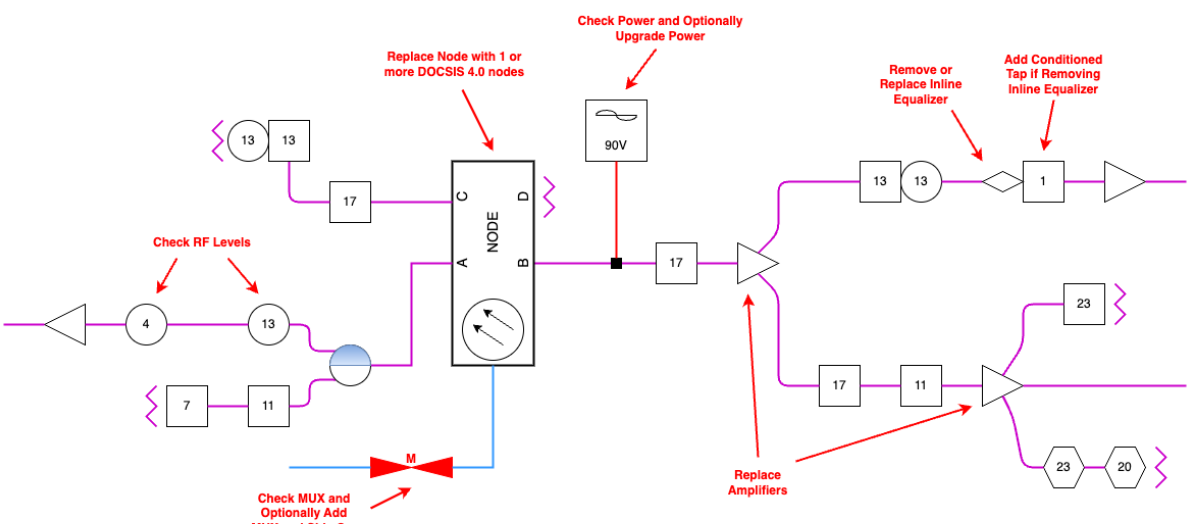

Figure 7: DOCSIS 4.0 Node Upgrade Overview

6.2.1. Dictionary Management

The design and drafting system includes a dictionary that specifies the set of equipment that can be used for drafting. The dictionary elements specify metadata such as manufacturer and model along with operational parameters such as power usage and output levels. Dictionary elements are organized by equipment type (nodes, amplifiers, RF Taps, coaxial cables, etc.). The equipment dictionaries specify both equipment that can be used for drafting today and historic equipment that has been used for drafting in the past.

Design automation needs additional information in the equipment dictionaries to identify which equipment can be used by design type. Some equipment may apply to multiple types of design automation. Design automation needs to be able to programmatically examine the equipment dictionary and find the candidate equipment definitions for each design type.

6.2.2. Nodes

6.2.2.1. Node Segmentation

Node segmentation refers to the number of downstream and upstream communications channels dedicated to a single node housing. A single downstream and a single upstream channel shared by all subscribers serviced by that node housing is referred to as 1x1 node segmentation. A digital node with two downstream channels and four upstream channels is referred to as 2x4 node segmentation.

DOCSIS 4.0 nodes will be deployed with 1x1 and 1x2 node segmentation. Existing nodes that are being upgraded and have more downstream or upstream channels will require a node split. Another condition for a node split occurs when one bus leg of the original node housing has significantly more homes passed than the other bus legs. For example, there may be a large multi dwelling unit (MDU) that has been added to the node after the original design.

6.2.2.2. Node Replacement

Node replacement is a straightforward process. The replacement node is positioned at the original node housing location. All DOCSIS 4.0 node housings in the equipment definitions currently have the same characteristics, and therefore selection comes down to a vendor preference from the region or market.

The DOCSIS 4.0 node housing only requires two fibers – one downstream and one upstream. If the node housing is configured with 1x2 node segmentation, the upstream fiber will carry data from both node segments multiplexed together on the same wavelength. Since these are digital nodes, the “multiplexing” is simply handled by tagging the messages appropriately.

Design automation must also address the impact of the design changes on the network map. If the original node housing and DOCSIS 4.0 node housing do not use the same symbol on the map, then it is possible that the insertion and connection points on the node symbols differ. If this is the case, then the position of the connections to the fiber cables and coaxial cables will change. A symbol change requires recalculation of the connection point and moving the end points of the fiber and coaxial cables appropriately to line up with the symbol’s connection points.

6.2.2.3. Node Split

Node splits are more complex than they may seem. Simply replacing the original node with two co-located DOCSIS 4.0 nodes may not lead to optimal performance of the DOCSIS 4.0 network. By installing three or four DOCSIS 4.0 nodes and moving the nodes away from the central point and into the bus legs, the number of cascaded amplifiers decreases, which leads to better network performance. An ideal location to install the node housings would be existing amplifier locations. Amplifiers typically have multiple output that can easily be connected to the RF ports on the replacement node housing. Power is guaranteed to be available at this location.

The figure below shows the node housing and amplifiers of an example network before the node split. The amplifiers colored in red are targets for the new DOCSIS 4.0 node housings. Note that an amplifier replaces the existing node housing when the A and C bus legs are combined.

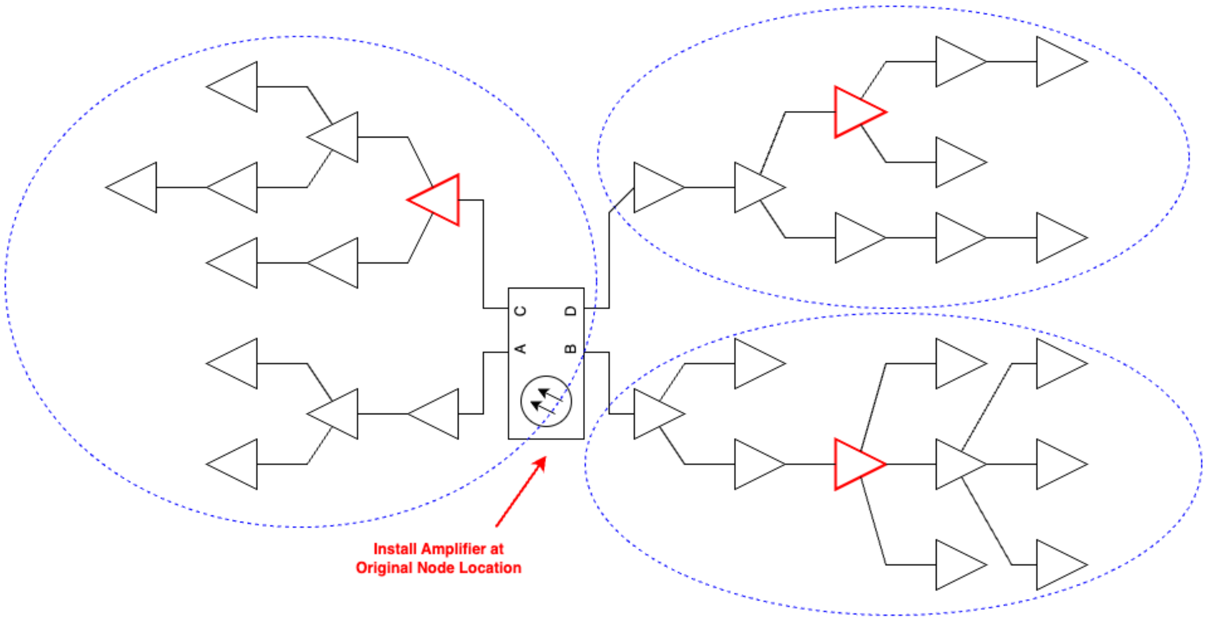

Figure 8: Node Split Analysis

With a small number of amplifiers, it might be possible to simply calculate every combination of two to four node housings at each amplifier location to find the optimal network layout. However, as the number of amplifiers in the RF network increases, the number of combinations increases exponentially. Therefore, a generative design solution is appropriate.

Generative design searches through a set of possible solutions to select the "best fit" option. Since it may not be possible to examine every combination of solutions, the "best" solution may not be optimal, but is the best of the potential solutions examined that meets the requirements and constraints of the system. For the node split case, the generative design algorithm provides the original RF network with requirements to split the network into a set of sub networks, inserting a DOCSIS 4.0 node into each sub network. Constraints are added to limit the maximum cascaded amplifier count, balance homes passed, and ensure RF level requirements are met.

Visual adjustments are needed at each of the DOCSIS 4.0 node locations. Place the DOCSIS 4.0 node housings at the original amplifier locations to minimize equipment overlap. The connection points on the DOCSIS 4.0 node housing do not align with the connection points for the original amplifier that was replaced. Coaxial cables or RF equipment that connected to the amplifier RF ports need their position adjusted.

With the node split, the original node boundaries are no longer accurate. New boundaries must be generated based on the area serviced by each of the DOCSIS 4.0 nodes.

6.2.3. Amplifiers

Amplifiers need to be upgraded to DOCSIS 4.0 capable amplifiers. When traditionally upgrading amplifiers, the new amplifier would need to have similar frequency characteristics as the amplifier it was replacing. This includes the impact of internal pads and equalizers.

DOCSIS 4.0 amplifiers are "smart amplifiers." These amplifiers dynamically adjust based on communications with customer premise equipment (CPE) devices and peer DOCSIS 4.0 amplifiers. Therefore, the amplifier replacement is simplified to selecting a DOCSIS 4.0 amplifier with the correct number of output ports and optionally matching the preferred manufacturer.

6.2.4. Inline Equalizers and RF Taps

The DOCSIS 4.0 network is operated with a frequency range of at least 1.0 GHz. If the existing RF network is operated at lower frequencies, such as 750 MHz or 860 MHz, then the design automation needs to evaluate whether the existing inline equalizers and RF taps support the increased spectrum.

Inline equalizers that do not support the spectrum requirements are removed and the subsequent RF tap replaced by a conditioned RF Tap. The figure below shows an example RF network where removal of the inline equalizer triggers replacement of the subsequent RF tap.

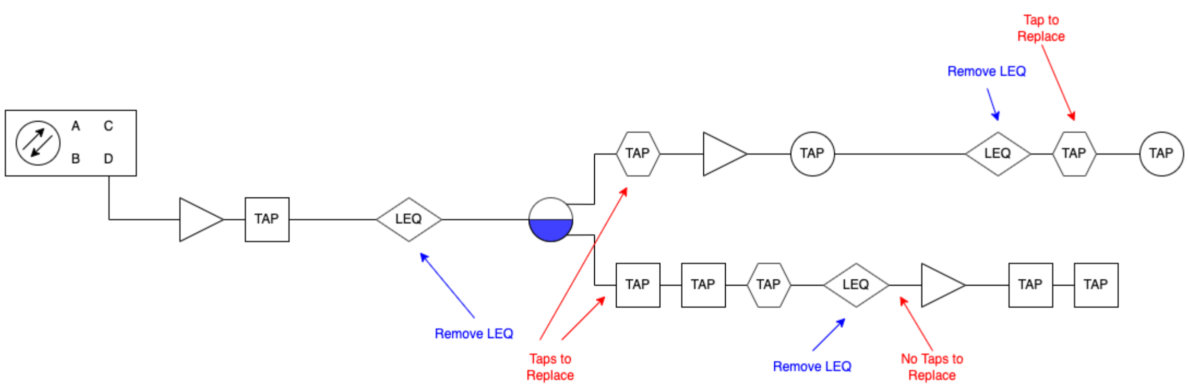

Figure 9: Replace RF Taps with Conditioned Taps when Removing Inline Equalizers

The inline equalizer and conditioned taps have internal equalizer and pads to shape the RF levels. Design automation must find replacement equipment with similar frequency characteristics.

Removing an inline equalizer requires map updates since a gap remains at the inline equalizer's original location. In the figure below, the inline equalizer is shown as the diamond shaped symbol.

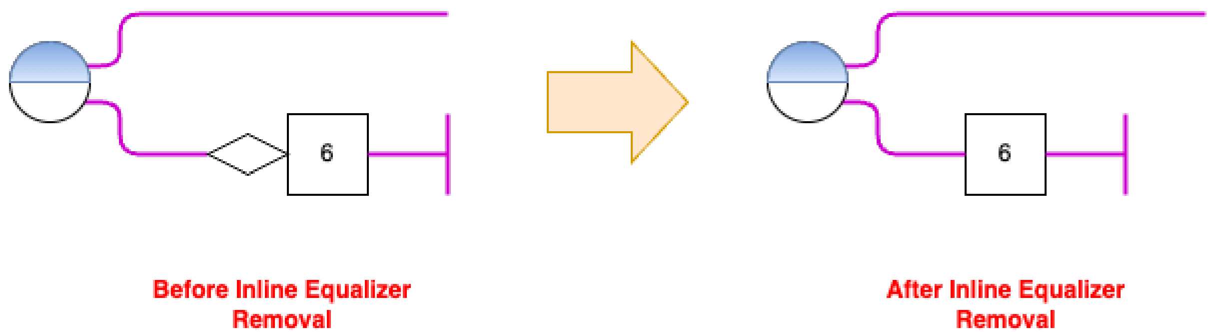

Figure 10: Example Drafted Inline Equalizers

When removing the inline equalizer, design automation options for fixing the map include adjusting the position of adjacent equipment or extending coaxial cables to fill the gap.

6.2.5. Fiber and Multiplexers

Node housings connect upstream to headends and hubs through the fiber transport network. Multiple wavelengths may be carried on each fiber to increase the fiber capacity. An outside plant (OSP) multiplexer (MUX) splits the wavelengths from a single transport fiber using wavelength division multiplexing (WDM) onto individual fibers dedicated to carrying specific wavelengths to fiber ports on nodes. DOCSIS 4.0 nodes require use of a digital OSP MUX.

If the original node housing connects through a legacy analog OSP MUX or does not use a MUX at all, the design automation must update the fiber network to connect the DOCSIS 4.0 nodes through a digital OSP MUX. An analog OSP MUX can only be swapped for a digital OSP MUX if all nodes being fed by that analog OSP MUX are upgraded at the same time as DOCSIS 4.0 nodes.

Design automation examines other OSP MUX in the same splice case and in adjacent "side cars" (splice case connected via jumper through the existing splice case). If a digital OSP MUX is found in these locations and has capacity, a new OSP MUX is not required. Design automation adjusts the connections to route the fiber through one of the available ports on these compatible OSP MUX.

6.2.5.1. Add OSP MUX to Current Splice Case

In most cases, the existing analog OSP MUX needs to be maintained since it services other node housings which do not support a newer digital OSP MUX. For these cases, it may be possible to install a new OSP MUX in the existing splice case. Design automation needs to verify that the current splice case has capacity for a digital OSP MUX. Additionally, there needs to be a spare or open fiber available that traces back to the same hub or headend feeding the legacy OSP MUX.

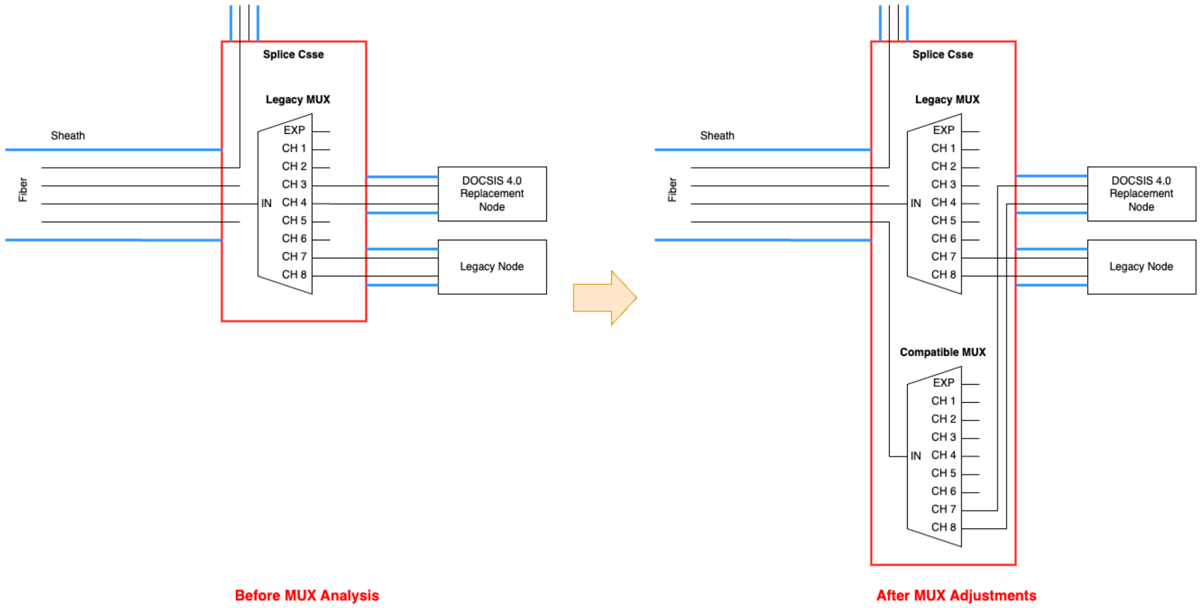

Figure 11: Add OSP MUX to Existing Splice Case

Multiple MUX options with different numbers of mux ports or optical wavelengths of digital OSP MUX exist in the Equipment Definitions. Selection of a new digital OSP MUX size must consider not only the DOCSIS 4.0 nodes being upgraded in this construction job, but the potential future upgrades to other nodes fed by the analog OSP MUX's in the splice case.

There are no visual updates for the map since the OSP MUX is internal to the splice case.

6.2.5.2. Add OSP MUX to Side Car

If a legacy OSP MUX cannot be swapped out and a digital OSP MUX cannot fit within the existing splice case, then a "side car" can be added to house the new digital OSP MUX. A side car is a splice case that will be connected to the original splice case through a jumper (short sheath) and mounted on the same support as the existing splice case. This design requires a spare or open fiber that traces to the hub or headend feeding the legacy OSP MUX.

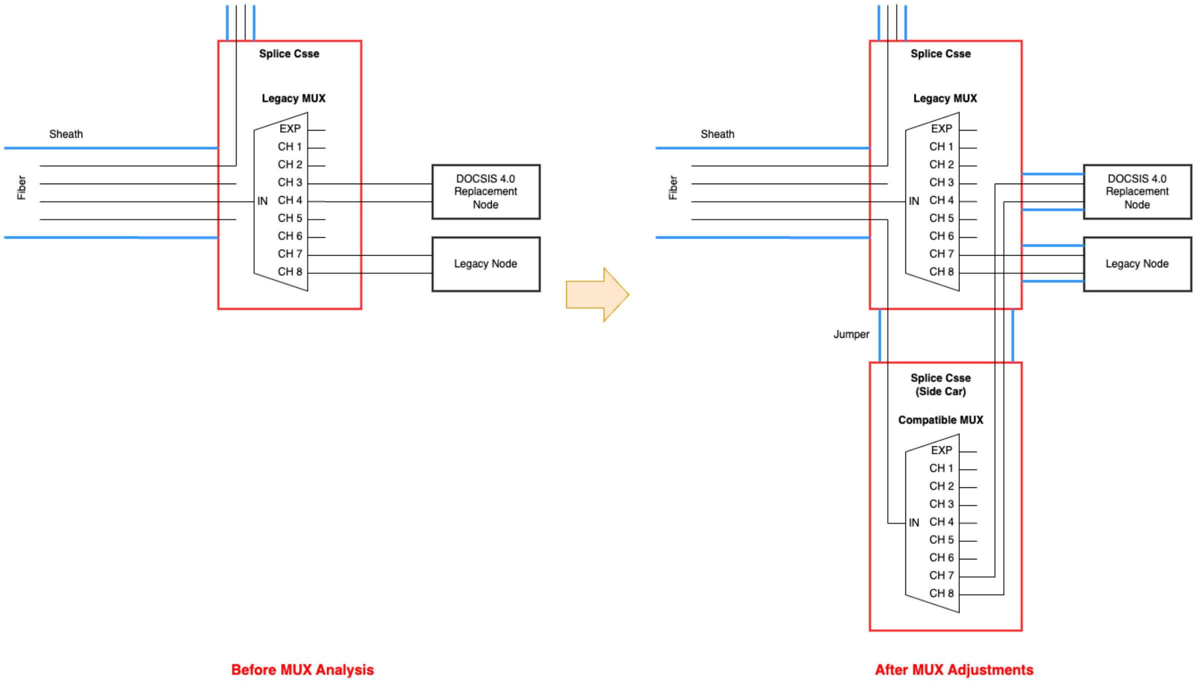

Figure 12: Add Side Car and OSP MUX

Visual updates are required for the map. Design automation search for available white space on the map proximate to the existing splice case. The jumper connects to the center points of the existing splice case and the side car. An example is shown below:

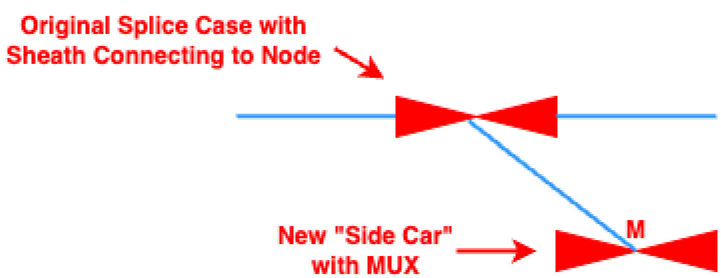

Figure 13: Example "Side Car" with MUX

6.2.6. RF Analysis

DOCSIS 4.0 and "smart" amplifiers automatically adjust RF levels to best service the downstream users. However, this does not mean that design automation can skip the RF leveling step. RF leveling can still detect if tap values and associated drop losses will impact the passings and whether the coaxial cables lengths are too long to properly service the passings. Design automation executes RF level calculations automatically once all equipment has been upgraded and alerts the designer of any issues.

6.2.7. Power Analysis

The last step in the design automation sequence is to verify the power for the RF actives in the network. This is a three-step process that includes (1) identifying the power supplies and power network, (2) calculating and validating power, and (3) optionally upgrading the available power in the RF network.

Each of the RF actives in the RF network needs power from a power supply. An RF active includes the DOCSIS 4.0 node housings, DOCSIS 4.0 amplifiers, and any Wi-Fi or 5G devices. The best method for design automation to identify power supplies is to perform a power trace. The power trace examines the drafted network to determine the path through which power flows. A power trace can be initiated at any power supply or RF active.

Each RF active must be powered by a single power supply. However, there may be multiple power supplies that power different segments of the RF network. The figure below shows an example where the node housing is powered by one power supply and the amplifier is powered by a different power supply.

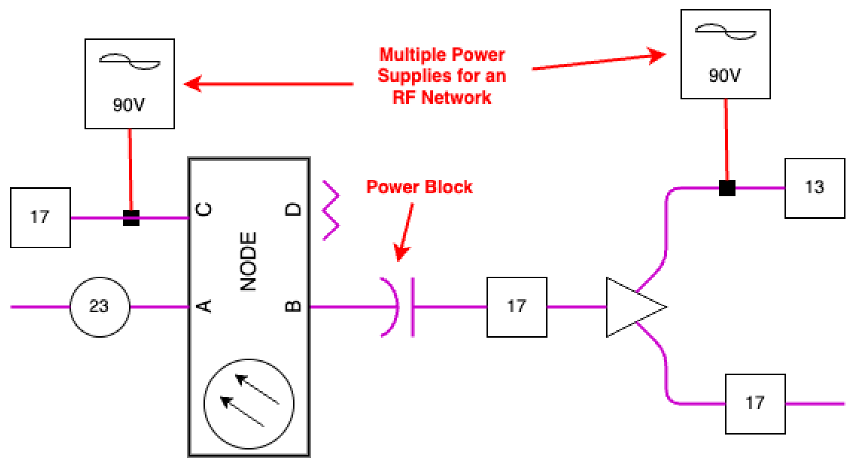

Figure 14: Multiple Power Supplies in RF Network

Design automation performs the power calculation for each power supply and the equipment in its power network. Design automation verifies that each RF Active has sufficient input voltage and the power supply's total power draw does not exceed the power supply loading policy value. DOCSIS 4.0 nodes and amplifiers require more power than their non-DOCSIS 4.0 counterparts. Therefore, a power upgrade is likely to be required for RF networks with many amplifiers or in the node split case.

Power upgrade options include replacing the existing power supply, bridging power from an adjacent power supply, and adding a new power supply. Upgrading an existing power supply is the most straight forward option, since it involves replacing the existing power support with a new power supply that has either higher voltage or current draw.

Bridging power to an adjacent power supply offloads some of the power requirements from the existing power supply. There are several challenges to this method. An adjacent plant must be identified that is powered by different power supplies. The power supplies need to be evaluated to determine whether they have sufficient power to offload the current power supply. Support structure needs to be in place or added to bridge the networks.

If power bridging is not possible, the final method to upgrade power is to add a new power supply. The easiest solution is to install the smallest required power supply in the network.

An optional optimization when installing an additional power supply is to optimize the size of both the new power supply and existing power supply. For example, if there is an 18A power supply in the network, instead of adding a 12A power supply, replace the original power supply with a 12A power supply and insert another 12A power supply in the network.

This is where generative design shines. The generative design algorithm is provided with the original power network. The algorithm must split the graph into two sub networks, inserting a power supply into each sub network. The preference is to use the lowest possible power while meeting the constraints of powering the RF actives and current draw limits of the power supplies.

6.3. Design Automation Future

Design automation will start automating specific capabilities and design types, but the expectation is that it will expand to cover a diverse set of construction jobs and network upgrades. Design automation will not just contribute to the initial design, but in the future, the drafting tools will invoke specific portions of design automation to perform a complex multi-step process in a single click.

7. Conclusion

The journey to ideate, develop and deploy a toolset that can build, automate, and visualize HFC plant maps and act as a single source of truth for outside plant information was lengthy and not without challenges. The data migration effort was substantial and accommodating the uniqueness of each regional area is an ongoing opportunity. Development of a hybrid data model to support both old and new toolsets during the 12-month migration proved critical to gaining field support of the new tool.

Identification of a set of subject matter experts to be early adopters allowed us to build a level of anticipation and excitement that helped to pave the road for a smooth transition. Creation of an intense two-day training course held during the launch window ensured that our design teams would hit the ground running as soon as the launch was finished.

Building a product that combined an innovative platform and database model addressed many of the concerns expressed by our design partners, including startup speed, uncluttered user interfaces and workflow tools that simplified complicated tasks like fiber splicing and port assignments. The integration with our business tools opened the door for doing automated designs using an easily accessible web interface.

Design automation capabilities benefit both the multiple system operator (MSO) and subscribers due to increased network reliability, easier troubleshooting, and faster delivery of capacity upgrades and network expansion.

Abbreviations

5G	fifth generation cellular network technology
A	amperage
CPE	customer premise equipment
DOCSIS	data over cable service interface specification
EPON	ethernet passive optical network
ETL	extract, transform, load
GHz	gigahertz
HFC	hybrid fiber coaxial
JDA	joint development agreement
MDU	multiple dwelling unit
MHz	megahertz
MSO	multiple system operator
MUX	multiplexer
MVP	minimum viable product
OSP	outside plant
OTDR	optical time domain reflectometer
RF	radio frequency
rOLT	remote optical line terminal