Outside-Plant Design: Fusion Splicing vs. Connectorization

Comparing all the costs and benefits of conventional outside-plant design with plug-and-play designs suggests that in most cases, the conventional design remains more economical.

By David Stallworth ■ *OFS*

Using plug-and-play technology in the outside plant has been hailed as a labor-saving, cost-effective approach to deploying fiber to the home. The advantages of this approach, which involves connectorizing fiber drops at the factory and plugging them into terminals in the field, are often promoted with little discussion of the implications for network design or operation. As usual, however, the devil is in the details.

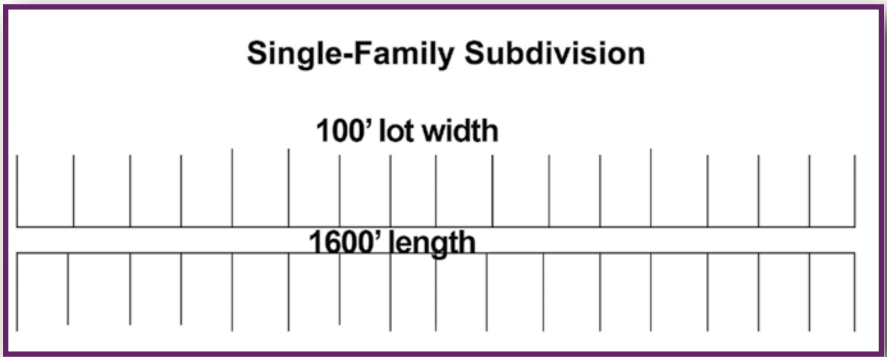

Figure 1: The study area used as the basis for calculations in this article

Drops that are connectorized on both ends may help technicians turn up service faster. A technician simply plugs one end of a drop into a connectorized port on a factory-made terminal and the other end into customer-premises equipment. However, this faster turn-up must be weighed against additional administrative, stocking, engineering and operational costs. Plug-and-play also eliminates some design choices for locating splitters, which may require higher capital investment.

Connectorized drops may help technicians turn up service faster, but they entail additional costs for engineering, operations and administration.

Plug-and-play solutions require factory-hardened terminals with external ports that accept connectors from factory-connectorized drops. Each terminal includes a fiber stub cable that is used to splice it into the network; the length of this stub cable must be specified when the terminal is ordered. Plug-and-play does not reduce splicing but rather moves the splicing from the drop to the end of the stub, which must be spliced back into the network somewhere.

Two alternatives to full plug-and-play solutions are available: fusion-splicing both ends (splicing each drop into a cable at the drop closure and splicing each pigtail into an optical network terminal, or ONT, at the customer end) and fusion-splicing the cable end of each drop while plugging a factory-installed connector into an ONT at the customer end. This article examines the differences in design, operation and administration between fusion-splicing drops and using fully connectorized drops. Single-ended connectorized drops are not discussed in this article; the main issue with this alternative is inventory management.

DESIGN OPTIONS

Figure 1 shows a single-family subdivi-

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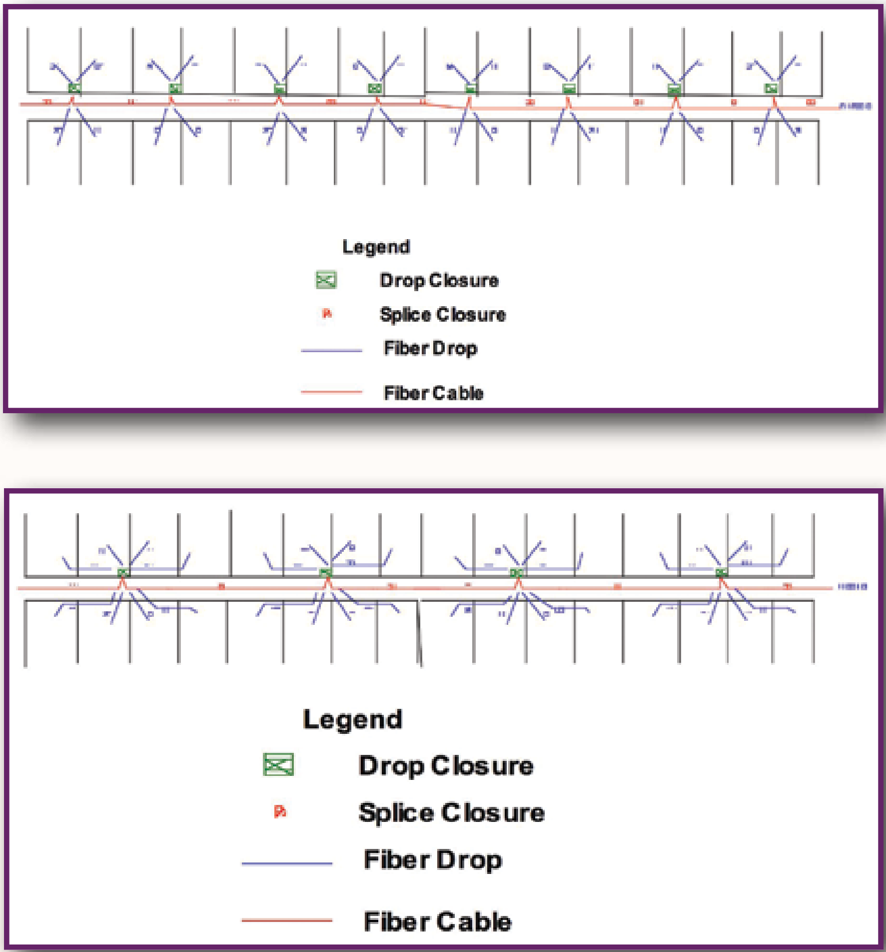


Figure 2: Conventional four-port design (above) and eight-port design (below)

sion consisting of 32 lots, each with a 100-foot frontage along the road. The central-office feed is at the right of the diagram. The road right-of-way is typically 50 feet. In most cases, whether fiber is placed underground or aerially does not substantially affect the design.

If fusion splicing is used, the conventional design calls for four-port or eight-port drop closures. A fiber cable is usually placed on one side of the street, and the drop closures serve houses on both street sides. Figure 2 shows these two designs.

The eight-port design is more common for FTTH because it reduces the number of drop closures needed, which, given typical urban lot sizes, outweighs the additional cost of longer drops. In this analysis, we assume the eight-port design is used. As shown in Figure 2, this design requires 1,400 feet of cable from the leftmost drop closure to the right-of-way.

In the conventional design, cable is looped through the drop closures, but no splicing need occur until a service order is received. At that point, a fiber is assigned in the drop closure, and a technician cuts the assigned fiber and splices it to the drop. The only splicing performed prior to the drop is for the cable that leads out from the splitter. This splice is also needed when plug-and-play terminals are used.

For plug-and-play, a designer must determine where to splice the fiber stub from each terminal into the network cable. This splicing cannot be deferred until service orders are received; the hardened terminals must be spliced initially. The designer must also produce terminal construction documents that define what is to be spliced and incorporate these into cable records.

Serving 32 homes with eight-port terminals requires four terminals, each of which must be spliced into a fiber cable. There are a number of ways to do this.

1. Take all four fiber stubs from the terminals back to a point where the 32-home area begins, and splice them into a cable at that point. Figure 3 shows this direct-feed design. Note placing the splicing point close to the starting point results in placing multiple, parallel stubs in the same sections. This increases costs, as contractors charge for placing additional cables in the same infrastructure.
2. Move the splice point to the middle of the 32-home area. Figure 4 shows this design, which we call direct-feed quad.

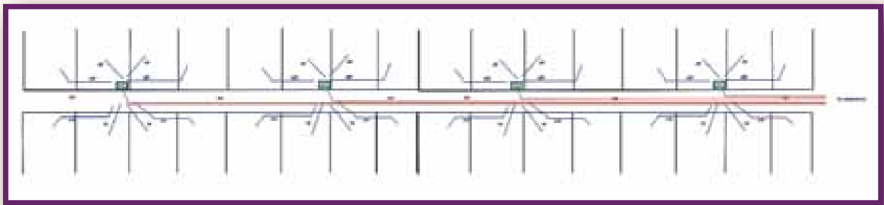


Figure 3: With the direct-feed design, all terminals are spliced where the cable enters the area.

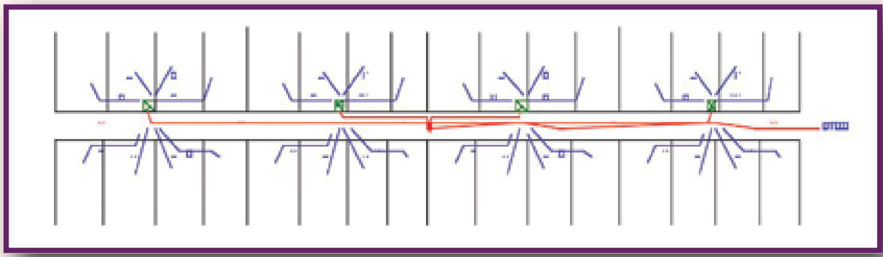


Figure 4: Direct-feed quad design: All terminals are spliced in the center of the study area.

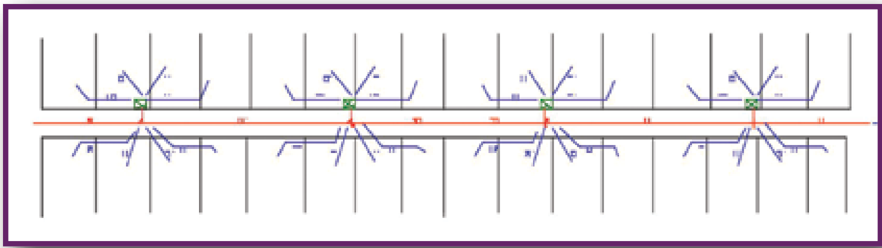


Figure 5: Spliced-feed design: Each terminal is spliced at its placement point.

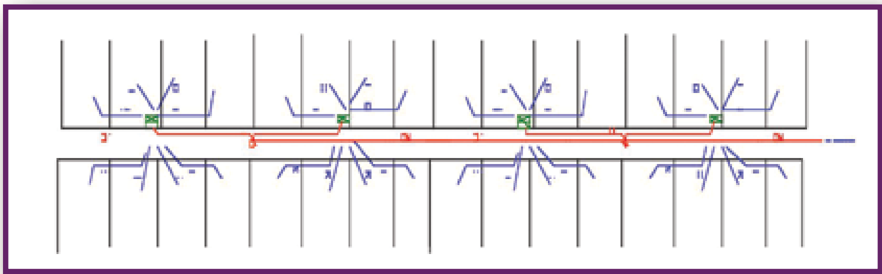


Figure 6: Double spliced-feed design: Two splice points are placed inside the study area.

3. Splice the stub into the feed cable at each point where a terminal is placed. Figure 5 shows this spliced-feed design option.
4. Place two splice points in the 32-home area and feed two terminals from each splice point. Figure 6 shows this double spliced-feed design.

Placing costs. The direct-feed design increases the amount of cable placed to 3,200 feet from 1,400 feet. Placing costs can easily double, and the supporting structure may have to be increased close to the splicing point to support the four cables required. Materials costs may be higher as well – 3,200 feet of 12-fiber cable may cost more than 1,400 feet of 36-fiber cable. Last, the drop cables cost more because they have factory-spliced connectors and because their fixed length requires slack to be stored in a special closure arrangement. The combination of all these added costs makes this one of the highest-cost alternatives.

The direct-feed quad design requires placement of an additional 1,600 feet of stub cable, along with 800 feet of feed cable. In addition, a new splice is required in the area, and support structure may be needed for that location. All 32 fibers of the four stubs need to be spliced at this location. (As mentioned earlier, the plug-and-play system does not reduce splicing because the stubs have to be spliced into the network. In effect, the drop splice has been moved to the stub splice). The placing and materials costs for this alternative are much higher than for the conventional method.

The spliced-feed design requires that every terminal be spliced at its location in the field. This adds four additional splice locations in each 32-home area and may require an additional support structure or perhaps a larger structure than the conventional design. Each terminal must also be spliced into the feed cable, which is the same length as the conventional design cable (1,400 feet). This alternative reduces cable and stub placement costs but increases materials cost, as four additional closures are needed to house the splice.

The double spliced-feed design has two terminals fed by a single splice point inside the study area. It has a higher placement cost because the stubs must be routed to the two terminals from a single location. The location of the splice closure relative to the two terminals is not critical, as the costs are similar. This alternative has two additional splice cases and requires placement of 800 feet of stub cable and 1,000 feet of feed cable, compared with a total of 1,400 feet of cable in the conventional plan.

Capital expenditures. The plug-and-play system requires more cable and splice closures than the conventional design method. (As explained earlier, terminal stubs must be spliced into the network.) In addition, because plug-and-play terminals are factory-made, optical splitters cannot be placed inside them. In areas with high take rates, placing splitters inside drop closures is often economical because it allows the use of smaller cable sizes – at least 256 homes can be served from a single 24-fiber cable. However, because plug-and-play eliminates this alternative, splitters must usually be placed in cabinets that serve several hundred homes. Although this alternative may be viable for low-take-rate areas, it may add as much as $100 per home passed.

Last, plug-and-play may require more time to engineer because the engineer must determine where to splice the fiber stubs of the terminals into the network. The more network elements in a fiber design, the more engineering is needed to properly design those elements. Adding more support structure to handle the cables may also require more engineering. Additional engineering records must be produced to show which fibers to splice into each terminal, and these records must also be entered into fiber assignment records.

Administration. Plug-and-play requires maintaining inventories of many different lengths of factory-connectorized drops. Managing this inventory requires keeping a daily tally of drop lengths used, monitoring the supply of cables in each drop length and constantly forecasting installations to insure that enough drops are available in the correct lengths. Inventory levels must be kept high enough to allow time for new material orders to be processed, shipped, received and placed into inventory. Some deployers have had to pre-survey installations to determine drop lengths; this added truck roll for each installation increases installation costs by $100 to $200, making plug-and-play uneconomical at any labor rate.

In most areas of the U.S., operators maintain emergency stock for disaster recovery. The more network elements there are, the higher the cost of main-

A connectorized OSP solution requires keeping drop cables in many lengths available at all times.

taining this disaster inventory. Because plug-and-play systems require more network elements than conventional designs, emergency inventory costs are higher, though these additional costs are not always easy to determine.

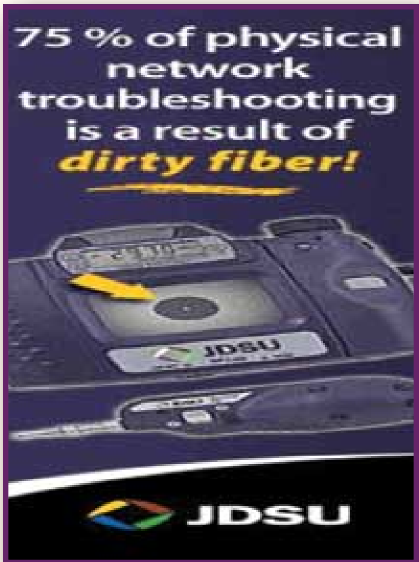
Last, because factory-made drops have fixed lengths, there is a substantial amount of excess drop cable. This slack can be stored either at the terminal or at the home. Because storing slack for up to eight drops at a terminal may present space problems, in most cases slack is stored at the ONTs at customer homes. However, requiring ONTs to accommodate up to 50 feet of excess drop increases the cost of the ONTs.

Network Performance. By introducing additional connectors into the network, plug-and-play increases both the risk of network failure and the total optical loss. Even though fiber is less sensitive to environmental conditions than copper, and fiber networks are therefore more reliable, they are not immune to failure. Connectors and jumpers are the main sources of network failure because they are the points at which technicians have access to the network. Human error, carelessness and the need to be productive can drive technicians to cut corners, especially when cleaning connectors.

Connectors require cleaning before they are installed and whenever they are unplugged. They may even be ineffective in weather conditions such as rain, snow and dust storms.

Plug-and-play connectors are more difficult to clean and require special fiber cleaning kits. The advertisement by JDSU (see below) says it all: Most troubles are caused by connectors' introducing dirt into networks. Why design more of them into a network when there is a viable alternative?

Plug-and-play systems have higher optical loss than conventionally designed systems because they have more connectors and just as many splices. Even though the loss from each connector is small, the increase may cause a problem if the loss budget is close to maximum. Losses have a tendency to increase over time and may become significant over a network's 30- to 40-year life.



Some argue that connectorized drops give technicians test points for analyzing networks. This is a very weak argument. The end of the fiber is only a few hundred feet away, at the customer's home; testing from that point, using a standard connector, makes much more sense and is better for detecting problems with the hardened terminal and connectors. Testing at a plug-and-play terminal requires a special connector to fit into the slot of the terminal. After testing, a technician must thoroughly clean the drop connector before re-inserting it. Therefore, the plug-and-play system does not offer any better test methods or test points and may contribute to a higher trouble rate as it ages.

Equipment requirements. One advantage of plug-and-play over the conventional design is that it does not require a fusion-splicing machine to establish service. Although plug-and-play does not reduce the overall splicing required, it does move the splicing from installation to initial construction. Today's fusion splicers are small and capable of making thousands of splices. However, they can cost $6,000 or more, adding $5 to $10 per home passed. (This cost may be avoided by reorganizing the workforce as described below.)

Organizational considerations. Some operators organize outside technicians into two groups, one responsible for installations and the other for maintenance and repair. Deploying FTTH technology inspires companies to take another look at their organization, and some are changing the two-group arrangement to what could be described as multitask technicians (MTTs). An MTT has responsibility for all installation and maintenance in a geographic area. Such a technician has complete training about the network and is generally more valuable to the company.

(Small operators have been using MTTs for years, as they cannot afford to do otherwise.)

Using MTTs may reduce the total required workforce for several reasons. First, windshield time can be reduced as technicians are assigned smaller service areas. Second, companies may find that technicians who take ownership of their areas do a better job all around. For example, technicians may be more careful with installations to avoid being embarrassed with trouble calls about their previous installation work. Finally, MTTs who encounter signal problems while installing drops are more likely to have the knowledge, skills and equipment to fix these problems themselves and avoid maintenance calls later. The impact on customer satisfaction is obvious.

In a workforce of MTTs, fusion splicers take on a new light. Maintenance technicians must be equipped with fusion splicers, so MTTs carry splicers on their trucks and can use them to fusion-splice drops. The cost of each fusion splicer can be split between maintenance and installation – which, along with the possibility of reduced workforce size, better work quality, improvement in meeting customer service dates and more versatile technicians, may make fusion splicing a more attractive choice.

DEVELOPING A COST MODEL

Addressing all these issues in a single cost model requires establishing a level playing field for all alternatives.

Determining the materials costs for the various alternatives is relatively easy, with one exception: the extra cost of the slack storage mechanism for the connectorized drops. As that cost must be taken into consideration, the model allows it to be inserted at the discretion of the user. Other materials prices can be changed by users for purposes of sensitivity analysis.

The cost of placing feed cable is the same for all alternatives because the feed cable must traverse the entire 32-home study area to feed other areas. However, for comparison purposes, the amount of feed cable for the study area is included in the study.

Contract placement labor is also needed to route plug-and-play stub cables from the terminals to the locations where they are spliced. This cost is different for each alternative, and the model reflects this.

We can safely assume that the cost of placing conventional drop closures is equivalent to the cost of placing plug-and-play terminals. However, some plug-and-play alternatives may require extra supporting structure to house a splice case. The model accounts for this cost in the "additional structure cost" cell.

The model also assumes that the cost of placing drops is the same regardless of which alternative is selected. This assumption may favor plug-and-play slightly as placing plug-and-play drops may require extra time to protect the connectors and to determine the right length of drop to use. If plug-and-play drop costs prove to be higher, connectorized drop costs can be adjusted upward in the model to account for this.

Materials costs for drops are calculated based on lot width and can be adjusted by changing the lot width.

The items labeled "additional maintenance cost per home passed," "additional engineering cost per home passed," "additional fusion-splicer cost per home passed" and "administrative cost" are highly variable and difficult to calculate. However, these are clearly real costs that should be accounted for.

Additional maintenance cost per home passed. Because plug-and-play alternatives use more connectors, they contribute to higher maintenance and repair costs over the life of a network. This cell allows a user to input an additional cost per home passed, which may vary depending on whether the facilities are aerial or underground. A minimum of a few dollars per home passed seems reasonable, perhaps more if the conditions warrant.

Additional engineering cost per home passed. Because more network elements and documents are used in plug-and-play alternatives, a higher engineering cost is reasonable. The engineer must determine splice closure locations and design more lengths of cable. More field work may be necessary to develop proper measurements for the longer lengths of cable and stubs. More material must be accounted for in bills of material and verified. Because plug-and-play terminals must be spliced into the network, the engineer must designate which fibers are assigned to which terminals at the time of construction and generate another document with assignments for each terminal. This is not necessary in the conventional model, because all the fibers are available in each drop closure and can be assigned on a next-available basis. Adding at least a few dollars per home passed for this extra effort is reasonable.

Additional fusion-splicer cost per home passed. The conventional design requires a fusion splicer that is not needed for the plug-and-play alternatives. This is accounted for by adding the splicer cost on a per-home-passed basis. A few dollars in this cell seems appropriate; the amount depends on how much the splicer is used for installation versus maintenance and new construction. Some companies prefer to lease fusion splicers or to use a combination of lease and purchase.

Administrative cost per home. Plug-and-play requires carefully managing and storing an inventory of connectorized drops of various lengths. Failure to manage inventory properly results in missing service order appointments or incurring extra time and expense to handle additional slack. Administrative cost includes employee time and building cost and is a recurring cost for the life of the network. The "administrative cost per home" cell allows a user to input an amount to cover this cost.

Conventional drop splice time. One of the most important inputs into this model is the labor rate used for installation and splicing. This rate is pitted against the higher capital cost of plug-and-play alternatives and all associated secondary costs. If the labor rate were $0, the capital cost of plug-and-play would provide no benefit, as no time or cost would be saved. Above some labor rate, plug-and-play costs are more than

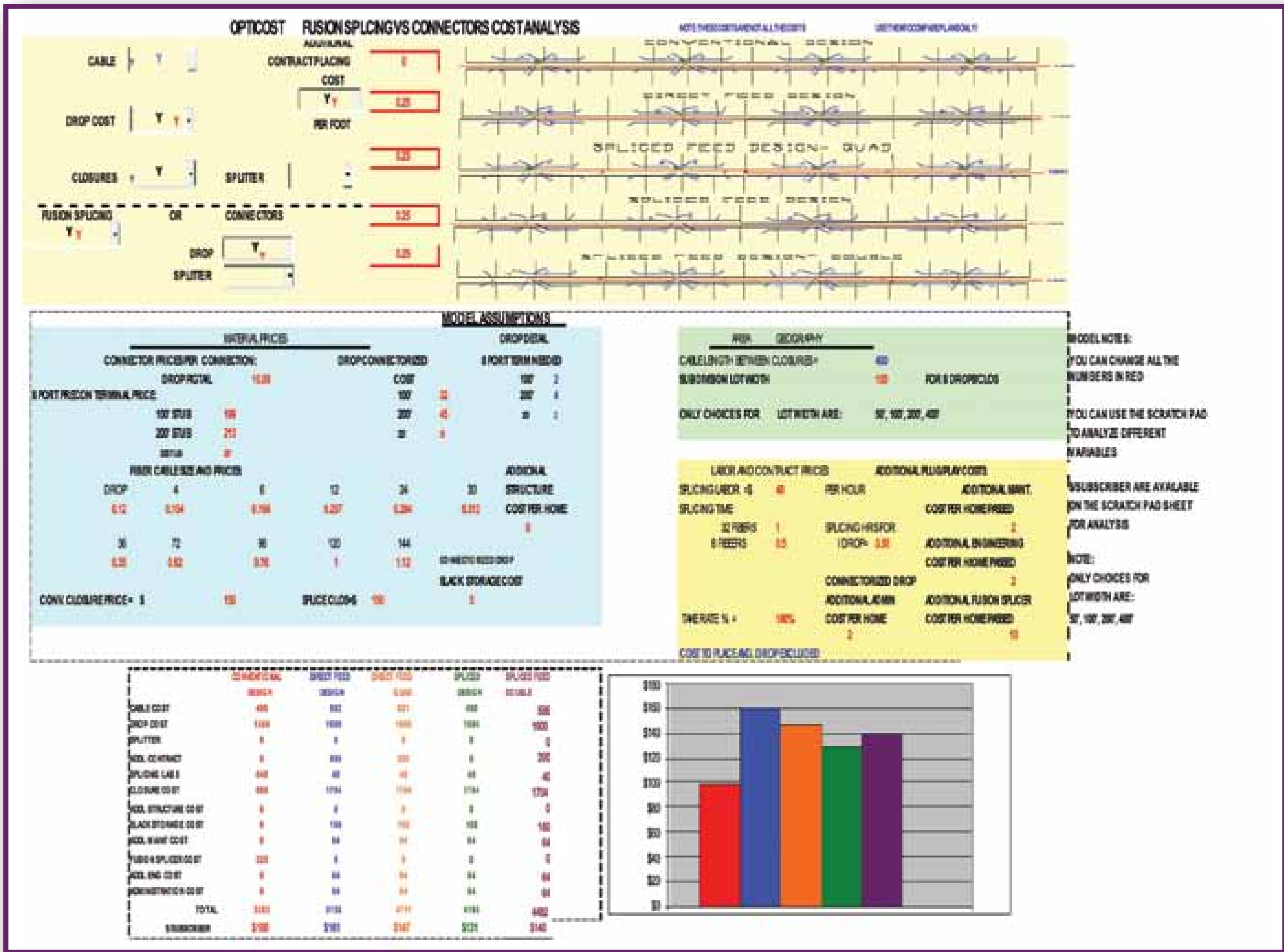


Figure 7: Cost model for evaluating splicing-versus-connectorization decisions in the outside plant

offset by the time savings, and plug-and-play should begin to be the economical choice. (Of course, all the costs discussed must be considered to find the crossover point.)

At what labor rate does the crossover occur? The cost model allows users to vary the labor rate to determine how it affects overall network cost. There is also a cell for the amount of time required to splice a drop into a closure. This amount should be the difference between plug-and-play time and fusion-splicing time (how much longer it would take to fusion-splice versus plug in the drop after the technician sets up at the closure and is ready to make the connection). The combination of the labor rate and time required can be compared with the added capital investment of plug-and-play.

Determining how long splicing fibers in a cable takes is important. Remember that all alternatives require splicing plug-and-play terminals' fiber stubs into the network at some point. (Though some vendors provide factory splice points into which terminal stubs can be plugged, this does not diminish the need to splice the stub into the network but only changes how the splicing is done. This factory splicing cost should be used to input this cost into the model.)

Though the time to fusion-splice the terminal stub is often ignored, it offsets some of the splicing time for the drop. Whether splicing is done in a factory or in the field is of little consequence.

In summary, the cost study pits the conventional design's smaller capital outlay and longer installation time against plug-and-play's higher capital cost, higher labor costs and higher associated costs. The model allows an in-depth study of these relationships.

USING THE MODEL

The model, shown in Figure 7, has three parts. The top part lists all the options to study and has cells available to add extra contract cost for placing the terminal stub. Costs can be turned on or off, but for this study, all costs are activated.

The middle section is the heart of the model. Users can change the numbers in red to study all the variables and their relationships, including materials cost, labor rates, splicing time for drops and cables, and associated costs for administration, maintenance, fusion splicers and so forth. On the right are notes to help users operate the model.

The third section adds the costs and divides by homes passed to arrive at dollars per home passed. A scratch-pad sheet gives users other tools to study alternatives. Generic prices and costs are listed initially but should be tuned to users' actual numbers.

The bar charts in Figures 8 through 11 show the results of an initial study, color-coded to display the following alternatives:

Conventional Design	Direct-Feed Design	Direct-Feed Quad Design	Spliced-Feed Design	Double Spliced-Feed Design

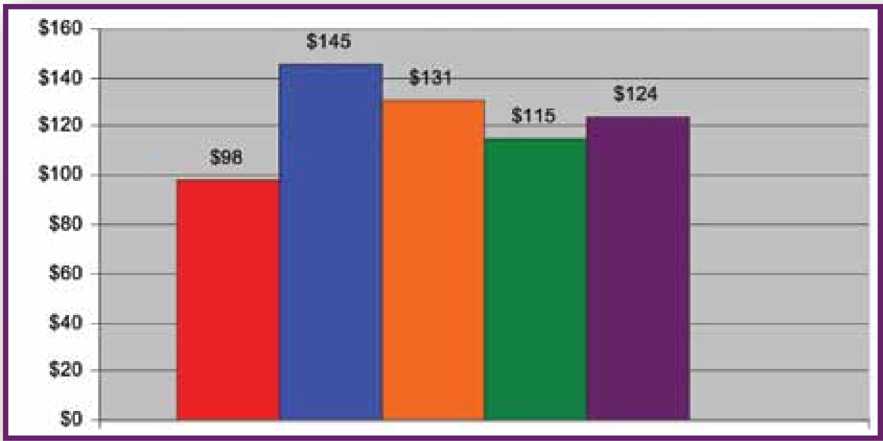


Figure 8: Labor and materials costs per home passed (labor at $40 per hour)

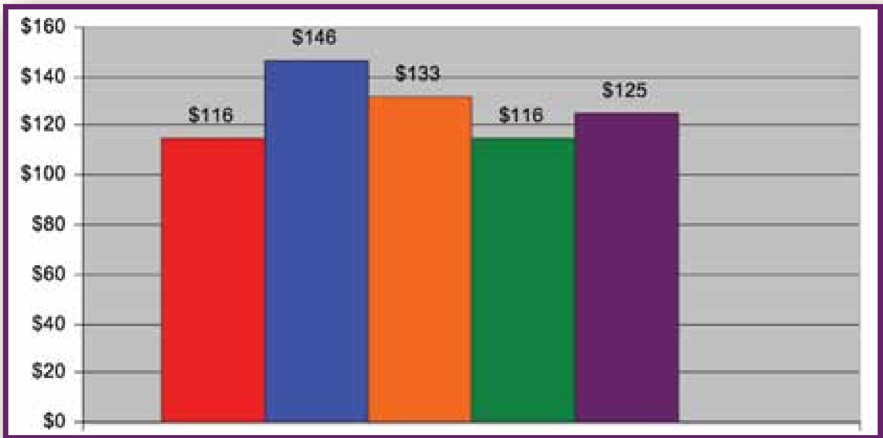


Figure 9: Labor and materials costs per home passed (labor at $75 per hour)

Figure 8 shows labor and materials costs of the five alternatives without added costs such as slack storage, maintenance, extra engineering and administration. This analysis assumes 30 minutes for splicing a drop at $40 per hour and one hour for splicing the 32 fibers of the plug-and-play stub into the network. This model input is biased toward plug-and-play alternatives because it shows the effects of capital cost differences without the extra, more "subjective" inputs. Even with this bias, the conventional design is about 20 percent more economical than the best plug-and-play alternative (spliced-feed design, shown in green).

For any plug-and-play alternative to begin to be economical, the labor rate would have to be about $75 per hour, as shown in Figure 9. This is much higher than most telephone and cable companies' labor rates, but it may be applicable for large ILECs.

The initial model was based on 100-foot lot widths. Varying the lot width affects the outcome. Figure 10 uses the same input but varies the lot width from 50 feet to 100 feet, 200 feet and 400 feet. (Generally, lot sizes smaller than 50 feet indicate multifamily housing, which warrants an altogether different design pattern.)

As lot width increases, so does the cost difference between the conventional design and plug-and-play alternatives. This relationship, shown in Figure 10, is due to the increase in terminal stub length required as lot size increases.

The pro-plug-and-play bias discussed above can be removed by assigning costs to the "subjective" categories. In Figure 11, which assumes a labor rate of $40 and a lot width of 100 feet, with all other inputs remaining constant, the following costs per home passed were added to the model input:

Slack storage: $5
Additional structure: $200
Administration: $2
Maintenance: $2
Engineering: $2

Assigning these costs results in a cost difference of more than 50 percent between the conventional design and the best plug-and-play alternative. These components increase the cost by about 30 percent over the initial 20 percent difference. Adding in all the costs associated with plug-and-play makes clear that this alternative is not economical except for extremely high labor rates.

The model indicates that plug-and-play in the outside plant is economical only at very high labor rates – generally much higher rates than small telephone and cable companies are likely to pay.

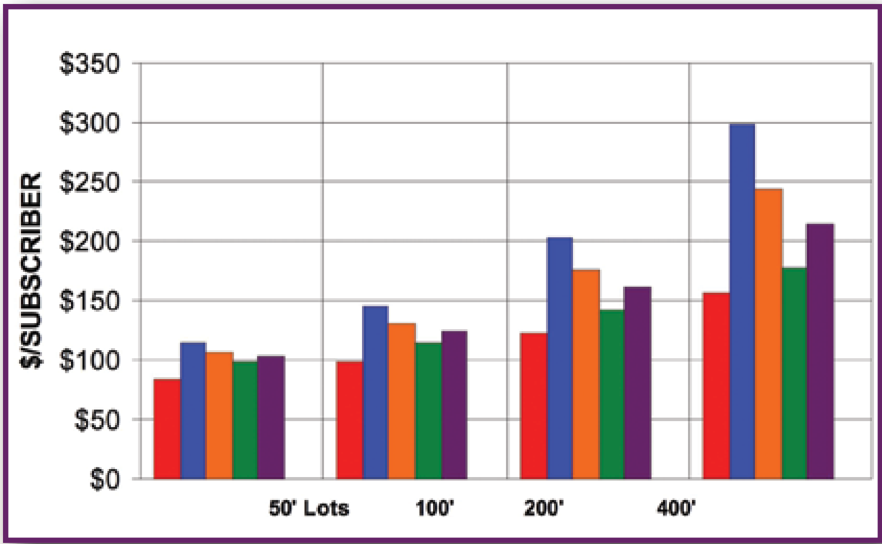


Figure 10: Relationship between lot size and relative advantage of conventional design

Figure 11: Total costs per home passed

TAKE RATES

Examining how the take rate, or total number of customers divided by homes passed, affects the cost analysis is important. Eighteen to 24 months after deployment, the take rate starts to level off. This final rate is the take rate that needs to be studied.

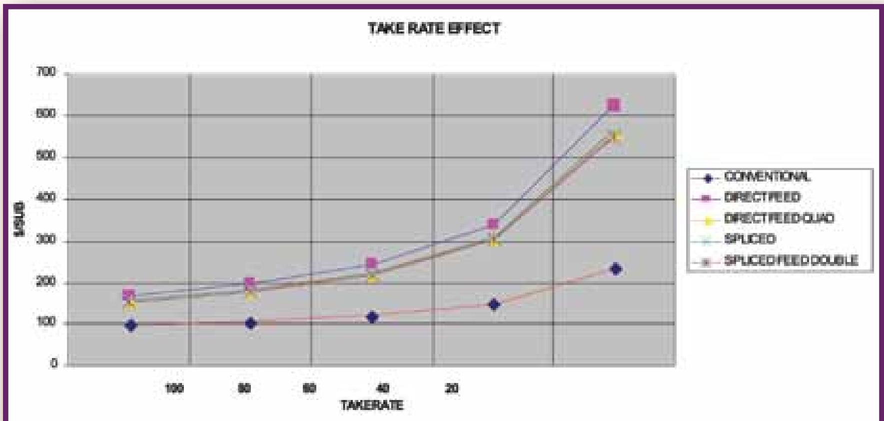


Figure 12: Relationship between take rate and relative advantage of conventional design

TRADE-OFFS BETWEEN CONVENTIONAL DESIGN AND PLUG-AND-PLAY

Advantages of Conventional Design:

- More economical when labor rates are under $75 per hour or perhaps even higher when all costs are considered
- Simpler design requiring fewer elements to manage and stock
- Lower overall optical loss
- More reliable and therefore less expensive to maintain
- More design options for splitter placement
- Lower engineering cost
- Less warehouse space required
- Less vulnerable to impact of lower take rates
- Better capital utilization enabling more revenue

Disadvantages of Conventional Design:

- Requires a fusion splicer
- Slightly longer installation time
- Not economical for labor rates over about $75 per hour

Advantages of Plug-and-Play:

- Slightly faster installation time
- No fusion splicer needed
- Economical for labor rates over about $75 per hour

Disadvantages of Plug-and-Play:

- Higher capital cost
- Higher total operational cost
- Less reliable
- Requires more administration
- Requires more engineering
- Requires additional warehouse space
- Higher overall optical loss
- Eliminates some economical design options
- Vulnerable to impact of low take rates
- Fewer homes passed and less revenue per capital dollar invested

The cost difference between the conventional method and plug-and-play grows wider as the take rate declines. At take rates of 60 percent and below, plug-and-play costs about twice as much.

Figure 12 shows the effect of varying the take rate from 100 percent down to 20 percent. (Any take rate below 20 percent probably does not justify a business case.)

The figure clearly shows that the cost difference between the conventional method and plug-and-play grows wider as the take rate declines. This may be the final nail in the coffin of plug-and-play. At take rates of 60 percent and below, plug-and-play is about twice the cost of the conventional design. The difference grows exponentially as the take rate is reduced.

A competitive provider, municipality, or any company that is second or third into a market typically experiences take rates below 60 percent. Even incumbent telephone companies that opt to retain their copper networks for voice services, deploying FTTH only for video and data, may experience take rates in the 60 percent and below category. Because the costs of deploying plug-and-play are so high at this take rate, these companies pass fewer homes with the same investment, compared with the conventional design. In other words, the conventional design yields more homes passed for the same budget amount. When more homes are passed, more revenue can be generated, and the business case may be more successful.

SUMMARY

For most companies, conventional outside-plant design is more economical for FTTH deployment, especially after taking into account the effects on network operations. Even deployers that build FTTH networks for sale rather than for operation must consider the fact that their networks' high operational costs may make them harder to sell.

The conventional design allows FTTH deployers to "button up" the plant, leave it alone and enjoy the benefits of reliable performance year after year. This design allows more homes to be passed, especially if a lower take rate is expected, yielding a better business case outcome. Minimizing the number of network elements makes networks simpler to install, manage, and maintain and results in very economical networks that can produce more revenue. ❖