

Challenges for wiring harness development

We are living in an era of major disruption in the automotive industry. Driven by the rapid development of new technologies and the proliferation of automotive start-ups, both trends have implications on the development of vehicle wiring harnesses.

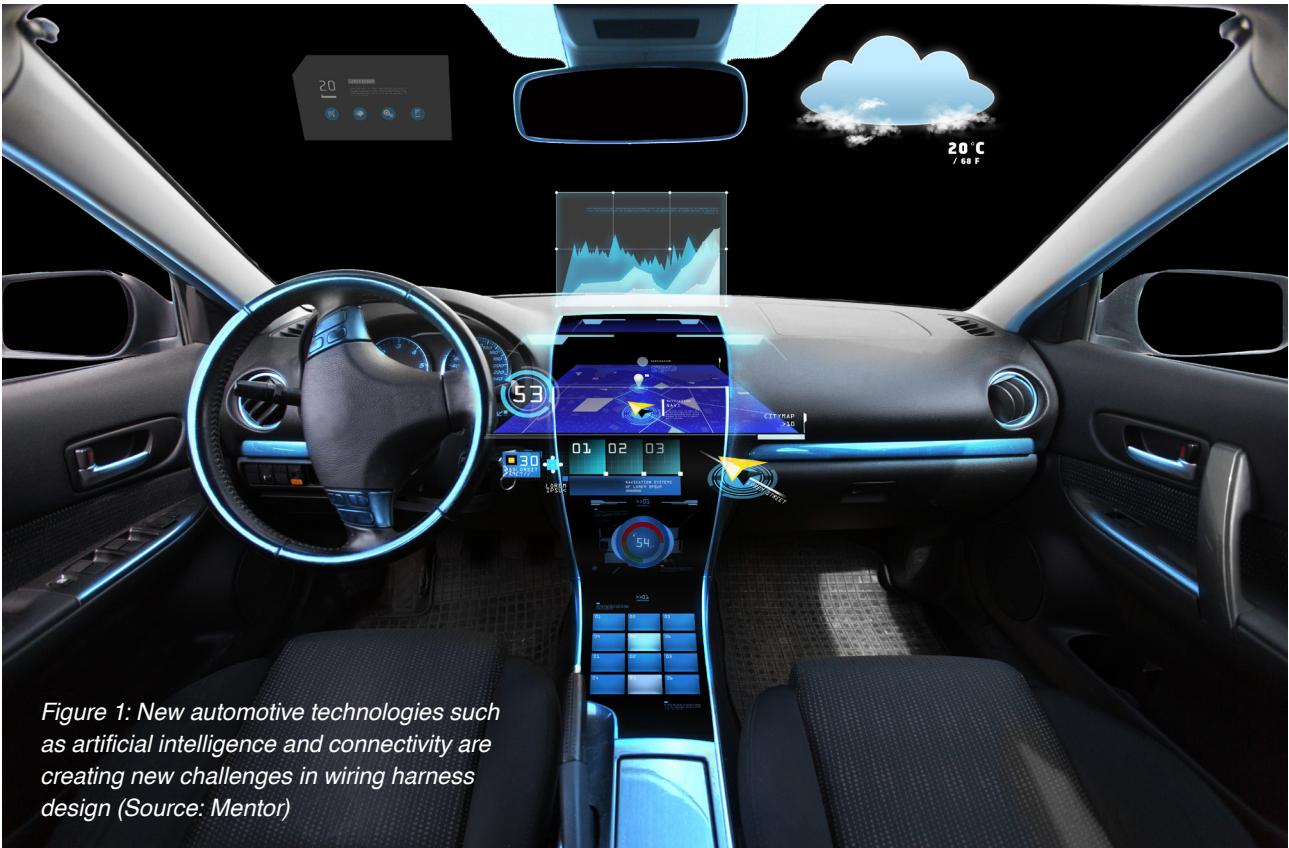


Figure 1: New automotive technologies such as artificial intelligence and connectivity are creating new challenges in wiring harness design (Source: Mentor)

The never-ending development of new technologies and their addition to modern vehicles leads to a phenomenon that can be labeled as the content dilemma. The content dilemma represents the conflict between the technology content that vehicle manufacturers try to integrate into their vehicles, and the weight, cost, and packaging space required for wiring harnesses.

Examples of recent technology trends that are driving the content dilemma include (Figure 1):

- ◆ Electrification
- ◆ Autonomous driving
- ◆ Artificial intelligence
- ◆ Connected vehicle

A key competitive factor for customers in an electric vehicle is range. The more miles a vehicle can drive with one charge, the better. Vehicle mass plays a key role in determining a vehicle's range, therefore, minimizing weight in an electric vehicle is crucial to bringing a competitive and successful vehicle to market. New vehicle technologies, however, require additional electrical wiring and other electronic components, increasing the weight of the

vehicle. The introduction of the electric powertrain alone adds about 30 % more weight compared to an internal combustion engine powertrain.

Autonomous driving requires the addition of a multitude of hardware redundancies and fail safe mechanisms to prevent single points of failure that could disable the autonomous system unexpectedly. System redundancies are critical because unexpected failures may cause the vehicle to crash if the driver isn't paying attention or actively involved in the driving and steering process. However, these safety redundancies can add significant weight and cost to the wiring harness by duplicating networks, powerlines, and some electronic control units (ECUs).

Artificial intelligence in vehicles enables facial recognition, computer vision, and other machine learning algorithms to help personalize the user experience and vehicle settings by processing and 'learning' from incoming data. This requires the inclusion of a myriad of cameras and other hardware all over the vehicle. These cameras are usually connected to an electric control unit via high bit rate networks. Most automotive networks use unshielded twisted

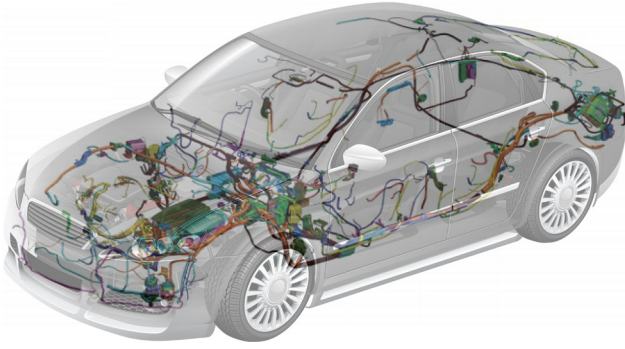


Figure 2: Growing electrical and electronic content in vehicles is increasing bandwidth demands in the vehicle. OEMs are responding by incorporating additional networks, both standard and specialized, leading to harnesses that are heavier, costlier, and more complex. (Source: Mentor)

pairs of wires, such as CAN. In a CAN network, cables can sometimes even be twisted during harness assembly to avoid the use of costly specialty cables in the wiring harness. Higher bit rate networks, on the other hand, are more likely to need special grades of cable, shielding, and sometimes more complex pre-assembled cable types like Coax. These specialty cables are significantly larger, heavier, and more expensive than conventional automotive wiring. Therefore, it is typically preferred to minimize the usage of these where practical.

Last, but not least, vehicles are becoming highly connected as part of the Internet of Things and Internet of

Vehicles, transforming the vehicle into a seamless interface between our connected lives at home and at work. The integration of screens and displays into almost any imaginable interior surface demonstrates the vehicle's growing role as a hub for entertainment, communications, and productivity.

All this technology has to be connected together, driving OEMs (original equipment manufacturers) to incorporate more networks, such as CAN, and leading to wiring harnesses that are heavier, larger, costlier, and more complex (Figure 2). Some modern vehicles contain close to 40 different harnesses, comprised of roughly 700 connectors and over 3 000 wires. If taken apart and put into a continuous line, these wires would exceed a length of 2,5 miles (4 km) and weigh approximately 132 lbs (60 kg). In addition, OEMs will need to integrate high bit rate networks with specialty cabling to support the increased features and functionality of new vehicles. Modern vehicles can contain more than 70 specialty cables, such as coax, high speed data, and USB cables. In older cars, this number was closer to ten.

How can today's automotive manufacturers solve the content dilemma? Via the introduction of methods that help development teams to reduce the impact of added content and technology on the weight, cost, complexity, and packaging space required for wiring harnesses.

One solution is to develop technologies that reduce harness weight. Ultra-small diameter wiring (0,13 mm²) is one good example. Unfortunately, the industry is still ▶

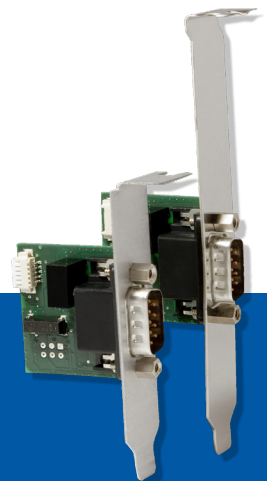
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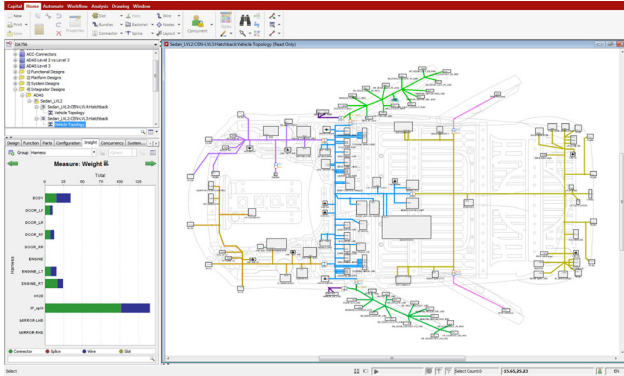


Figure 3: Capital enables tradeoff studies with cost, weight, and bundle size metrics to optimize a harness design. (Source: Mentor)

struggling to develop a sufficient number of terminal substitutions for all currently existing terminals that can crimp to such a small wiring diameter. Reducing the wire size on common circuit types, such as CAN networks, can achieve quick weight savings without necessitating a complex subset of connectors and pins, but the available products on the market currently do not support a large-scale migration to ultra-small diameter wiring.

The same applies to aluminum wiring. For small diameter wiring, pure aluminum is too brittle and thus not a feasible option. Terminal suppliers have begun developing optimal aluminum alloys for the specifications of their terminals. This has led to a multitude of different alloys on the market that, in most cases, are incompatible with other suppliers' terminals. This, in turn, means that a vehicle would have to be solely comprised of one supplier's connectors to be able to use aluminum across the full vehicle, which is not realistic.

Additionally, switching to aluminum wiring would require the compression of the aluminum core to reduce bundle sizes in addition to weight. Due to its material characteristics aluminum wire diameters have to be upsized by at least one size to keep the same conductivity as copper wiring. Switching to larger diameter aluminum wires across an entire vehicle, or even a portion of the vehicle, would result in a significant increase of bundle sizes and require more packaging space.

Finding alternatives to specialty cables will further reduce the weight, cost, and bundle diameters of harnesses. The number of cameras and displays will only increase in the future. OEMs must balance between using high bit rate networks that require specialty cabling or installing a greater quantity of lower bit rate networks, based on the resulting cost, weight, complexity, and risk of the harness. In the near term, widely used standards, such as CAN FD, that provide higher bit rates while operating on inexpensive twisted pair wiring may provide an easier and lower risk upgrade path. Alternatively, finding ways to multiplex these signals onto one shared specialty cable and having multiple devices tap into these cables, will have the same effect: reducing harness weight, cost, and bundle diameter.

Another approach is using advanced software solutions, such as Capital from Mentor Graphics, that support tradeoff studies to optimize module locations and identify any modules that can be combined to save weight, cost,

and reduce bundle sizes (Figure 3). With the ability to compare and analyze layouts for their impact on harness weight, cost, and bundle diameter will enable engineers to choose the most optimal system architecture.

The advent of automotive start-ups

Over the last 10 years to 15 years, the automotive industry has been revolutionized by a second trend: the proliferation of automotive start-ups. Today, it is not just the established legacy OEMs like Ford, VW, or Toyota anymore. Since the founding of Tesla in 2003, more and more electric vehicle (EV) start-ups keep entering the market. This brings its own group of challenges with it.

EV start-ups face unique challenges such as:

- ◆ Reduced time-to-market
- ◆ Lack of infrastructure
- ◆ Bottom up design
- ◆ Constant change

Reduced time-to-market leads to something called the timing dilemma. New vehicle development cycles at an established OEM take about four years or five years. In comparison, most start-up EV companies commonly aim to launch a vehicle in a much shorter period of time, sometimes less than half of the time of an established OEM budgets. Further amplifying this dilemma is that start-up EV manufacturers are starting their development from scratch, without the legacy of previous vehicle programs. This short time to market leads to very short iterations or development phases.

Shortened iterative cycles and development phases are not problems in themselves, but become problems when paired with the long lead times needed for harness development. The usual lead-time for harnesses, from design release to product delivery, is approximately 23 weeks to 26 weeks. Variance in lead-time depends on the number of changes and the amount of progress that a project has made in the development cycle. To meet deadlines for the next development phase, harnesses have to be frozen (where the data/design is released and has to go through formal change management processes to be updated) leaving little-to-no time to examine or implement lessons learned in between development phases. Frequently, vehicle testing has not even started when the next freeze comes due. This can lead to massive rework efforts once the next build phase starts, or "machine gun" change requests to implement changes into the harness design as quickly as possible before the next freeze. Both alternatives can deteriorate the quality of the harnesses and can cause unnecessary delays during functional validation.

Reducing lead times during the engineering and manufacturing phases will benefit all the engineering teams. More lead-time provides teams with more time to find issues, determine appropriate wiring changes, and implement those changes in the design for the next validation phase. How can this lead-time reduction be achieved? By eliminating manual steps and automatically cascading information from one step to another. This significantly reduces mistakes and the need to double check work results. The goal is to create a seamless integration between the vehicle manufacturer's and supplier's tool chains. ▶

Lack of infrastructure

Start-ups endeavoring to develop new vehicles must also contend with a lack of business and engineering infrastructure. During the early stages of a start-up there are no processes in place. Specifically related to wiring development, there is no device transmittal database to help with the gathering, organization, and verification of the electrical data needed for the harness design. Start-up manufacturers also do not have a component library of certified connectors, terminals, seals, or company standards for network implementations. At an OEM, this kind of infrastructure has been built up and tested over a long period. At a start-up, all of this has to be created from scratch, requiring a lot of time and effort when resources are limited, and deadlines are looming.

With more and more start-ups entering the market, harness development tools with an integrated device transmittal database and component library will provide a profound advantage to wiring teams. They eliminate the need for tedious data gathering via Excel sheets and the manual data transfer into logical schematics, a process prone to human error. They can also assist with the implementation of CAN and other network standards. As engineers work they can capture knowledge gained in design rules, helping to build company IP. Harness development tools will streamline and automate the process to reduce mistakes and improve the overall harness quality from early design stages.

Such a database can also run automated reports for open-ended circuits, missing load information, and more. Having a component library in place will considerably reduce the need for part research to find terminals, seals or mating connector part numbers. Incorrectly pinned connectors, caused by operator error or incorrect information on the endview definition, are among the most common errors. A component library that provides endviews for each part number will eliminate the guesswork when assigning pin numbers to cavities and prevent these mistakes.

Design differences

Usually, established OEMs employ a top-down approach to system design. In a top-down approach, the system is broken down into subsystems that are further broken down into components. Each component is then custom-designed to support a particular vehicle feature and follow specific requirements, for example, using a connector from a limited set of connector families from approved suppliers.

The timing and budgetary restrictions present in a start-up do not usually allow a top-down approach. Instead, the engineering teams use a bottom-up design of the vehicle. The engineering teams are directed to use off-the-shelf parts that are closest to fitting the intended application. The systems engineering and wiring teams then are tasked with trying to fit all these puzzle pieces together to make up the vehicle functionality and create connectivity. Unfortunately, off-the-shelf parts cannot be altered or customized without significant investment. This regularly leads to compromises that result in the addition of wiring to the harness to integrate the part.



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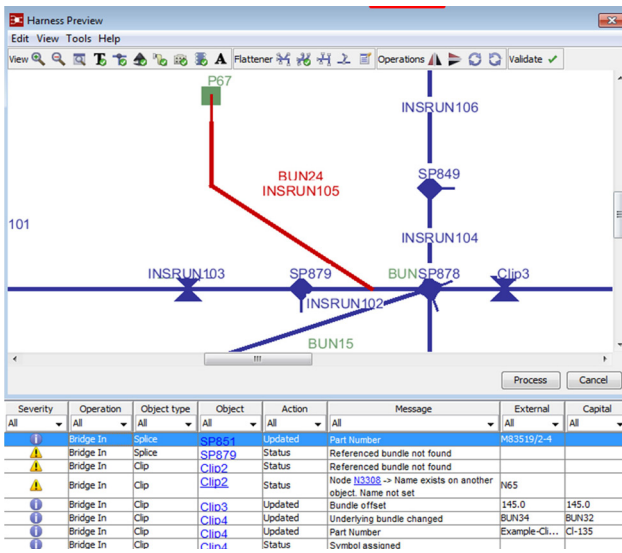


Figure 4: Modern harness design solutions have automated change management solutions (Source: Mentor)

One solution to this is to use a custom gateway or domain controller ECUs to manage the incompatibility between off-the-shelf ECUs using custom software or network configurations. Additionally, instead of having a few selected and approved connector families, the wiring team is often forced to incorporate a wide variety of connector types that can lack UsCAR certification, be difficult to procure, or be suboptimal for quality and manufacturing. The ideal harness development tool needs to be able to support bottom-up design flows and a multitude of connector types.

Change management

After the initial creation phase, most duties of the wiring engineer are related to implementing changes. The Greek philosopher Heraclitus' said "everything changes and nothing stands still". This is the daily routine for a wiring engineer. Change is a constant in wiring harness design and engineering. In start-ups, this is even more prevalent due to stricter time constraints, ad hoc processes, and "greener" engineers.

New experts join different departments almost on a weekly basis, bringing new insights to the team. These could be a better approach to solving a problem, or new technologies they were exposed to or developed in their previous roles. These new team members are excited to leave their mark and the start-ups are hungry for such input. As a result, these ideas likely will be implemented within a short period of time and with little regard to the overall system impact. This is paired with an environment where there are few processes in place, and where change discipline is still in its infancy. In such an environment, changes are not unified, making it difficult to track the most up-to-date design revision.

By comparison, legacy OEMs have established highly efficient and rigorous change management processes. These processes have been optimized over many years and projects, and have very high organizational buy-in. Not so at a start-up. This results in constant change requests regardless of the freeze dates or current project stage.

Furthermore, not all suppliers are sourced from the beginning of the project, contributing to the recurring need for design changes. It can take a long time to source certain parts. To compensate, engineers resort to estimating data to meet the first few harness freeze dates. Once the supplier is sourced, the actual requirements usually do not match the engineer's assumptions, requiring change orders to have a functional part. In some cases, suppliers cannot meet program timing, or decide to terminate their participation. This means the parts have to be resourced. New parts rarely meet the exact electrical specifications of the original part. This leads to even more change requests modifying the harnesses.

It is extremely important to develop a structured and disciplined approach to change management early on in the project. Again, an advanced portfolio of harness development tools can provide an elegant solution. The integrated device transmittal database discussed earlier can be enhanced with certain change control mechanisms. With these enhancements, this database will provide the necessary structure and automatic change management immediately (Figure 4).

The release engineer of a device can draft the device transmittal directly in the database and submit it for approval. Upon approval, the change will be updated automatically in the logical schematics. This eliminates the error-prone process of manually updating schematics from Excel files. It also prevents release engineers from making changes to outdated local copies found on their hard drives, and overwriting changes made to the device transmittal since the last update. Lastly, for each released set of logical schematics there will be an automatically generated list of change requests implemented in each release, thus linking each change back to a specific harness revision for future reference.

The rapid introduction of new technologies and the influx of automotive start-ups into the market lead to a multitude of challenges for harness development. OEMs and start-ups alike must consider the number and sophistication of technology features they integrate into their vehicles as they have a direct effect on networks, harness weight, bundle diameter, and cost. Electrification, autonomous drive and driver assistance, artificial intelligence, and connectivity features all place additional burden on the wiring harness. These features require the introduction of dozens of new sensors into a vehicle that all must connect to the wiring harness. These additional connections can be supported by adding new networks that are either twisted pair such as Classical CAN/CAN FD, or higher bit rate requiring specialty cabling.

Start-up automotive companies face additional pressures as they race to get products to market. Start-ups lack the foundation of legacy designs and the resources needed to custom design parts for optimal performance. Without these resources, engineers at these companies must turn to a bottom-up design approach in which off-the-shelf parts are adapted to meet functional requirements. Start-ups also lack established procedures for managing and tracking change. While established OEMs possess more tenured change management processes, they tend to rely on manual data entry and communication between teams. This leads to inefficient data exchange that is prone to errors.

Complexity in basic cars - Seat Ateca SUV has 2,2 km of wire, 100 sensors, and control units

Cars have been evolving with increasingly complex circuitry. Seat's Ateca crossover features a complex arrangement of wires more than 2,2 km long. The wires, ranging from one millimeter to one centimeter in thickness, are behind the car's lighting, sound system or driving assistants such as the blind spot detector. Up to 100 sensors and control units interact with each other whenever a vehicle function is activated.

Models such as the Seat Ateca contain more than 1 350 wires which, when laid out in a straight line, would stretch more than 2 200 meters in length, similar to an airport runway. The wires branch off into more than 30 circuits that "ensure the operation of nearly every car function and transfer power from location to another, just like blood flowing through an organism", said Pedro Manonelles, an engineer at the Seat Technical Centre. Most of the wiring is concentrated in the area of the front instrument panel,



where more than 200 wires form strands of more than four centimeters in thickness.

All the wiring on a car such as the Seat Ateca weighs slightly more than 40 kg.

It takes a team of 20 engineers three years to define the routing of the wires, the power distribution and the data transmission among control units and sensors.

Assistants such as the blind spot detector are an example of how the car's electronic system works. When the driver activates the left turning indicator, a signal travels from the main control unit to the rear mounted radars in a fraction of a second. If there is a car in the blind spot that the driver cannot see, the radars will detect it and activate and send a warning light to the door mirror. Thanks to this alert, the driver knows whether it is safe to change lanes.

Multiple CAN networks are implemented. The current CAN network protocol reduces the complexity of vehicle wiring by replacing direct wiring with a two wire signal network so that device computers and sensors can communicate with each other. There are ideas to replace much of this wiring with an ultra fast central processing unit and bus instead of the current slower distributed processing systems.

Source: [Green Car Congress](#)

Figure 5: In some of today's Seat models there are more than 12 000 wiring combinations; this figure could increase in the future (Source: Seat)

Modern harness design and engineering tools provide an elegant solution to the problems being wrought by automotive innovation. Using tools such as Capital, with high levels of automation, advanced metrics and analytical capabilities, engineers can perform tradeoff studies to optimize materials, component placement, and routing for minimal harness weight, cost, and bundle diameter. Next, modern design tools can automate data transition between engineering teams and even between manufacturers and suppliers. Finally, innovative harness design software suites feature integrated change management tools that ensure all teams are working with up-to-date data. By adopting these solutions, established automotive OEMs and start-ups can better tackle the challenges of the new automotive landscape. ◀

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