Configurator and CAD modeler: gathering the best of two worlds

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Abstract

Our communication deals with the design of electrical/electronical wiring system for automotive industry. For this kind of product, we want to show how configuration techniques can be a significant assistance for design. After a brief presentation of the product and design requirements, we propose a design method, then we show how and why configuration and CAD modeler can assist the designer in a smooth cooperation in order to achieve quick and error free design. An industrial case illustrates the proposed approach.

1 Introduction

The Electrical/electronical Wiring Systems (EWS) complexity in automotive industry increased a lot in recent years, due to a growing demand for car comfort and vehicle safety. Now, EWS account for approximately 10% of total vehicle cost [Price, 2000] and are designed as an assembly of pre-defined elements (wire of different diameters, various connectors, information processing devices, ...). Most of the time, the EWS designer uses a CAD system to select elements and locate their position in the car. The EWS element selection is subject to various constraints coming from the customer (car maker) and from the supplier (EWS provider). The EWS growing complexity now requires this design activity to be assisted with some tools that can:

- manage the combinatory explosion of possibilities (the number of possible EWS for a single car model can be counted in millions) with a good level of confidence (low number of errors),
- speed up solutions generation in order to enable some evaluation and comparison between different solutions (most of the time two or three solutions are investigated in detail).

Generally speaking, configuration is defined [Mittal and Frayman, 1989] [Kuhn, 1999] [Freidrich and Stumptner, 1999] [Aldanondo *et al.*, 2000] as:
"given:

(i) a generic model of a configurable product able to represent a family of products with all possible variants and options, in which a generic model is a set of predefined components plus a set of various constraints,

(ii) a set of customer requirements, in which each requirement can be expressed by a constraint,

finding at least one component set that satisfies all the constraints".
For us, the generic model is DCSP based [Mittal and Falkenhainer, 1990]. The variables represent components and product characteristics. Configuration is interactive and achieved by assigning a value to each variable interesting the user.
The EWS design seems to be very close to this definition. Therefore, our goal is to show how configuration techniques can be a significant assistance for EWS design and try to extend these results for other products. Our communication is divided in four parts, the first one characterizes the EWS product, then EWS design activity is presented and decomposed in steps, we present afterwards how configuration can be used efficiently to assist the design and a discussion concludes the paper. An example dealing with the front door window lifter EWS part illustrates our ideas throughout the communication. Product generic modeling is discussed thanks to the dynamic constraint satisfaction problems approach proposed by [Mittal and Falkenhainer, 1990].

2 The EWS product, process and demand

The purpose of this section is to identify the EWS characteristics that are well suited for interesting and efficient operating of configuration techniques. We first speak of the product, then deal with some manufacturing process aspects and conclude with the demand.

2.1 The EWS product

The person who drives a car interacts with the EWS through various switches (electronic key, window switch, sunroof button, ...) and activators (airbag, window lifter, stereo system, ...). To him, the EWS is just a physical support for functions eventually decomposed in sub-functions that can be:

- always present in any finishes of a car model, for example: "light system" function decomposed in "stop lights, high beam" sub-functions,
- present according to the demand, for example "fog lights" sub-function.

Therefore an EWS can be seen as a set of functions/sub-functions. These functions can be characterized by attributes, for example "number of loudspeakers" for an audio function.
For the engineer who is involved in design, an EWS is a set of elements connecting the components: activators (motors, lights, . . .) with captors: sensors (heat, speed, . . .) or switches (button, key, . . .). EWS elements gather wires, computers and connectors. Activators, captors and switches do not belong to the EWS but interact it through connectors. These components are pre-defined with frozen characteristics.
During the design, EWS components must be:

- selected, with respect to the requirements,
- associated with a computer, different functions can rely on a same computer,
- located in the car body according to some geometrical constraints of the car.

Most of the time, some wire grouping is necessary (for example a power wire can gather energy supply for more than one activator). The resulting EWS can be eventually decomposed in physical modules (requiring extra relevant connectors) in order to distribute manufacturing in different facilities (mainly in low cost production countries).

2.2 The EWS manufacturing and assembly process

The EWS final assembly is most of the time close to the demand and therefore to the car assembly line. EWS elements and physical modules, if any, can be manufactured everywhere. Therefore three kinds of industrial facilities can exist: EWS final assembly, physical module assembly and element manufacturing. This is an important aspect of design, which significantly affects the operating cost of the company providing EWS.

2.3 The EWS demand and response

The EWS demand can be specific for each car ordered by a private person, or gathered in packs.
For the first case, a specific EWS is configured for each demand, then assembled and provided to the car assembly line while elements are manufactured according to a long-term commercial forecast. This industrial situation is called "assemble to order" as explained in [Aldanondo *et al.*, 2000]. The diversity of demand is enormous (millions of different EWS for a same car model), but configuration and just-in-time management prove to be a good response. EWS final assembly facilities are close to the car assembly line while the element manufacturing ones can be located in low cost countries. Physical modules do not exist in this situation.
The second case avoids this diversity by splitting the demand in "packs" such as, for example: basic, standard, comfort and luxury, an EWS existing for each pack. Manufacturing and assembly is achieved according to mid-term commercial forecast, and the suitable EWS pack is picked, in real time, in inventory according to the demand. We are therefore in a "pick to order" industrial situation [Aldanondo *et al.*, 2000]. Element manufacturing and physical module assembly facilities (if any) can be located everywhere while EWS final assembly facilities are either close to the car assembly line or located in a low cost country with an inventory close to the car assembly line.
The first solution is complex to manage and expensive due to the total element assembly that should be made close to the car assembly line. This solution is mainly used for expensive cars. There is no hard EWS design problem.
The second solution is easier to manage and is cheaper, in spite of pack over equipment, due to the little number of EWS final assembly facilities. This solution is frequent for first and mid price car. For that case, there is a hard "pack set" design problem stressing the following questions: (i) how many packs? (ii) which functions should be gathered in each pack? (iii) what is the result of packs design in terms of operating cost for the EWS supplier company?.

2.4 Conclusion and EWS design approach

Our contribution clearly deals with the design of EWS packs. A solution is defined for each car model as shown in Figure 1, through (i) decision about the number of EWS packs, (ii) design of each pack and (iii) quantitative evaluation of total cost (material, process and logistics) for each solution.

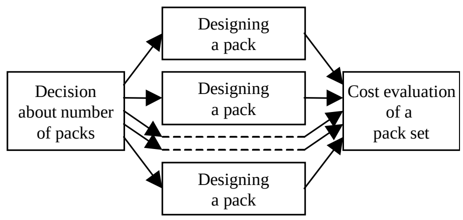

Figure 1: EWS design with a pack approach

A good car model EWS solution will be accepted after the study and evaluation of various solutions. Therefore a method and some computer-aided tools are necessary to speed up and secure each pack design. In the following, we will just deal with the second job "pack design".

3 The pack design

In this section, we describe a two steps method that we propose for the design of each pack and underline the requirement for computer-aided assistance.

3.1 Requirements identification and processing

Two kinds of requirements are taken into account; those dealing with functional or ergonomic aspects and those dealing with EWS technology.
Functional or ergonomic requirements correspond with:

(i) Selection of functions/sub-functions belonging to the pack.
They are for example: light, window, heating, door locking, stereo equipment, safety devices, . . . Generally, most of these functions are present in any car model. Differences appear at the sub-function level, for example "fog light" is not always present. Some other functions like "electrical sunroof" may be optional.

(ii) Characterization of each function/sub-function.
Each existing function/sub-function is supported by captors (sensor, switch, button, ... and actuators (motor, light, acoustic devices, ...). It is very often necessary to select ergonomical characteristics that influence the pack. For example, the front window lifters command can need four single buttons on a driver's door (right and left front window auto and pulse) or two "fancy" buttons (mixing auto and pulse window movements). In some cases, the location of a button can be chosen among several possibilities (front window lifter on each door or on the dashboard).

(iii) Checking the consistency of these requirements.
Of course, these selections are mutually dependant (no pinch protection for a window lifter pulse button), and it is necessary to check that all the requirements of a single pack are consistent. As many pack designs must be achieved with a rather large combinatory, some configuration process seems to be well suited for the processing of these requirements.

The result of this step is a consistent logical schema with a rough position of captors and activators and their logical links as shown in Figure 2.

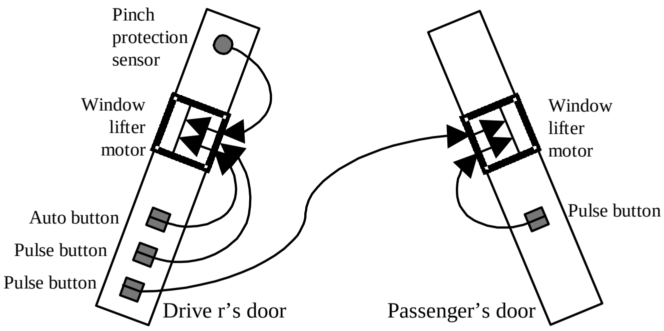

Figure 2: Logical schema for front window lifter

EWS technology requirements correspond with:

(i) Identification of information processing devices.
Each function, sub-function, captor and activator must be linked with an information processing device. Most of the time, there are three or four computers (or electronic calculators) in a car. They are generally dedicated to the engine, safety devices and car body. In some cases, computers can be physically distributed in the car (underhood, dashboard, doors, rear body). Therefore, it is sometimes necessary to determine the computer quantity and their location in the car.

(ii) Association of information processing devices with functions.
Once computers are identified and located, each function, sub-function, captor and activator must be associated with a computer. When a function is directly associated with a computer, all relevant sub-functions, captors and activators must be linked with this computer.

(iii) Checking the consistency of these associations.
There is no hard consistency checking problem. The constraints describing the possible associations are not numerous and rather simple, and configuration should be able to assist this activity. Most of the time, the power supply is connected with the computers.

The result of this step is a complete logical pack schema or, an extension of the previous schema with a rough position of computers and power supply and their logical links. This is shown in Figure 3 where it has been decided that each door will have its own computer.

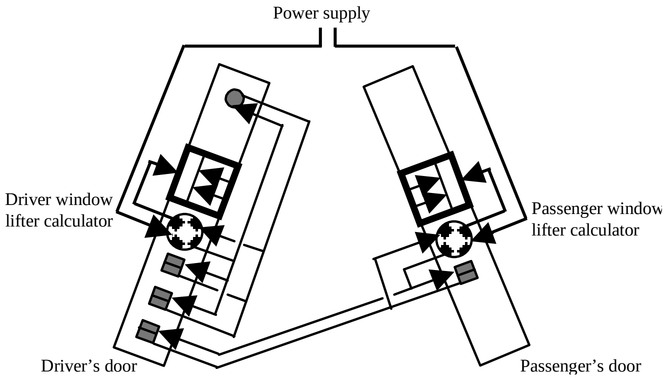

Figure 3: Logical schema with associated computers

3.2 Layout and geometrical constraints processing

Once the logical schema with wire connecting captors, activators, computers and power supply is obtained, it is possible to accurately locate captors, activators, computers and power supply and to design a layout for the entire pack. Then some wire grouping and physical module decompositions can be done.
The EWS final layout design is established with:

(i) the identification of the exact location of each component.
The locations of each captor, activator, computer and power supply is defined in an absolute referential with three coordinates (X,Y,Z). Most of the time, this data is provided by the car manufacturer who knows where each component can be.

(ii) the physical layout design of the pack.
According to these exact locations and the complete logical pack schema (results of requirements identification and processing), wires paths in the car can be derived according to a pack physical architecture. A pack architecture is a network showing accurately where "logical wires" can be routed. The pack architecture terminations locations correspond with components: captors, activators, computers and power supply locations. Most of the time, according to the car manufacturer only a few architectures exist as shown in Figure 4.

When there is no loop possibility in the architecture, the superposition of a complete logical pack schema with a selected

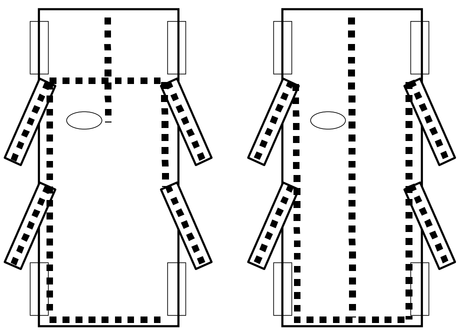

Figure 4: Two pack physical architectures

architecture generates the detailed physical layout of the pack. In the case of loops, some optimizations may be necessary to select the appropriate wire route.
The result of this step is a complete physical pack schema or pack layout as the one shown in Figure 5.

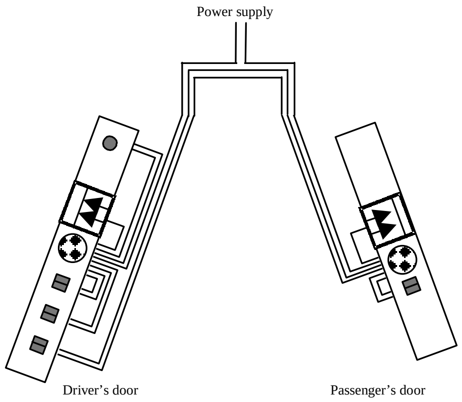

Figure 5: Pack layout

Wire grouping and physical module decomposition correspond with:

(i) The grouping of wire pieces
Once the pack layout is defined, it happens that different wires can be replaced by a single one. This reduces the amount of wires although connectors are needed. This is mainly used for power supply wires, one wire being able to carry power to different computers or activators as shown in Figure 6 thanks to the necessary connectors.

(ii) Physical modules definition
In order to allow EWS manufacturing and assembly in different facilities, EWS can be decomposed in physical modules that are stored and assembled close to the car assembly line. Decomposition can be achieved according to the location or the functional role of the EWS elements. In the first case, EWS physical module can correspond for example with: body module, under-hood module, doors module, rear module … In the second case, modules can correspond for example with engine control, safety, security, lighting …

The Figure 6 shows a decomposition according to the location providing a physical module for each door with relevant connectors.

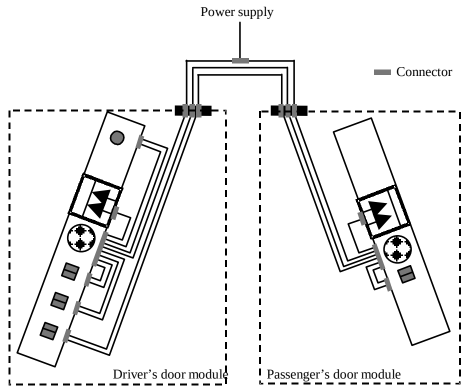

Figure 6: Modules and connectors

3.3 Conclusion

Two main steps have been identified for EWS pack design:
- step 1: requirements identification and processing,
- step 2: layout and geometrical constraints processing.
The following section will investigate how these steps can be assisted with some computer tools.

4 EWS pack design and assistance tools

According to the presented design approach gathering “pack set design” and “pack design”, it becomes obvious to provide the designer with a maximum of computer aided tools for pack design in order to evaluate and compare many solutions. The main goals of these tools are to provide quick and error free solutions. Each pack design is achieved once the pack quantity has been determined.
It is during step 1 (requirements identification and processing) that various pack requirements are processed. Due to the important combinatory, the constraints existence and the need of consistent result, we propose (in section 4.1) to use configuration techniques to assist the first step.
As step 2 (layout and geometrical constraints processing) is much more a geometrical process with some geometrical reference architectures and graphical entity manipulation, we suggest (in section 4.2) to use a CAD modeler with some simple (mainly procedure oriented with very light constraints) computing processing.

4.1 Requirement processing and configuration

As it has been seen in section 3.1, this first step is decomposed in two sub-steps (i) functional or ergonomic requirements processing and (ii) EWS technology requirements processing. For each of these steps, we will present a configuration model based on the Dynamic Constraint Satisfaction Problem proposed by [Mittal and Falkenhainer, 1990] and illustrated in [Aldanondo *et al.*, 2000].

Configuration purpose for “functional or ergonomic requirements processing” is to generate a set of logical links between captors and activators according to:

- functional or ergonomic requirements,
- a configuration generic model.

Logical links are defined between each activator and its relevant captors. The configuration generic model describes all the possibilities of requirement and link grouping. According to [Aldanondo *et al.*, 2000] [Soininen *et al.*, 1998a] [Soininen *et al.*, 1998b] [Falfering *et al.*, 2000], we mix explicit and implicit modeling or variables corresponding with components and product characteristics. The resulting model is shown in Figure 7 for the car front door window lifters example. Underlined variables and values in bold characters represent the configured system of Figure 2.
Product characteristics variables represent the functional or ergonomic requirements and allow capturing the EWS pack description. They are organized in a tree structure (function/sub-functions) and located in the “left part” of our model. These variables are subject to compatibility and activity constraints representing what can be gathered. In our example, these variables represent various possibilities of button type (pulse, auto and fancy), button position (driver’s door, passenger’s door, dashboard), sensor existence (pinch protection) or sub-function existence (electrical window lifter).
Component variables show the components that can be used to support the required function/sub-function. They are organized with respect to the function/sub-function tree and gather captors and activators; a logical link exists between each activator and its relevant captors. They are located in the right part of our model. Some compatibility and activity constraints can exist between them.
Activity constraints link these two kinds of variables and identify, according to product characteristic variables values, components that must be linked by the EWS pack elements.
The use of configuration for “EWS technology requirements processing” consists in affecting computer device to each function or sub-function or captor/activator:

- according to the set of logical links between captors and activators (resulting of the previous step),
- according to the designer’s requirements,
- with respect to a configuration generic model.

The configuration generic model describes all the possible computer affectations in the Figure 8 of the following page. A computer can be affected at the function, or sub-function or captor/activator level. A lower level inherits of the upper level affectation decision. Variables and values in bold type characters represent the configured system of Figure 3.
Each variable of the generic model of Figure 8 corresponds with a function/sub-function/captor/activator (and possibly its location) identified during step 1 (right part of Figure 7). The possible values of these variables are the computers that can be selected. In our example, three computers can exist and are located: centrally in the dashboard, in the driver’s door or in the passenger’s door.
The compatibility constraints show the possible affectations

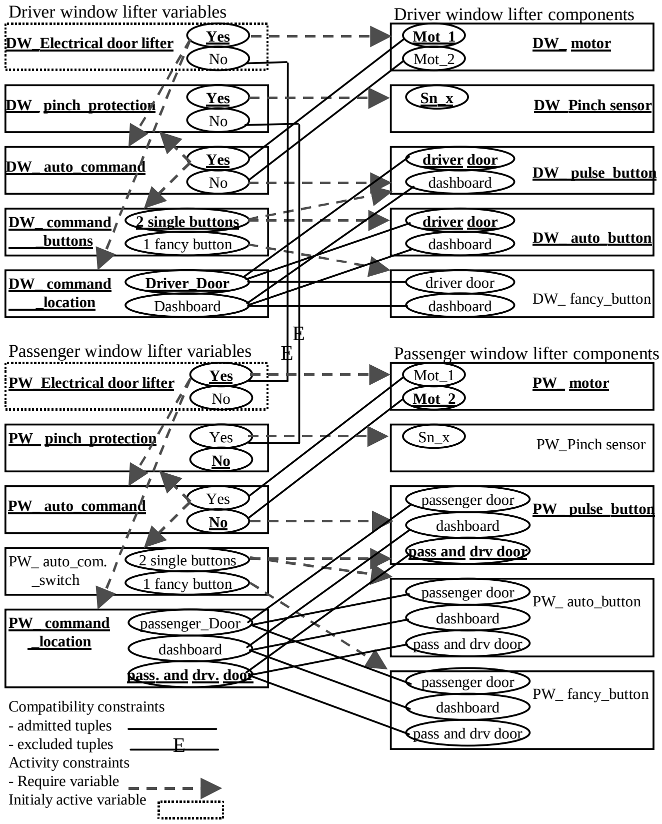

Figure 7: Configuration generic model

and inheritance mechanisms.
For these two sub-steps, configuration is mainly interactive and the main designer assistance comes from constraint propagation that allows quick and error free EWS pack solutions, if the generic model is consistent.
These two configuration steps enable to define logical schema for each pack in a friendly user computer aided tool. Many solutions can be quickly defined in order to allow EWS pack layout design.

4.2 Layout processing and CAD techniques

As showed in section 3.2, this second step is decomposed in two sub-steps (i) EWS final layout design and (ii) Physical modules definition. These design activities being mainly procedure oriented, we will only give some ideas about the data processing of each of these steps.
The data processing for “EWS final layout design” requires:

- to identify the exact location of each component,
- to identify pack architecture with routing matrixes,
- to route the wire in the car body.

The two first identified elements represent some kind of a generic model for layout design. The last one corresponds with some data processing.
Each captor, activator and computer possible location is defined in an absolute referential with three coordinates (X,Y,Z).

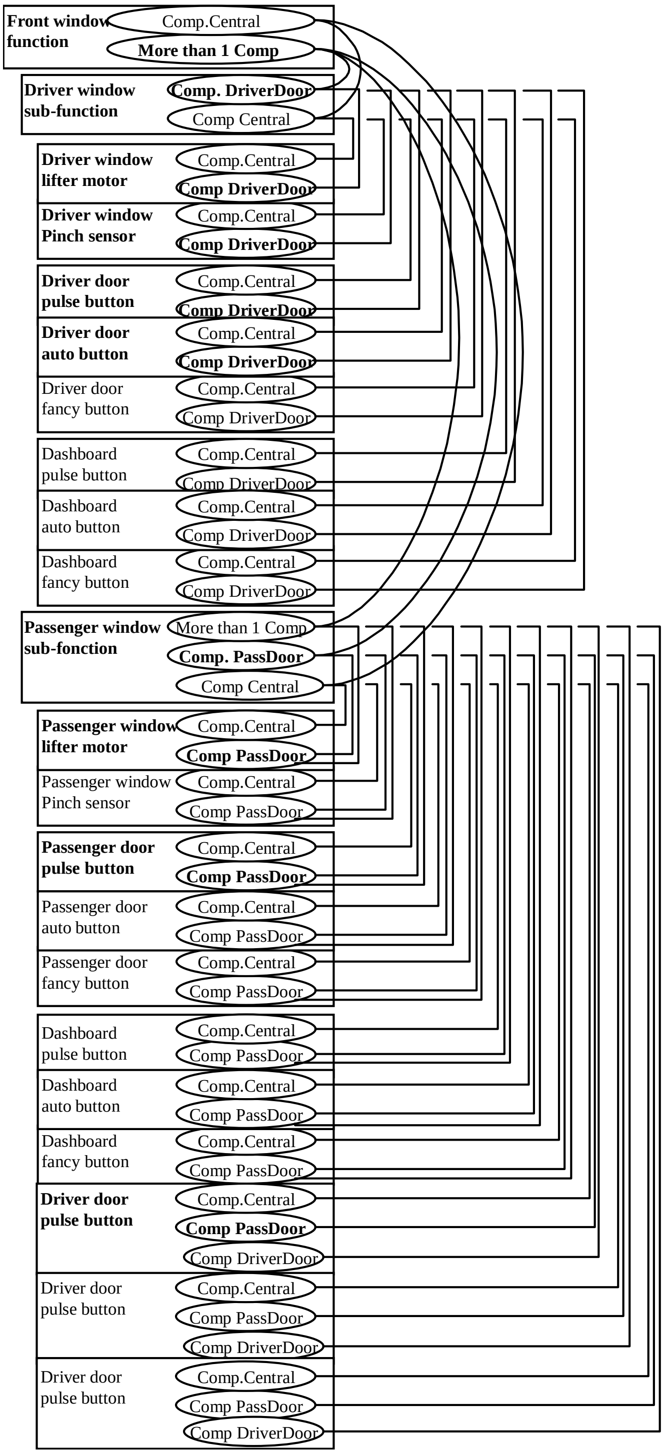

Figure 8: Configuration generic model

This information is provided by the car manufacturer and is valid for any configured EWS pack of a single car model. These locations correspond with the terminations of the EWS pack and relevant connectors.
Each location is inputted in the first row and first column of a square matrix, and corresponds with EWS ending points. EWS routing points, defining where wire pieces can be routed, are added to this column and this row. An "X" at the intersection of a column (i) and a row (j) indicates that a wire piece can be routed in a straight line between point *i* and point *j* that can be either ending points or routing points. Such a matrix is a pack architecture that is valid for any configured EWS pack. For our example of Figure 5, Figure 9 shows ending points for driver's door (labeled 001 to 006) and passenger's door (008 to 012), the other points are routing points. In a drawing clarity purpose, wires are represented by different lines but most of them should be single lines. The corresponding matrix would be like the one presented in Figure 10 where underlined ending points and X square correspond with the Figure 9 layout.
Once ending points existence are identified (as a result of requirements processing) and if no loop exists in the matrix, the EWS layout design is just a procedural processing providing the physical path for each piece of wire connecting two ending points.
Most of the time, a CAD viewer of the solution is used in order to make light manual modifications or adjustments of the generated solution.

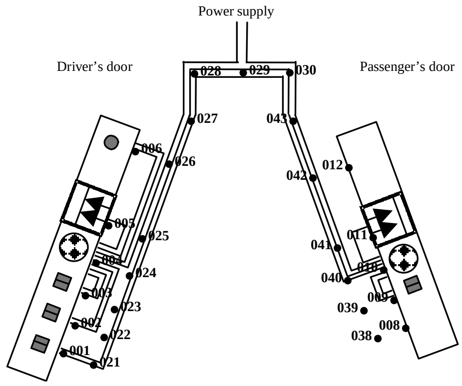

Figure 9: Ending and routing points for a pack architecture

The data processing for "Physical modules definition" requires:

- to group some pieces of wire,
- to cut and gather pieces of the EWS pack.

These two design activities can be achieved by some CAD manipulation possibly assisted by some procedural processing that will be not detailed in this communication.
The replacement of a group of wires by a single does not modify the EWS previous layout. Only wire piece definitions and relevant connectors change.
Wires cutting and gathering for modules definition is just a generation of references for production management and likewise does not change the EWS layout.
For these two sub-steps, the designer is mainly assisted by a traditional CAD modeler tool and some data processing. CAD is a necessity in order to see the EWS layout, the connectors and the car body "on the screen". CAD modeler presents also an interest for storing the exact shape of the manipulated enti-

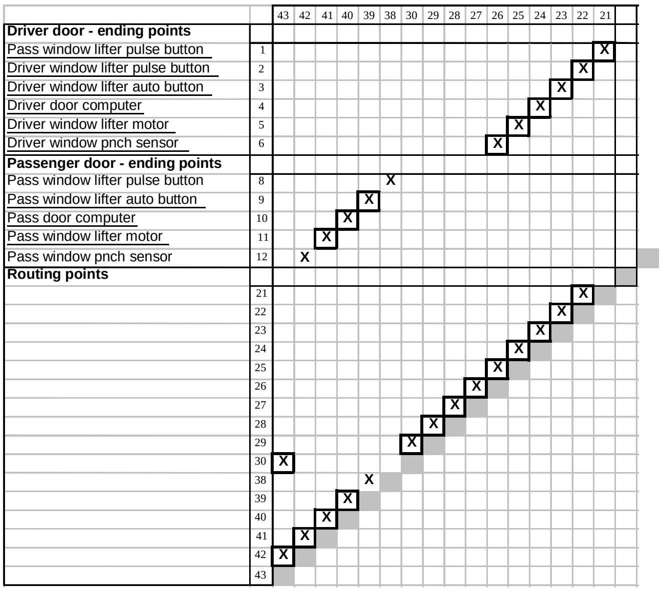

Figure 10: Architecture routing matrix

ties and permits a realistic vision of the designed wiring system in the car body.

5 Conclusions

In our communication dealing with EWS design for automotive industry, two main design steps have been identified: (i) requirements identification and processing and (ii) layout and geometrical constraint processing. It has been shown:

- that configuration techniques can be a significant assistance for the first step in order to support the diversity of EWS pack demand,
- that a CAD tool is a necessity for the second step in order to allow graphical entities manipulation and solution viewing.

The cooperation of these two aiding design tools has been clearly established through information flows between these two steps.
As far as we know, most industrial ready to use software are either oriented towards configuration or towards graphical CAD. Some integrated software gathering these two kinds of tool begin to appear but are most of the time dedicated to a certain kind of product design, as the one presented in [Heiderscheit and Skovgaard, 1999].
The growing demand of customized products, the increasing presence of product modularity and more and more frequent assembly to order customer/supplier relations will require the type of design approaches we developed. Therefore, computer aiding design tools and methods gathering configuration and CAD techniques will become a necessity.
Like our industrial product, EWS pack for automotive industry, many industrial domains can take advantage of this approach mixing method and tools, such as machine tool, home furniture, aircraft cabin, private house, ... We are currently working on integrating these tools and designing a pack set solution evaluation process.
A major automotive EWS supplier working for main automotive industries provided the industrial case. Their main goals are to speed up the time required for designing EWS pack set and to reduce design errors. Their main interests for a configuration approach are (i) that during specifications with the car maker, configuration allows to investigate quickly many different solutions and to answer easily question like "what if ..." or "how much if", (ii) when the EWS is designed and manufactured, configuration models can be actualized with integration of new components or functions in an existing EWS model in order to provide new versions for a same car model (EWS design are approximately updated each year). The presented case was of course a simplified version of the real problem.

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