Title:
A Method for the Cost Optimization of Industrial Electrical Routings

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Introduction and related works:
The cost reduction is one of the most spread strategy adopted by companies for guaranteeing profits in a competitive market. The most important player who can reduce costs is the designer since he/she is responsible of about 80% of the manufacturing and assembly cost. The cost optimization is the process through that designer can reduce the cost without changing the product functionalities. Cost optimization is a general method that can be applied to different kind of products. The paper focuses on industrial electrical routings generally used for complex products (e.g. power plants, refineries).

The routing optimization is an important step toward the cost optimization of an electric cable harness. In such a field, the literature contains several research works presenting solutions for this aim. A group of approaches, such as *Ittner et al.* [1] and *Pillai et al.* [6], deals with the cable routing problem for the cost minimization, by using a heuristic method. Another group of works, such as *Kloske et al.* [4] *and Ma et al.* [5], presents streamlined approaches (e.g. genetic algorithms) for the cable routing optimization for bulk cable harness. The first kind of approaches consider the cost but cannot be easily used for industrial electrical routings made by thousand cables. The second one do not consider the cost. Similarly, *Wedzik et al.* [7] presents a methodology for the simultaneous optimization of network layout and cable cross-sections in a wind farm based on MILP (Mixed Integer Linear Programming) algorithms with the aim of reducing the investment costs. By using this method, it is possible to consider a lot of constrains (cable dimensions, number of feeders, etc.), demonstrating at the same time high precision within a modest computational time. In the same way, *Zhu et al.* [9] provide a Knowledge-Based optimization technique for the automatic routing of an aircraft wire harness, taking into account constrains such as the total costs and the hot points. Another work describes a cost model for wire harnesses which includes product and manufacturing costs in order to reach an optimum level between product variant complexity and material costs [8]. This method is based on MATLAB simulation and it is useable for automotive application.

Despite the many approaches, the abovementioned methods are not based on CAD systems, forcing the designers to use specific tools, in addition to the commonly used design tools, to perform the cost optimization.

Many of the software tools used by the electrical engineer are able to optimize the layout and the routing of wire harness to reduce cable length and to avoid interference. These tools (e.g. Catia Electrical® by Dassault System®, NX Electrical® by Siemens®) are having a rapid development due to the growth of the electrical cars sector where the wire harnessing plays a fundamental role. However, these software provide only path optimization functions for reducing the path length. Such tools do not consider the cost of electrical components and the installation cost. It is important to underline, especially in case of big and complex structures, that the shortest path is not always synonymous of cost saving because the installation cost could exceed the material cost.

This paper presents an approach for the cost optimization of industrial electrical routings. The optimization process consists of two levels: the arrangement of the cables within the cable trays (CTs) and the 3D routing of the cable trays for connecting the modules of a product. The arrangement of the power and signal cables and the selection of the cable trays are carried out considering specific configuration rules (e.g. power cable cannot be overlapped, cable trays can move only along perpendicular directions). The cost functions consider the preliminary analysis of the project, raw material (cable trays, cables, support systems, multiple cable transfer etc.), manufacturing operations (e.g. cutting, crimping, screwing), installation phases (e.g. support and multiple cable transfer mounting, cables arrangement) and tests.

The optimization process has been used for optimizing a portion of the electric cable harness of a gas turbine power plant with a size of 44x20 meters, and a total of 40,60 kilometers of cables. The optimization process let to a cost saving of about 15% compared to the original design.

Method:

The presented optimization process helps electrical engineers to determine the best arrangement of cables within cable trays and to find the optimal routes that minimize the cost of a cable harness.

A cable harness consists of several cable trays, used to support and to steer insulated electric cables. They are required in those installations where wiring changes are possible at the construction site. Cable trays are classified by material, type, cable levels and orientation. While ladder trays are used for power cables (over 1.5 kW) due to the thermal dissipation need, slotted trays are suitable for instrumental cables. A tray could be straight, elbow, with a T-transition or cross. A commercial tray has a standard length of 3 m, even if it can be cut during the assembling for respecting the electric layout.

The cost of a cable tray wiring system mainly consists of the raw material (*RMc*) and relative installation (*PAc*, *Ic* and *Tc*) costs (Eq. 1). The latter relative to the preliminary assembly operation, cable tray system installation and final test.

$$Cost = RMc + PAc + Ic + Tc \tag{1}$$

The raw material cost (Eq. 2) calculation is a BoM-based costing approach.

$$RMc = \left(\sum_i RMcc_i + \sum_j \left(RMsc_j + RMsc\_scraps_j + RMtc\right)\right) \cdot \left(1 + \frac{RMoc}{100}\right) \tag{2}$$

The unitary cost of each item ($RMcc_i$, $RMsc_j$) is retrieved from specific databases of commercial and electrical components (e.g. https://octopart.com/). The semi-finished components require additional operations before their use. For semi-finished components, the raw material cost (*RMsc*) should consider also the relative scraps ($RMsc\_scraps_j$). The cost of the raw material has to be increased for an overhead factor that consider a mark-up for management-related activities (*RMoc*). The cost of semi-finished parts need also to consider its transformation (*RMtc*). For instance, where a cable path requires cutting a commercial tray, the sawing and beveling operations determine supplementary costs.

The installation-related costs refer to a list of operations required for the complete realization of a cable tray wiring system, once completed the design stage. The operations considered by the cost models are the preliminary analysis, installation and test.

The preliminary analysis aims to establish a work plan and finding/solving technical issues of the wiring system. This cost item (*Pac,* Eq. 3) is a percentage (*PAcp*) of the overall cost.

$$PAc = (RMc + Ic + Tc) \cdot \frac{PAcp}{100} \tag{3}$$

The installation cost (Eq. 4) of each component consists in multiplying the installation time ($Ti_{i,j}$) by the hourly rate of the cost center (*CUi*) and a corrective factor (*If*). The installation time is a value relative to standard installation conditions (e.g. one worker, not in elevation, etc.). The corrective factor is a parameter for adjusting the standard time with the actual installation conditions.

$$Ic = \sum_{i,j} \left(Ti_{i,j} \cdot CUi\right) \cdot If \tag{4}$$

The test of the electrical system aims to verify that the overall installation was perfectly done (Eq. 5). The approach is similar to the installation cost.

$$Tc = \sum_z (Tt_k \cdot CUt) \tag{5}$$

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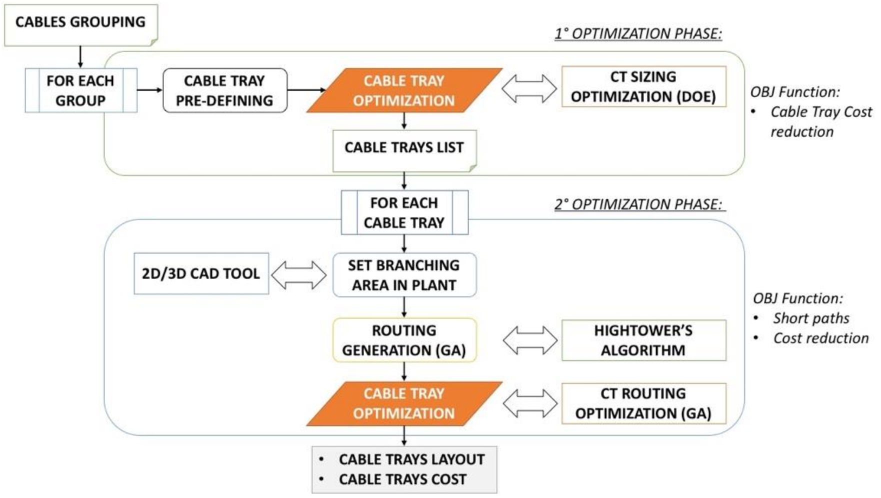

Fig. 1: The proposed design methodology for the cost optimization of electrical cable trays.

Fig. 1 describes the design methodology for the cost optimization of electrical cable trays. The input data is the list of electrical cables and the layout of the plant. An electrical cable list includes information such as the equipment units to be connected, the level of power, the emission per each wire, the cable size and the specific weight. The plant layout is the 2D and 3D representation of the building structure with the equipment units of the electrical installation to be connected. During the design process of a cable harness, the electrical engineer firstly defines the cables routing made by several bundles of cables. The bundle selection depends by the power level, the equipment to be connected and the type of the electrical system to which a cable belongs. The electrical system is a functional group of the complete electrical installation. Therefore, the cable list groups the same cables typology, inside the same electrical system, with a common starting connection. A group of cables, as defined, can be bundled in the same cable tray system. Therefore, the engineer has to define a cable tray route, which allows each cable to be connected with the related destination equipment. From a geometric point of view, the path of a cable tray should to be drafted close to each unit to be connected. After each electrical connection, a cable tray changes its section, because the cable tray is split in two ways so that the number of wires decreases. Therefore, the optimization of a cable tray concerns each section of the path.

The described approach starts optimizing the cable trays to find the best cables arrangement within the relative cable tray (Fig. 1.). The output of this phase is a list of cable trays with relative dimensions, which allows to minimize the cost while ensuring the correct arrangement of all the cables. This result is the input for the second optimization level, where the cable trays list is used to estimate the costs and compare every possible route.

First of all, it is necessary to define the starting and the ending points of the cable trays. The starting point could be, for example, the power panels while the ending points could be gas turbines, generators, heaters, etc. Power and instrumental cables can be grouped in subcategories depending on the size, the insulation material, the armoured, etc. This classification is necessary to arrange the electrical cables inside the cable trays. Indeed, power cables cannot be overlapped in order to facilitate heat dispersion and to avoid overheating whereas, in case of different instrumental cables, an internal separator is essential to reduce electromagnetic interference. In this manner, a linear arrangement is defined for the power cables while a volumetric arrangement for the instrumental cables.

Once the starting/ending points and the cables configurations has been defined, the optimization of the cables trays dimension starts (first optimization level). An Excel-based tool containing the database with all the available cable trays is used to calculate their size and quantity necessary to serve the selected skids. Moreover, this database also includes the cable trays cost information in order to compare the different solutions elaborated during the optimization process. This tool is interfaced with an optimization software tool, which is able to change, in an automated way, cable trays number and dimensions according to the database. Working in an iterative manner and using formalized rules and proper algorithms, this software collects information about the cables arrangement and costs for each possible configuration. In this way, it is possible to evaluate a very large number of combinations to find out which one minimizes the cable trays cost for meter.

While the first level of optimization only regards the best selection of components for each route and sub-route of a cable tray, the second level of optimization concerns the study of the best geometrical path for a system of cable trays. The two levels of optimization are based on two different approaches. The first approach regards a study of optimization based on the solution of a defined DoE planning [1]. On the other hand, the second study focuses on genetic algorithm to solve the routing optimization. Regarding the method described in Fig. 1, after the definition of the sections of each cable try to be arranged, the designer must define the path of the wiring harness. The proposed approach aims to define an area for each branching point of a cable tray. The electrical engineer has the task to draft these graphical objects to the 2D/3D CAD model of the plant.

The problem of generating the route of a cable tray is simplified by considering many simple paths defined by the branching points of the whole route. The position of each branching point is constrained in an area defined by the user. A genetic algorithm (2° OPTIMIZATION TOOL) changes the position of each branching point in order to optimize the cost of the electrical installation.

The route generation of each sub-path (from two defined points) is defined by the Hightower's algorithm [2]. This algorithm is a vector router that sends two lines in orthogonal directions both from the starting point (S) and from target point (T) until an obstacle is reached. From there, this method repeats the process until the segment originated from S intersects the segment originated from T. It is very suitable when there are few obstacles but relatively long distances to be covered and it has been chosen for its rapidity in finding the solution.

Case study and results:

This section presents a case study for evaluating the proposed methodology. It concerns the cost optimization of the electrical cabling of an on-shore module for power generation in oil & gas sector. The proposed test case is focused on the optimization of a 400-m electrical harness which interests different types of electrical cables (power, transformer and instrumental cables). This analysis has been carried out with the collaboration of an oil & gas multinational company.

The origin point of the electrical system, from which all the cables depart, is represented by the local electric room (LER), namely the cabin containing all the power and control panels. The end points are represented, instead, by the various items to be connected. The cable routing cost of the module under investigation, considering both the cost of material, installation, preliminary analysis and test is about 4% of the total cost.

According to the proposed method, the inputs for the cost optimization are the list of electrical cables and the layout of the plant. The first step of the methodology is the definition of the starting and target points. To simplify the discussion of the case study, only the connections between LER (yellow box in Fig. 2.) and four plugged-in items (red boxes in Fig. 2.) are analyzed. Then, the installation preferences must be set. In this case, we choose aerial installation as cable-laying method, covered CTs and fiberglass as CTs material. Then, for the first optimization level, the variables for the DoE have been defined. Cable trays dimension has been chosen as variable. At this point, the best cables arrangement is reached via an optimization software (Isight® by 3DS®) coupled with the Excel® tool that contains all the necessary algorithms and rules for the cost minimization. The output of this level of analysis is the list containing the number and the dimensions of cable trays that allow to optimize the cost for meter. The output of this optimization level has been set as input for the second one. The designers must set the branching points and define an area around where the points can be moved. The coordinates of these points have been chosen as variables in the optimization software imposing as constrains the maximum dimensions of the area, tailored for each equipment. The CAD system (AutoCAD® by Autodesk®) has been opportunely customized by using its API (Application Programming Interface), to modify the layout and to recognize possible clashes between the cable trays and the obstacles. The genetic algorithm of the optimization software varies the position of the branching points and then, the Hightower's algorithm written in the programming code draws the route of the cable trays. At the end of the sketching, total cost information has been calculated. In an iterative and automated way, many feasible solutions can be analyzed, showing the total cost for each one. In this manner, it was possible to redesign the routing of the module saving about 15% of cable routing cost compared to the designer's solution.

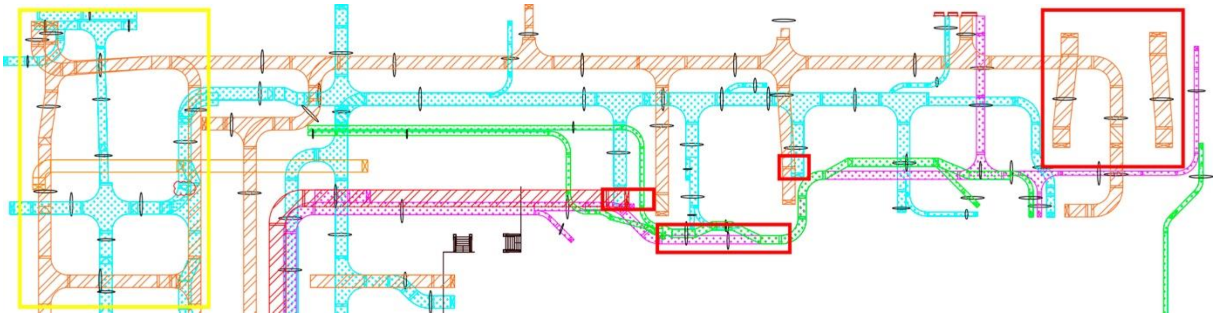

Fig. 2: Optimal 3D routing of the cable trails.

Conclusions and future works:

The paper presented a cost optimization method for electric cable harness, based on the analytic cost analysis and routing process. The inputs of such a method are the cables list and the layout of the plant. The method presented in this paper, even if focused on electrical cabling, can be also extended to other arrangements such as piping. The method, once implemented within a prototypal software tool, has been applied for the cost optimization of the cable routing of an on-shore module for power generation. Thanks to the use this methodology, it was possible to save up to 15% of electrical cable routing cost. However, the layout modification is limited only to the position of the branching points and thus it is not possible get an overall change of the layout (only sub-optimal solutions can be achieved). For this reason, future works will address the development of algorithms exploring a wider range of solutions.

References:

[1] Box, G.E.P.; Hunter, S.J.; Hunter, W.G.: Statistics for Experimenters: Design, Innovation, and Discovery, Wiley and sons, New Jersey, 2005.

[2] Hightower, D. W.: A solution to line routing problems on the continuous plane, Proceedings of the 6th annual Design Automation Conference, 1969, 1–24. https://doi.org/10.1145/800260.809014

[3] Ittner, A. E.; de SÁ, C. C.; Sasse, F. D.: A Heuristic Approach to the Cable Routing Problem in Electrical Panels, Proceedings of the VI Congress of Logic Applied to Technology – LAPTEC'07, 2007, 55-66. http://dx.doi.org/10.3233/978-1-58603-936-3-55

[4] Kloske, D. A.; Smith, R. E.: Bulk cable routing using genetic algorithms, TCGA Report No. 94001, University of Alabama, Tuscaloosa, 1994.

[5] Ma, X.; Iida, K.; Xie, M.; Nishino, J.; Odaka, T.; Ogura, H.: A genetic algorithm for the optimization of cable routing, Systems and Computers in Japan, 37(7), 2006, 61-71. http://doi.org/10.1002/scj.10250

[6] Pillai, A. C.; Chick, J.; Johanning, L.; Khorasanchi, M.; de Laleu, V.: Offshore wind farm electrical cable layout optimization, Engineering Optimization, 47(12), 2015, 1689–1708. http://dx.doi.org/10.1080/0305215X.2014.992892

[7] Wedzik, A.; Siewierski, T.; Szypowski, M.: A new method for simultaneous optimizing of wind farm's network layout and cable cross-sections by MILP optimization, Applied Energy, 182, 2016, 525–538. http://dx.doi.org/10.1016/j.apenergy.2016.08.094

[8] Wei, W.: Complexity management of vehicle wiring harnesses: an optimized model to analyse trade-offs between product and manufacturing costs, Ph.D. Thesis, University of Windsor, Windsor, Ontario, 2012.

[9] Zhu, Z.; van Tooren, M.; La Rocca, G.: A KBE Application for Automatic Aircraft Wire Harness Routing, 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, 2012. http://dx.doi.org/10.2514/6.2012-1843