

Development of a mathematical model for automated design of LAN cable routing

Vladislav Trubin, Olga Khristodulo

Abstract—Traditional methods of automated design of LAN cable routes rely primarily on minimizing the physical length of the path, neglecting engineering standards, installation costs, electromagnetic compatibility, and the semantics of the premises. This paper develops a mathematical model for multi-criteria optimization of low-current cable routes. The design space is discretized into a hybrid graph combining geometric reference points and semantic nodes at the boundaries of functional zones. For star topologies, an approximation of the Steiner problem is applied through a sequential search using a modified A* algorithm with dynamic edge weight updates. The model formalizes industry codes as a system of constraints and penalty factors, enabling the automatic generation of technically and economically feasible routes. The developed framework is ready for integration into BIM/CAD/GIS environments and is designed to reduce design time by minimizing manual route adjustments.

Keywords—cable routing, hybrid graph, mathematical model, multicriteria optimization, local area networks.

I. INTRODUCTION

The problem of automated design of indoor local area network (LAN) cable routes is a special case of the more general problems of routing and path planning in a confined, obstacle-ridden environment [1]. Traditional approaches based on minimizing the Euclidean distance or using pathfinding algorithms on planar graphs often neglect critical engineering, economic, and operational factors, such as the type of facility, labor costs, ease of subsequent maintenance, and compliance with industry standards.

The goal of this paper is to develop a mathematical model that takes these factors into account. The model is intended to serve as the formal basis for a decision support system [2][3] that ranks options by total cost of ownership, taking into account the above factors, to make cost-effective decisions, both when designing new indoor LAN systems and upgrading existing ones.

II. REVIEW OF EXISTING SOLUTIONS

Automated design of LAN cable routes is a spatial optimization problem with strict geometric and regulatory constraints. Historically, methods have developed in two parallel directions: minimizing the physical route length and

taking into account engineering and operational requirements. Modern approaches can be roughly divided into four groups.

A. Geometric and graph pathfinding methods

Classical solutions rely on spatial discretization and shortest-path algorithms. The most common are Dijkstra's algorithm, A*, and their modifications on grid-based or visibility graphs [4][5]. In the context of cable systems, such methods effectively minimize the Euclidean or Manhattan route length and have a low computational complexity of $O(N \cdot |V| \cdot \log|V|)$. However, they operate exclusively on spatial geometry, ignoring the semantics of spaces and industry standards. As a result, the algorithm may suggest routing through undesirable zones, such as spaces with strict fire safety requirements, making the resulting solution unsuitable for practical applications [6]. In the related field of cable harness installation in 3D environments, probabilistic roadmapping methods (PRM) and RRT algorithms are used, but they are focused primarily on industrial installations and do not take into account the specifics of low-current networks of civil buildings [1][5].

B. Rule-based and BIM-integrated approaches

Modern design actively utilizes BIM environments, where routing is performed semi-automatically based on predefined rules [7]. The engineer specifies constraints: maximum segment length, permissible routing zones, minimum distances to power lines, and entry points to utility shafts. The rules are implemented as rigid logical filters rather than optimization functions, resulting in ad hoc, often suboptimal routes requiring manual adjustment. Semantic enrichment of the model with data on room types improves the realism of the routing, but this must be done manually or using machine learning for pattern recognition [8], which introduces an additional layer of error.

While modern BIM environments support automated rule-checking for MEP (Mechanical, Electrical, and Plumbing) systems to validate designs against codified requirements [9], these systems typically operate as rigid logical filters rather than continuous multi-criteria optimization functions. Described model bridges this gap by integrating semantic rules directly into the objective function's penalty coefficients.

C. Multicriteria optimization and Steiner problems

Modern LANs, to allow for flexibility in future upgrades, are designed using a star topology, which assumes a hierarchical tree structure. This can be reduced to the Steiner problem [10] of finding the minimum spanning tree connecting a set of points, since additional points can be

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V. Trubin is with the Ufa University of Science and Technologies, Ufa, 450076 Russian Federation (e-mail: trubin.vd@ugatu.su).

O. Khristodulo is with the Ufa University of Science and Technologies, Ufa, 450076 Russian Federation (e-mail: o-khristodulo@mail.ru).

added during the design process to reduce the overall length of the connections. As early as 1972, Yang and Wing proposed a suboptimal algorithm for the wire routing problem, which became the basis for many subsequent developments in cable system design [11]. This early approach demonstrates the fundamental connection between routing problems and the Steiner problem.

Algorithms based on the Steiner problem can minimize the cost of deploying fiber-optic networks while meeting reliability and performance requirements. In [12], the authors presented mathematical models and algorithms for designing fiber-optic cable networks in tree-structured view, where the Steiner problem is used to determine the optimal network topology. These approaches can significantly reduce infrastructure costs while ensuring the required coverage.

For exact solutions to the capacitated network design and Steiner tree problems, multi-commodity flow formulations and Mixed-Integer Linear Programming (MILP) [13] models are considered the standard approach. However, their high computational cost limits their applicability to small-scale or offline scenarios, motivating the need for the polynomial-time heuristic proposed in this work.

D. Application of artificial intelligence methods

In particularly complex configurations, traditional algorithms often fail to construct an optimal route. Consequently, artificial intelligence (AI) methods are becoming increasingly popular: genetic algorithms [14], [15], [16], neural networks [17], ensemble methods [18], and heuristic swarm intelligence algorithms. Reinforcement learning, which is used to solve traffic routing problems [19], is also worth noting.

E. Conclusions

An analysis of the solutions presented revealed:

- 1) A lack of semantics in the context of route construction. Graph methods do not consider the purpose of the rooms and regulations, while algorithms based on BIM models do not provide mathematical optimization.
- 2) A lack of a unified metric. Approaches consider diverse factors influencing the constructed route, but a single objective function is missing.
- 3) The weighting factors in existing systems are fixed and selected empirically, while a more "expensive" route is often selected for the sake of efficiency.

The mathematical model proposed in this paper closes these gaps by moving from a geometric graph to a hybrid one (with semantic information at vertices and edges), introducing a modular system of normalized penalty coefficients, explicitly formalizing flow constraints and physical limits within a single objective function, and adaptively adjusting the weight vector to balance short-term costs and long-term reliability without changing the algorithm structure.

III. STATEMENT OF THE PROBLEM AND ASSUMPTIONS

A. Initial conditions

To solve the problem, we define the input data as follows:

- A digital floor plan with layered semantic data (vector map, BIM model, CAD drawings).
- Sets of locations for the endpoints of the computing infrastructure P_{term} (workstations, sockets) and intermediate interconnecting equipment P_{distr} (switches, routers):

$$P_{\text{term}} = \{t_1, \dots, t_n\} \quad (1)$$

$$P_{\text{distr}} = \{d_1, \dots, d_m\} \quad (2)$$

For a digital floor map, these point sets must be contained in the corresponding semantic layers.

- A set of static obstacles O with geometry and type (load-bearing walls, columns, partitions):

$$O = \{o_1, \dots, o_k\} \quad (3)$$

- A set of semantic zones Z with attributes: functional purpose, permissibility of installation, electromagnetic background level, cost:

$$Z = \{z_1, \dots, z_p\} \quad (4)$$

- Cable specifications: maximum segment length L_{max} , minimum bending radius R_{min} , noise susceptibility coefficient γ_{EMI} , specific cost;
- Vector of weight factors λ , defining the relative importance of specific factors:

$$\lambda = (\lambda_{\text{len}}, \lambda_{\text{obs}}, \lambda_{\text{bend}}, \lambda_{\text{type}}, \lambda_{\text{noise}}, \lambda_{\text{cab}}), \quad (5)$$

Where:

- λ_{len} is the cable's physical length factor;
- λ_{obs} is the obstacle factor;
- λ_{bend} is the sharp bend factor;
- λ_{type} is the room's intended use factor;
- λ_{noise} is the electromagnetic interference factor;
- λ_{cab} is the cable's properties factor.

The maximum segment length L_{max} and minimum separation distances from power lines are explicitly governed by industry standards, such as TIA/EIA-568 [20] and ISO/IEC 11801 [21], which are formalized in the model through the constraint system and the K_{noise} penalty factor.

This factors are determined in such a way as to satisfy the condition:

$$\sum \lambda_c = 1, \lambda_c \geq 0 \quad (6)$$

Having defined the target design scenario for a specific case, it will be sufficient to modify the weighting factors.

The model's output data will be:

- a set of traces $T = \{\tau_1, \dots, \tau_N\}$, where each trace τ_i is an ordered sequence of edges in the weighted graph $G = (V, E, W)$;
- a network structure that satisfies the specified device connection topology;
- quantitative quality metrics: total weighted cost W_{total} , physical length L_{total} , and degree of compliance with industry standards.

B. Assumptions

The following assumptions should also be made:

- The routing is considered within a single floor or technical level.
- The vector map geometry does not change during the route search.
- The continuous spatial design is approximated by a finite undirected graph, where vertices correspond to geometric and semantic nodes, and edges correspond to valid linear route segments.
- The problem is formulated for finding a "source-destination" route. The source is considered to be the distribution node ($s \in P_{distr}$), and the destination is the terminal point ($t \in P_{term}$).
- Dynamic interference (electromagnetic fields, transient interference) is not taken into account, since their influence on the final result can be neglected.

C. Problem Statement

For each pair (s, t) , where $(s \in P_{distr})$, $(t \in P_{term})$, find a continuous trace $\tau_{s \rightarrow t}$ that minimizes the objective function of the total weighted length, subject to the constraint system Φ .

In a discrete graph representation, the trace $\tau_{s \rightarrow t}$ is defined as a subset of edges ($E_\tau \subseteq E$). Let $x_e \in \{0, 1\}$ be a binary variable equal to 1 if edge e is included in the route and 0 otherwise. The optimization problem is formulated as follows:

$$\min_x F(\tau) = \sum_{e \in E} \omega(e) \cdot x(e) \quad (7)$$

subject to the constraint system Φ :

1. Flow preservation and connectivity:

$$\sum_{e \in \delta^+ V} x_e - \sum_{e \in \delta^- V} x_e = \begin{cases} 1, v = s \\ -1, v = t \\ 0, \forall v \in V \setminus \{s, t\} \end{cases} \quad (8)$$

2. Physical segment length limit

$$\sum_{e \in E} d(e) \cdot x_e \leq L_{max}^{cab} \quad (9)$$

3. Prohibition of crossing solid obstacles:

$$\sum_{e \in E(o_{solid})} x_e = 0, \forall o_{solid} \in O_{solid} \quad (10)$$

4. Semantic and normative constraints: $x_e = 0$, if

$$K_{type}(e) = +\infty \text{ or } K_{noise}(e) = K_{noise}^{max}.$$

5. Geometric constraints on bends: the angle between successive edges

$$\theta \geq \theta_{min} = \arccos\left(1 - \frac{R_{min}}{d(e)}\right), \text{ enforced by the penalty } K_{bend}(e) \text{ or by hard edge filtering at the graph construction stage.}$$

Given a set of terminals $T_s \subset P_{term}$ for a single source s , the problem formally reduces to constructing a minimal Steiner tree with constraints. The exact solution to this problem is NP-hard, so the assumptions described earlier are used in practical implementation.

IV. MATHEMATICAL MODEL

The design space is discretized into a weighted undirected graph $G = (V, E, W)$, whose vertices carry both geometric and semantic information. The set of vertices V is formed as the union:

$$V = V_{geom} \cup V_{sem}, \quad (11)$$

where $V_{geom} = P_{term} \cup P_{distr} \cup P_{add}$ are geometric nodes (terminal and distribution points, as well as additional reference points such as room corners, doorways, entrances to utility shafts); V_{sem} are entry/exit nodes to semantic zones $z \in Z$, located at the boundaries of ∂Z . To account for surface mounting practices, a subset of design nodes is additionally introduced into V_{sem} :

$$V_{sem} = \partial Z_{grid} \cup P_{proj} \quad (12)$$

where $P_{proj} = \bigcup_{p \in P_{term}} \bigcup_{p \in P_{distr}} \Pi(p, \partial Z_{vis})$. Here $\Pi(p, \partial Z_{vis})$ is the set of points of the orthogonal projection of equipment p onto the visible boundaries of the zones. Each node $v \in V_{sem}$ is assigned a label $L(V) \in \{1, \dots, |Z|\}$, indicating the functional purpose of the zone. This ensures that penalties are correctly calculated for all edges incident to semantic nodes, including projection points V_{proj} .

The edge set E is constructed based on the principle of local visibility: an edge $e_{ij} = (v_i, v_j) \in E$ exists if the following conditions are met:

1. $d(v_i, v_j) \leq \delta_{max}$ where δ_{max} is the given discretization step;
2. $\text{seg}(v_i, v_j) \cap \text{int}(O_{solid}) = \emptyset$, i.e., the segment does not intersect the interiors of absolute obstacles but can be located on its boundaries.

Each edge $e \in E$ is associated with a physical route segment and is characterized by its Euclidean length $d(e)$, slope angle, and intersection with zones/obstacles.

The key element of the model is the modular weighting function $w(e)$, which translates disparate engineering factors into a single scalar cost metric:

$$w(e) = d(e) \cdot \left(1 + \sum_{c \in C} \lambda_c \cdot K_c^{\text{norm}}(e) \right), \quad (13)$$

where:

$C = \{\text{len}, \text{obs}, \text{bend}, \text{type}, \text{noise}, \text{cab}\}$ is the set of criteria taken into account;

$\lambda_c \in [0, 1]$ is the importance weighting coefficient of criterion c , $\sum \lambda_c = 1$;

$K_c^{\text{norm}}(e) \in [0, 1]$ is the normalized penalty coefficient of criterion c on edge e .

The factor 1 in parentheses ensures that for $\lambda_c = 0$ for all $c \neq \text{len}$, the model degenerates into a search for the shortest path based solely on physical length.

For each criterion, analytical dependencies should be introduced before normalization:

1. Obstacle Factor K_{obs} : penalty for crossing lightweight partitions or temporary structures:

$$K_{obs}^{\text{raw}}(e) = \sum_{o \in O_{light}} \alpha_o \cdot \frac{\text{len}(e \cap o)}{d(e)} \quad (14)$$

where $\alpha_o \in (0, 1]$ is the difficulty coefficient of overcoming obstacle o .

2. Bending coefficient K_{bend} : depends on the angle $\theta \in [0, \pi]$ between the current edge e and the previous edge e_{prev} in the route:

$$K_{bend}^{\text{raw}}(e) = \left(\frac{\pi - \theta}{\pi} \right)^2 \quad (15)$$

The value is 0 for a straight line continuation and tends to 1 when turning 180 degrees.

3. The room type coefficient K_{type} : is determined by the labels of the edge's end vertices:

$$K_{type}^{\text{raw}}(e) = \frac{1}{2} \left(f_{\text{zone}}(L(v_i)) + f_{\text{zone}}(L(v_j)) \right) \quad (16)$$

where $f_{\text{zone}}: \{1, \dots, |Z|\} \rightarrow [0, +\infty)$ is a table function specified during design (from 0 for expected installation zones, such as a technical corridor or shaft, to $+\infty$ in prohibited areas).

4. Electromagnetic interference coefficient K_{noise} : increases with decreasing distance to power lines and increasing length of parallel wiring:

$$K_{noise}^{\text{raw}}(e) = \gamma \cdot \frac{L_{\text{par}}(e)}{d_{\text{sep}}(e) + \varepsilon} \quad (17)$$

where $L_{\text{par}}(e)$ is the length of the parallel section, $d_{\text{sep}}(e)$ is the minimum distance to the power cable, $\varepsilon > 0$ is the regularizer, $\gamma > 0$ is the empirical sensitivity coefficient.

5. Cable property coefficient K_{cab} aggregates cost, rigidity, and noise immunity:

$$K_{cab}^{\text{raw}}(e) = \beta_1 \frac{C_{\text{cost}}}{C_{\text{max}}} + \beta_2 \frac{R_{\text{min}}}{R_{\text{max}}} + \beta_3 \cdot \gamma_{\text{EMI}} \quad (18)$$

where $\sum \beta_i = 1$, and the parameters are normalized to the maximum values in the project specification.

To ensure comparability of heterogeneous criteria, raw coefficients are scaled to the range $[0, 1]$:

$$K_c^{\text{norm}}(e) = \begin{cases} 0, & K_c^{\text{raw}}(e) \leq K_c^{\min} \\ \frac{K_c^{\text{raw}}(e) \leq K_c^{\min}}{K_c^{\max} \leq K_c^{\min}}, & K_c^{\min} < K_c^{\text{raw}}(e) < K_c^{\max} \\ 1, & K_c^{\text{raw}}(e) \geq K_c^{\max} \end{cases} \quad (19)$$

The boundaries $K_c^{\min}, K_c^{\max}$ are determined during the floor plan modeling stage.

The weight vector λ is calibrated for the target design scenario. In practice, the analytic hierarchy process is used: an expert fills out a matrix of pairwise comparisons of criteria, after which λ is calculated as the eigenvector corresponding to the maximum eigenvalue.

To demonstrate the practical application of the proposed weighting function (13), consider a simplified numerical illustration. Let a route segment e have a physical length $d(e)=5$ m. Assume the normalized penalty coefficients

for this segment are: $K_{\text{type}}^{\text{norm}} = 0.8$ (passing through a non-ideal zone), $K_{\text{noise}}^{\text{norm}} = 0.2$ (moderate distance to power lines), and others are 0. For a design scenario prioritizing reliability over pure length, let the weight vector be $\lambda_{\text{len}} = 0.4, \lambda_{\text{type}} = 0.4, \lambda_{\text{noise}} = 0.2$. The composite weight is calculated as: $w(e) = 5 \cdot (1 + 0.4 \cdot 0.8 + 0.2 \cdot 0.2) = 6.8$.

This illustrates how the model penalizes semantically undesirable paths, steering the A* algorithm away from them, unlike a pure Euclidean distance metric which would assign a cost of exactly 5.

V. ALGORITHMIC REALIZATION

Based on the mathematical model described above, the search for optimal routes is implemented using a hybrid algorithm that combines deterministic graph search with iterative updating of weight parameters. The calculation occurs in three sequential stages: constructing a hybrid graph from a vector plan, calculating composite edge weights, and iteratively searching for routes while taking into account topological and physical constraints.

A. Hybrid graph construction

From the input data (digital floor plans with layer-by-layer semantic decomposition), the geometry of obstacles O , semantic zones Z , and equipment points $P_{\text{term}}, P_{\text{distr}}$ are extracted. The graph is formed based on the following algorithm:

1. Node initialization. $V_{\text{geom}} \cup P_{\text{term}} \cup P_{\text{distr}} \cup P_{\text{add}}$, where P_{add} includes room nodes, doorways, and entrances to utility shafts.
2. Generation of semantic and projected nodes. The set V_{sem} consists of entry/exit points into semantic zones located on their boundaries ∂Z . A subset of

projected nodes P_{proj} is introduced. Each point $p \in P_{\text{term}} \cup P_{\text{distr}}$ is orthogonally projected onto the nearest visible sections of the zone boundaries ∂Z_{vis} under the following conditions:

- The segment $[p, \text{proj}]$ does not intersect $\text{int}(O_{\text{solid}})$;
- The distance limit condition $d(p, \text{proj}) \leq \delta_{\text{wall}}$ is satisfied to exclude excessively long routes through open space (δ_{wall} is specified by the user, or a typical value of 3-5 meters is taken);
- When the projection falls within the ε neighborhood, nodes are merged to control the graph's dimensionality.

The resulting set of vertices is: $V = V_{\text{geom}} \cup V_{\text{sem}}$, where $V_{\text{sem}} = \partial Z_{\text{grid}} \cup P_{\text{proj}}$.

3. Each node $v \in V_{\text{sem}}$ is assigned a label $L(v)$ that inherits the semantics of the adjacent zone $z \in Z$ or the status of a transition boundary.
4. For each pair (v_i, v_j) with $d(v_i, v_j) \leq \delta_{\text{max}}$, a raycasting is performed. If $\text{seg}(v_i, v_j) \cap \text{int}(O_{\text{solid}}) = \emptyset$, then the edge (e_{ij}) is added to E . The P_{proj} nodes naturally connect to the equipment origins from which they were projected and to adjacent architectural nodes, forming process corridors along the walls, reducing the number of bends in the open space.
5. Isolated vertices are removed, the basic Euclidean lengths $d(e)$ are calculated, intersections with zones/noises are determined and weights $w(e)$ are initialized according to formulas (13)-(19).

When using spatial indexing to speed up intersection checks, the computational complexity of this step is $O(|V|^2 \cdot \log|O|)$.

B. Routing

Since the objective function $F(\tau)$ is linear in $x(e)$ and the edge weights are non-negative, the A* algorithm [22] is used for pairwise routing.

The priority of a node in the queue is defined as $f(v) = g(v) + h(v)$, where $g(v)$ is the accumulated

cost from source s and $h(v)$ is a heuristic estimate of the remaining path. Unlike the standard Euclidean metric, the model uses a scalable heuristic:

$$h(v) = d_{Eucl}(v, t) \cdot w_{min}^{norm} \quad (20)$$

$$w_{min}^{norm} = \min_{e \in E} \frac{w(e)}{d(e)} \quad (21)$$

The multiplier w_{min}^{norm} reflects the minimum unit cost per meter of route in this project and is calculated once at the previous stage. This form guarantees the admissibility of the heuristic ($h(v) \leq h^*(v)$), since for any admissible path, the total weight cannot be less than the product of the direct distance and the minimum coefficient w/d . This preserves the optimality of the search according to the objective function $F(\tau)$ while simultaneously reducing the number of expanded vertices. During graph traversal, vertices leading to edges with $K_{type}(e) \rightarrow (+\infty)$ or violating L_{max}^{cab} are pruned before being included in the queue.

C. Multi-cable scenario handling and tree approximation

For a star network topology or a hierarchical tree distribution, the exact solution to the Steiner problem is NP-hard. Therefore, the model uses an approximation scheme for serially connecting terminals:

1. Sorting the set of terminals $T_s \subseteq P_{term}$ for a source $s \in P_{distr}$ in ascending order of Euclidean distance.
2. Alternate search for the path τ_i from s to t_i using the A* algorithm.
3. After fixing the route τ_i , the weights of all edges $e \in \tau_i$ are updated taking into account the occupancy of the cable channels:

$$w_{new}(e) = w_{old}(e) \cdot \left(1 + \frac{\rho \cdot n_{occ}(e)}{C_{max}} \right) \quad (22)$$

where $n_{occ}(e)$ is the number of cables already laid along edge e , C_{max} is the standard channel capacity (specified by the user based on the physical dimensions of the channel, industry standards, and the project specification), $\rho \in [0.2, 0.5]$ is the empirical channel congestion factor (defined by the user based on the project specification).

4. If $n_{occ}(e) \geq C_{max}$, the edge is marked as temporarily unavailable ($w(e) \rightarrow (+\infty)$) for subsequent iterations.

This scheme ensures compliance with physical filling limits, minimizes spatial conflicts of traces, and brings the result closer to the optimal Steiner tree without exponential growth of the computational load, which is important for interactive design.

It is acknowledged that this greedy sequential routing with dynamic edge weight updates (22) is an approximation and does not guarantee a global optimum. Exact approaches, such as Integer Linear Programming (ILP) or multi-commodity flow formulations for capacitated Steiner tree problems, can find optimal solutions but suffer from exponential computational complexity [23]. In the context of interactive BIM/CAD decision support systems, polynomial time complexity $O(N \cdot |V| \cdot \log|V|)$ is a strict requirement. The proposed dynamic weight update acts as a congestion-avoidance heuristic, providing a practical trade-off: it yields a solution with a bounded suboptimality gap (analogous to classical 2-approximation bounds for Steiner tree heuristics) while preventing the spatial conflicts that would otherwise require extensive manual post-processing.

D. Algorithm flowchart

Based on the formulated mathematical model and the hybrid graph structure, the routing process is formalized in the form of flowchart (Fig. 1).

VI. MODEL LIMITATIONS

Despite its formal rigor and practical orientation, the developed mathematical model has a number of limitations due to the adopted assumptions.

A. Spatial approximation and discretization

The model operates in 2.5D, considering the layout within a single floor or technical level. Vertical transitions are formalized as nodes with fixed weighting, which prevents optimization of the 3D topology.

Furthermore, the quality of the result depends on the discretization step δ_{max} : excessive reduction leads to an increase in the computational load, while an increase leads to a loss of accuracy and the possible omission of narrow technical corridors. The choice of δ_{max} requires a balance between plan detail and calculation time, which in the current version of the model is achieved empirically.

B. Algorithmic approximation of multi-cable scenarios

For star and hierarchical tree topologies, greedy sequential routing with dynamic edge weight updates is used, which is not an exact solution to the Steiner problem. On the other hand, this guarantees a polynomial complexity of $O(N \cdot |V| \cdot \log|V|)$ and is applicable to interactive decision support systems. However, under high terminal density, it can lead to suboptimal utilization of shared cable channels. Furthermore, the weight vector λ is calibrated by experts or selected from predefined user presets, which introduces a subjective factor and does not provide automatic adaptation to historical data.

C. Simplifying physical limitations

The model takes into account static obstacles and semantic zones, but does not simulate dynamic changes in the environment. Physical limitations on bending radius and cable tension are included as penalty coefficients $K_{bend}(e)$ and $K_{cab}(e)$, but do not replace detailed engineering calculations. Regulatory requirements are partially formalized. Basic prohibitions and length limits are taken

standards, or specific industry standards require additional manual verification by the user.

Fig. 1: Routing algorithm flowchart

D. Limits of applicability and development prospects

The developed model demonstrates high efficiency with hundreds of terminals and a static room configuration, which can be used in the design of LANs for office buildings, educational centers, and small industrial facilities. Vector floor plans with delineated semantic zones are required for each facility.

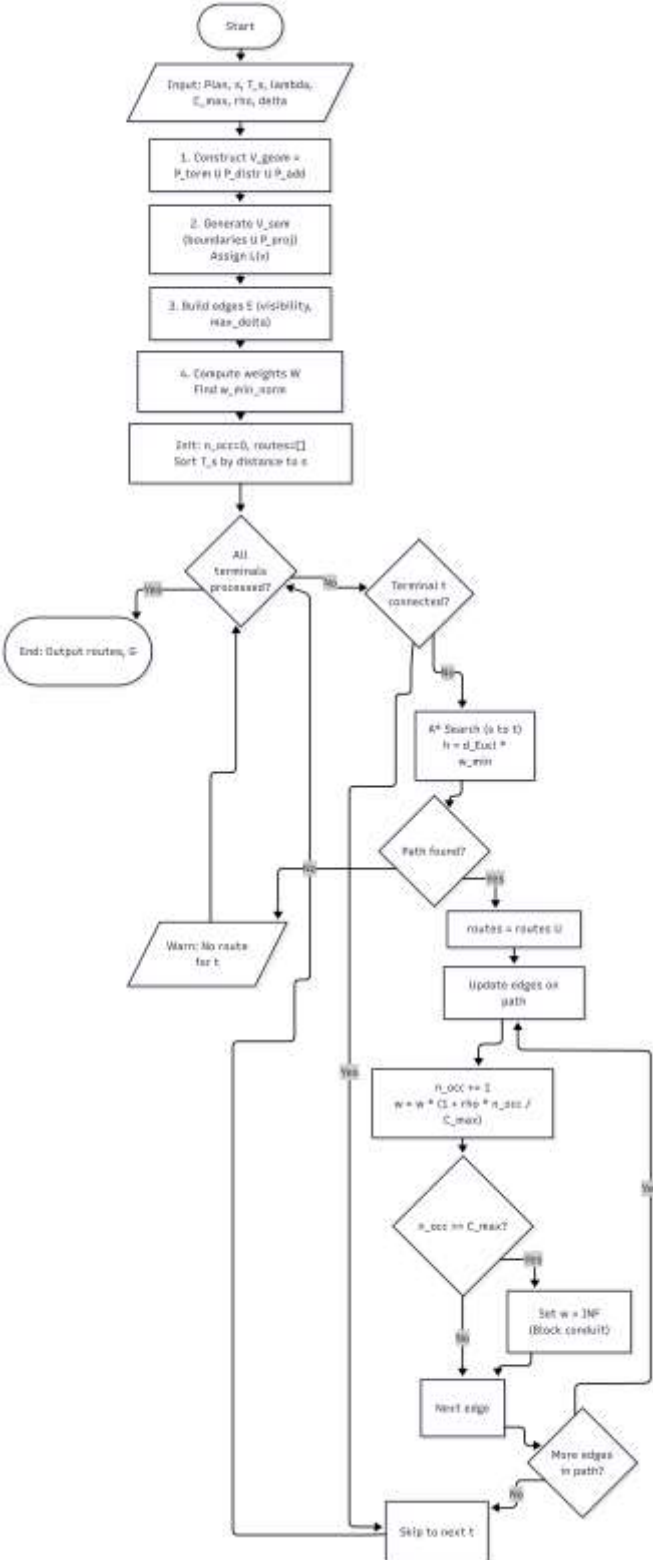
Future developments include the transition to full-fledged 3D discretization taking into account vertical paths, the integration of machine learning methods for automatic λ calibration based on completed projects, and the development of an open LAN routing benchmark for standardized algorithm evaluation in BIM environments.

Thus, despite its limitations, the model represents a complete formal framework for automated multi-criteria design. While this paper establishes the rigorous theoretical and mathematical foundation for multi-criteria routing, large-scale empirical benchmarking against baseline methods (e.g., standard A*, rule-based BIM routing) and scalability studies are the subject of ongoing software implementation work. The current model provides the formal basis for such future experimental validation.

VII. CONCLUSION

In this study, a mathematical model for the automated design of local area network cable routing was developed and formalized. The key result is a shift from traditional one-dimensional optimization based on physical length to multi-criteria design based on a hybrid graph representation of space. The model explicitly incorporates engineering standards, facility semantics, and operational factors into a single objective function through a modular system of normalized penalty coefficients and an adaptive weight vector. The proposed sequential routing algorithm with dynamic edge weight updating provides polynomial computational complexity of $O(N \cdot |V| \cdot \log|V|)$, making the model applicable to interactive decision support systems. The practical significance of this study lies in reducing the cost of designing cable systems. The model enables the automatic generation of routes that are optimal in terms of material consumption, installation and maintenance costs, and compliance with industry standards. The limitations of the model, related to the 2.5D approximation, empirical calibration of the weights, and the approximate nature of the Steiner problem solution, do not diminish its practical value but rather provide a vector for further research.

Thus, the proposed mathematical model provides a ready-made theoretical basis for developing tools for automated design of local area network cable routing. Its further development will facilitate the development of digital twin solutions that support not only the design but also the entire lifecycle of building and structure cable infrastructure



into account, but complex fire safety regulations, acoustic

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