# An Automated Cable Route Analysis Method for Fire Safe Shutdown Analysis Using Object Recognition in Cable Drawings

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**Keywords:* Fire Hazard Analysis, Post-Fire Safe Shutdown Analysis, Cable Routing Analysis, Object Recognition

## 1. Introduction

All nuclear power plants (NPPs) are designed with multiple divisions of components that perform safe shutdown functions, ensuring that at least one division's of safe shutdown capability is maintained even in the event of a fire [1], [2]. However, the 1975 Browns Ferry NPP fire in the United States is a representative example demonstrating that safe shutdown functions can be compromised due to the malfunction or spurious operation of safe shutdown components caused by fire damage to multiple cables [3], [4]. In response to this accident, fire protection regulatory guidelines and detailed requirements were established to supplement the existing design standards centered around General Design Criterion (GDC) 3 [5], and subsequently, analysis requirements for Multiple Spurious Operation (MSO) analysis were further refined [2]. As the importance of MSO analysis is being emphasized domestically [6], the accuracy and verifiability of cable routing data, which serve as baseline data for safe shutdown analysis (SSA) including MSO analysis, are becoming increasingly crucial. For this purpose, cable routing analysis is essential to identify the locations where safe shutdown related cables are routed; the results are then compiled into a safe shutdown cable routing database to determine whether cables of different divisions coexist within the same fire area.

In practical SSA, the NPP cable management program database has been used as primary reference data for cable routing analysis. This data consists of cable name, cable type, division, from/to equipment, raceway, and compartment, and can be converted into an Excel sheet format. However, as errors were discovered in this reference data, the route database has been manually created by reading cable drawings to compensate for them. This method is not only inefficient but also susceptible to human error during the process, such as incorrect entry of raceways or the omission of certain sections; furthermore, errors in this source data lead to reduced reliability of the analysis results and an increased burden in reviewing the findings.

This paper proposes a method to automate the cable routing analysis for SSA to overcome the limitations of manual work and improve the reliability of the route database. The method involves importing cable electrical drawings in image format into design automation software, mapping the raceway, compartment, and drawing object information created on the drawings, and generating a routing database by integrating this with a list of raceways for each cable.

## 2. Existing Cable Routing Analysis Method

Safe shutdown cable routing analysis involves selecting the components that perform safe shutdown functions and the cables connected to them, and then reviewing relevant databases and drawings to identify which fire areas the cables traverse [7]. In practice, this was primarily done by utilizing the reference database or manually creating a routing database by reviewing cable drawings.

In the case of Korean standard nuclear power plants (KSNP), the cable routing analysis was previously performed manually, and in the process of compiling a route database for about 2,800 cables, there were about 76,000 raceways that require drawing review. However, since it is practically impossible to individual review the compartment information for the entire raceway from the drawings, the compartment information was based on the reference database. Subsequently, to verify the validity of the routing database, the safe shutdown cable routing were drawn on the electrical drawings, and a review was conducted to confirm whether Division A/B cables coexisted within the same fire area. Even during this process, human errors such as incorrect raceway entry and omission of data were found, and it was confirmed that up to 89 cables shared a single raceway section.

The limitation of the existing methods is that the task of reading electrical drawings for the same raceway is repeated for every cable. As the number of cables sharing a single raceway increases, the burden of review and work inefficiency accumulate. In particular, electrical drawings are in the form of images that do not support optical character recognition (OCR), making it impossible to directly search for raceway names; furthermore, compartment boundaries are not clearly distinguished, posing limitations to drawing review.

If duplicates among the raceways through which cables pass are removed, the number of raceways to be analyzed is reduced to less than 10%. Therefore, if the information on raceways and their corresponding compartments and drawings is accurately organized just once and reused, it is expected that repetitive work during routing database construction can be significantly reduced. The SSA requires a significant amount of time and manpower as it necessitates reviewing vast amounts of data at a

consistent level, thus demanding automation of the routing database construction process to support this [8].

## 3. Automated Method for Cable Routing Analysis

The proposed method in this paper consists of seven steps: drawing import, raceway list extraction for each cable, analysis object creation, object information extraction, region determination, data mapping, and result generation. Steps 1 to 3 are performed manually, while Steps 4 to 7 are executed automatically. The overall procedure is shown in Figure 1.

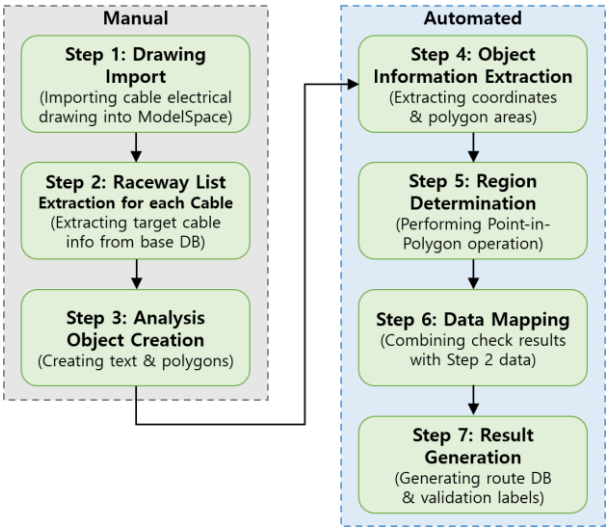



Fig. 1. Process of the Cable Routing Analysis

### *3.1 Raceway List Extraction for each Cable*

The raceway list for each cable specifies the sequence of raceways traversed by a given cable. From the reference database, only two items are used: the cable id and the list of raceways traversed. The raceway list itself is assumed to be error-free at this stage. The list is structured such that each cable occupies a single record, with its traversed raceways listed in sequential order.

### *3.2 Analysis Object Creation and Object Information Extraction*

In the method, characters within the cable drawings are not recognized by OCR; instead, an analyst reviews the drawings and creates text objects corresponding to the raceway IDs, room IDs, and drawing IDs, together with the polygon objects for region determination. This is because the target drawings are frequently managed as scanned images with low resolution or with portions of the raceway identifiers omitted, which makes it difficult to ensure the reliability required for routing database construction through image-based character recognition alone.

The layer function of AutoCAD™ was applied to classify object types, and only the objects on the designated layers were used as analysis targets. In this paper, these layers are referred to by their functions as the raceway, the room, and the drawing-region layers. The text objects on the raceway layer were defined as raceway IDs, the polygons on the room and drawing-region layers were used as area boundaries, and the text objects located within each polygon were identified as the room ID and the drawing ID, respectively, for that area.

During the drawing data loading step, ModelSpace was traversed only once, and text information, insertion point coordinates, and polygon region information for each object were collected into program memory. In this context, ModelSpace refers to the workspace of the CAD software. To reduce comparison errors arising from string formatting differences, formatting codes and unnecessary whitespace in text objects were removed during preprocessing.

### *3.3 Region Determination and Object Recognition on Drawings*

To determine the room and drawing region to which each raceway belongs, this paper applies a ray-casting based point-in-polygon (PIP) technique that uses the text insertion point of the raceway object as the reference point. The PIP is a technique used to determine whether a point lies inside or outside a polygon. The ray-casting algorithm, a representative implementation of PIP, casts a virtual ray from the point and uses the number of boundary intersections to determine point inclusion (odd: interior, even: exterior). An example is shown in Figure 2.

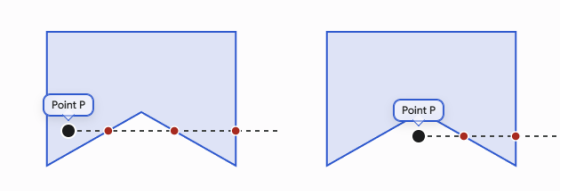



Fig. 2. Example of determining inside/outside of a polygon using the ray-casting algorithm

However, performing the PIP test directly on all raceway objects would substantially increase computing overhead; therefore, a pre-screening step is applied first. A bounding rectangle is pre-computed for each room and drawing-region polygon, and the PIP test is executed only when the insertion point of the raceway object lies within that rectangle. Examples of this pre-screening are shown in Figure 3.

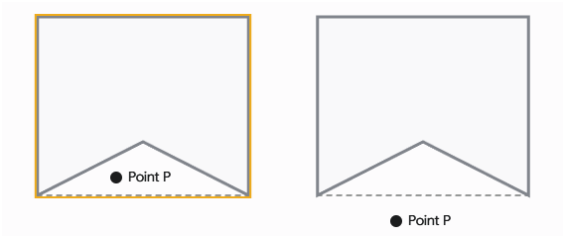



Fig. 3. Examples of the pre-screening step

The region determination results are stored as a composite (three-element) key for each raceway, consisting of raceway, room, and drawing IDs. Since post-fire SSA is performed based on fire areas, the results at the room level need to be mapped to the fire area level.

### *3.4 Routing DB and Verification-Label Generation*

The routing database is generated automatically by integrating the CAD-API based region determination results with the raceway list for each cable. The main output fields are cable, raceway, drawing, and room IDs. To map the two datasets, a dictionary indexing and lookup approach was applied so that the region determination result for each raceway is reused for every cable routed through it.

Furthermore, to enable confirmation of the generated routing database on the drawings, a verification-label generation function was implemented in parallel. The label follows the format of sequence number, cable ID, and room ID and is created on a dedicated layer for each cable. An example is shown in Figure 4.

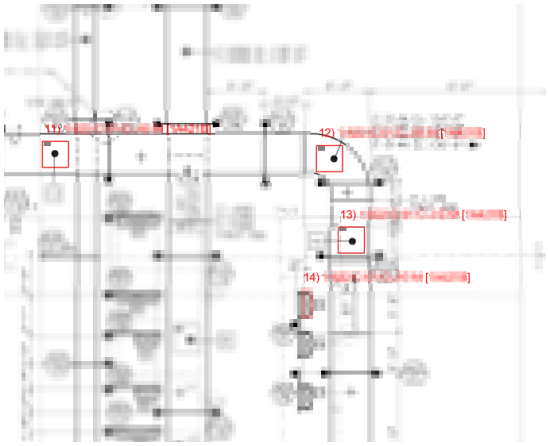


Fig. 4. Example of the verification label generation

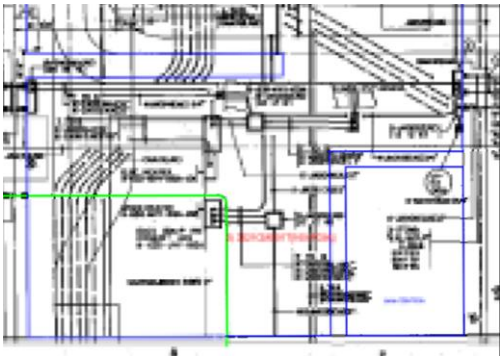
## 4. Application Example

The proposed cable routing analysis method was applied to a KSNP.

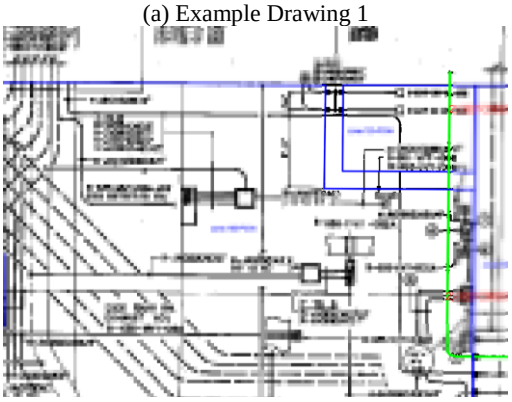
In the primary review, the continuity of cable routes from start to end points was verified using the automatically generated routing database. Specifically, based on fire area drawings, route continuity was confirmed by checking whether the rooms associated with preceding and succeeding raceways were adjacent and whether drawing transitions properly connected to adjacent drawings.

In the secondary review, cable routes were plotted on the drawings based on the verification labels to reconfirm whether they traversed rooms and drawings in the sequence recorded in the routing database. This process verified the consistency between the automatically generated routing database and the actual drawings, serving as a complementary review step to identify errors in the electrical drawings themselves or in the creation of analysis objects.

In plotting the cable routes, colors were differentiated by division so that segments where Divisions A and B coexist within the same fire area could be visually verified. Examples of drawing errors identified as a side effect of cable route plotting are shown in Figure 5 and Table 1, and the identified error types and resolution measures are summarized in Table 2.



(a) Example Drawing 1



(b) Example Drawing 2

Fig. 5. Error example 1: incorrect entry of the raceway route

Table I: Error example 2: omission of the room information

| Cable | Raceway | Room | Fire area | Remark |
|---|---|---|---|---|
| *615CV** | *326***A02 | 165-P01B | A165-P01B | |
| *615CV** | *326***A03 | 165-P01B | A165-P01B | |
| *615CV** | *326***A04 | 165-P01B | A165-P01B | |
| *615CV** | *326***A11 | 165-P03B | A000-PABB | |
| *615CV** | *326***A12 | 165-P03B | A000-PABB | |
| *615CV** | *326***A13 | 165-P03B | A000-PABB | |
| *615CV** | *325**B015 | 165-P03B | A000-PABB | |
| ***615CV**** | ***325**B015** | **144-P02B** | **A144-P02B** | **Added** |
| *615CV** | *325**B015 | 144-P01 | A144-PACR | |

Table II: Identified error types and corrective actions

| Source | Error type | Corrective action |
|---|---|---|
| Drawing | Incorrect entry of the raceway route | Check the relevant design properties or Site walk-down |
| Ref. DB | Entry of an incorrect room | Correct the room ID |
| | Omission of room information | Add the omitted room |

The quantitative and qualitative effects evaluated by applying this method to the target NPP are summarized in Table 3:

Table III: Example of the application effects

| Item | Value | Basis of estimation |
|---|---|---|
| No. of Total cables | ~ 3,000 | Sum of the selected cables |
| No. of Total raceways | ~ 121,000 | before de-duplication |

| | | |
|---|---|---|
| Duplicated raceways | ~ 115,000 | Sum of the duplicated |
| Reduction | ~ 95% | - |
| Region determination | ~ 800 sec. | PIP test computing time |
| Data mapping | ~ 3 sec. | - |
| Routing DB output | < 0.5 sec. | Routing DB sheet output |
| Label Generating | ~ 700 sec. | Time to generate on drawings |
| Total elapsed time | < 1,500 sec. | Total execution time |

Among the approximately 121,000 target raceways, nearly 95% of the duplicate raceways were reused via a single region determination, which reduced the simple review workload by about 90%, and the routing database was generated in approximately 25 minutes.

From the region determination step onward, after the analysis object creation, the entire process is performed by an automated computer program, which reduces the human errors at the source. The errors that may arise in the input stage are also minimized through the two-tier review, that is, the first route continuity review and the second visual route review.

Because this approach always produces consistent results for the same drawings and input data, it can serve as objective evidence during the re-verification and audit response processes.

## 5. Conclusions and Discussion

This paper proposed an automated method for generating cable routing database for the SSA by recognizing the objects created on the cable drawings using CAD software. The proposed method improved the work efficiency substantially by narrowing the scope of the routing analysis from the full set of raceways to a de-duplicated set, and it ensured the reliability of the routing database by minimizing human errors through the two-tier review. However, the automatically generated results by this method still require verification against independent, separate reference materials.

Ultimately, the cable routing database generated by this method is expected to enhance the reliability of post-fire SSA outputs, including the MSO analysis performed on its basis.

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