IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

SPECIAL SECTION ON INTELLIGENT LOGISTICS BASED ON BIG DATA

Received June 5, 2020, accepted June 16, 2020, date of publication June 23, 2020, date of current version August 13, 2020.

*Digital Object Identifier 10.1109/ACCESS.2020.3004447*

# End of Life Vehicle Disassembly Plant Layout Evaluation Integrating Gray Correlation and Decision Making Trial and Evaluation Laboratory

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This work was supported in part by the Nantong Science and Technology Plan Project under Grant JC2019093, and in part by the Jiangsu College Students' Innovation and Entrepreneurship Training Program under Grant 201910304153H.

**ABSTRACT** End of life vehicle (ELV) is a significant renewable resource with enormous economic value and environmental value. This paper introduced a novel approach that combines the gray correlation and Decision Making Trial and Evaluation Laboratory (DEMATEL) with an interactive technique in order to consider both quantitative and qualitative features simultaneously in ELV plant facility layout problem. The gray interval number of gray correlation is used as the expert's evaluation score of the impact factor of the ELV dismantling plant, DEMATEL constructs a direct impact matrix by analyzing the causal relationship between various influencing factors in the system. The proposed approach is applied to the case of a realistic ELV dismantling plant, and the evaluation framework for an ELV plant layout alternatives and design assessment analysis also conducted. The results show that it provides a systematic decision support tool and a feasible approach for evaluation of ELV disassembly plant layout alternatives.

**INDEX TERMS** End of life vehicle, dismantling, facility layout evaluation, gray correlation, decision making trial and evaluation laboratory.

## I. INTRODUCTION

End of life vehicle (ELV) is a significant renewable resource with huge economic value and environmental value [1]. With the current resource scarcity and increasing environmental pressure, the ELV recycling industry is increasingly concerned by academia and business [2]. Lots of micro-researches of ELV recycling network and recycling technology through the algorithm and experimental simulation of partially to optimize a link in the industry [3]–[5]. However, ELV recycling and dismantling enterprises require a reasonable facility layout, which directly relates to the dismantling efficiency of ELV and the quality of the recycling products caused by advanced disassembly technology [6], [7]. It can be concluded that the ELV disassembly plant facility layout is affected by multiple factors, and it is difficult to accurately decide which factors have a great impact on the layout design.

Arranging facilities of ELV disassembly plant is a complicate task that demands careful consideration of various factors. For example, occupied area, handling distance, transportation cost, production time, and environmental factors need to be recognized in layout design [8]–[10]. Three crucial factors affected the advancement of facility layout are locating input/output points, arranging facilities, and material flow network, respectively. In order to obtain the problem solution simply, many previous studies determined the distance between two facilities by considering the distance between the centers, which results in a layout far away from realistic. Thus, a method determining input /output points locations and material flow design in the facility layout determining process has been widely studied.

Reviewing the previous research, typical plant layout problems include static plant layout problems, dynamic plant layout problems, and stochastic plant layout problems.

The associate editor coordinating the review of this manuscript and approving it for publication was Guangdong Tian.

Grobelny [11] put forward a linguistic pattern approach, which takes the relationship degrees for the plant into account, costs of installation of each facility in each possible place, and the distance between location places in the form of fuzzy sets. Friedrich *et al*. [12] presented the connection paths for material handling, which was then replaced by aisles.

Therefore, to obtain full results by only one optimization object was not applicable, and multi-objective layout work has carried out and achieved consistent results [13]–[16]. Ripon *et al*. [17] solved plant layout design by the adoption of a multi-objective approach that combined an adaptive strategy and a variable neighborhood search. Gomez *et al*. [18] proposed a multi-objective genetic algorithm with the consideration of aisles in the plant layout for solving the facility layout problem. Also, in the work conduct by Aiello *et al*. [19] and Aiello *et al*. [20], the Electre method and a multi-objective genetic algorithm was employed for optimization from the view of closeness request material handling cost and distance request. In addition, in order to consider more than one objective, both Purnomo *et al*. [21] and Saraswat *et al*. [22] applied the methodology suggested by Sherali *et al*. [23]. What's more, the particle swarm optimization approaches are suggested to handle the multi-objective plant facility layout problem. These methods coupled a heuristic configuration mutation operation with a subsequent local search. Liu [24] and Liu [25] took distance requirements and material handling cost into account, hence, they presented a multi-objective ant colony optimization algorithm to discuss the plant facility layout problem. García-Hernández *et al*. [26] and García-Hernández *et al*. [27] put forward an effective genetic approach that was employed to recycling plant layout for acknowledging both material handling cost and the decision-maker preferences.

In dealing with facility layout problem in practice, approximate factors should be considered dramatically. As in the current study, multiple researchers adopted fuzzy logic-based solution approaches for the solution of the facility layout problem. Bashiri *et al*. [28] proposed details on the applications of fuzzy technique for order performance by similarity to ideal solution (TOPSIS) for facility layout issue of a textile company with an excellent location selection. In addition, Ertugrul and Karakasoglu [29] combined fuzzy analytic hierarchy process (AHP) and fuzzy TOPSIS for selecting of the location of a textile company in Turkey. Mohamadghasemi and Hadi Vencheh [30] proposed an integrated synthetic value of fuzzy judgments and a nonlinear programming methodology for ranking the facility layout patterns. They incorporated qualitative criteria besides the quantitative criteria into facility layout design problem. Furtherly, Hadi and Mohamadghasemi [31] present decision-making methodologies using nonlinear programming model and AHP to deal with the facility layout design after considering both the quantitative and qualitative data simultaneously. Singh *et al*. [32] introduced the concept of three-level AHP heuristic approach with a new normalization procedure and a new heuristic method to generate objective weights for a multi-objective facility layout issue. Sharma *et al*. [33] applied the fuzzy TOPSIS methodology to the best selection of procedural approach for facility layout planning. Kumar *et al*. [34] proposed a hybrid interpretive structural modeling (ISM) and decision-making trial and evaluation laboratory (DEMATEL) method approach to figure out the hierarchal and contextual relation structure among the barriers of e-waste recycling management. Dixit *et al*. [35] introduced an interesting two-stage approach combining the fuzzy goal programming model and the fuzzy similarity index to elicit the alternative layouts and relationship charts. Evolutionary algorithms of the class of meta-heuristics are extensively applied by researchers to address the evaluation of R&D projects in practice. Fuzzy FEMATEL is the most widely utilized evolutionary algorithms because of its attractive ability of global searching [36]–[40]. Fuzzy DEMATEL method is employed on the facility layout design, analysis of supplier selection criteria [41], improvement of the effective model for solid waste management, and assessment of significant success factors in new production development.

In a summary, facility layout problem of ELV disassembly plant is one of the most important problems in a huge range of vehicle industries and services organizations. Simultaneous study of some qualitative and quantitative parameters like closeness relationship between facilities, physical constraints such as input/output points and how to arrange facilities can play a key role to determine the facility layout. Considering these parameters can lead to reduce production costs, increase production capacity, and remove additional displacements. However, determining how to evaluate the ELV disassembly plant layout scientifically is still a problem that needs to be solved. Generally, two types of approaches are employed to address this issue in the view of multi-criteria decision making (MCDM): 1) correlation degree assessment approaches, e.g., weighted sum [42]–[44], TOPSIS [28], [45], AHP [46] and fuzzy synthetic evaluation [33], [47], [48] and 2) the approaches DEMATEL [29], [49]. On the other hand, to our knowledge, hybrid gray correlation and fuzzy DEMATEL approaches have not been employed to solve the ELV plant facility layout problem. Considering this gap, a fuzzy DEMATEL-based solution approach for ELV plant facility layout problem is proposed in this study.

In this paper, we introduced a novel approach that combines the gray correlation and DEMATEL with an interactive technique, in order to consider both quantitative and qualitative features simultaneously in ELV plant facility layout problem. It consists of two phases, the gray interval number of gray correlation is used as the expert's evaluation score of the impact factor of the ELV dismantling plant, DEMATEL constructs a direct impact matrix by analyzing the causal relationship between various influencing factors in the system. Therefore, we can evaluate the ELV disassembly plant layout design alternatives more objectively and more rationally.

The remainder of this paper is structured as follows. Section II presents the employee evaluation methods.

In Section III, the proposed approach is described and applied to the case of a realistic ELV disassembly plant facility layout. The evaluation framework for an ELV plant layout alternatives and design assessment analysis was also conducted in Section IV. Section V ends the paper with the conclusion and further research topics.

## II. EVALUATION APPROACH

In this paper, a gray correlation is employed to evaluate a design's logistic performance. DEMATEL is used to determine the weight of performance indices, and gray correlation-DEMATEL is adopted to obtain the final rank of all concerned design alternatives.

### A. GRAY CORRELATION

Gray correlation is a practical multi-criterion decision-making approach to evaluate design alternatives via a gray relational closeness index [50]–[52]. Its idea is described as follows: it adopts a gray relational degree of similarity among data sequences as a measurement scale through analyzing similarity curve geometry and geometric relations among data sequences. Usually, the closer the curve is, the larger the gray relational degree; otherwise, the smaller the gray relational degree. For an MCDM problem, if a specific design alternative has a larger gray relational degree with its positive-ideal alternative, it is considered close to the ideal alternative. Otherwise, if it has a larger gray relational degree with its negative-ideal alternative, it is far from the ideal alternative. Thus, constructing the gray relational closeness index among design, positive-ideal, and negative-ideal alternatives can evaluate design alternatives. gray correlation has the following steps.

Step 1: Based on the above-normalized decision matrix and ideal solutions, calculate the gray correlation coefficient between the $i$th alternative and positive-ideal alternative about the $j$th index

$$r_{ij}^{+} = \frac{\min_i \min_j \left| z_j^{+} - z_{ij} \right| + \varsigma \max_i \max_j \left| z_j^{+} - z_{ij} \right|}{\left| z_j^{+} - z_{ij} \right| + \varsigma \max_i \max_j \left| z_j^{+} - z_{ij} \right|} \quad (1)$$

where $\varsigma$ denotes the resolution factor, $\varsigma \in [0, 1]$. We choose $\varsigma = 0.5$ in this paper. Then, the gray correlation coefficient matrix between each alternative and the positive-ideal alternative is found as follows:

$$R^{+} = \begin{bmatrix} r_{11}^{+} & r_{12}^{+} & \cdots & r_{1\mathrm{m}}^{+} \\ r_{21}^{+} & r_{22}^{+} & \cdots & r_{2\mathrm{m}}^{+} \\ \vdots & \vdots & \ddots & \vdots \\ r_{\mathrm{n}1}^{+} & r_{\mathrm{n}2}^{+} & \cdots & r_{\mathrm{nm}}^{+} \end{bmatrix} \quad (2)$$

Thus, the gray relational degree between the $i$th alternative and positive-ideal alternative is obtained as follows:

$$R_i^{+} = \frac{1}{m} \sum_{j=1}^{m} r_{ij}^{+}, \, (i \in \{1, 2, \ldots, n\}) \, . \quad (3)$$

Step 2: Calculate the gray correlation coefficient between the $i$th alternative and negative-ideal alternative about the $j$th index as follows:

$$r_{ij}^{-} = \frac{\min_i \min_j \left| z_j^{-} - z_{ij} \right| + \varsigma \max_i \max_j \left| z_j^{-} - z_{ij} \right|}{\left| z_j^{-} - z_{ij} \right| + \varsigma \max_i \max_j \left| z_j^{-} - z_{ij} \right|} \quad (4)$$

Then, the gray correlation coefficient matrix between each alternative and the negative-ideal alternative is obtained

$$R^{-} = \begin{bmatrix} r_{11}^{-} & r_{12}^{-} & \cdots & r_{1\mathrm{m}}^{-} \\ r_{21}^{-} & r_{22}^{-} & \cdots & r_{2\mathrm{m}}^{-} \\ \vdots & \vdots & \ddots & \vdots \\ r_{\mathrm{n}1}^{-} & r_{\mathrm{n}2}^{-} & \cdots & r_{\mathrm{nm}}^{-} \end{bmatrix} \quad (5)$$

Thus, the gray correlation degree between the $i$th alternative and negative-ideal one is obtained as follows:

$$R_i^{-} = \frac{1}{m} \sum_{j=1}^{m} r_{ij}^{-}, \quad (i \in \{1, 2, \ldots, n\}) \quad (6)$$

Step 3: Based on the results from Steps 1 and 2, the gray correlation closeness index $Ri$ for the $i$th alternative is computed as

$$R_i = \frac{R_i^{+}}{R_i^{+} + R_i^{-}} \quad (i \in \{1, 2, \ldots, n\}) \quad (7)$$

According to the above description, the gray correlation is used to evaluate design alternatives based on the gray correlation degrees among data sequences. The results reflect the proximity between each design and the positive-ideal (negative-ideal) alternative.

### B. DEMATEL

The original DEMATEL was focus on the fragmented and antagonistic phenomena for integrated solutions, and it becomes a comprehensive method for building and analyzing a structural model involving causal relationships between complex factors.

Digraphs are more useful than directionless graphs because digraphs can demonstrate the directed relationships of subsystems. Moreover, the digraph portrays a basic concept of contextual relationships among the elements of the system, in which the numeral represents the strength of influence. The DEMATEL is based on digraphs, which can separate involved factors into cause group and effect group and includes four primary steps as below [53].

Step 1: *Determine the influence factors*. Analyze and determine the influence factors of the system, and use $G = \{g_1, g_2, \ldots, g_n\}$ to represent, in which $g_i$ denotes the $i$-th influence factor of the system.

Step 2: *Discuss and determine the relationship between influence factors*. The invited expert group determines the influence relationship between various factors and constructs the corresponding directed graph on this basis. If $k_i$ has a direct influence on $k_j$, mark a one-way arrow from $k_i$ to $k_j$, and so on to draw a directed graph of the relationship between all influencing factors.

Step 3: *Generating the direct-relation matrix*. Experts judge the strength of the direct influence relationship between the influence factors. Thus the initial direct influence matrix $K = [k_{ij}]_{n\times n}$ of the system is obtained as follows:

$$K = \begin{bmatrix} 0 & k_{12} & \cdots & k_{1n} \\ k_{21} & 0 & \cdots & k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ k_{n1} & k_{n2} & \cdots & 0 \end{bmatrix} \tag{8}$$

where $k_{ij} = S_{i\rightarrow j}$ ($i = 1, 2, \ldots$, n; $j = 1, 2, \ldots$, n; $i \neq j$) represents the direct influence of $g_i$ on $g_j$, if $i = j$, let $g_{ij} = 0$ Therefore, all the main diagonal elements of the initial influence matrix $K$ are 0.

Step 4: *Calculate the standardization direct influence matrix*. The initial impact matrix $K$ is standardized, and the normalized direct impact matrix $D$ is obtained as follows:

$$D = \frac{K}{\max\limits_{1\leq i\leq n} \sum\limits_{j=1}^{n} k_{ij}} \tag{9}$$

where the value range of the elements in the non-main diagonal in $D$ is [0, 1], and the value of the main diagonal elements is 0.

Step 5: *Measure the comprehensive impact matrix*. The comprehensive influence matrix $T$ is obtained as follows:

$$T = \left(t_{ij}\right)_{n\times n} = D\,(I - D)^{-1} \tag{10}$$

where $I$ denote the identity matrix.

Step 6: *Calculate the degree of cause and centrality of each factor*. The row and column sums of matrix $T$ are obtained as follows:

$$p_i = \sum_{j=1}^{n} t_{ij}, \quad i = 1, 2, \ldots n \tag{11}$$

$$o_i = \sum_{i=1}^{n} t_{ij}, \quad j = 1, 2, \ldots n \tag{12}$$

where $p_i$ represents the sum of the direct and indirect influences of the factor $g_i$ on other factors, which is called the influence degree of the factor $g_i$, $o_i$ represents the sum of the direct and indirect influences of the factor $g_i$ on other factors, which is called the influenced degree of the factor $g_i$. The centrality of the factor $g_i$ is recorded as $p_i + o_i$, which represents the overall impact of the factor $g_i$ on the system and the widespread impact of other factors on it. The centrality reflects the importance of the factor $g_i$ in the entire system, and it is inferred that the cause of the factor $g_i$ is ($p_i$-$o_i$), which is the degree of influence of factor $g_i$ on the system minus its impact. Generally, when ($p_i$-$o_i$) is positive, it means that the influence degree of $g_i$ is higher than the influenced degree, which is called the cause factor. Otherwise, when ($p_i$-$o_i$) is negative, it means that the influence degree of $g_i$ is higher than the influence degree, and it is called the resulting factor.

Step 7: *Draw a relationship diagram of system influenced factors*. Taking the cause degree as the ordinate and the center degree as the abscissa, according to the value of the array ($p_i + o_i$, $p_i$-$o_i$). Annotate each factor with a visual graphic, and then characterize the relationship of each factor in the system. In the causality diagram, the factors above the abscissa are classified as the cause group, and the factors below the abscissa are classified as the resulting group.

### C. HYBRID GRAY CORRELATION AND DEMATEL METHOD

To more objectively and more rationally evaluate the ELV disassembly plant layout design alternatives, this work proposes a novel hybrid MCDM approach by integrating Gray correlation and DEMATEL. This approach makes full use of quantitative analysis and weight allocation features of gray correlation and comprehensive assessment ability of DEMATEL. It consists of two phases, the gray interval number of gray correlation is used as the expert's evaluation score of the impact factor of the ELV dismantling plant, DEMATEL constructs a direct impact matrix by analyzing the causal relationship between various influencing factors in the system.

## III. PROGRAM EVALUATION WITH INTEGRATED GRAY CORRELATION AND DEMATEL

In this section, the use of integrated gray correlation and DEMATEL is illustrated by evaluating the green layouts of ELV dismantling plant.

### A. BACKGROUND AND DATA COLLECTION

The rapid development of the vehicle industry and market in China have made considerable contributions to the national economy in recent decades [54]–[56]. Currently, China's vehicle ownership has reached 260 million and ranked first in the world. However, the subsequent disposal of a large number of ELV as a crucial factor will affect the sustainable development of the automobile industry and even the national economy.

The average life cycle of vehicles is 10-12 years without significant changes of operating conditions in China, and it can be predicted that the amount of ELV in the next ten years will be basically equivalent to the current supply, that is, the annual amount of ELV may reach 25 to 29 million around 2030. However, at present, China's annual recycling volume of ELV is less than 2 million, while in 2018, China's car ownership exceeded 230 million, and the recycling rate is less than 1%. From the perspective of developed countries, the average car recycling rate is 4% to 6%, and the German has even reached 7%. Even considering that China's automobile market is still developing rapidly, the recycling rate will be relatively low, but the recycling rate of 1% is also significantly lower than the average level, which cannot objectively and genuinely reflect the actual number of ELV in China. There may be the following three reasons for the difference: 1) many vehicles reaching the end-of-life have not been dismantled in accordance with the formal procedures, but have flowed to underdeveloped areas or rural areas, 2) A large number of ELV entered the illegal dismantling market and 3) the gray area of related vehicle management makes it difficult to recycling.

However, China has enacted a series of policies and regulations that require manufacturers to reclaim and recycle ELV to mitigate their life-cycle environmental impacts and to improve resource efficiency. In addition, most published articles have emphasized the development of disassembly technologies for recovering the materials from ELV and reducing their environmental impacts. Therefore, deciding how to ensure/evaluate the disassembly plant layout remains to be resolved. Thus, we evaluate three kinds of ELV disassembly plant alternatives via the proposed integrated gray correlation and DEMATEL based on the hierarchical structure of green design evaluation.

Related information and initial data can be gathered from experts with professional knowledge and managerial experience, e.g., scholars of college and supervisors of the enterprise, through the questionnaire survey. In this research, five experts have been consulted to obtain pairwise comparison matrixes of each criterion and the decision matrix for the evaluation of three ELV disassembly plant alternatives, including three scholars who specialize in logistic selection, four supervisors from related companies with reputation, and two customers who have handled ELV is a legal procedure. This investigation was carried out in December 2018.

### B. HIERARCHY CRITERIA/FACTORS OF ELV DISASSEMBLY PLANT LAYOUT

First of all, the main factors affecting the dismantling of ELV have been clarified based on the related literature and expert interview. After a comprehensive and scientific selection, five kinds of criteria and their parameters have been given. We establish a hierarchical structure for their layout evaluation, which is shown in Fig. 12 and includes three levels, i.e., goal, criterion, and factor. Goal level($G$) is ELV disassembly plant layout evaluation($G_1$); criterion level(A) is environmental($A_1$), resource($A_2$), technology($A_3$), economy($A_4$), and society($A_5$) properties. The environmental property includes two factors, i.e., air pollution($E_1$) and waste solid and liquid pollution($E_2$). Resource property includes two factors, i.e., unit product resource consumption energy types($E_3$) and Recyclable product utilization($E_4$). Technology property includes two factors, i.e., disassembly technology($E_5$) and management technology($E_6$). The economy property includes three factors, i.e., transportation and storage cost($E_7$), dismantling cost($E_8$), and other costs ($E_9$). Society property includes one factor, i.e., government policies($E_{10}$).

It will be analyzed from five aspects: environment, resources, technology, economy, and society, which are shown in Fig. 1.

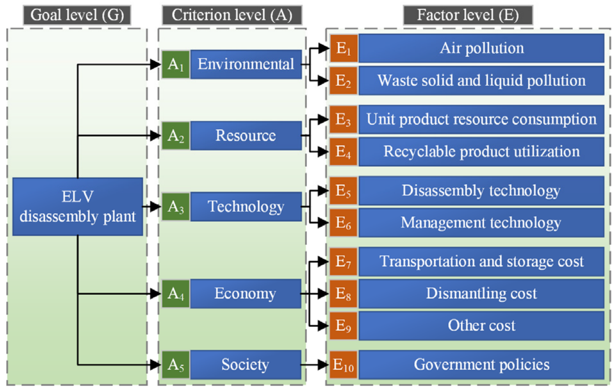


**FIGURE 1. Influence factors of ELV disassembly plant.**

### C. WEIGHT DETERMINATION VIA USING INTEGRATED GRAY CORRELATION AND DEMATEL

In this paper, an algorithm combining gray correlation and DEMATEL method is used to evaluate the facility layout of ELV disassembly plant in this paper. For the interval gray number, recorded as $\otimes x = [\underline{\otimes} x, \bar{\otimes} x]$, where $\underline{\otimes} x$ is the lower limit of $\otimes x$, and $\bar{\otimes} x$ the upper limit of $\otimes x$, the calculation formula is as follows:

$$\otimes x_1 + \otimes x_2 = \left[\underline{\otimes} x_1 + \underline{\otimes} x_2, \bar{\otimes} x_1 + \bar{\otimes} x_2\right] \tag{13}$$

$$\otimes x_1 - \otimes x_2 = \left[\underline{\otimes} x_1 - \underline{\otimes} x_2, \bar{\otimes} x_1 - \bar{\otimes} x_2\right] \tag{14}$$

$$\otimes x_1 \times \otimes x_2 = \begin{bmatrix} \min\left(\underline{\otimes} x_1 \underline{\otimes} x_2, \underline{\otimes} x_1 \bar{\otimes} x_2, \bar{\otimes} x_1 \underline{\otimes} x_2, \bar{\otimes} x_1 \bar{\otimes} x_2\right), \\ \max\left(\underline{\otimes} x_1 \underline{\otimes} x_2, \underline{\otimes} x_1 \bar{\otimes} x_2, \bar{\otimes} x_1 \underline{\otimes} x_2, \bar{\otimes} x_1 \bar{\otimes} x_2\right) \end{bmatrix} \tag{15}$$

$$\otimes x_1 \div \otimes x_2 = \left[\underline{\otimes} x_1, \bar{\otimes} x_1\right] \times \left[\frac{1}{\underline{\otimes} x_2}, \frac{1}{\bar{\otimes} x_2}\right] \tag{16}$$

When determining the weight of an influencing factor, experts often have uncertainties in their semantic evaluation, and the gray number shows this uncertainty well. The gray interval number is used as the expert's evaluation score of the impact factor $i$ on the $j$ of the ELV dismantling plant. The interval grey number corresponding to the semantic evaluation is shown in Table 1.

**TABLE 1. Interval gray number corresponding to semantic evaluation.**

| Linguistic variable | Gray interval |
|---|---|
| Null (N) | [0,0] |
| Very Low (VL) | [0.00,0.25] |
| Low(L) | [0.25,0.50] |
| High (H) | [0.50,0.75] |
| Very High (VH) | [0.75,1.00] |

**TABLE 2.** Interaction degree of different factors.

| | $E_1$ | | $E_2$ | | $E_3$ | | $E_4$ | | $E_5$ | | $E_6$ | | $E_7$ | | $E_8$ | | $E_9$ | | $E_{10}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_1$ | | | VL | L | L | VL | N | VL | L | VL | VL | N | N | VL | L | VL | VL | N | VL | VL |
| | | | VL | VL | L | N | VL | VL | L | VL | VL | VL | VL | L | L | H | VL | N | L | L |
| $E_2$ | VH | L | | | H | VL | VL | N | N | VL | VL | N | VL | VL | L | VL | L | N | VL | L |
| | H | H | | | VL | L | VL | L | VL | N | VL | N | VL | N | VL | L | VL | N | VL | VL |
| $E_3$ | VL | H | VL | N | | | VL | N | VL | L | VL | L | L | L | VH | L | VL | L | L | L |
| | H | L | VL | VL | | | VL | N | VL | VL | VL | L | VL | L | H | H | VL | VL | VL | L |
| $E_4$ | VL | L | L | L | N | VL | | | VL | H | VL | H | VL | VL | VL | L | VL | N | N | N |
| | VL | VL | VL | N | VL | L | | | VL | L | L | L | VL | L | L | L | VL | VL | L | VL |
| $E_5$ | VL | N | VL | N | VL | N | L | H | | | VL | H | VL | VL | VL | H | VL | L | VL | N |
| | VL | N | VL | L | VL | VL | VH | L | | | L | L | VL | L | L | L | VL | VL | VL | VL |
| $E_6$ | N | VL | L | VL | VL | L | VL | N | L | VL | | | VL | N | VL | L | VL | N | N | VL |
| | VL | L | VL | H | L | VL | VL | N | VL | N | | | L | N | L | VL | VL | N | L | N |
| $E_7$ | VL | L | VL | VL | L | VL | H | VH | L | H | L | VH | | | VL | L | VL | N | VL | N |
| | L | VL | VL | N | VL | VL | H | L | VL | L | VH | H | | | VL | H | N | VL | N | VL |
| $E_8$ | VH | H | H | VH | H | VH | VL | N | VL | L | VL | N | VL | N | | | VL | N | VL | L |
| | H | H | L | H | VH | L | VL | L | VL | H | N | VL | N | L | | | VL | N | VL | N |
| $E_9$ | VL | L | VL | VL | VL | VL | VL | N | N | VL | VL | N | VL | VL | VL | L | | | VL | H |
| | VL | L | VL | L | VL | N | VL | N | N | VL | N | N | L | VL | N | VL | | | L | L |
| $E_{10}$ | VL | N | VL | L | VL | VL | N | N | VL | N | VL | N | VL | VL | VL | L | L | VL | | |
| | VL | L | L | VL | VL | N | N | VL | N | VL | VL | N | N | VL | VL | N | L | L | | |

With the comprehensive analysis, the interaction degree of different factors is shown in Table 2.

For the convenience of subsequent calculations, the interval gray evaluation obtained in the above table is cleared, and the results are as follows in Table 3:

**TABLE 3.** Analysis results.

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ | $E_7$ | $E_8$ | $E_9$ | $E_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $E_1$ | 0 | 0 | 0.062 | 0.312 | 0.125 | 0.312 | 0 | 0.187 | 0.125 | 0.375 |
| $E_2$ | 0.500 | 0.687 | 0 | 0 | 0.187 | 0.437 | 0.062 | 0.250 | 0 | 0.125 |
| $E_3$ | 0.312 | 0.562 | 0 | 0.187 | 0 | 0 | 0 | 0.125 | 0.062 | 0.312 |
| $E_4$ | 0.062 | 0.312 | 0.125 | 0.312 | 0.062 | 0.25 | 0 | 0 | 0.187 | 0.437 |
| $E_5$ | 0 | 0.125 | 0.062 | 0.25 | 0 | 0.187 | 0.437 | 0.687 | 0 | 0 |
| $E_6$ | 0.062 | 0.25 | 0.187 | 0.437 | 0.125 | 0.375 | 0 | 0.125 | 0.062 | 0.25 |
| $E_7$ | 0.125 | 0.375 | 0 | 0.187 | 0.062 | 0.312 | 0.5 | 0.75 | 0.25 | 0.5 |
| $E_8$ | 0.562 | 0.812 | 0.500 | 0.750 | 0.562 | 0.812 | 0.062 | 0.250 | 0.187 | 0.437 |
| $E_9$ | 0.125 | 0.375 | 0.062 | 0.312 | 0 | 0.187 | 0 | 0.125 | 0 | 0.125 |
| $E_{10}$ | 0.421 | 0.146 | 0.174 | 0 | 0.614 | 0.483 | 0.781 | 0.054 | 0 | 0 |

The main principle of the DEMATEL method is to construct a direct impact matrix by analyzing the causal relationship between various influencing factors in the system, as shown in Table 4.

**TABLE 4.** Factor solution value (C, R, R + C, R-C).

| Criteria | R | C | R+C | R-C | Weights |
|---|---|---|---|---|---|
| $E_1$ | 2.854 | 2.416 | 5.270 | 0.438 | 0.146 |
| $E_2$ | 1.327 | 2.123 | 3.450 | -0.796 | 0.081 |
| $E_3$ | 2.845 | 1.655 | 4.500 | 1.190 | 0.106 |
| $E_4$ | 2.245 | 2.025 | 4.270 | 0.220 | 0.137 |
| $E_5$ | 1.524 | 0.92 | 2.440 | 0.604 | 0.067 |
| $E_6$ | 0.138 | 0.092 | 0.230 | 0.046 | 0.052 |
| $E_7$ | 3.112 | 2.928 | 6.040 | 0.184 | 0.158 |
| $E_8$ | 2.365 | 2.345 | 4.710 | 0.020 | 0.133 |
| $E_9$ | 1.785 | 1.924 | 3.710 | -0.140 | 0.082 |
| $E_{10}$ | 0.862 | 0.768 | 1.630 | 0.094 | 0.038 |

Where R is influence degree, C is influenced degree, R + C is the central degree, R − C is the cause degree.

It can be concluded from the above table that transportation and storage costs, recyclable product utilization, and environmental impact are all parts that weigh heavily.

## IV. EXPERIMENTS AND RESULTS OF CASE STUDY

### A. PLOT OF THE UNIT AREA OF THE JOB

The entire process of drawing an operating unit location-related map should be systematic and explicit. This process is focused on excellence, and generally follows the steps below.

(1) Select an appropriate drawing scale for drawing. Here, the selected scale is 1: 1000, and the drawing unit is mm.

(2) Enlarge the relevant picture of the position of the work unit onto the coordinate paper, leaving as much space as possible between each work unit symbol in order to arrange the establishment of the work unit. To keep the drawing simple, only essential relationships are drawn.

(3) According to the order of the comprehensive approach, each unit is arranged from big to small on the map. In a drawing, the shape of the work unit is drawn with the symbol of the work unit as the center. The buildings in the operating unit are generally rectangular, and different layout drawings can be obtained by the rotation angle of the shape. When the reserved space is insufficient, the position of the operating unit needs to be adjusted. But we must adjust the position symbol to operate the requirements of the unit position correlation diagram.

(4) After continuous adjustment and redrawing, the following correlation diagram of the operating unit area is obtained, as shown in Fig. 2.

The interrelationship level is presented by the number of lines, as showed in Table 5.

### B. DETAILED LAYOUT OF THE PLANT

By synthesizing the position correlation map, area correlation map, and correction factors, the following three plant layout

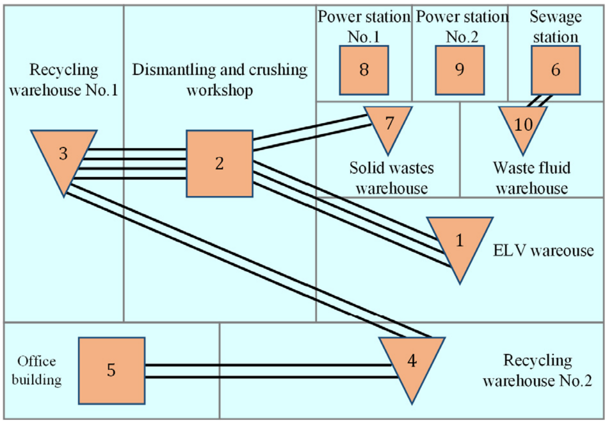


**FIGURE 2.** Relevant diagram of the operating units.

**TABLE 5.** Interrelationship level.

| Level | Line number |
| --- | --- |
| Absolutely important | //// |
| Very important | /// |
| Important | // |
| General important | / |
| Unimportant | |
| Unwilling to close | ········· |

alternatives can be obtained, and the first alternative is shown in Fig. 3.

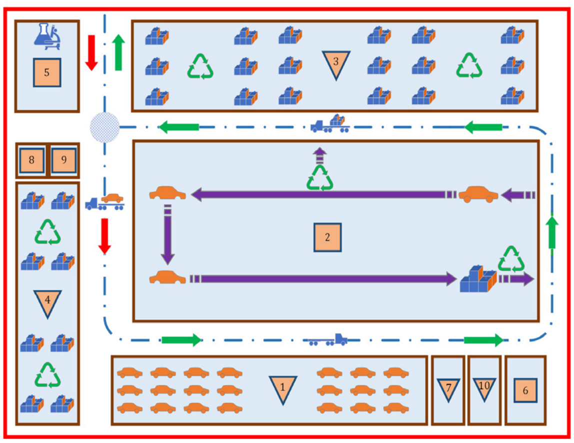

**FIGURE 3.** ELV disassembly plant layout alternative 1.

Unlike the parallel and decentralized layout of the existing plant area, this is based on the symmetry line of the reserved area, and the dismantling, crushing, and fine dismantling of the assembly component operation area is integrated into a workshop and concentrated in the central area. In order to strengthen the logistics connection between the operation areas, the ELV warehouse and the recycling warehouse No.1 are arranged on the south and north sides respectively, and the office building is arranged on the west side, adjacent to the factory door. Moreover, the pollution control area and power supply facility area are arranged in the southeast, and recycling warehouse No.2 is arranged in the west. Therefore, the ELV disassembly plant is generally divided into six function areas, including management area, ELV storage area, product storage area, pollution control area, power supply facility area, and remanufacturing area. Each functional area is demarcated by the road within the plant, and the regional boundaries are clear. In addition, the office building and other areas can be isolated from other areas by fences or green belts.

Features of alternative 1 are proposed with the least correction. Based on the area correlation map, the position of each operating unit basically completely matches the position correlation map. ELV are inspected and weighed in the office building before sending the ELV warehouse, and then the ELV stored in the warehouse are transported to the dismantling and crushing workshop by forklift trucks. Some severe damage or technology in poor condition ELV which cannot be refining dismantled are sent to the rapid disassembly area. When the scrap storage capacity reaches a certain amount, transportation vehicles of ELV transport the scrap to the steel plant for processing. The remanufacturing parts are delivered to the recycling warehouse No.2, and the qualified parts are sent to the recycling warehouse No.1 after repairing treatment. Those parts with direct useability or remanufacturing ability are transported to other remanufacturing enterprises. The second option is shown in Fig. 4.

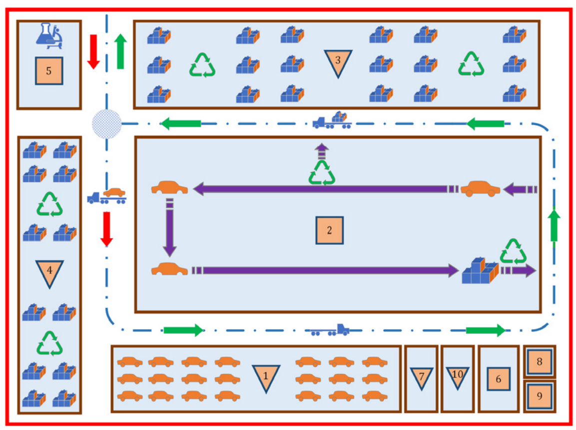

**FIGURE 4.** ELV disassembly plant layout alternative 2.

Features of alternative 2 mainly consider the correction factors such as pollution noise and the efficiency of the auxiliary department during the layout. The most significant amendments are adding an office, a changing room, and a shorted ELV body shell temporary storage area, moving the transformer substation to the southeast corner of the plant is convenient for power supply. In addition, keep all operating units away from sewage treatment and waste liquid warehouse to reduce the negative impact of noise and pollution. Other operating units try to satisfy the position. The logistic of this option is similar with the option 1. The third option is shown in Fig. 5.

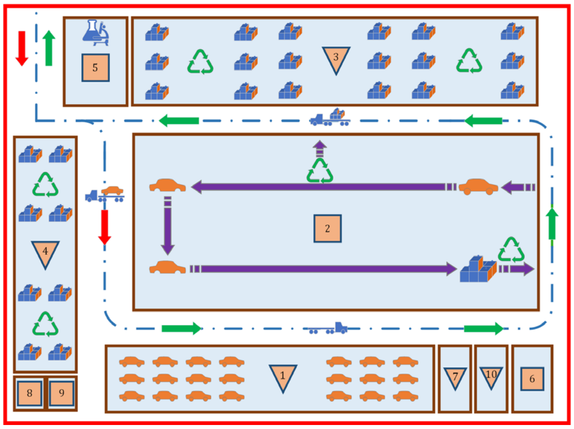


**FIGURE 5.** ELV disassembly plant layout alternative 3.

Features of alternative 3 revised the layout of storage efficiency and brought storage departments with similar functions closer to each other, making the entire planning area distinct. The office building is next to the recycling warehouse No.1, and the power station is moved to the southwest corner, which is next to the recycling warehouse No.2. Likewise, the logistic of this option is similar to alternative 1. In the reference position correlation diagram layout, all auxiliary departments are concentrated on the same side of the plant.

### C. OVERALL ASSESSMENT FOR ELVS DISASSEMBLY PLANT LAYOUT DESIGN ALTERNATIVES

In the evaluation of specific projects, a fuzzy evaluation set needs to be established. The typical evaluation set is 5 levels of excellent, good, medium, weak, and poor. Five evaluation levels are corresponding to the fuzzy evaluation score one by one, and the evaluation matrix C = (100, 75, 50, 25, 0). The expert group participating in the evaluation is used to give a reasonable rating for the solution, and the evaluation set corresponds to the fuzzy score one to one to obtain the desired solution score.

From the weights of each influencing factor obtained according to integrated gray correlation and DEMATEL, the relative weights of the two sub-factors included in the environmental factor can be obtained: $R_1 = (0.643, 0.357)$; Relative weights of the two sub-factors of the resource factor: $R_2 = (0.436, 0.564)$; Relative weight of two sub-factors of technical factors: $R_3 = (0.563, 0.437)$; Relative weight of three sub-factors of economic factors: $R_4 = (0.424, 0.347, 0.219)$; Relative weight of a sub-factor of social factors: $R_5 = (1.00)$.

The formula $G = R \times A \times C$ can get the weight corresponding to each level of indicators.

Alternative 1 was finally evaluated as 74.245;

Alternative 2 was finally evaluated as 82.463

Alternative 3 was finally evaluated as 69.568

It can be seen that the final layout alternative of the ELV disassembly plant of the third alternative is the most reasonable.

## V. CONCLUSION

The practical evaluation of ELV disassembly plant layout designs plays a significant role in remanufacturing development, and it is a complex decision-making problem, including multiple influencing factors. However, current MCDM methods mainly consider the location relationship or situation changes among data sequences. It may lead to some misleading conclusions without considering comprehensive features and be not precise enough. In addition, by considering that each criterion associated with design characteristics should have different influence degrees by identifying the main design characteristics of the desired layout. In this work, a systematic hybrid MCDM approach combining gray correlation and DEMATEL is adopted to assess the performance of the ELV disassembly plant layout alternatives, and its application for ELV disassembly plant layout assessment is shown. The future work will focus on moving from the existing assessment method to integrate the evaluation procedure into a computer-assisted design support system for the ELV disassembly plant layout alternatives. Moreover, the information of experts has an uncertain and imprecise feature; some MCDM methods integrating uncertain theory for ELV disassembly plant layout alternatives need to be developed in the future.

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