Journal of Mines, Metals and Fuels, *71(12D): 280-287; 2023. DOI: 10.18311/jmmf/2023/48344*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Optimizing Facility Layout for Welding Electrode Manufacturing: A Fuzzy - TOPSIS Approach

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Abstract

The present work focuses on optimizing the existing facility layout of an electrode manufacturing industry to meet the growing demand for welding electrodes. The present layout space utilization is initially evaluated by applying a facility planning algorithm called computerized relationship layout planning. Through this algorithm, four alternative layouts are proposed. The proposed layouts are assessed against criteria such as emergency exit, comforts, accessibility, ease of movement, light facilities, ventilation facilities, safety, efficient movement of material and space utilization by applying a multi-criteria decision-making method known as the technique for order of preference by similarity to ideal solution (TOPSIS). The criteria considered in the present work are qualitative; therefore, the concept of fuzzy logic is used to convert them into quantitative data. Applying fuzzy-TOPSIS, the alternative layout A4 with a closeness coefficient of 0.524 evolved as the best layout, followed by A1, A3 and A2. Thereafter, sensitivity analysis is implemented by interchanging the weightage of two criteria at each step to visualize the effect of change in weightage on the ranking. From sensitivity analysis, layout A4 emerged as the best alternative in 35 combinations out of the maximum possible 36 combinations, which justifies the robustness of the developed model.

Keywords: *Facility, Fuzzy, Layout, MCDM, Planning, TOPSIS*

1.0 Introduction

The process of physically arranging all the production variables in a production system to satisfy the organization's strategic goals is known as Facility Planning and Design (FPD). An effective FPD must ensure that production schedules are fulfilled at a lower cost in the short, medium and lengthy duration. The available space of a layout must be used appropriately while ensuring a certain level of flexibility for future re-layouts. FPD is considered one of the critical design decisions in operational business strategy[1]. Additionally, it dramatically impacts how productive and effective manufacturing systems are. Inefficient layouts can lead to bottlenecks, congestion, inefficient space utilization and excess work-in-process. These often result in employee inefficiency, workplace calamities and hardship in managing operations and people.

Moreover, if the organization's work centres are not sufficiently close to one another, the working day cannot be used optimally for transportation-related operations, which adds no value. This is one of the critical causes of longer production times and lower workplace productivity levels. FPD is a challenging issue to resolve due to multiple and conflicting objectives and inputs in qualitative and quantitative forms[2]. Despite the high degree of complexity, some methods address them by offering workable solutions with reasonable computation times. An intricate and iterative procedure that depends on scoring the components forming the goods/services production system determines the facility layouts that will best serve an organization's needs. The material

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flow is not likely to remain constant over time in many manufacturing systems; hence it may not be practicable to contemplate a single design. However, when demand is seasonal or significantly varies, it may be more beneficial to consider a dynamic approach for the optimal layout of the facility. Methods such as Systematic Layout Planning (SLP), Computerized Relationship Layout Planning (CORELAP), and Automated Layout Design Program (ALDEP) are being used in facility planning to increase productivity and reduce material handling costs[3]. A brief review of the methods used in facility planning and their outcomes are outlined herein.

Suhardini *et al.*[4] found four alternatives based on an existing layout's Systematic Layout Planning (SLP). Each alternative was evaluated based on two criteria: material handling cost and processing time by simulation. They achieved a 37.5% increase in production capacity and a 10.98% decrease in material handling cost. Bibin and Boby[5] improved 7.98% productivity by optimizing the material flow pattern of a steel forging industry using the Total Closeness Rating (TCR) in the CORELAP method. Fifteen machines were relocated in the existing layout to optimize the material flow using the CORELAP algorithm. Deshpande *et al.*[6] reduced an alloy steel industry's annual material handling cost by 23% using an Automated Layout Design Program (ALDEP), equivalent to savings of 44.75 lacs per annum. Hakim and Istiyanti[7] reduced the material handling distance by 9.017% in the proposed layout evaluated from CORELAP compared to the existing layout of a pharmaceutical company in Indonesia. Sembiring *et al.*[8] focused on designing a classroom layout to optimize space utilization, wherein the total distance of 2062.5 m from the initial layout was reduced to 1753.5 m using CORELAP, which was 14.98% more efficient compared to the initial layout. Tjusila *et al.*[3] implemented CORELAP, ALDEP and SLP methods to optimize the flow movement in a packaging manufacturing industry. They found the SLP method to be the most optimum, wherein distance and material handling costs were reduced by 60.21% and 44.29%, respectively.

From the literature, it can be inferred that CORELAP is an effective method for generating a layout based on the closeness of each department. However, it is not a suitable technique for selecting the optimum layout from a pool of alternative layouts. Thus, the CORELAP method is employed in the present study to generate alternative layouts of an electrode manufacturing industry. Thereafter, the concept of fuzzy logic coupled with the technique for order of preference by similarity to ideal solution (TOPSIS) is used to find the optimum layout in terms of ergonomics, workplace environment and lean service.

2.0 Methodology

The overall methodology of the present study is shown in Figure 1. Through a walk-through of the plant, the placement of machines and the location of each department are observed. From this observation, the initial layout is drafted. For implementing the CORELAP algorithm, information regarding department dimensions and inter-relationship between departments is required. The dimensions of each department are collected through the blueprint of the plant. Elsewhere, the inter-relationship between each department is collected through the feedback/opinion of the decision-makers. From the above information, an optimal department sequence is calculated. Subsequently, using this optimal sequence, four alternative layouts are derived.

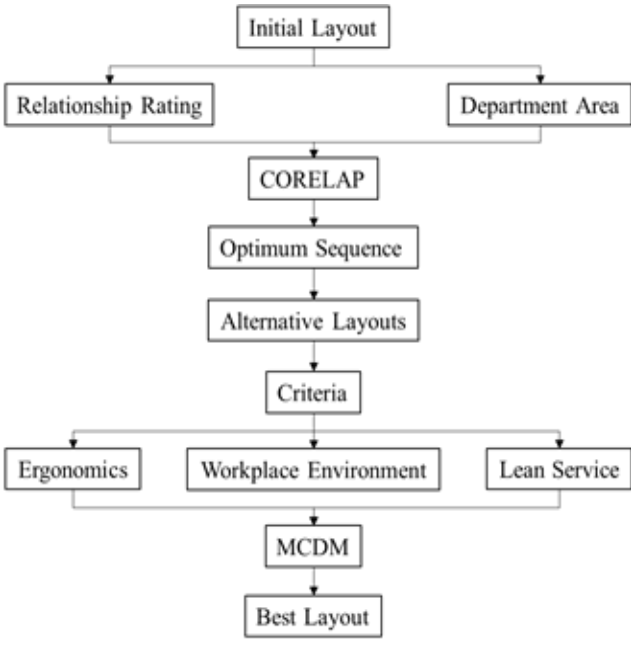


Figure 1. Flowchart of methodology

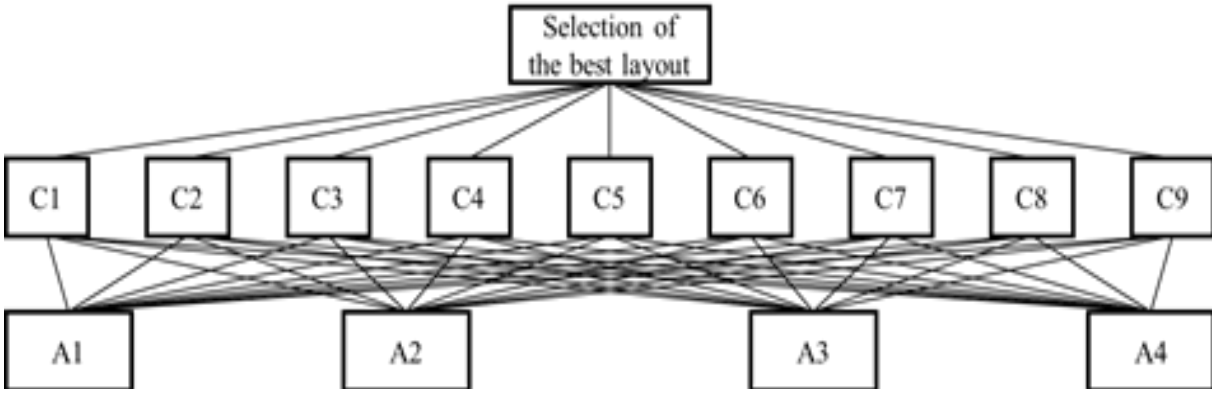


Figure 2. Decision hierarchy of plant layout selection.

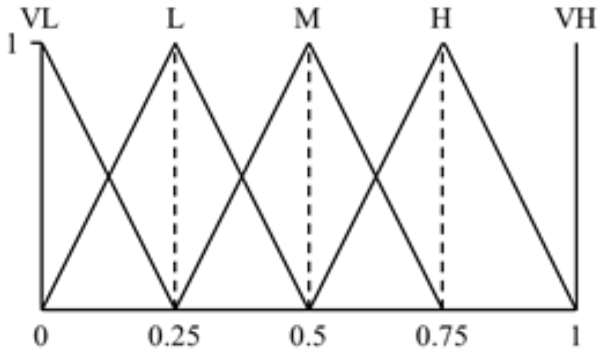


Figure 3. Triangular membership functions of linguistic terms.

The factors affecting the layout selection have been divided into three categories: ergonomics, workplace environment and lean service. Several attributes are considered in each of the three criteria, such as emergency exit (C1), comforts (C2), accessibility (C3) and ease of movement (C4) in ergonomics criterion; light facilities (C5), ventilation facilities (C6) and safety (C7) in workplace environment criterion; efficient movement of material (C8) and efficient space utilisation (C9) in lean service criterion. Then, a prominent multi-criteria decision-making (MCDM) method known as the technique for order of preference by similarity to ideal solution (TOPSIS) is used to find the best alternative layout. The decision hierarchy consisting of all criteria attributes (C1 to C9) and alternative layouts (A1, A2, A3 and A4) is shown in Figure 2. The hierarchy is organized into three levels. The aim of the study, i.e., selection of the best layout, is in the first level. The criteria attributes (C1 to C9) affecting the selection of plant layout and the alternative layouts (A1 to A4) are in the second and third levels, respectively.

In any MCDM problem, assigning weightage to the criteria is challenging. In general, weightage has to be given to each criterion as per their priority [9]. However, most often, the assignment of weightage involves assumptions, which lead to uncertainty in the outcome. The concept of fuzzy logic, a mathematical theory of approximate reasoning, helps to overcome this uncertainty by assigning weightage to criteria. Fuzzy logic permits modelling humans' reasoning processes in linguistic terms based on instinct and judgement. The linguistic terms represented by Triangular Fuzzy Numbers (TFN) assigned to each criterion and their corresponding fuzzy weight are shown in Table 1. The triangular membership functions of the linguistic terms considered in the present study are displayed in Figure 3. A board of four experts

Table 1. Linguistic variables for criteria

Importance	Abbreviation	Fuzzy weight
Very Small	VL	{0, 0, 0.25}
Small	L	{0, 0.25, 0.5}
Medium	M	{0.25, 0.5, 0.75}
Large	H	{0.5, 0.75, 1}
Very Large	VH	{0.75, 1, 1}

Table 2. Importance weights of the criteria by decision makers and aggregated weight

Criteria	DM-1	DM-2	DM-3	DM-4	Average fuzzy weight
Emergency exit	H	H	M	M	{0.38, 0.63, 0.88}
Comforts	M	M	VL	VL	{0.13, 0.25, 0.50}
Accessibility	VH	H	M	H	{0.50, 0.75, 0.94}
Ease of movement	VH	M	H	M	{0.44, 0.69, 0.88}
Light facilities	H	H	M	M	{0.38, 0.63, 0.88}
Ventilation facilities	M	H	H	M	{0.38, 0.63, 0.88}
Safety	H	M	H	M	{0.38, 0.63, 0.88}
Efficient movement of material	VH	H	H	M	{0.50, 0.75, 0.94}
Efficient space utilisation	VH	H	H	H	{0.56, 0.81, 1.00}

has been designated as Decision-makers (DMs). Then, each expert's opinion has been taken in linguistic form against all the criteria, and their average fuzzy weight is computed, as depicted in Table 2.

3.0 Results and Discussion

Initially, the CORELAP algorithm is applied to carry out the redesign of the layout. Table 3 represents the inter-relationship between the various departments of the facility.

The relationship is collected from decision-makers opinions, where the letters A, E, I, O, U and X represent absolutely necessary, especially important, important, ordinary closeness, unimportant and not desirable5. Then, the TCR table is formed using the data available in the activity relationship chart, wherein TCR is the sum of the relationships with other departments (Table

Table 3. Inter-department relationship chart

	De-rolling (D1)	Cutting (D2)	Coating (D3)	Recoating (D4)	Oven (D5)	Lift (D6)	Packaging (D7)	Inventory (D8)
De-rolling (D1)		A	E	O	X	U	X	X
Cutting (D2)			A	U	X	X	U	X
Coating (D3)				A	X	X	X	U
Recoating (D4)					X	U	O	X
Oven (D5)						A	I	X
Lift (D6)							A	E
Packaging (D7)								A
Inventory (D8)								

Table 4. Total closeness rating of the departments

	D1	D2	D3	D4	D5	D6	D7	D8	A	E	I	O	U	X	TCR
D1		A	E	O	X	U	X	X	1	1	0	1	1	3	19
D2	A		A	U	X	X	U	X	2	0	0	0	2	3	19
D3	E	A		A	X	X	X	U	2	1	0	0	1	3	22
D4	O	U	A		X	U	O	X	1	0	0	2	2	2	18
D5	X	X	X	X		A	I	X	1	0	1	0	0	5	15
D6	U	X	X	U	A		A	E	2	1	0	0	2	2	23
D7	X	U	X	O	I	A		A	2	0	1	1	1	2	23
D8	X	X	U	X	X	E	A		1	1	0	0	1	4	17

4). Finally, the optimum sequence of the departments is constructed by the following steps:

- Step 1: The department with the highest TCR is chosen.
- Step 2: The first department is placed initially in the layout.
- *Step 3:* The following department is chosen as the one with an A (E, I, O, U and X) relationship with the already placed department. If there is a tie between two departments, the one with the highest TCR value is chosen.
- *Step 4:* The procedure in Step 3 is continued until all the departments have been placed

From the above procedure, the optimum sequence of departments attained is D6-D7-D8-D5-D4-D3-D2-D1. Thereafter, four alternative layouts (Figure 4) are generated through various permutation and combinations, which are in line with the optimum sequence of the departments.

The fuzzy-TOPSIS method is implemented to find the optimum layout. The steps followed in the fuzzy-TOPSIS method can be found in a study reported by Sun and Lin [10]. The decision matrix consisting of linguistic terms against all the criteria for each alternative is displayed in Table 5. The linguistic terms have been designated to the criteria based on the opinions of a committee of experts. The linguistic terms in Table 5 are then replaced by their corresponding TFNs (Table 1), which represent the fuzzy decision matrix, as shown in Table 6. The weighted normalized matrix and closeness coefficients with ranking are shown in Tables 7 and 8, respectively. The The Fuzzy

Table 5. Decision matrix with linguistic terms

Alternatives	**Criteria**								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
A1	H	VH	H	H	H	H	VH	M	H
A2	M	L	VL	M	L	M	L	H	L
A3	M	M	L	M	H	H	M	H	M
A4	VH	H	H	H	VH	H	VH	VH	M

Table 6. Decision matrix with TFNs

		Alternatives				Average fuzzy weight
		A1	A2	A3	A4	
Criteria	C1	0.5, 0.75, 1	0.25, 0.5, 0.75	0.25, 0.5, 0.75	0.75, 1, 1	{0.38, 0.63, 0.88}
	C2	0.75, 1, 1	0, 0.25, 0.5	0.25, 0.5, 0.75	0.5, 0.75, 1	{0.13, 0.25, 0.50}
	C3	0.5, 0.75, 1	0, 0, 0.25	0, 0.25, 0.5	0.5, 0.75, 1	{0.50, 0.75, 0.94}
	C4	0.5, 0.75, 1	0.25, 0.5, 0.75	0.25, 0.5, 0.75	0.5, 0.75, 1	{0.44, 0.69, 0.88}
	C5	0.5, 0.75, 1	0, 0.25, 0.5	0.5, 0.75, 1	0.75, 1, 1	{0.38, 0.63, 0.88}
	C6	0.5, 0.75, 1	0.25, 0.5, 0.75	0.5, 0.75, 1	0.5, 0.75, 1	{0.38, 0.63, 0.88}
	C7	0.75, 1, 1	0, 0.25, 0.5	0.25, 0.5, 0.75	0.75, 1, 1	{0.38, 0.63, 0.88}
	C8	0.25, 0.5, 0.75	0.5, 0.75, 1	0.5, 0.75, 1	0.75, 1, 1	{0.50, 0.75, 0.94}
	C9	0.5, 0.75, 1	0, 0.25, 0.5	0.25, 0.5, 0.75	0.25, 0.5, 0.75	{0.56, 0.81, 1.00}

Table 7. Weighted fuzzy normalized matrix

	Alternatives				
Criteria		A1	A2	A3	A4
	C1	0.19, 0.47, 0.88	0.09, 0.31, 0.66	0.09, 0.31, 0.66	0.28, 0.63, 0.88
	C2	0.09, 0.25, 0.50	0.00, 0.06, 0.25	0.03, 0.13, 0.38	0.06, 0.19, 0.50
	C3	0.25, 0.56, 0.94	0.00, 0.00, 0.23	0.00, 0.19, 0.47	0.25, 0.56, 0.94
	C4	0.22, 0.52, 0.88	0.11, 0.34, 0.66	0.11, 0.34, 0.66	0.22, 0.52, 0.88
	C5	0.19, 0.47, 0.88	0.00, 0.16, 0.44	0.19, 0.47, 0.88	0.28, 0.63, 0.88
	C6	0.19, 0.47, 0.88	0.09, 0.31, 0.66	0.19, 0.47, 0.88	0.19, 0.47, 0.88
	C7	0.28, 0.63, 0.88	0.00, 0.16, 0.44	0.09, 0.31, 0.66	0.28, 0.63, 0.88
	C8	0.13, 0.38, 0.70	0.25, 0.56, 0.94	0.25, 0.56, 0.94	0.38, 0.75, 0.94
	C9	0.28, 0.61, 1.00	0.00, 0.20, 0.50	0.14, 0.41, 0.75	0.14, 0.41, 0.75

Positive Ideal Solution (FPIS) of and Fuzzy Negative Ideal Solution (FNIS) of (0,0,0) are considered for evaluating the distance of each alternative from FPIS (d^+) and FNIS (d^-), respectively. Finally, the Closeness Coefficient (CC) of all the alternatives is computed and ranked in descending order. From the ranking, A4 evolved as the best layout with a CC_i of 0.524, followed by A1 (0.503), A3 (0.409) and A2 (0.310).

Table 8. Closeness coefficients and ranking

Alternative	d+	d-	CC	Rank
A1	5.061	5.127	0.503	2
A2	6.811	3.058	0.310	4
A3	5.934	4.112	0.409	3
A4	4.807	5.291	0.524	1

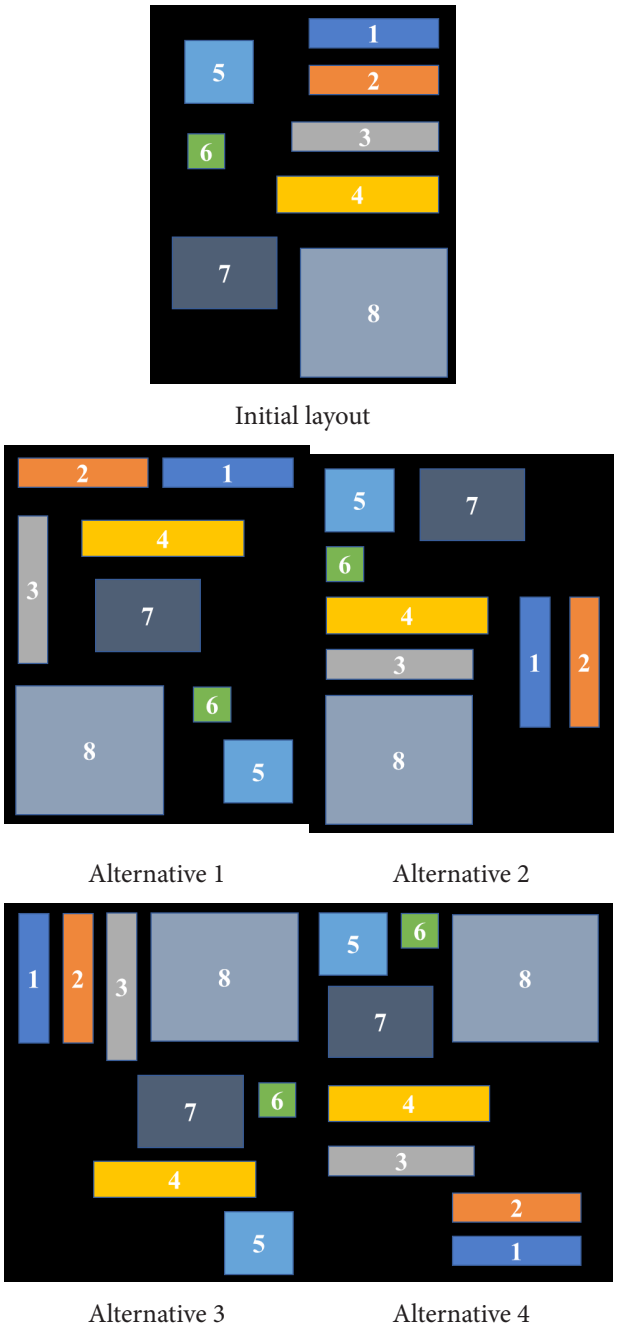


Figure 4. Schematic of existing layout and alternative layouts (*1: De-rolling, 2: Cutting, 3: Coating, 4: Recoating, 5: Oven, 6: Lift, 7: Packaging, 8: Inventory*)

The findings of the fuzzy-TOPSIS method have been authenticated by conducting sensitivity analysis, where two criteria's weightage are interchanged each time while preserving the others. From sensitivity analysis, A4 emerged as the best alternative in 35 out of 36 possible

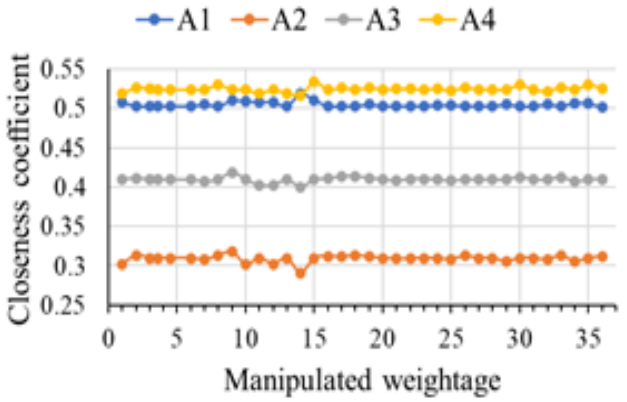


Figure 5. Closeness coefficient values in sensitivity analysis.

instances (97.22%), as shown in Figure 5. Similarly, A1, A3 and A2 also prevailed as second, third and fourth layout (in descending order of) in the 35 combinations. The outcome depicts that the initial result of A4>A1>A3>A2 is less sensitive to the variation of weightage of criteria. The sensitivity analysis's result signifies the proposed model's robustness and validates its initial outcome.

4.0 Conclusions

The present study focused on developing a fuzzy-TOPSIS model to determine the best plant layout from a pool of four alternatives. Initially, the TCR of all the departments was calculated from their inter-relationship, representing the desirability of placing one department beside the other. Then applying the CORELAP algorithm, the optimum sequence of departments was attained. Based on the optimum sequence, four alternative layouts were proposed. The essential criteria affecting the selection of a plant layout were identified in the form of ergonomics, workplace environment and lean service. Then, fuzzy logic was applied in allocating weightage to the criteria and forming the alternatives and criteria decision matrix. Thereafter, applying fuzzy-TOPSIS, layout A4 evolved as the best alternative with a CC of 0.524, followed by A1 (0.503), A3 (0.409) and A2 (0.310). Finally, from sensitivity analysis, where two criteria's weightage was interchanged each time while keeping others constant, A4 emerged as the best layout in 97.22% of the cases. Thus, the proposed model can be used as a tool for selecting alternative layouts, wherein decision-making is a critical task.

5.0 References

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