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Application of Analytical Hybrid-Ranking Technique for optimization of Production Facility

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ABSTRACT -The Analytical Hybrid Ranking Technique (AHRT) is an automated facility design tool that enhances cost-effectiveness and space utilisation in manufacturing industries. It is an integration of hybridised facility layout techniques such as the hybrid hierarchy technique and the ranking technique in combination with the meta-heuristic technique. It is a technique that is data-based and data-driven on real-time analysis. A study is carried out on a production company: Frigo Glass Plc, whose operations is standard. Several analyses are carried out, and the result is that the AHRT technique reduces their space allocation significantly. From the study, the intermediate products were measured at 24-hour intervals in a 120-hour process involving many batches. Following multiple iterations, a substantial number of inactive cells were removed, and the project's net worth was calculated for each group of cells using a comparison analysis. The project's net worth was reduced to 19,697 from 23,228. The mean variance was reduced by 29%, and the system achieved a peak performance of 71%. Additionally, the material transportation flow was increased by 84%. The flow process was graphically examined, and the results showed that AHRT was more stable than Frigo Glass Plc's existing flow rate.AHRT,s operation is based on departmental interactions and interdependencies, not addressing facility layout issues related to exchange timing costs and material flow expenses.

Keywords- analytical hybrid ranking technique, data-base, date-driven, integration of hybridized layout techniques and production facilities.

I. INTRODUCTION

The multi-disciplinary field of facility planning encompasses not just architects and engineers but also managers and urban planners. With the rise of computerized techniques and technologies, there is a need to modify or redesign existing facilities to meet current demands and dynamics. Layout research has provided predictions of future experiences, leading to concurrent engineering approaches to layout and production systems foroptimization(Pérez-Gosende, 2016). Manufacturing efficiency and productivity are greatly affected by layout design, which entails physically organising production aspects to align with an organization's strategic goals. Technology development, particularly information technology, has strongly influenced the application of known methods, particularly in analogue and digital planning. A proficient layout ensures production schedules are met efficiently, while minimizing health security risks. Unproductive layouts can lead to bottlenecks, congestion, and poorly used space, affecting workers' work environment and operation control.

II. REVIEW OF RELEVANT LITERATURE

Challenges with plant architecture have significant impact on production system efficiency. Since 1955, the United States has spent 8% of its budget on new facilities, with good facilities planning lowering material handling costs by 10% to 30%, making it critical for annual investment(Tompkins and Schaffer 1996). This course benefits from an integrated re-layout strategy due to its unified design and implementation phases. In dynamic manufacturing processes, quantitative objective factors such as proximity attractiveness may be more important, whereas material flow is often given greater weight.Materials movement is based on operational data, making it the ideal layout criterion. When solving unstructured situations, both subjective and quantitative aspects must be considered. Automated systems must take into account both design-oriented judgement calls and computer-oriented numerical judgements. The basic layout difficulty is to assign discrete tasks to single locations. Pas et al. (2017) provided solutions to factory layout challenges, such as goal functions, minimum space, handling, rearranging, and backtracking. This study assessed and merged essential models to create the Analytical Hybrid Ranking Technique.

The optimal procedural strategy for developing facility layouts was shown by Sharma and Sandeep (2017) using a few chosen parameters. The study considers some important features such as initial data required (IDR), use of charts, use of graph and diagrams (UGD), future expansion considered, constraints considered, procedure implementation and material handling equipment selection consideration (MHC). The modified digital logic (MDL) is used to assign weights to the selected features. Fuzzy logic-based multiple attribute decision (MADM) approach is also applied for a selected scenario and is proven to be efficient and effective. Their research focused on material cost and not space utilization.

Turanoğluand Gökay (2018) developed a new hybrid heuristic algorithm called simulated annealing that is based on bacterial foraging optimisation to address the dynamic facility layout problem. They emphasised that a key aspect of modern production is the ever-changing product demand, and that these problems attempt to strike a balance between handling and moving costs. They further noted that classical optimisation techniques may not always be enough to solve these complex combinatorial optimisation problems, and that finding a solution within a reasonable computation time is essential. As a result, the study recommended a new hybrid heuristic algorithm based on bacterial foraging optimisation. They usedsimulated annealing technique for their optimization. Their methods were heuristics nature.

Singh and Supriya (2019) used biogeography-based optimisation (BBO), non-dominated sorting BBO (NSBBO), and non-dominated sorting genetic algorithm (NSGA) II Metaheuristic Algorithms to solve a facility layout problem. The study analysed quantitative and qualitative objectives and how important they are for solving facility layout problems. The model used the weight approach and non-dominated sorting methods to formulate each cell as a quadratic assignment problem. They were also considered optimised using biogeography-based optimisation algorithms and non-dominated sorting biogeography-based optimisation algorithms. The computational results showed that their approach had a better result compared to previous multi-objective methods but its metaheuristic nature limited its precision in peculiar applications.

Also, Lira-Flores et al. (2019) analysed production optimisation using facility design tools, highlighting potential problems and uncertainties in the whole process. Their work focused on addressing issues by employing a conceptual modelling tool to understand unique simulations and facility design with high uncertainty, using a case study of three scenarios. The study found that using characterisation criteria production models can help reduce uncertainty in facility design.

Ahmadi-Javid and Amir (2020) categorised problems by kind, strategy, and design stage, as well as production facility features, when configuring material handling systems and generating layout options. The study used mathematical optimisation models to generate layout alternatives, including discrete quadratic programming for similar sized departments and continuous linear and non-linear mixed integer programming for different departments. Other methods for generating layout choices included specialist knowledge and specialised software tools. Their method improved facility layout but was also in nature heuristic.

Ayoub et al. (2022) studied challenges faced by industrial facilities, including coordination issues that cause delays in assembly departments. The industry's decentralised system and inefficient activity flow resulted in decreased productivity and higher material handling costs. The study used the CORELAP algorithm to address the company's current industrial challenges. The model they used imposed a non-overlapping department constraint, limiting network traffic.

Pablo et al. (2023) conducted research on dynamic facility layout planning, which involves determining the optimal arrangement of production system elements for each time period within the planning horizon. The layout optimisation paradigm follows a top-down approach, starting with the block layout (BL) and progressing to the detailed layout (DL) for each work cell. The block layout technique created area limits during the detailed phase, limiting its application. The multi-objective mixed integer non-linear programming (MOMINLP) model was used to address the layout problem by focussing on three objectives: minimising total material handling cost (TMHC) and maximising total closeness rating.The layout optimisation paradigm follows a top-down approach, starting with the block layout (BL) and progressing to the detailed layout (DL) for each work cell. The block layout technique created area limits during the detailed phase, limiting its application. Pablo et al. (2023) conducted research on dynamic facility layout planning, which involves determining the optimal arrangement of production system elements for each time period within the planning horizon. The layout optimisation paradigm follows a top-down approach, starting with the block layout (BL) and progressing to the detailed layout (DL) for each work cell.

III. MATERIALS AND METHODS

3.1 Materials

The study uses AHRT, a data-driven decision-making technique, to examine material movement elements in manufacturing facility layouts. It examines the facility setup using analytical and hybrid ranking techniques integrated into computer applications as viable tools for facility layout optimization. In lieu of any tangible material, data from test cases and computer tools will be used for this experimentation.

These are the methodical approaches that the study used in itshybridisationprocess.

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i. Identifying departmental relationships: Identifying departments with related activities and their interdependencies to ensure a smooth flow.

ii. Analyse demand structure and product mobility, including batch influx in unit cells and flow rate to other cells.

iii. Allocate space based on activity and volume.

iv. Identify departmental interactions: Material flow rate within departments with similar activities or progressive flow rates.

v. Use the unit connect exchange methodology to calculate the project's net worth.

3.2. Methods

Kumar and Surya, 2017 study suggested that future cost of material movement within a facility can vary greatly; thus, a uniform distribution is expected to offer a conclusive result. Their study investigated inter-departmental flows under flexible conditions, using slack variables to get definitive conclusions, as seen in Equation 1.

$$\mathrm{Non\_MHCost}_i = \sum_{K=1}^{n_i} \mathrm{MHCost}_{ij} \qquad (1)$$

where, $\mathrm{Non\_MHCost}_i$ is non-adjacent material handling cost per unit distance for departmentI, MHCost_{ij} is material handling cost per unit distance between departmentsI and j which are not adjacent, $n_i$is number of departments that are not adjacent with department I.

Given the departmental split, Equation (1) will be fused with coordinates j_i and i_k to produce Equation (2).

$$\mathrm{Non\_MHCost}_i = \sum_{K=1}^{n_i} \mathrm{MHCost}_{j_i i_k}, \qquad (2)$$

where, $\mathrm{MHCost}_{j_i i_k}$,as material handling cost per unit distance between departments I and k which are not adjacent.

Furthermore, Equation (3) expresses the calculation of the overall materials movement cost matrix using combinatorial movement within cells as well as movement (merged and split cells) between cells, inserting slack variables when needed.

$$= \sum_{K=1}^{n_i} \mathrm{MHCost}_{M_1(PF_K + PV_K + D) + xy + n_1 + 1} \qquad (3)$$

when,M_1ismovement cost matrix.

Assertion 1 discusses using the unit connect exchange algorithm to create an initial layout by estimating MHCost in relation to departments, noting that key variables like the number of departments, their space, and flow values between pairs are considered unknown, as referenced in Equation (4) from Kulture-Konak (2017).

$$\mathrm{Mf} = \min \sum_{i=1}^{n} f_{ij} d_{ij} \qquad (4)$$

where,Mfis movement function, n is the number of departments, $f_{ij}$is the total flow between departments I and j, d_{ij} is the distance between departments Iand j, Hence, to determine the expression for material flow between departments considering adjacency, we input material handling costin Equation (4) to obtain Equation (5).

$$\mathrm{Mfd} = \min \sum_{i=1}^{n} f_{ij} d_{ij} \sum_{K=1}^{n_i} \mathrm{MHCost}_{\mathbf{M_1}} \qquad (5)$$

where,Mfdis material between departments.

To calculate production loss costs during period t due to work-center Pp, the analysis uses Equation (5) to select a product unit exchange path based on workstation adjacency. Each workstation is considered for improvement by linking total material flow and connection fixtures with inter-department distances. Equation (6) quantifies production loss over time, factoring in these adjacencies.

$$\mathrm{Pp} = \min \sum_{i=1}^{n} (f_{ij} C_{ij} d_{ij}) \qquad (6)$$

where, Pp is production loss as a result of unavailable work-centers, I and j (f_{ij}), distance between departments I and j (d_{ij}), connection per fixtures c_{ij}.

Having obtained cost of production loss

during period t caused by unavailable work-centers, the material movement with lag it time as a result of bottleneck is considered. Consequently, calculating the cost of productionloss per timet due to unavailability of work centres at intervals with Equation (8).

$$Pp_{3t} = Tt - Ts\sum_{i=1}^{np}(f_{ij}\, C_{ij}\, d_{ij}) \text{ x } PLA_{ij} \quad (7)$$

where, Pp_{3t} is unavailable work-centers at intervals, PLA_{ij} is lost volume of product at intervals with period t.

Assertion 2: The cost function per unit volume of the manufacturing system is determined by considering frequency, along with the process movement matrix, material handling cost per unit distance, and production loss. These factors are analyzed to evaluate the cost function based on available and unavailable space over a period (Equation 9).

Therefore,

$$Pp3ti = \text{Max} + \frac{\text{Min}}{f}\sum_{1}[W(p,t)t + RT(p)]x(Fcosti + ProfitT)(8)$$

The AHRT automation system necessitates integration for optimal performance of its components and analytics. This integration enhances the system's efficiency, effectiveness, conformance, and dependability. It features tools for joint design and re-layout simulation, including the calculation of cell-to-cell distance matrices, consideration of activity sequences, prioritization, area plotting, and evaluation of material movement costs and combinatorial movements.

Table 1 shows the intermediate products taking 12 hours intervals and considering material flow and interaction within the 15 departments of Frigo Glass Plc. From the data obtained, the departmental interaction is determined and also the interdependencies of the flow process.

Table 1: Intermediate Product Chart.

	Intervals (Set hours = 120hrs)														
Dept	12hrs	24hrs	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hrs	120 hr	**Mean Response**	**Nom flow**	**Batch mean (Hrs)**	**Int. Dem. factor**	**Ext. Dem factor**	**Intermediate Product (AHRT)**
Quary	23	26	25	18	24	28	26	20	22	18	23	15	6	29	13	**22**
Bay	18	25	24	20	23	17	16	24	22	17	20.6	14	5	26	11	**20**
Silo and Hopper	29	27	22	32	17	21	29	19	18	23	23.7	16	6	30	14	**23**
QA andQC	32	19	26	23	22	27	31	18	30	24	25.2	17	6	32	16	**24**
R. Mat	25	18	30	16	15	22	19	29	29	18	22.1	15	6	28	12	**21**
Batching	23	26	27	20	21	23	22	28	32	16	23.8	16	6	30	14	**23**
Furnance	26	17	30	26	21	17	21	16	17	20	21.1	14	5	26	11	**20**
Forehearths	29	26	29	17	28	16	21	17	18	28	22.9	15	6	29	13	**22**
Forming	30	27	24	29	31	29	20	30	32	28	28	19	7	35	20	**27**

C and E Inspect E	25	27	30	25	18	25	16	20	19	15	22	15	6	28	12	**21**
C and E Surf T.	19	30	31	23	20	18	19	18	26	29	23.3	16	6	29	14	**22**
A. lehr	21	28	29	25	29	30	25	20	26	20	25.3	17	6	32	16	**24**
T.E Treatment	30	26	19	28	16	28	16	31	18	18	23	15	6	29	13	**22**
Paring	24	16	15	26	25	17	16	32	30	31	23.2	15	6	29	14	**22**
Warehouse	16	25	16	21	15	31	23	19	32	25	22.3	15	6	28	13	**21**
Sum(M)	**370**	**363**	**377**	**349**	**325**	**349**	**320**	**341**	**371**	**330**	**350**	**233**	**89**	**437**	**209**	**334**
M. Avg	**25**	**24**	**25**	**23**	**21**	**23**	**21**	**22**	**24**	**22**	**23**	**15**	**5**	**29**	**13**	**22**

From evaluation, the intermediate product interaction between cells with the introduction of slack variables determins the mean response, nominal flows, the batch mean, the intermediate demand factor, external demand factor and the intermediated product.

The analyses also took cognizance of absence of individual workstations which might be leading to production loss and to the introduction of dummies as a result of redundancy reducing the load per interdepartmental flow as well as creating alternate routes to mitigate lag in time and excess clusters using flow evaluation from Assertion 2.

Thus, from Table 1 the various parameters obtained are further iterated executing a combinatorial geometry to obtain an improved structure and also bounding functions to eliminate large numbers of ineffective material movement. The product of the combinatorial analysis is shown in Table 2.

Table 2: Project Net Worth (PNW) with Slack Variables.

Inter-departmental Relationship (Departments are connoted with figures)

Inter-departmental Relationship (Departments are

Dept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	PNW
Quary	0	150	137	153	117	32	129	122	129	114	91	118	63	77	165	1597
Bay	75	0	36	83	21	158	186	52	15	80	177	44	127	78	165	1296
Silo and Hopper	22	86	0	37	49	119	19	117	185	98	28	66	183	150	26	1184
QA andQC	163	88	66	0	107	6	129	82	92	28	177	141	182	141	9	1411
R. Mat	169	121	29	93	0	178	29	189	134	30	69	13	155	148	9	1367
Batching	21	117	125	81	116	0	137	23	96	119	164	11	61	90	86	1247
Furnace	24	88	24	52	169	29	0	107	10	31	74	128	93	158	146	1132

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Foreh earths	119	135	108	146	125	159	158	0	167	116	103	3	102	128	30	1598
Forming	18	28	107	144	76	30	107	63	0	92	123	110	103	45	106	1153
C and E Inspect E	37	185	126	87	63	26	133	33	62	0	182	89	104	171	14	1310
C and E Surf T.	74	93	176	92	33	45	15	31	135	153	0	67	174	21	84	1190
A. lehr	141	5	63	31	50	69	100	117	81	140	180	0	55	162	34	1227
T.E Treatment	83	32	67	134	161	141	41	29	8	57	126	86	0	122	23	1110
Paring	27	141	24	180	14	114	133	156	147	-12	36	10	137	0	121	1228
Warehouse	105	112	151	81	186	11	144	173	56	147	4	188	165	124	0	1648
PNW	1076	1382	1239	1393	1288	1117	1459	1295	1315	1192	1534	1073	1702	1614	1018	19697

The second approach is to execute a comparative analysis exploring Assertion 2. Thus, the project net worth is obtained in 2-D with respect to the departmental flow and interaction as shown in Table 2. This also determines cost functions and material handling costs with respect to the mean averages at critical intervals. The determinants of the project net worth are evaluated against the initial response as shown in Table 3.

Table 3: Material Movement Analyses.

Dept Rel		Project Net Worth PNW$_1$	PNW$_2$	Mean Variance MV$_1$	MV$_2$
1	Quarry	1,597	1,076	1,956	1,748
2	Bay	1,296	1,382	2,160	2,080
3	Silo and Hopper	1,184	1,239	1,352	1,554
4	QA and QC	1,411	1,393	1,867	1,389
5	R. Mat	1,367	1,288	1,923	2,279
6	Batching	1,247	1,117	2,157	2,100
7	Furnace	1,132	1,459	2,102	2,032
8	Fore hearths	1,598	1,295	1,883	1,428
9	Forming	1,153	1,315	1,796	1,858
10	C and E Inspect E	1,310	1,192	1,745	1,692
11	C and E Surf T.	1,190	1,534	1,560	1,800
12	A. lehr	1,227	1,073	1,727	1,547
13	T.E Treatment	1,110	1,702	1,499	2,454
14	Paring	1,228	1,614	1,954	1,525
15	Warehouse	1,648	1,018	1,805	1,964

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From the material handling analyses, the overall variance in project net-worth and mean variance is determined by a comparative analysis as shown in Table 4.

Dept Rel	**V_1**	**V_2**
Quary	359	672
Bay	864	698
Silo and Hopper	168	315
QA and QC	456	-4
R. Mat	556	991
Batching	910	983
Furnace	970	573
Forehearths	285	133
Forming	643	543
C and E Inspect E	435	500
C and E Surf T.	370	266
A. lehr	500	474
T.E Treatment	389	752
Paring	726	-89
Warehouse	157	946

Table 4: Comparative Analyses I.

Table 5: Comparative Analyses II.

	MV_1	**PNW_1**	**V_1**	**MV_2**	**PNW_2**	**V_2**
Quary	1,956	1,597	359	1,748	1,076	672
Bay	2,160	1,296	864	2,080	1,382	698
Silo and Hopper	1,352	1,184	168	1,554	1,239	315
QA andQC	1,867	1,411	456	1,389	1,393	-4
R. Mat	1,923	1,367	556	2,279	1,288	991
Batching	2,157	1,247	910	2,100	1,117	983
Furnance	2,102	1,132	970	2,032	1,459	573
Forehearths	1,883	1,598	285	1,428	1,295	133
Forming	1,796	1,153	643	1,858	1,315	543
C and E Inspect E	1,745	1,310	435	1,692	1,192	500
C and E Surf T.	1,560	1,190	370	1,800	1,534	266
A. lehr	1,727	1,227	500	1,547	1,073	474
T.E Treatment	1,499	1,110	389	2,454	1,702	752
Paring	1,954	1,228	726	1,525	1,614	-89
Warehouse	1,805	1,648	157	1,964	1,018	946

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Table 4, the data in V_1 are all positive flow, which can be described as progressive in this case, while the values of two cells in V_2 (QA and QC with Pairing) are negative, which indicates declines, pointing out critical cells where bypass can be introduced as a result of redundancies. Thus, the outcomes of the comparative flow analysis are summarised in Table 4.5. It shows the variance based on initial data and the data obtained from AHRT analyse

The third approach is performed by executing a reverse combinatorial flow analysis. The study also developed a material movement analysis applying the reverse flow (back-to-front) technique to determine the consistencies in departmental interaction and their interrelationship as shown in Figure 1.

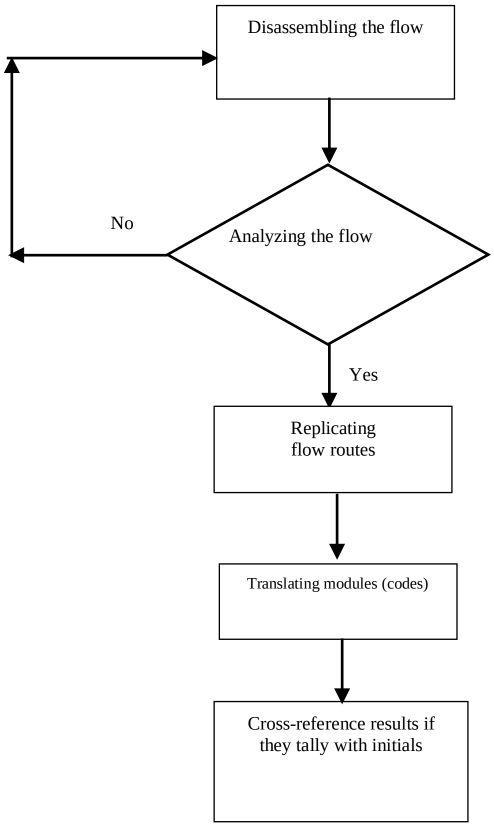

Figure 1: Reverse Combinatorial Flow Algorithm.

When the consistency of data is determined, the automation process then generates an initial layout using the unit connect exchange algorithm with graphical flow as described in Table 5 and Figure 1. Thus, the results obtained are progressive data from Table 6 of AHRT in comparison with Frigo Glass Nigeria in a combinatorial flow analysis adding slack variables and in a reversed operational flow sequence as shown in Table 6 and Figure 2.

Table 6: Reverse Combinatorial Flow.

Departments	AHRT	Frigo Glass Nigeria
A. lehr	1,255	1,956
Batching	1,613	2,160
Bay	1,446	1,352
C and E Inspect E	1,626	1,867

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C and E Surf T.	1,503	1,923
Fore hearths	1,303	2,157
Forming	1,702	2,102
Furnace	1,511	1,883
Paring	1,535	1,796
QA and QC	1,391	1,745
Quarry	1,790	1,560
R. Mat	1,252	1,727
Silo and Hopper	1,986	1,499
T.E Treatment	1,883	1,954
Warehouse	1,432	1,805

For a fixed distribution length, the sequence takes a tour with various options to strategically re-select an optimal flow sequence. From the re-selection process, the reverse combinatorial flow is determined to obtain a realistic flow. To determine the efficiency or disparity in the system, the algorithmic.

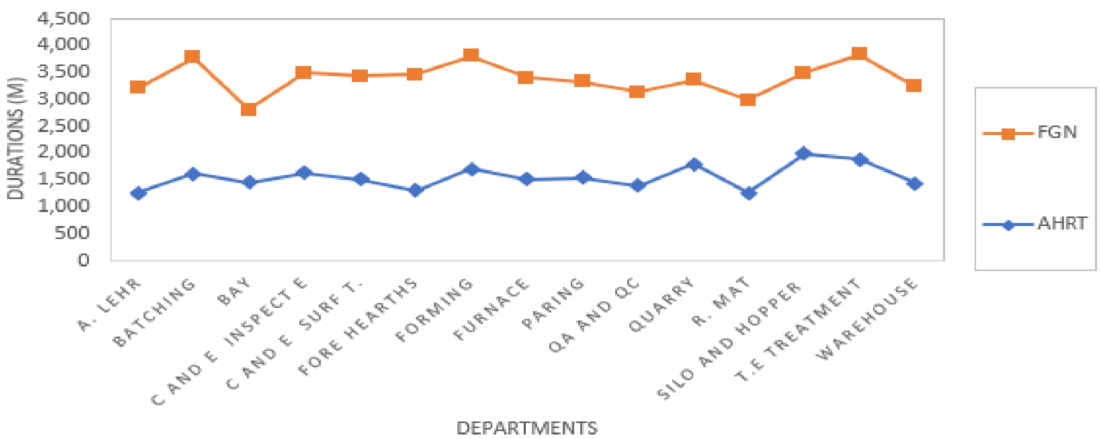

Figure 2: Reverse Combinatorial Flow.

From the results obtained in Table 6 and the graphical expression in Figure 2, the reverse combinatorial flow and the comparative flow analyses prove that AHRT (the blue line) is more stable than Frigo Glass Nigeria (the orange line); thus, the analyses are practically efficient and effective with conformity and reliability.

The study focuses on performance metrics like interdependency and survival ratio, while the probability cost function is determined iteratively using a departmental relationship chart to minimize transportation costs.

IV. CONCLUSIONS

The proposed analytical hybrid ranking (AHRT) was applied using three test cases, one of which is mentioned in this journal. The data from which the experimentation was executed is from Frigo Glass Plc. Based on the study, the intermediate products were determined using 24-hour intervals in a 120-hour operation comprising several batches. After several iterations, large numbers of ineffective cells were eliminated, and then the project's net worth was determined for each set of cells with a comparative analysis. The project net worth was decreased to 19,697 from 23,228.

Thus, the mean variance was also reduced by 29% with a peak performance of 71% for the system. Also, the material movement flow was enhanced by 84%. The flow process was graphically analysed, and based on the analysis, AHRT was more stable than the existing Frigo Glass Plc flow rate.

V. RECOMMENDATIONS

The study recommends conducting a more robust dynamic investigation and analysis, taking into account the cost versus time of effective space utilisation during the simulation process.

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