Material Handling Factor Impact to Attaining Optimal Approach in Facility Layout Design in the Plywood Industry

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Abstract – The research work designed to optimize the material handling operations of Piedmont Plywood Industry Port Harcourt of Rivers State in Nigeria, to improve upon the productive efficiency of their current facility layout. In the current state of the facility layout, material handling labour ratio is 0.25 while the improved modification confirmed 0.1591. This relates to more efficient utilization of labour, and the manpower requirement was trimmed down from 11 to 7 active personnel. Labour cost reduction of 20.62% was achieved. The modification of the material handling operation increases the productivity index from increased it from 0.000275m3/Naira to is 0.000281m3/Naira (that is 2.18% improvement). Thus the implementation of the findings of material handling factor will engender more significant financial recovery in certain cost aspects of the company's economic policy.

Keywords: Productivity index, material handling operations, facility layout optimization, financial recovery.

INTRODUCTION

Material handling operations are subject storage utilization, effectiveness in human resources use, and material handling equipment is potent factors in influencing the efficiency of production endeavours in production factories. In the sixth international conference in industrial engineering and operation management (IEOM), 2016 at KuallaLamput Malaysia, material handling operations in a facility layout was discussed to have a diverse effect on production industry's competitiveness concerning cost, processes, capacity and flexibility. However, it has been observed that spiralling inflation, deforestation and climate change and depletion of forest resources have led to increased production cost in the wood industry with a resultant drastic reduction in profit margin (Fuller, 2009). Table 1 shows the wood consumption trend by different countries of the world from 2013 to 2017.

Table 1: Wood Products Consumption (*Source: fuller (2009)*)

Wood Resources Consumption (Domestic +Net export) in a million cubic meters					
	2013	2014	2015	2016	2017
Lumber					
U.S	178.5	158.3	136.8	121.9	168.3
Africa	104.4	109.4	97.5	89	98
China	30.3	34.2	34	30.8	35.5
TOTAL	313.2	301.9	268.3		
Plywood					
U.S	16	14.1	12.1	10.4	12.7
Africa	8	8.4	8	7.2	7.9
China	30.6	33	3.4	27.5	30.2
TOTAL	54.6	55.5	23.5	45.1	50.8
Particle Board					
U.S	10.1	9	7.8	6.7	8.7
Africa	34.8	36.4	33.8	30.5	34

China	8.1	8.9	8.3	7.4	9
TOTAL	53	54.3	49.9	44.6	51.7
MDF/HDF					
U.S	6.6	6.2	5.4	5.4	6.6
Africa	11.7	21.1	12.3	11.4	12.5
China	25.2	27.8	25.5	22.7	27.8
TOTAL	43.5	55.1	43.2	39.5	46.9

This research work is on Plywood as a product of the wood industry. The United State is the second-largest consumer of plywood products next to china. The consumption trend nose-dived between 2014 and 2015. It shows tremendous improvement between 2015 and 2016 and marginally between the year 2016 and 2017. These two countries use the product for building construction, repairs and modelling. The consumption rate by the two countries represents 63% of plywood product usage (Spelter, 2006). The focus of this research is redesigning the facility layout of Piedmont Plywood as a case study. The alternative redesigned layouts are to portray the beauty of cost and processes productivity optimization of a proper facility layout.

LITERATURE REVIEW

Apple (1990) broadly categorized facility layout into plant layout and material handling. Sarin (1992), in his eclectic approach, defined the various aspects of factory layout to include flexibility, safety and ease to supervise factory operations, among others. Drira (2007) injected that personnel, machine and everything that participates in manufacturing is part parcel of facility layout. Tompkin (2003) highlighted that the fusion between plant layout and material handling is imperative in the optimal design of facility layout, and it is a huge part of enhanced productivity. To create a definitive understanding of the Tompkin concept of productivity, Heinz and Render (2018) define productivity as the ratio of output (products) to input (resources, capital, etc.). The depletion of these resources reduces productivity. It has been emphasized by Tompkin (2003) that a better facility layout will lead to 10% to 30% increase in operating cost reduction. Tompkin (2003) agreed with Frazelle (1986)'s statement that cost optimization could be achieved by reducing material handling activities. On a common platform of thought, they both agreed that material handling contributes 20% to 30% of production cost in the factory. Hence factory layout design is integral in the decision-making process of the industries.

To design and redesign existing factory layout, according to Apple (1977) impact must be on two factors, mainly plant factor and material handling factor. The plant layout factor objectively minimizes flow paths and to optimize on direct flow paths. Tompkin defined direct flow path as flow from origin to destination excluding backtracking. According to Mayer and Steves (2005), backtracking is any backward movement in the flow. Any flow path should be designed to get of backtracking and cross trafficking to a more significant measure. The reason behind this novel idea is to drastically reduce material handling time between work stations to optimize on distance and cost of material handling. Flow path optimization subject to backtracking and cross trafficking issues has qualitative and quantitative implications.

Material handling is the moving, controlling and protecting materials in the work stations (Tompkin, 2003). Apple (1977) categorically stated that material handling constitutes 50% to 70% of the activities in a factory. Tompkin (2003) added that it has about 15% to 70% cost-effective in the expenditure in the manufacturing industry.Summarily, material handling labour factor, according to Sule (1982), is defined as:

$$Material\ labor\ ratio = \frac{Personnel\ Assigned\ to\ Handling\ Activities}{Total\ Operating\ Personnel} \tag{1}$$

Sule (1982) also defined storage space utilization ratio as :

$$Storagespaceutilizationratio = \frac{StorageSpaceOccupied}{TotalAvailableStorageSpace} \tag{2}$$

Facility layout evacuation measures the impact of factory layout on cost and productivity.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Productioncost}}{\text{Laborcost+capitalcost}} \quad (3)$$

The monthly record of output and input resources are measured from cost records.
Referring to the productivity formula labour resources include employees salaries and remuneration while capital resources are raw materials, cost of machines, equipment, etc. Productivity report of the current or existing layout is compared alongside the proposed alternatives to derive the facility layout factor on productivity.

RESEARCH SIGNIFICANCE

The significance of this research is to project the impact of material handling operations in facility layout redesign to attain efficiency in labour utilization, reduction in personnel handling cost and equipment cost. This modification is to enhance optimal productivity advantages in a facility layout.

MATERIAL AND METHODS

A Preamble

In industrial engineering, Yin (2009) defined a case study as the acquiring depth of understanding with the aid of real-life situations. This research utilizes Piedmont Plywood Industry to investigate the cost and process productivity of a proper facility layout with due regard to the impact played by material handling capability.

B Data Required

The data required to analyze the cost and production implications of the proposed redesigned layout are made up of the components in Table 2 with due preference to material handling derivatives.

Table 2: Components for the Plant Layout

Facility Layout	Data
Plant Layout	Form to chat Activity relationship Distance between process activities Transportation cost a unit load Flow patterns
Material Handling	Unit load Utilization Personnel delegated to material handling activities Total plant operating personnel Space utilization data equipment used to move a unit load

According to Eisenhardt (1986), a case study used as a research tool comprises a lot of data integration method including questionnaires, interviews, archive documents etc. He also suggested that a proper case study management discuss available qualitative and quantitative research data. The interviews with the company's top management technical staff as a source of qualitative research data is shown in Table 3.

Table 3: Interviews with Management Technical Staff

Name	Company Position	Date	Interview duration
Engr OfonUbong	Operational manager	06-08-2018	1hr 20mins
Mr Gift Simon	Supervisor 1	06-08-2018	55mins
MrAnsalem Ola	Supervisor 2	08-08-2018	50 mins

C Plywood Manufacturing Process

The process of manufacturing plywood is made of the processes in Figure 1. The process follows a simple route where the only disparity occurs in the work-in-progress 2 (WIP2) and the dimensional cutting process.

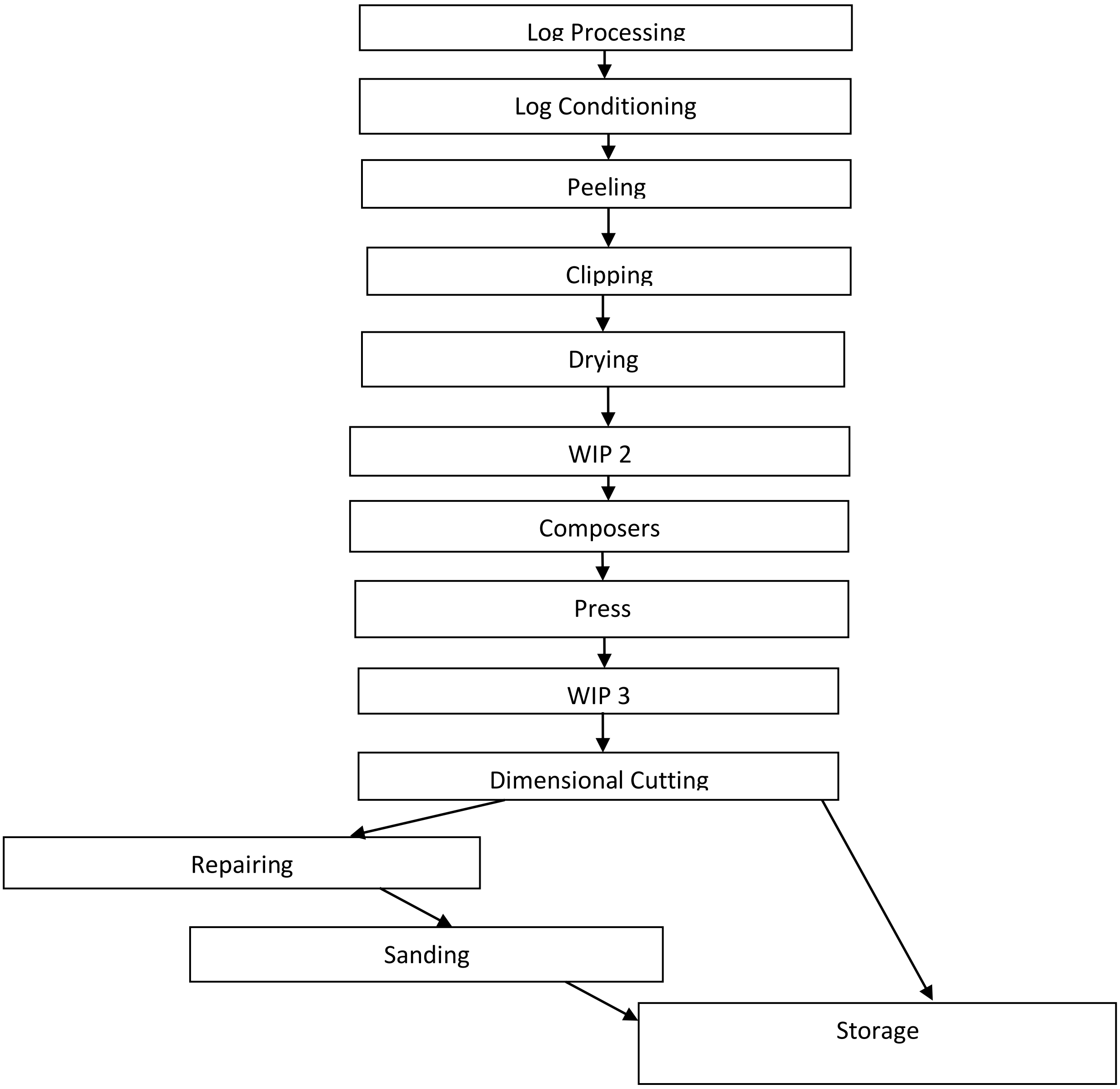

Figure 1: Process Algorithm

Log Processing: After Acquiring Forest Logs, the barks are removed by a machine with a special knife and are cut into required length and prepared for conditioning process. Then they are transported to the next process.

Log Conditioning: After debarking the logs, the logs are immersed in a huge hot water body at about 80°C to obtain softness and plasticity. The immersion lasts for about two weeks. Then the logs are loaded for peeling.

Peeling: After conditioning, the logs are peeled by the peeling machine at 40°C temperature. The peeled bark from the peeling is utilized as fuel to power the factory boiler. After peeling, logs are sent for the clipping by a conveyor.

Clipping: This process involves the cutting of the logs to uniform layers (veneers), then treated according to specifications to remove defects and stacked before being transported to the dryer. The treated veneers are called randoms.

Drying: In this process, the veneer goes through the dryer to lose humidity after which veneers are stack in the storage area (work in progress area 2) to be stored for 48 hours to stabilize its temperature. Then moved to the next process in a trolley.

Composer: At this stage, knives are used to cut the randoms to eliminate defects. Then the composers are glued to obtain short Veneers.

Glueing and Assembly: From the composer, short veneers received are glued and are assembled until the required thickness is achieved according to specification. They are then moved for pressing.

Press: The glued veneers are moved into a cold pre-press where they are compressed together. Afterwards, they are moved for the hot press. In this stage, the pressure is applied to the veneer to finish the assembled glueing and then moved to the work in progress 3 for 12 hours cooling.

Dimensional cutting: After cooling, the plywood in this stage are cut according to dimension, then veneers are moved between either three possible routes. They are sanding, preparing or straight for storage. The state of plywood produced will determine the route.

Repairing: In this stage, the defected plywood is repaired by removing the top defected part of the plywood and repaired with polyurethane. Repaired plywood are moved for sanding.

Sanding: The finished plywood is sanded for finishing and then moved for storage.

D Plant Layout Factor Analysis

The current state of the plant was designed previously in the installation of the industry. Figure 2 is the schematics of the current layout.

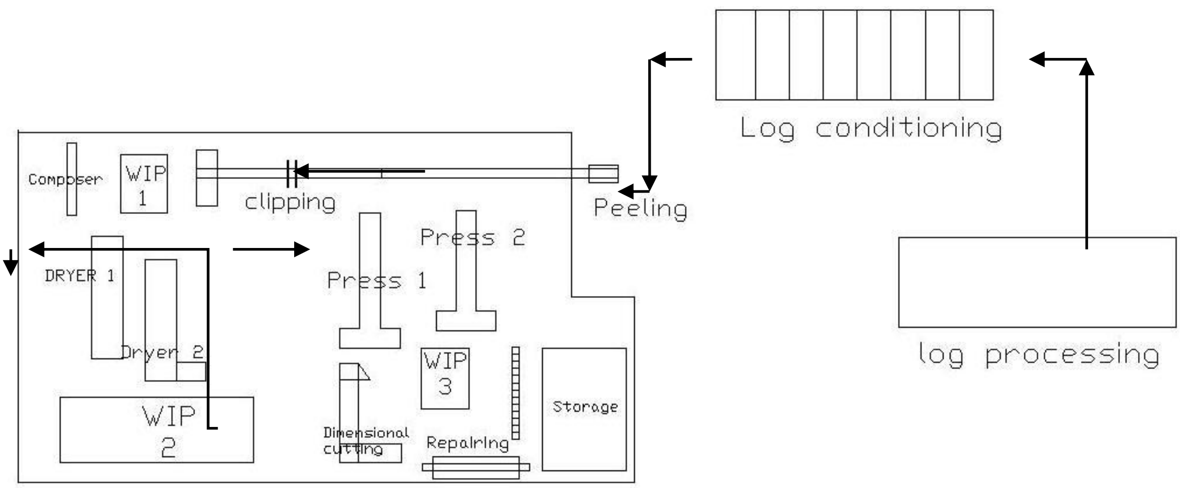

Figure 2: Current Layout Schematics

This current layout is an s-shape pattern plant layout. This design is good mainly because it effectively utilized the space. Despite the merit of the s-shape pattern, there are backtracking concerns that increase the process of transportation and the increases likelihood of cross trafficking. Figure 3 shows the s-shape pattern.

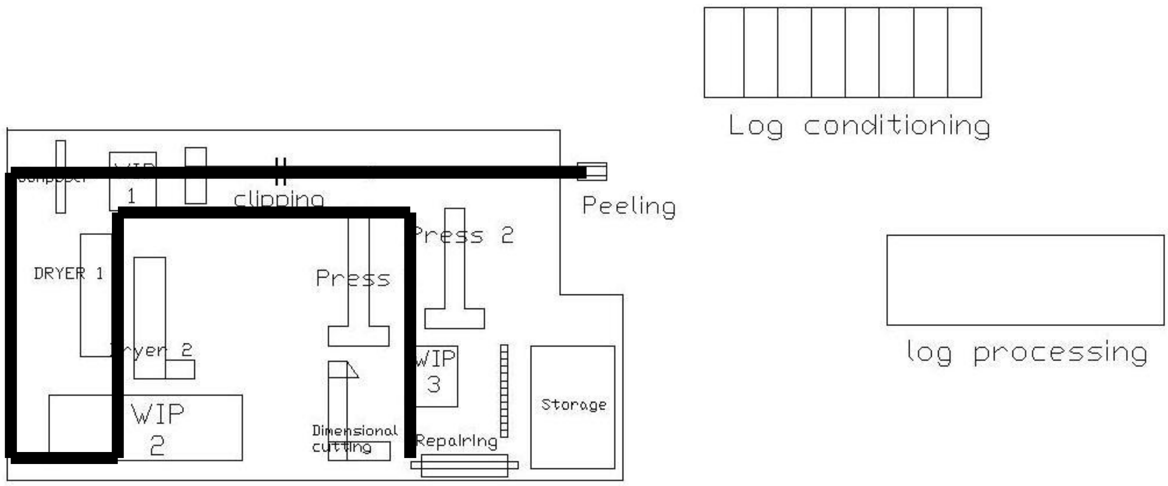

Figure 3: The s-shape pattern.

After careful study, the two reasons why the s-shape pattern fits the plywood industries are

1. The process has one route until the dimensional cutting. The s-shape is good because the available space can be utilised appropriately without the concerns of cross-traffic amongst processes.
2. Reduced process time: if the process were not s-shaped, the entire process would consume more time, and space will not be duly utilized.

E Backtracking

The problem of backtracking adds to the distance of the material travel and increasing transportation. In this regard, the current existing layout has two problems

1. Between the work-in-progress two and the composer, after drying, the veneers must travel back towards the composer located near dryer1. This concept increases the total transportation travelled. Figure 4 illustrates the back track.

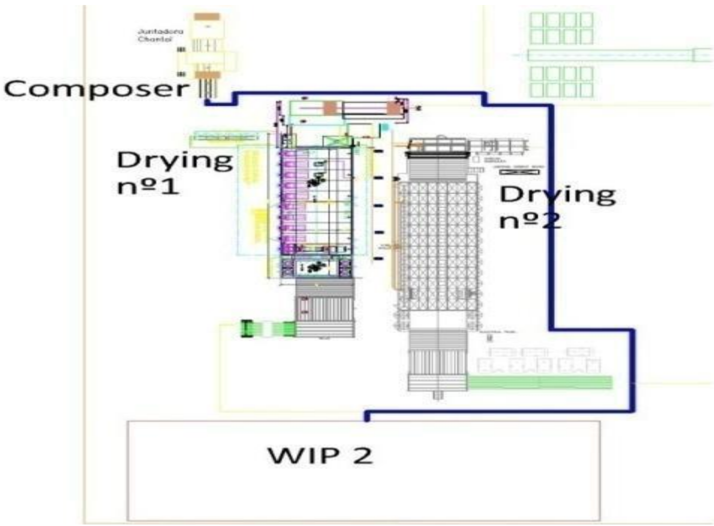

Figure 4: Back Tracking 1

2, after the second pressing machine 2, the veneer travels backwards towards the Dimensional cutting is shown in figure 5.

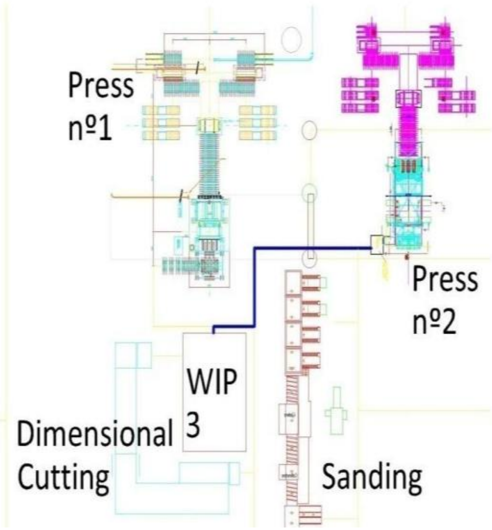

Figure 5: Back Tracking 2

F Cost evaluation

The cost evaluation of distances is the major way of evaluating the process flow. The distance is measured from the beginning of the process, and to the end of the process as displayed in Table 4 below. The glue and assembly distance are not added because they are categorized to the pressing process and have negligible distance between them.

Table 4: Process distance

Processes	Path Number	Distance (meters)
Log Processing → Log conditioning	1	24.15
Log conditioning → Peeling	2	26.89
Clipping(upper output) → drying		35.33
Clipping(upper output) → drying	3	44.80
Clipping(upper output) → drying		18.87
Clipping(upper output) → drying	4	14.25
Drying → WIP 2		34.81
Drying → WIP 2		36.14
WIP 2 → composer	5	18.67
Composer → WIP 1	6	14.26
WIP 1 → Press 1	7	34.81
WIP 1 → Press 2	8	139.46
WIP 2 → Press 1	9	143.62
WIP 2 → Press 2	10	172.63
Press1 → WIP3	11	18.04
Press 2 → WIP3		33.61

WIP 3 → Dimensional Cutting	12	4.15
Dimensional → Cutting repairing	13	20.59
Dimensional → Cutting sanding		44.67
Dimensional Cutting → storage(finished product)		78.63
Repair → Sanding	14	59.02
Sanding → Storage (finished product)		40.64

Although the added distance due to backtracking cannot be completely removed, the distance due to backtracking will be considerably reduced in the proposed modified plant layout.
Table 5 displays the different length of the path. The clipping and press are integrated into one output because of their average distance for simplicity.

Table 5: Distance in the paths

Path	Distance (meters)
1-2-3-4-5-6-9-10-11-12-13-14	424.38
1-2-3-4-5-6-9-10-11-13-14	389.44
1-2-3-4-5-6-9-10-11-14	482.76
1-2-3-4-5-6-7-8-9-10-11-12-13-14	541.16
1-2-3-4-5-6-7-8-9-10-11-13-14	506.22
1-2-3-4-5-6-7-8-9-10-11-14	499.54

The processes with considerably close average distance are merged into one output to simplify the comparison of the corresponding path between the current and the proposed layout redesign. The distance in the path is represented in Table 5.

In Table 5, the backtracking distance shows the longest distances. They are;

1. The distance between the work in progress2 and the composer
2. The press2 to work in progress3

In evaluating the existing layout, it is good to define the process flow and transportation cost for the unit load explicitly. The best method is the form to chat method showing the factory's production summary.

	From/to (unit load=3 m3)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Log Processing	x	8435,67												
2	Log Conditioning		x	4499,02											
3	Peeling			x	2399,5										
4	Clipping				x	2207,52									
5	Drying					x	1942,62								
6	WIP 2						x	300,33		1642,29					
7	Composer							x	285,31						
8	WIP 1								x	285,31					
9	Press									x	1889,05				
10	WIP 3										x	1889,05			
11	Dimensional cutting											x	944,52	566,71	377,81
12	Repairing												x	944,52	
13	Sanding													x	566,71
14	Storage														x

Figure 6: Form to chat activity relationship

Operations are achieved by two materials handling equipment, moving materials between processes. These equipment are the front loader, and the crane fork and they have the same capacity of approximately $3m^3$. Thus the unit load is defined as $3m^3$. The front loader performs log processing, Log conditioning and peeling while the crane fork performs other movements throughout the process.

The operation cost of transporting a unit load by crane fork established by the company is N1500.00, and the front loader is N5000.00. This cost includes operators' salaries, fuel and maintenance.

These costs values are estimated values the company spends to rent these machineries monthly.

Table 6 shows the incurred cost in the many route materials can flow. Materials flow is divided into two main parts. They are

1. From the log processing to work in the process area
2. From the press to the dimensional cutting.

Table 6: Transportation cost in the path

Path	Cost (N/month)
1) 1-2-3-4-5-6	3,596,160
a) 6-9	483,000
b) 6-7-8	1,490,009
2) 9-10-11	198,169
a) 11-12-13-14	182,698
b) 11-13-14	89,924
c) 11-14	55,255
Total	6,099,215

The table above displays that the processes with the highest cost are the ones performed by the crane fork because the front loader has considerably high expenses compared to the crane fork. Also, the processes of the early stages that involve forest resources are moved much distance than the later processes considerably. In path 2b, the incurred cost for process 13 and 14 are not included owing that it has already been included in path 2a. Thus the monthly total incurred cost is N 6,099,215.

G Productivity Evaluation

Productivity is derived by comparing the output to the input and is given by the formula

$$Productivity = \frac{Production(m^3)}{labour+Capital(naira)} \tag{4}$$

The input in this statistics only includes the volumetric produce of 5,600m^3 worth of finished plywood for one month period without including equipment purchase and others.

Table 7: Resources and cost

Recourse	Monthly values
Output	5,600 (m^3)
Production	
Input	
Labor	2,808,000
Capital	
Raw materials	10,715,364
Machine maintenance	432,000
Material Handling Equipment Transportation	6,099,215
Electricity	
Others	180,000
	150,000
Total	20,384,579

The variables from Table 7 will be utilized to ascertain the productivity factor and the proposed alternative layouts modification design can be compared. Therefore, the productivity (productivity factor) for the current or existing layout is computed as :

$$Productivity = \frac{production}{labour + capital} = \frac{5{,}600(m^3)}{2{,}808{,}000 + 17{,}576{,}579(naira)} = 0.000275\text{m3/ naira}$$

H MATLAB ALGORTHM FOR PRODUCTIVITY

```
%Program that computes the productivity given,
% the total production, total labour cost and total capital cost
%
production = str2num(input('Enter the Production: '));
labourCost = str2num(input('Enter the total Labour cost '));
capitalCost = str2num(input('Enter the total Capital cost '));
ratio = production/(labourCost + capitalCost);
disp('Productivity = '+ratio);
```

IV Material handling Optimization

A The Current state

The Piedmont Plywood currently has two material handling equipment: the front loader and the crane fork. The front loader transports logs through the log processing and conditioning areas and introduces the logs to conveyor belts for peeling and clipping processes. After peeling and clipping, every other process material handling movement within the factory is performed by the crane fork. Hence, the material handling modification will be primarily on the crane fork and the front loaders. Figure 1 shows the routes of crane fork and the front loaders in the factory workspace.

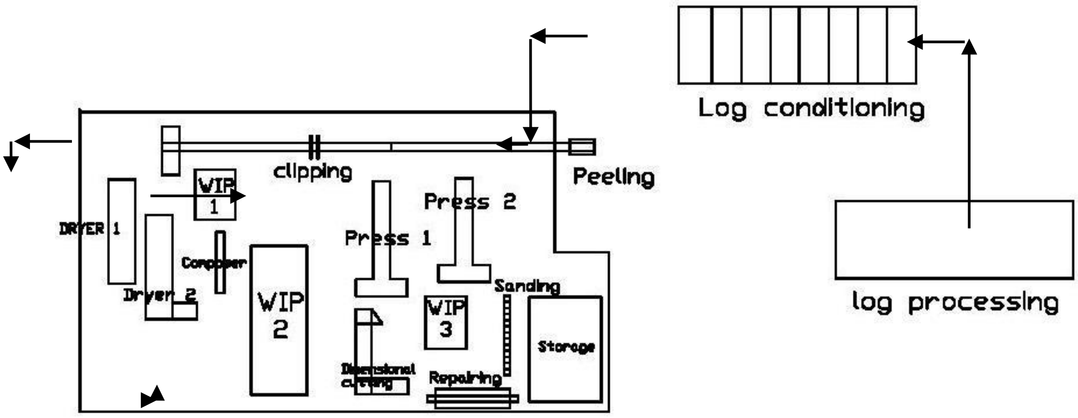

Figure. 7: Material handling equipment routes

The factory possesses five crane forks, figure 7 shows its routes as indicated below:

1. Between the clipping and dryers
2. Transporting materials within the two dryers.
3. For transporting veneers through the composer and the pressing process.
4. For transporting the pressed veneer to work in process area 3 and to through dimensional cutting and/or repairing and/or sanding.
5. To transport finished plywood between the storage areas and loading for dispatch

For stacking purposes, customized trolleys shown in Figure 8 are used to stack veneers.

Figure. 8: Veneer Trolley

The factory has four stacking workers per shift, and the Material handling labour ratio measures the ratio of workers that perform material handling duties to the total factory operation personnel.Table 8 shows the material handling transportation personnel per shift.

Table 8: Number of personnel per activity

Process	Number of personnel
Log processing	2
Log conditioning	2
Peeling	2
Clipping	1
Drying	2
Composer	1
Press	8
Dimensional cutting	3
Repair	4
Sanding	2
storage	2
Material handling duties	
Front loader	2
Crane fork	5
Staking	4
Total	44

$$Material\ handling\ labor\ ratio = \frac{Personnel\ assigned\ to\ material\ handling\ duties}{Total\ plant\ operating\ personnel} = \frac{11}{44} = 0.25$$

The storage area space utilization ratio is an important parameter in relation to material handling optimization. This is the ratio between the storage area space to the total available storage area space in the facility (Sule, 1986). The measured data for the storage space is as displayed in Table 9below.

Table 9: Storage Space

Storage Space	Area (m^2)
Storage Space Occupied Work in process Area 1 Work in process Area 2 Work in process Area 3	 110.38 937.12 130.72
Total	1178.11
Total Available Storage Space Storage Space Occupied Storage warehouse	 1178.11 1993.7
Total	3171.81

$$Storage\ Space\ Utilization\ ratio = \frac{Storage\ space\ occupied}{Total\ Availables\ torage\ space} = \frac{1178.11}{3171.81} = 0.3714$$

B Alternative Material Handling Modification

The main aim of material handling optimization is to save cost by the reduction of material handling labour ratio. Introducing an automatic stacking machine will cut down the number of workers for the stacking job, and the cost variation evaluated. The automated stacking machine can receive veneers from the dryer output by an additional conveyor belt to the storage location where the automatic stacking machine would stack veneers, thus eliminating the four stacking workers.

The automated stacking machine is shown in Figure 9.

Figure. 9: Automatic stacking machine

The implementation of this material handling modification would considerably reduce the material handling labour ratio.

$$material\ handling\ labor\ ratio = \frac{Personnel\ Assigned\ to\ material\ handling\ duties}{total\ plsnt\ operating\ personnel} = \frac{7}{44} = 0.1591$$

By eliminating the four stacking workers per shift, the company saves N160,000.00 per shift monthly. This amount is equivalent to N40,000.00 per worker monthly. Labour cost is substantially reduced, thus impacting on the productivity value.
For 3 shifts, labor cost reduces by N160,000.00 x 3 shifts = N480,000.00 per month.
Thus, monthly labor cost reduces to N2,808,000.00 – N480,000.00 = N2,328,000.00.
Input resources after material handling modification are as in Table 10.

Table 10: Resources input for material handling modification

Recourse	Monthly Cost
Output Production	5,600 (m^3)
Input Labor Capital Raw materials Machine maintenance Material Handling Equipment Transportation Electricity Others	 N2,328,000 10,715,364 432,000 6,099,215 180,000 150,000
Total Labor	N2,328,000
Total Capital	N17,576,579
Total Input	N19,904579

The productivity for alternative modification is as determined:

$$Productivity = \frac{production}{labour + capital} = \frac{5{,}600(m^3)}{2{,}328{,}000 + 17{,}576{,}579(naira)} = 0.000281\text{m3/naira}$$

It is evident that the material handling modification substantially led to an increase in daily production. It is also apparent that when factory operations are automated, the volume of production will be increased considerably with respect to time.

RESULTS AND DISCUSSION

The resultant data of the research work are displayed with regards to material handling modification. See Table 4. The effect of the material handling modification carried out in this research was basically on labour cost reduction as some manufacturing workers were eliminated. With the introduction of the conveyor belt at the dryer output and the automatic stacking machine for stacking veneers at storage, four personnel per shift was eliminated in the operations.

Table 11: Material Handling Labor Factor

Material Handling Layout	Labour cost	Cost Reduction	% Labor cost Reduction	Productivity index (m^3/naira)	% productivity increase
Current State	N2,808,000	-	-	0.000275	-
Modified State	N2,328,000	N480,000	20.62	0.000281	2.18

The labour cost for the current and modified layout is as shown on the bar chart in Figure 10.

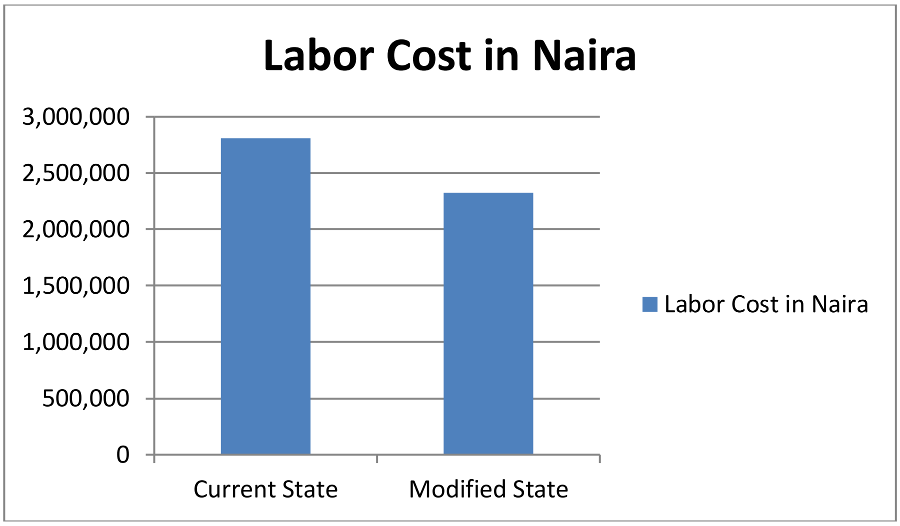

Figure. 10: Labor cost in Naira

The Annual cost reduction for the company from the modified state in the material handling is N480,000.00× 12 = N5,760,000.00

Although the material handling modification saves the company money if implemented, the cost of acquiring and installing this extraneous equipment might also be high. Also, the acquisition and installation cost was not included in the scope of this dissertation. Still, it should be put into consideration when management and operational decisions are to be taken.

CONCLUSION

Implementation of the alternative material handling modifications accrued to approximately annual cost reduction for the company to the tune of six million naira (N6,000,000.00). At this figure, the rate of recovery on investment is considerable enough for the fact that improvement in productivity is 2.18%. It is also worthy to note that labour cost reduction is 20.62%. Thus the implementation of the findings of material handling factor will engender greater financial recovery in certain cost aspects of the company's financial policy.

RECOMMENDATIONS

The Piedmont Plywood Company is advised to implement the findings of the alternative material handling modifications. It is strongly believed that the impact of material handling coupled with plant layout factor would have a tremendous influence on of facility layout in terms of savings in space, labour and material handling costs.

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