NJEM, Vol. 5, No. 3, 2004

IMPROVING CAPACITY UTILIZATION THROUGH MATERIAL HANDLING AUTOMATION: A CASE STUDY OF A FOOD PROCESSING PLANT

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ABSTRACT

This study is about the use of automated material handling system to eliminate bottlenecks on production line in order to achieve higher system capacity utilization. It was applied to the milling plant of a food processing company. Detailed study of the milling plant work system's parameters was carried out to give a basis for the selection of a suitable new transfer system. Facility layout analysis to determine floor space requirement as well as work system design analysis and cost/ benefits analysis were also used. A pneumatic conveyor system has been designed to replace manual handling in a critical portion of the flow line. Costs and benefits analysis indicate that an overall increase of 30% in revenue at a cost of 8.4% increase in input resources is achievable if the proposed subsystem is installed. Productivity will also increase by 29% by the proposed automation.

Keywords: Material handling, Automation, System Development, Capacity Utilization, Productivity, Pneumatic Conveyor

1.0 INTRODUCTION:

Capacity of a production system may be defined as the maximum level of value added activity over a period of time that the process can achieve under normal operating conditions (slack, 1998). It can also be defined as output per line per unit time period for a given product mix and operating plan. There are different types of capacities such as maximum machine capacity, planned machine capacity, and planned available capacity (Burbidge, 1968).

Capacity utilization is the process of providing and utilizing the manufacturing assets of an organization. It is a measure of the amount of the output of a production facility relative to its maximum capacity. Many experts have identified the problem of low capacity utilization as a serious problem of the Nigerian economy. Factors responsible for low capacity utilization may be grouped into two categories, namely, system internal factors and system external factors. External factors include problems such as erratic power supply, non-availability of raw materials to buy, industrial and civil unrests and similar factors, which are not within the control of the production system designers and operators. Internal factors are those ones resulting from or inherent in the production system design. They may be things like bottlenecks as a result of plant layout, machine breakdown, maintenance schedule, job schedules, material handling systems' capacity etc. These factors can be improved or eliminated, most times, through schemes like facility layout redesign, employing more hands, automation, better control of the entire production system or some of its subsystems. One area where substantial improvement in overall system capacity utilization can be easily achieved is in the area of material handling subsystem. It has been estimated that in many plants, about 50 tons of materials must be handled to produce one ton of finished product (Armie et al 1987). Production cost can be reduced when raw materials are moved through processing in the shortest possible time and in away that in-process inventory be reduced. The goal of achieving higher material handling efficiency is one of the challenges of the industrial engineer. The industrial engineer is faced with the challenge of determining or detecting areas responsible for high in-process inventory due to improper handling methods and proffering solutions within the limits of several interdependent constraints.

The objective of this study is to show how, and to what extent, capacity utilization of a typical production plant can be improved by eliminating observed bottleneck through the incorporation of appropriate automated material handling system. The milling plant of a Lagos based food processing plant is used as a case study.

1.1 Case Background

The Company under study is a producer of food and beverages and has been in business for over 20 years. Apart from being a household name in the food industry, it is also a leading name in pharmaceutical and cosmetic products worldwide. As part of the effort towards meeting the increasing customer demand for cereal products, the management plans to carry out the following:

i. Improve the capacity utilization of the milling plant and Better utilization of space.
ii Reduce manual handling of in-process materials to the minimum for higher product quality.

2.0 MATERIALS AND METHODS:

The system development life cycle (SDLC) concept, commonly used for building information system (Stair 1992, Munro and Davis 1997) was adapted for this work. The project was divided into four formal stages of the SDLC as shown in Fig. 1.

2.1 System Investigation

At this stage, the issue of whether or not the organization has a problem and whether the problem can be solved through a new or enhanced production system was addressed. The problem definition constitutes the problem as expressed by the management. An initial observation (check) of the production line showed that a problem of capacity under utilization occurred on the line. It was then concluded that the system could be improved through appropriate automation.

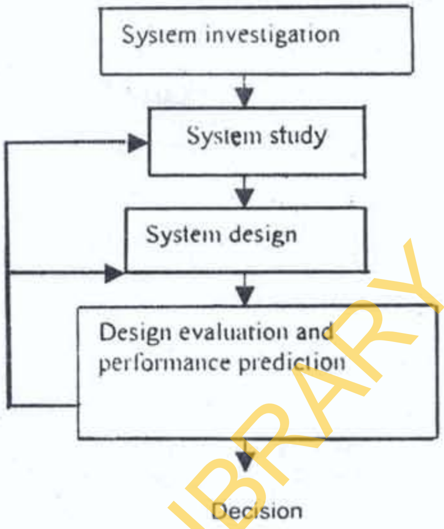


Fig. 1: System Development Life Cycle as used in the Project

2.2 System Study

At this stage, the problem of the existing milling plant were analysed, objectives to be attained were defined and various solution alternatives were defined and examined for considerations. The demand for cereal product, which is the output objective, is 28 tons /day while the current output is 22 tons per day. The following steps were taken in carrying out the study stage.

i. The existing workflow pattern, a flow-shop (Fig. 2) and work layout were thoroughly analysed using some concept of work-study.
ii. The input /output relationships existing between successive stages were analysed to uncovered any source of present or suppressed bottlenecks.

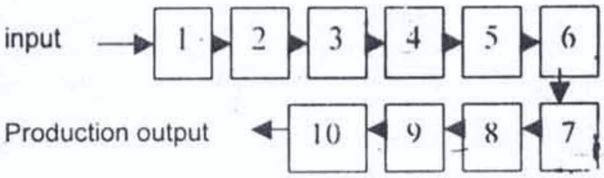


Fig. 2: Existing flow shop

The following notations are used in describing the system:

IP{i} = available input into stage i ,
Op{i}= present output from stage i ,
minOp{i} = stage with the minimum output ,
Optar = target output

Note that IP{i}=Op{i-1}and Op{i} = IP{i+1} where stage i+1 is precedes stage i in the flow shop system as shown.

Bottleneck occurs at stage i if: IP{i} > Op {i+1}.

For achieving the target output: Optar (28 tons/day in this case), min Op {i} ≥ Optar.

This study indicates that raising the output of the system will require increasing production rate at bagging section (stage 10). This section happens to be the only manual subsystem in the production line.

Three probable solutions were considered, which are:

i. employing more workers on this subsystem,
ii. replacing the subsystem with an automated conveyor or mechanized system and
iii. combining 1and 2.

Solution number 1 will negate the idea of reducing manual handling as desired by management. Also, space and ventilation will pose health problems. A Combination of 1and 2 will be complicated to implement given space factors. Therefore option 2 was proposed for implementation.

2.3 System Design

The objective of the design is to eliminate the observed bottleneck, through an appropriate conveyor mechanism as suggested in the system study stage. Factors like space availability, cost, integration with existing system and of materials to be handled favour the use of pneumatic conveyor system.

2.4 Pneumatic Conveyors system

Pneumatic conveyors are employed in the movement of materials suspended in a stream of air over horizontal and vertical distances raging from few to hundreds of feet. Materials ranging from fine powder through 6.35mm pellets and bulk densities of 16 to more than 3200kg/m^3 can be handled (Perry et al 1998)

The capacity of a conveyor system depends on the following factors

i. Product bulk density
ii. Energy content of the conveying air over the entire system and
iii. Equivalent capacity of the conveying line. Also pneumatic conveyors are, generally, classified into five basic types; Pressure, vacuum, combination of pressure and vacuum, fluidising and blow tank (Fig. 1). A vacuum type was selected for the system.

3.0 PROCEDURE FOR DESIGNING THE PROPOSED CONVEYOR LINE

A design philosophy that involves selecting appropriate off the shelf components was adopted. Availability of components within Lagos or Ibadan was also a constraint. The comprehensive design is contained in Eze (2002). A design procedure, certified by chemical engineers for conveyor system design, (Perry et al 1998) involving the use of Nomographs charts (Table 2) was adopted to determine the design specifications of the conveyor system.

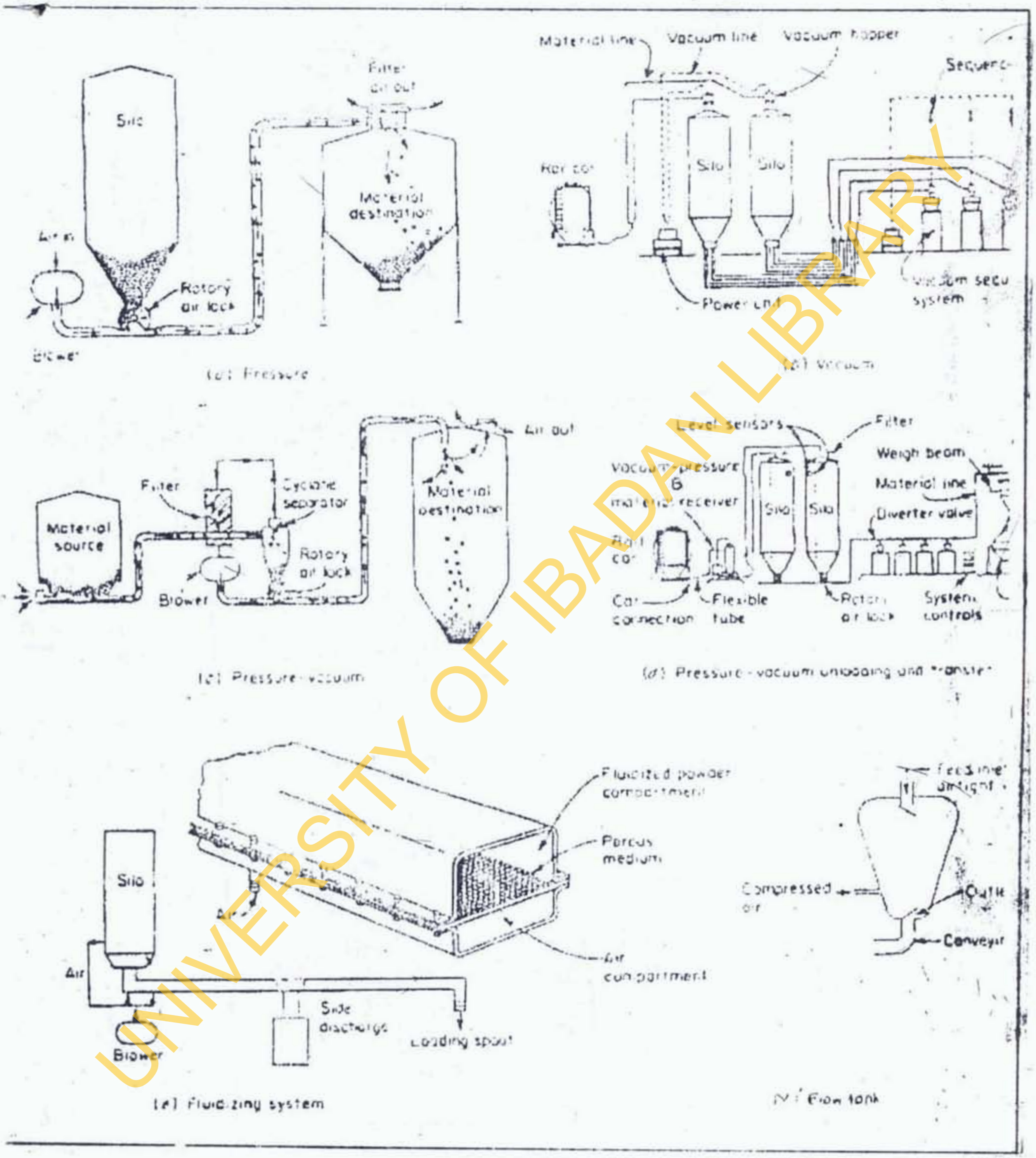
The steps for determining the conveyor size and power for a given product bulk density are summarised below.

a) Find the equivalent length L of the system from the space analysis result. L= sum of vertical distances (VL) + sum of vertical horizontal distances (HL) + pipe fittings allowances. (Note 90^0 elbow pipe = 7.6m &45^0 elbow pipe = 4.6m)

b) Choose an initial air velocity

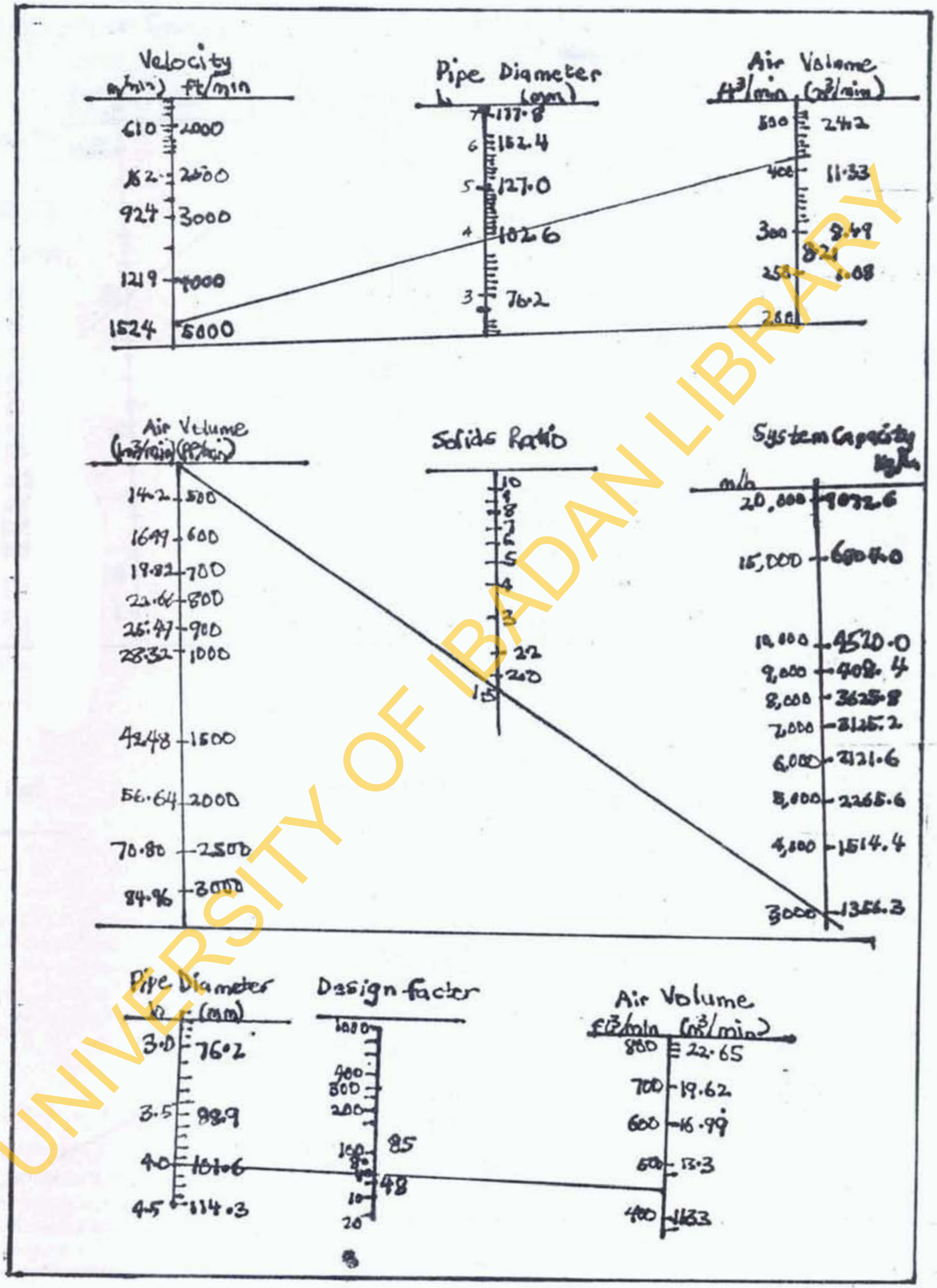
c) Begin the following iterative steps by assuming your preferred pipe diameter D.

   i. On Nomograph 1 (Table 1) find the air volume from pipe diameter and air velocity assumed. **Power Demand** A 6.1HP or 4.5 kW pneumatic conveyor systems was obtained.
   ii. On Nomograph 2 (Table 1), use the air volume and the required system capacity to find the solid ratios R. If R> 15 then a larger line size is assumed.
   iii. On Nomograph 3 (Table 1), use the air volume and pipe diameter to locate the design factors F

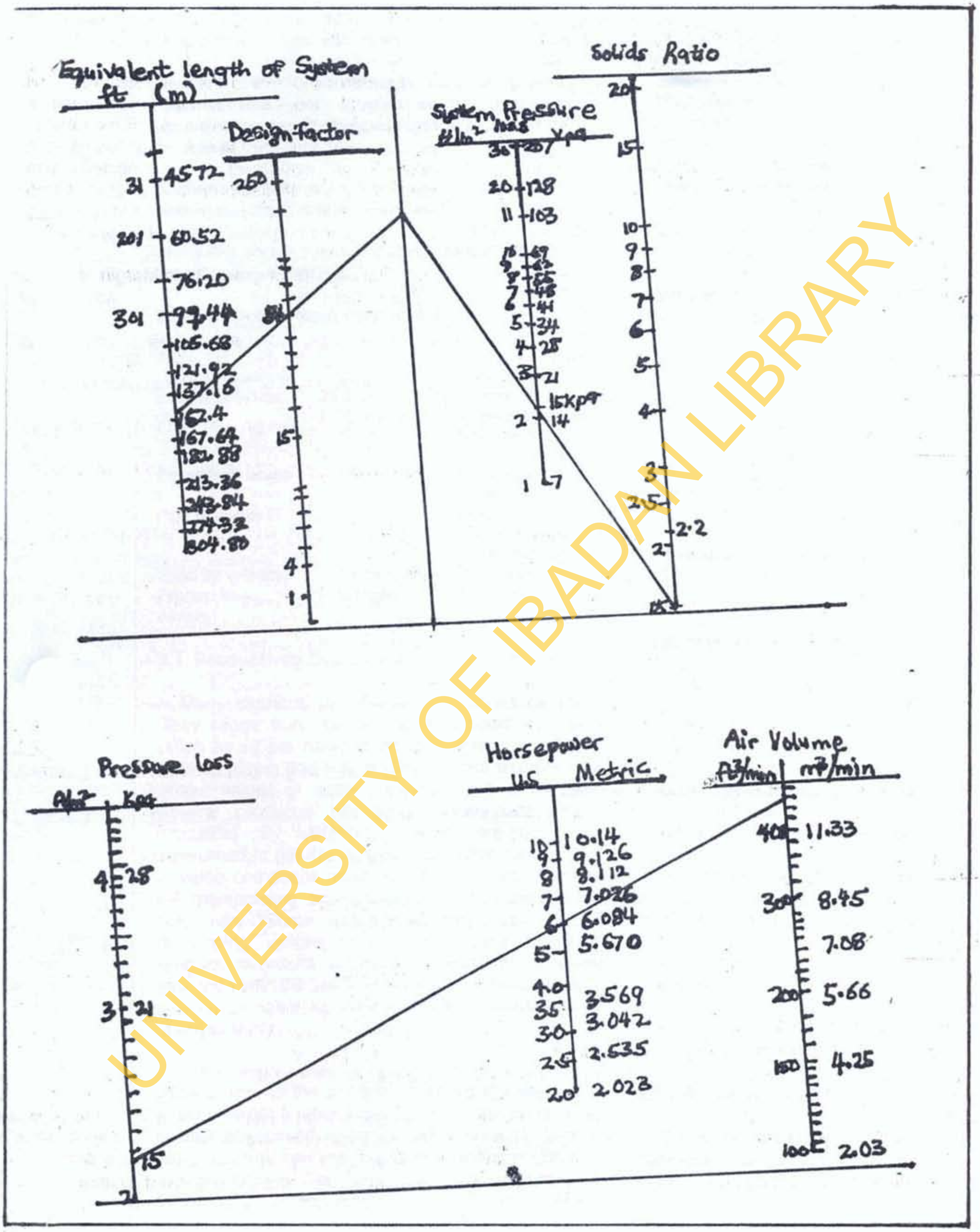


. 1: Types of Conveyor Systems

Table 1: Conveyor Design Monographs (**Steps** 1. 2 and 3)



able 2: Conveyor Design Monographs (Steps 4 and 5)



d) The pressure loss P is obtained from Nomograph 4 (Table 2) using the design factor F and equivalent length L. If P >70kpa then assume a larger pipe diameter and repeat all previous step beginning with Nomograph 1 otherwise turn to Nomograph 5 (Table 2)

e) Obtain horsepower for the system on 5 using pressure loss P and air volume

Using the above steps, the design input parameters are as given in Table 3.

Table 3: Design Input Parameters

Input Parameter	Value	Remark
Expected System capacity	28.6 tons/day (1300kg/hour)	28 tons /day target set by Management
Equivalent, length L	150m	From space analysis
Pipe diameter D	10cm	Pipes Availability in the market
Initial air velocity	1500m/min.	Assumed
Product bulk density	6.4kg/m^3	Measured

3.1 Productivity Evaluation

Many methods for measuring productivity exist. They range from simple partial productivity ratios (such as kg per hour) to comprehensive multifactor models (Craig and Harris 1973), which combine the output values of various sources (e.g. sales from several products) into single, composite output indicators. By weighting together the resources consumed to get this output, multifactor models also develop composite input indicators. Also schemes for manipulating and analysing outputs and inputs also vary. Some approaches focus on the on developing indices that compare the ratios of outputs to inputs in given periods (or in given systems) with the value of those same ratios in base periods (or systems). These indices indicate change in productivity.

Other approaches carry productivity performance assessment to the profit level where the statistic of interest is not a ratio or an index but rather the Naira impact of productivity performance on profit growth. Such approaches are based on quantifying change in productivity in the following relationship. Profitability = Productivity + Price Recovery (David 1984). Where price recovery represents the net effects of inflation

Therefore whenever inflation is zero, Profitability = Productivity, this is particularly the case when comparing between different systems rather than periods. So this profitability relationship can be relevant in evaluating the expected gain in productivity due to the proposed system. Using the definitions and notations bellow: Subscripts **a** and **b** for existing and proposed systems respectively.

i. Profitability (Pr) or gross Profit Margin = Gross profit / Net sales

ii. Unit Price per ton of output = P

iii. Output (in tons) before automation = Oa

iv. Expected Output (in tons) after automation = Ob

v. Total cost (Naira) of goods before automation = C.

vi. Expected cost (N) of goods after automation = Cb

Where Net sales = Output x Unit Price and Gross profit = Net sales – Total Cost of goods Therefore Profitability of existing system

$$P_{ra} = \frac{PxO_a - C_a}{PxO_a} \qquad 1$$

Also Profitability of proposed system is given by

$$P_{rb} = \frac{PxO_b - C_b}{PxO_b} \qquad 2$$

Therefore

$$D_p = \frac{P_{rb}}{P_{ra}} = \frac{(PxO_b - C_b)O_a}{(PxO_a - C_a)O_b} \qquad 3$$

where Eqn. (3) is the equivalent of the total dynamic productivity with respect to systems *a* and *b*, this index should be greater than one if system b is giving higher productivity

4.0 DATA ANALYSIS

Estimates of capital cost items for the proposed handling system are given in Table 4 while a comparison of production cost items between the present system and the proposed system is given in Table 5.

Operating cost. (Pc) This is mainly from Electric power consumption to power the 4.5 kW motor.

At N6.50 per kwhr. It implies that Pc= 4.5kw *24hr*N6.5/kwhr*365days=N256, 230.00/anum. Making adjustment for running on generator and transmission losses, adjusted index of 1.4 is used to obtain

Adjusted Additional operating cost, Apc = Pc*1.4=N358, 722.00/annum.

Additional Total operational cost = Apc + Depreciation

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With salvage value = N75, 000 after 5 yrs. Note no extra labour is required

Total operational cost = **N358, 722**+ (618,000-75,000)/5 =N467,322/year = **N1280/day**

4.1 Revenue and profit Estimate

Additional capacity (Acp), given 2 hrs for routine maintenances per day and a 3 shifts operation, 320 days of operation per year then Acp = Enhanced capacity - Present capacity.
Where Enhanced capacity =1300kg/hr*22hrs/day =28.6tons/day
<u>Therefore Acp =(28.6 – 22)=6.6 tons /day</u>

4.2 Productivity Indices

From equation 3 and given a selling price of P=N55,000 per ton, Oa=22.0, Ob=28.6. Ca= 770,00, Cb=835,280 . The Dynamic Productivity Dp = 1.29. This translates to a 29% increase in Productivity, which can be achieved through the proposed automation.

% Change in Revenue = (Acp* **Selling** price per ton /initial output*selling price)*100
Percentage change in revenue =Acp*P/ 22*P = 6.6tons/22tons *100 = 30%

Table 4: Installations or Capital Costs Estimate for Proposed Handling System

Item	Cost (N)**	Qty Required	Total Cost	Remarks
Blower package	250,000	1	250,000	
Electric Motor	90,000	2	180,000	
Piping	300/m	1160m	48,000	10m for likely waste
Metering Unit	50,000	1	50,000	
Installation expenses	90,000	-	90,000	
Total capital cost			618,000	

Table 5: Production Costs of Present and proposed System

		Existing	Proposed
Output (tons/day)		22	28.6
Cost (Naira/day)	Material Cost	180,000	234,000
	Admin. Cost	250,000	250,000
	Operating Cost	350,000	351,280
	Total Cost	770,000	835,280
	% Increase	8.4%	

5.0 CONCLUSION

This study has demonstrated how appropriate material handling automation can increase the capacity utilization of a typical production system. Some industrial engineering concepts like work-study, facility layout and system analysis were used. Also a framework for evaluating productivity and profit gain was developed for the case of automation. The productivity analysis shows that a 29% increase in productivity is achievable by a marginal investment of N618, 000.00 on material handling automation. It is recommended that similar analysis be carried out on several ailing production systems in Nigeria to see if their productivity can be improved with minimal spending on appropriate automation systems.

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