Dynamic Programming Approach to Plant Layout under Sequential Machinery Investment for Nigerian Entrepreneurs

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Abstract
This study employs dynamic programming approach to develop a model that helps entrepreneurs to populate pre-planned plant layout using sequential machinery investment techniques. The approach enables the use of little initial capital to sequentially invest in the most important machinery/machineries and factory and office space(s) as well as to provide sufficient working capital required by the industry to keep the plant working optimally per period. Using the developed model and a set of decision rules that was setup, total earnings obtained from previous periods are subsequently re-invested each period until all the planned machines and factory and office buildings have been fully put in place; there is also adequate working capital to efficiently run the plant. The model developed was implemented through a software named DYNAPLANT which was developed using C# programming language to facilitate the solution procedure.

Keywords: dynamic programming, plant layout, sequential machinery investment, entrepreneur, factory.

INTRODUCTION
Startup funds have always been a limiting factor for Nigerian entrepreneurs in the development of Industries, particularly for the procurement of fixed assets such as machines and also operating the machinery with adequate working capital. Although, some government agencies through Nigerian Industrial Development Banks and other special banks occasionally provide funds for fixed assets, other Nigerian commercial banks usually only provide limited funds for working capital at a very high interest rate on pledging building and machinery as collateral.

The only option for these entrepreneurs is to start small with the limited capital available by investing in buildings, machinery and provision of working capital. The hope is that the small scale starters will generate enough returns for further expansion in machinery and additional capital for working expenses.

In other words, the investment plan must under this tight circumstance provide for a flexible plant layout that is dependent on the short term constraints of capital but mindful of the long terms needs of the functional layout of the full complement of machinery for the plant (Aderoba, 1997). The plan must also provide for expansion in buildings in a modular form to cope with added machinery under the phased plan. This modular building expansion, machine selection for investment and provision of working capital requires a suitable systematic programming approach which will sequentially and effectively acquire and manage all resources optimally.

This project uses dynamic programming approach to present a model for sequentially scheduling investment in machinery, building and working capital on a modular basis to promote full functionality of a plant within the shortest possible time. Dynamic programming approach was used because of its flexibility in using the result of a sub problem in other to generate the solution for a main problem in that it systematically uses ploughed back earnings for further investment.

A review of relevant literature on past works on plant layout literally dealt with machinery selection or replacement which starts with the determination of the capacity required and the available capacity by deriving formulae’s which established machine required for each operation (Li, 1999). Various deterministic and stochastic approaches were used to give the expected number of machines required combined with mathematical programming techniques to determine the optimal subset of machines for selection (Hargrave and Ashwin, 2012).
A heuristic algorithm for the dynamic facility layout problem was also developed as a quadratic assignment problem whose algorithm is based on an ant colony algorithm used to solve the static and dynamic facility planning to find the layouts during the multi-period time horizon which saved the excess material handling more than the costs of rearrangements (Udomsakdigool and Bangsaranthip, 2010).

These studies (Li, 1999; Hargrave and Ashwin, 2012; Udomsakdigool and Bangsaranthip, 2010) regarded machinery investment process as a single stage decision making process where all the necessary machines will be acquired at once. In reality, this assumption is far from being valid especially with the recently not too palatable economy of developing countries around the world. Sequential selection of machines has rarely been considered in the literature except in machine replacement problems occurring as a result of adoption of new technological process which had to be executed in phases. A dynamic integer model was also developed using readily implementable heuristic which employs suitable decision rules for sequentially scheduling investment in machinery and building on a modular basis to promote full functionality of a job shop within the shortest possible time (Aderoba, 1997). However, the developed model do not take into consideration availability of working capital.

Computerized layout models such as CRAFT also emerged with later improvement to account for cases such as relocation. Since then, the emphasis in the literature has been shifting to more and more flexibility in layouts in cases like the use of computer as a tool to aid the planning of layouts in factories to reduce daily cost incurred using developed software (Ogedengbe et. al., 2012).

A web-based application named Reuse-Atlas, was also developed to support plant layout design activities as well as the reusability of engineering data. The application facilitates the development of new technical projects in the field of modular plant design which includes structures for the modules of different plant complexity like structural group- and plant group-modules and also allows more efficiency through the tracking of undertaken decisions and assumptions during the module development and design. The study therefore provides for simplicity in designing new plant layouts and modifying the old ones (Lukasz and Günter, 2010). Another model which performs space analysis and allocation of objects using a geometric reasoning approach for analyzing site space was also developed (Farnaz et. al., 2006). This model resembles the human reasoning process and addresses the gap between the way domain experts develop site layouts and the way computer-based models approach it (Farnaz et. al., 2006). In addition, the proposed model, through its open architecture, engages users in decision making at different stages (Farnaz et. al., 2006).

Having considered and reviewed recent and important contributions to plant layout designs and sequential machinery investment decisions, this study employed the dynamic programming approach for the development of a model that would provide and assist decision makers in making appropriate decision in sequentially investing in plant machineries and factory and office spaces alongside provision of adequate working capital with respect to the plant layout. A software was developed for the implementation and rapid application of the formulated model and the model was validated using an appropriate case study. The model developed is unique in that it has considered a dynamic and concurrent investment in machinery, building space and working capital as a basis for manufacturing strategy. It specifies not only the schedule for acquisition of machinery but also the schedule for development of the required factory space and its working capital. Also, it accounts for the minimum initial limited capital to invest on the plant and provide for updating this capital base for further expansion through reinvestment earnings. Furthermore the model utilizes essential decision rules for selecting machine(s), by priority, to be purchased in any period.

**MATERIAL AND METHOD**

**The Mathematical Model**

This entails the determination of the decision variables in form of what machines (m) to purchase at a particular quarter (t), how much factory space to construct within that quarter (a), and how much working capital (w) to expend within that quarter. The underlying assumption is that whatever investments (machinery, buildings and working capital) are made, it will be completed within the quarter (t) and can be fully put into operation by the next quarter (t+1). The decision variables are defined symbolically as follows:

\[ X_{mt} = \begin{cases} 1, & \text{if machine } m \text{ is purchased in quarter } t \\ 0, & \text{if otherwise.} \end{cases} \]

\[ X_{ot} = \begin{cases} 1, & \text{if office space is constructed in quarter } t \\ 0, & \text{if otherwise.} \end{cases} \]

The inherent assumption is that the final layout of the plant is known with all the data concerning the total machinery, building space and working capital. A further assumption of this model is that the required factory/building space is built in modular units and not rented. Decision rules for machine selection and a stopping rule was developed using the dynamic programming approach. The eight decision rules considered suitable for selecting machine for purchase as used in this model are as follows:
(a) Balance of production operation (note during last period which machines out of the remaining in the layout are very essential to the production activities of the factory).
(b) List machines on master layout, that are yet to be purchased in the appropriate order according to how the machines are essential to the production activities of the factory at this stage. Attach a priority value to each of the machines.
(c) Lowest value of Purchase cost, cm
(d) Highest value of net return, rm
(e) Highest value of return on investment, rm/cm
(f) Highest value of return on investment and building, rm/(cm + km)
(g) Lowest value of working capital, w
(h) Highest Value of return on total investment , rm/ (cm + km + w)

The investment focus and its major constraints are discussed hereafter towards ensuring availability of funds for fixed/working capital to arrive at equations (1)-(11):

**Investment Equation**

Machine index (m) of machine(s) purchased in quarter (t) incurs an investment cost, cm, while constructed space of the machine, am used up in that quarter costs km and constructed office space used cost, kmo, together with a running/working capital cost, w. In general, total investment at any quarter, t (Et) is given by:

\[ E_t = \frac{\sum_{m=1}^{M} (cm X_{mt})}{k} + \frac{\sum_{o=1}^{O} (ao X_{ot})}{w} \quad \text{for all } t \]  

(1)

where M is the total number of machines being considered for investment, O is the total office space to be constructed. m and o are machine index and office space index respectively. The working Capital, w per quarter can be expanded further to include the recurrent expenditure and operating expenses which encompasses major factors like:

(a) Salaries, Wages and Professionals Costs, Swc
(b) Raw Materials Purchase and Freight Cost, Rwc
(c) Utilities and Equipment Costs, Uwc which includes electricity, water, coolant, repairs and maintenance cost, etc.
(d) Other Expenses, Owc which might include consumables; telephone cost; postage, advertisement and publicity costs; government levies and tax; insurance/health bills; and other miscellaneous expenses.

\[ w_t = Swc + Rwc + Uwc + Owc \]

(2)

**Reinvested Earnings Equation**

In order to achieve the net returns of a particular machine, rm used in a given plant, a ratio of the capacity of the specific machine to the ratio of the capacities of the total number of machines in the plant is to be obtained and then multiplied by the unit price, p and the total quantity produced, q as expressed in equation (3)

\[ R_t = \frac{\sum_{m=1}^{M} (r_m X_{mt})}{Total Capacity of all machines required for Production} \quad \text{for all } t \]  

(3)

Hence, Total net returns ploughed back for investment in quarter, t can thus be represented using (Rt), which is given by:

\[ R_t = R_{t-1} + \left[ \frac{\sum_{m=1}^{M} (r_m X_{mt})}{Total Capacity of all machines required for Production} \right] \quad \text{for all } t \geq 1 \]

(4)

**Investment Funds Constraint**

The value of Ft (capital available for investment in quarter, t) is the sum of capital available in quarter (t-1) i.e. (Ft-1) and net returns for reinvestment (Rt) in that quarter less expenditure (Et-1) on buildings, machineries and working capital for the quarter.

\[ F_t = F_{t-1} + R_{t-1} - E_{t-1} \]

(5)

The capital expenditure in turns in quarter t, Ft must be less or equal to the funds available (Ft). This constraint is expressed mathematically as:

\[ E_t \leq F_t \]

(6)

**Space Adequacy Constraint**

This constraint ensures that there is enough factory space, α, to accommodate any machinery, m purchased at any particular quarter, t and also office for the staff to manage them. This is expressed mathematically as follows:

\[ \alpha_t \geq \left[ \frac{\sum_{m=1}^{M} (am X_{mt})}{k} + \frac{\sum_{o=1}^{O} (ao X_{ot})}{w} \right] \quad \text{for all } t \]  

(7)

**Modularization of Building Space**

Equation (7) mathematical formulation suggests that the size of the building space constructed in quarter t (a) could take any real magnitude, but it is normally dependent on the space area occupied by the selected type and number of machine(s) as well as staff office. The building is best in modular form with each new space being an integral multiplier of a standard modular space of Q. Hence, α = y, Q

(8)

Where Q is a standard modular space and y is an integer which can take any of the values 0, 1,… Expansion can then take place in multiples of Q. There is a need to put an upper limit on the space expansion, i.e

\[ \sum_{t=1}^{T} (a_t) \leq \Omega \]

(9)

Where Ω is the total space planned for the factory derivable from the chosen plant layout.

The formulation in equation (1) to (9) is the combined with the objective function of ensuring that the plant is fully functional and equipped within the shortest possible period of time, T, with full provision of machinery, building space and adequate working capital. This can be expressed as:

Minimise T  Such that \[ \sum_{t=1}^{T} (X_{mt}) = M \]

(10)

and \[ \sum_{o=1}^{O} (X_{ot}) = O \]

(11)
Subject to:
\[ E_t = \left( \sum_{m=1}^{M} (c_{m}X_{m}) + k(a_{m}X_{m}) \right) + k(\sum_{g=1}^{G}(a_{g}X_{g})) + \sum_{l=1}^{L} w_{l} \text{ for all } t \]
\[ R_t = R_{t-1} + \left( \sum_{m=1}^{M} (r_{m}X_{m}) \right) \text{ for all } t \geq 1 \]
\[ F_t = F_{t-1} + R_{t-1} - E_{t-1} \]
\[ E_t \leq F_t \]
\[ a_t \geq \left[ \sum_{m=1}^{M} (a_{m}X_{m}) \right] + \left[ \sum_{l=1}^{L} (a_{l}X_{l}) \right] \text{ for all } t \]
\[ \sum_{t=1}^{T} (a_t) \leq \Omega \]

MODEL SOLUTION PROCEDURE
Owing to the peculiar nature of the developed model, a heuristic was developed to solve the system problem. The steps of the heuristic are summarized below with details of the salient aspects elaborated on.

C System Data Input
Step 10: Input General factory Data: \( F_0, \ a_0, \ Omega, \ k, \ Q \)
Step 20: Input all machinery data: \( c_m, a_m, r_m \); for all \( m \in M \)

C Decision rules for machine selection
Step 30: Calculate decision index for all machineries
Step 40: Create file SELECT and list machineries in descending order of decision index

C System initialization
Step 50: Initialize time \( t = 0 \)
Step 60: Set \( X_{init} = 0, \ a_t = 0, \ a_t = 0 \) for all \( m, t \)

C Machinery selection and space development procedure
Step 70: Increase \( t \) by 1 i.e \( t = t+1 \)
Step 80: Select first machinery on file SELECT
Step 90: Calculate ploughed-back returns available from preceding quarter \( R_{t-1} \)
Step 100: Update investment funds, \( F_t \)
Step 110: Determine the minimum additional space to accommodate this machinery, i.e \( y_t Q \) \( (y_t = 0,1,2,\ldots) \)
Step 120: If available fund is insufficient to purchase and run the machinery in this quarter, go to step 190 (i.e \( F_t < c_m + w_t + ky_t Q \))
Step 130: Purchase this machinery in this quarter, i.e \( X_{init} = 1 \)
Step 140: Review existing building space in this quarter, i.e increase \( a_t \) by \( y_t Q \)
Step 150: Upgrade available space \( a_t \) by \( y_t Q \) less \( a_{init} \)
Step 160: Reduce available funds by \( c_m + w_t + ka_t \)
Step 200: If file select is empty, go to Step 240
Step 230: Go to Step 70
Step 240: Set \( T \) (the Scheduled time for full factory functionality) = \( t \)
Step 250: Print T and the scheduled \( \{X_{init}\}, \ A, \)
Step 260: STOP

MODEL IMPLEMENTATION AND VALIDATION
The model was implemented through a software named DYNAPLANT which was developed using C# programming language to facilitate the solution procedure. This programming language is suitable for this algorithm because it provides better mathematical computation. Also, it is easy to setup a user friendly interface with it. The developed software has a login page for authenticating user access. After login into the software a graphical user interface (GUI) that allows the user to either start a new project or continue with an existing project is loaded. Resuming an existing project leads to a dropdown menu indicating all the projects saved in the software database which can be recalled while the starting a fresh project command enables the user to create and name a project inside the project Name box. When starting a project a fresh the general factory data GUI (Figure 1) is loaded and required to be filled.

Figure 1: General factory data GUI

Here essential information about the entire factory as reflected in the Figure is expected to be supplied. Clicking SAVE on Figure 1 would load a
confirmation GUI where a summary of data inputted in Figure 1 is confirmed resulting in machine details GUI (Figure 2) being loaded for necessary information to be filled in.

Also to be supplied here are information related to each machine within the layout of the factory such as name, cost, usage, capacity, space required, operator’s stipend, etc as shown. After providing the details for all the machines in the layout and confirming them, the priority level GUI is loaded (Figure 3). Here questions are asked regarding all individual machines inputted into the software to determine priority levels for each machine. The user uses the information displayed on Figure 3 to guide his decision in answering the machine priority points for each machine. The entrepreneur also has the option of skipping a particular question by clicking on the skip button if it pleases him/her to move on to the next available question. Once all questions displayed by the software have all been answered, the finish button enables for the submission of all answers. Thereafter the software processes the user’s answers and displays a summary of it which should again be confirmed, after which Figure 4 is loaded.

Selecting the 'CONTINUE' button in Figure 4 automatically directs the user to the decision table section of the software which would normally provide a brief summary of the initial available fund (startup capital) as specified by the entrepreneur, the suggested machine(s) to purchase as determined by the priority levels and the net return on Investment, the total expense for that period and the total fund remaining. It also enables the entrepreneur to determine whether to continue with the purchase or not. However, if the initial fund was not sufficient to start up the plant, the software would pop out an error that the initial capital inputted was not enough to purchase the suggested machine(s).

The software and model were evaluated and validated using a case study of a mini palm oil mill plant. The mini palm oil mill plant with a plant layout design of 540 square meters land size is as shown in Figure 5 is located in Bayelsa State, Nigeria. The mills were designed specifically for the palm oil sectors and environment of Nigeria where small-to-medium scale production prevails over large scale industrial mass-production. The machineries essential for full functioning of the plant is also shown in Figure 5. The palm oil mill plant was chosen because it uses a technology that enables extraction of up to 80% oil from oil palm fruit using a modular mini plant mill. It was also selected because the end product which is palm oil is readily needed in our local environment and the traditional methods of extracting this product can easily be replaced with modern method at a very minimal cost and within the shortest possible time.
RESULT AND DISCUSSION

The values of the decision variables and the subsequent decisions compiled from manual computation as displayed on Table 1 was found to be in agreement with the computation done by the software as summarized on Figures 6 to 11. The DYNAPLANT software made the computation of the easier and faster with great accuracy.

If this entire plant was to be setup at a go, the total cost of setting it up at a fell swoop would amount to Total Building Cost (N2,720,000) + Total Machineries Cost(N4,075,000) + Total Working Capital(N2,234,998) = Grand Total (N9,029,998) as can be calculated on Table 1. However, results of this study shows that the application of the model can drastically bring down the initial capital investment to N1,500,000 by investing sequentially in both machineries, building and working capital to populate the entire plant within six(6) periods as shown on Table 1. Note that Naira (N) is Nigeria currency presently having an exchange rate of 185 to a US dollar (USD)
An initial available capital of an estimated value of at least N1,500,000 would be needed to startup the plant in line with the decision rules of the developed model. This is because the model has used its decision rules to select the first machinery to purchase. The minimum total costs hereby accompanied with the selected machine(s) would involve the purchase cost of the machine(s) selected together with all the working capital running costs of the machine and the total cost of constructing an applicable plant and office space to accommodate both machine and personnel needed.


### Table 1: Iterative process using all Decision indices

<table>
<thead>
<tr>
<th>Perio(d (t))</th>
<th>Capital Available (Naira)</th>
<th>Machine Purchased</th>
<th>Machine Space Built (square meters)</th>
<th>Office Space Built (square meters)</th>
<th>Total Cost of Space, Ks, (Naira)</th>
<th>Cost of Machine(s), Cm (Naira)</th>
<th>Working Capital, Wt</th>
<th>Total Recurrent expeditur(e</th>
<th>Remainin(g Balance</th>
<th>Quantity Processed (litres equivalent)</th>
<th>Price Sold</th>
<th>Net Returns Generated, r(n) (Naira)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,500,000</td>
<td>Fruit Digester</td>
<td>30</td>
<td>15</td>
<td>480,000</td>
<td>425,000</td>
<td>583,048</td>
<td>1,488,048</td>
<td>11,952</td>
<td>9,314.22</td>
<td>N160/litre</td>
<td>1,490,275.2</td>
</tr>
<tr>
<td>2</td>
<td>1,502,227.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>583,048</td>
<td>583,048</td>
<td>919,179.2</td>
<td>9,314.22</td>
<td>N160/litre</td>
<td>1,490,275.2</td>
</tr>
<tr>
<td>3</td>
<td>2,409,454.4</td>
<td>Revolving Drum Thresher/ Striping Machine</td>
<td>40</td>
<td>10</td>
<td>520,000</td>
<td>750,000</td>
<td>399,283</td>
<td>2,252,331</td>
<td>157,123.4</td>
<td>15,771.75</td>
<td>N160/litre</td>
<td>2,514,840.0</td>
</tr>
<tr>
<td>4</td>
<td>2,671,963.4</td>
<td>Fruit Bunch Sterilising Cookers</td>
<td>35</td>
<td>10</td>
<td>470,000</td>
<td>400,000</td>
<td>579,217</td>
<td>2,431,548</td>
<td>240,415.4</td>
<td>25,420.07</td>
<td>N160/litre</td>
<td>4,067,211.2</td>
</tr>
<tr>
<td>5</td>
<td>4,307,626.0</td>
<td>Hydraulic Press</td>
<td>35</td>
<td>10</td>
<td>470,000</td>
<td>1,700,000</td>
<td>371,764</td>
<td>4,103,312</td>
<td>204,314.6</td>
<td>31,319.08</td>
<td>N160/litre</td>
<td>5,011,052.8</td>
</tr>
<tr>
<td>6</td>
<td>5,215,367.4</td>
<td>Clarifier &amp; Dryer; Drain &amp; Storage Tanks</td>
<td>60</td>
<td>15</td>
<td>780,000</td>
<td>800,000</td>
<td>301,686</td>
<td>3,814,998</td>
<td>1,400,369.40</td>
<td>35,200</td>
<td>N160/litre</td>
<td>5,632,000</td>
</tr>
<tr>
<td>7</td>
<td>7,032,369.4</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
<td>STOP</td>
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</tbody>
</table>

### CONCLUSION

In conclusion, this research provides necessary logistics towards alleviating the common fears of startup of industries by small/medium scale Nigerian entrepreneurs. It helps the entrepreneur in incorporating the approaches of dynamic programming to sequentially invest in machineries needed, construction of building space and providing working capital to reach the project completion time at the shortest possible time.

### REFERENCES


