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Production-time Evaluation Technique for Small Manufacturing Plants

Small manufacturing plants usually experience challenges of inefficiency and low production yields. These problems have previously been addressed using methods to redesign plant layouts and reduce distance between workstations. Futhermore, assessment techniques like the machine-distance matrix method have then been required to evaluate layout performance. However, these assessments that rely only on distance evaluation are severely limited. In this paper, a new model called Production-time evaluation is presented for evaluating production layout efficiency. It involves computing the estimated time for production at workstations, time for movement between workstations and number of units of a product manufactured. It is then applied on a case study in small furniture plant. The existing layout of the plant was extracted and the production processes for its three products were outlined. A new layout was designed and both layouts were compared using the Production-time methodology, revealing improvements in reduced production time and increased daily production capacity by up to 37% for a product.

Keywords: Plant layout, Optimization, Machine Distance matrix technique, Production, Mathematical Modelling.

1. INTRODUCTION

Small manufacturing plants make important contribution to the technology base and economy in every country. For these plants to operate successfully and profitably, their production processes must be efficiently designed and organised [1-3]. The factors influencing this include raw material management, quality of technology [4-6] and innovation [7]. Summarily, the way resources (man, material, equipment and space) are laid out and managed determines the quality of output achieved.

The situation in developing countries is that many small production plants are faced with challenges that limit their performance. They are usually designed without consideration for efficient plant layouts. In addition, during the production process, poor resource handling results in problems like crisscrossing of materials. Hence, these plants struggle with huge cost of production, inefficiencies, poor yields, unnecessary delays and low revenue generated [8, 9].

To address this problem, techniques are needed to improve manufacturing procedures. It is proven that if the challenges can be identified and analysed, then production optimization can be applied in the plants to improve their output. Using furniture manufacturing plants as a case study, optimization has been carried out to enhance productivity after inherent problems like unorganized process flows, poor documentation, poor handling /control of materials were identified. Significant impro-

vements were achieved in the distance for travel of parts, material handling costs, machinery rearrangement, efficient utilization of space, safety, machinery and labour utilization and profitability [9, 10].List of other methods that have been applied in furniture manufacturing include computer modelling and simulation tools like Promodel, computerized relative allocation of facilities technique (CRAFT), development of matrices for process structure manufacturing and maintenance, formal methods for layout modelling, minimum product travel method and optimization methods like graph theory and genetic algorithm etc. The gains of these techniques include reduction in production cycles, idle times etc [11-14]. Some additional research works employing analytical and intelligent procedures are in [15-22]. Cost reduction is an important goal in manufacturing which is a key factor for sustainability of small to medium enterprises (SME) [23]. Reduction of cost helps to improve process control, waste elimination and improve profit margins. The common areas analysed for improvement and reduction of cost begin from the plant layout. The set-up and maintenance of machines also determine optimal batch sizes for a production run [24].

The emphasis of this research is on improving plant layouts to achieve more efficient production in small manufacturing plants. When an improved layout is designed for a plant, an assessment technique will be required to measure its performance. In this article, a new technique is presented for evaluation of small production plants, which uses production time as the key metric. The aim is to evaluate how long it takes for a unit of each product to be manufactured, from which daily production in the plant can be predicted. From this assessment, the economic viabilities from possible

layouts of the plant under investigation can also be estimated. This methodology is an improvement over the popular distance-based metric [9], which considers only the distance between workstations as evaluation metric.The metric based on time captures not only the distance between, but also the speed of movement between workstations. The technique is applied with positive results on the production layout of a real furniture manufacturing plant that was chosen based on its size. This technique is therefore a practical methodology for improving production processes of furniture plants based on their plant layout and process design, leading to higher production yields.

2. PREVIOUS RESEARCH

Various techniques have been presented in literature for enhancing furniture plants. FlexSim is a simulation tool presented in [14] used to redesign a furniture plant. First of all, the raw material requirements were identified and were divided according to their weights. Furthermore, this information was used for an inventory category technique known as ABC analysis. This revealed the importance of each type of raw material. The second step was to understand the existing process sequence. At every processing stage, the timing required per process was captured using a stop clock. In this way, capacity planning for the new plant was determined. The third step involved creating the layout by considering the available space, process interrelation between two successive departments and the capacity required to achieve the desired output rate. Finally, after the layout design, simulation was carried out by the simulator. When observing the simulation result, the capacity of each workstation and the bottlenecking location were identified and decisions were made on how to revise the plant capacity [14].

In [24], the authors evaluated the layout of a plant which included workstations for cutting, drilling, sanding and joining operations. A conveyor/transport system was used to move the completed products to the storage point. A simulator was used to model the layout and find ways to improve processes, while the input methods considered includedusing lot sequences and batches. Microsoft project was used to examine the implications of scheduling practices on the production time for layout processes. The operational planning model created wasuseful in testing out weekly/biweekly production schedules and to evaluate new cuttings.

Authors in [25] showedthe application of System layout planning (SLP) method to efficiently establish the layout of a productive enterprise. The plant layout problems were generalised into five important elements according to SLP method. They are: a) *Product* (end product, raw material, machining components and projects). b) *Quantity* (amount of production supply, utilization or service workload). c)*Route* (i.e. plant layout diagram, process route diagram, process flow chart). d) *Supporting service* (tools, maintenance, propulsion, deliveries etc), and e) *Time* (when and how long the production is which includes the operating time of every procedure).

The methodology used in this article is an extension of the studiesin [8, 9],where the distance matrix method was used to evaluate three layout models for a furniture plant. This method involves computing the total distance travelled during production based on the distance between workstations and the number of movements between workstations. Improved layouts can be obtained by reducing the distances between workstations to prevent long areas of movement during production. The most effective layout was found to be the one with the smallest total distance travelled. This method also helped to address the problem of crisscrossing during production. However, a challenge with this technique is that it overlooks the time it takes to make a product and considers only the distance of travel.This limitation is overcome through the new evaluation methodologyfor plant layouts presented in the next section that considers the total time required to make a product and estimates the number of products that can be manufactured from a given layout.

3. PRODUCTION-TIME EVALUATION METHODO-LOGY

Some of the common stages involved in typical furniture production include design, selection of raw materials, shearing, drying, fabricating individual parts, polishing, painting and final assembly. During fabrication, the plant layout is important and determines the efficiency of the process. It entails how equipment and facilities within the plant are arranged physically. It specifies the parameters for the production lines, storage facilities and stores, which affect cycle time and performance. When optimized, the chances of production optimization are higher since materials will be handled in a better way and the various distances that equipment and operators move will reduce [14]. A good layout ensures proper utilization of the floor space, reduced material handling costs, reduced hazards to personnel, efficient utilization of labour and improved productivity [25].

Therefore, the technique proposed in this paper aims at ensuring a better evaluation of the layout in a Production plant. This will allow several layouts to be properly evaluated and aid the selection of the optimal layout that will enhance productivity.

3.1 Comparison with Distance evaluation method

There are several benefits in extending the distance matrix method in [8, 9] to develop the production time evaluation technique proposed in this article. The accuracy of analysis is improved since other parameters apart from distance are considered including:

- Time spent at workstation sites (no movement)
- Total time for production captured.
- Equipment for movement between workstations and their speed and its effect on total time of production.
- Combined analysis for different products as against only one product.

3.2 Description of basic parameters

For this research, a unit of operation is chosen for ease of analysis. Let T_u be defined as a *basic* unit of *typical*

time spent at a workstation daily. T_u will obviously depend on the number of staff employed in the factory which determines the average time production activities are carried out per workstation. Therefore, T_u will be considered variable for different production scenarios that will be evaluated. The more staff are hired for production process, the lesser time will be taken at each workstation. T is also defined as the total time taken daily on manufacturing at the factory. If T^p is the time taken daily on each product being manufactured, then T is the sum of T^p for all products. T^p is further broken down into two:

- Time spent daily at workstations or workspaces, T_w^p
- Time taken daily during production to move between workstations or workspaces, T_w^p

where p is the product under consideration.

Therefore:

$$
\begin{aligned}
T &= T^a + T^b + T^c + T^y + T^z \\
&= \left(T_w^a + T_m^a \right) + \left(T_w^b + T_m^b \right) + \left(T_w^c + T_m^c \right) + \ldots \\
&\quad + \left(T_w^y + T_m^y \right) + \left(T_w^z + T_m^z \right)
\end{aligned} \tag{1}
$$

where $\{a,b,c,...,y,z\}$ are the identifiers for all products being manufactured.

3.3 New equation for daily Time spent on a Product, T^p

As earlier defined, for any given product p, the total daily time spent on p is considered as:

$$
T^p = T_w^p + T_m^p \tag{2}
$$

Assuming that for p, there are 'a' workstations and storage points, therefore T_w^p will be composed of 'a' values which can be summarized thus:

$$
T_w^p = \sum_{i=1}^{a} T_i^p \tag{3}
$$

Similarly, the time of movement of p, T_m^p, will be composed of a - 1 steps of movement between each of the workstation pairs from the beginning till the end. Therefore, T_m^p is given as:

$$
T_m^p = \sum_{j=1}^{a-1} N_j^p T_j^p \tag{4}
$$

where N_j^p is the number of movements at step j in producing product p and T_j^p is the time to move materials at step j.

However, T_j^p which is time of physical movement can be considered to depend on both distance and velocity since $\text{Time} = \dfrac{\text{Distance}}{\text{Velocity}}$. Expressing T_j^p in terms of distance and velocity gives:

$$
T_m^p = \sum_{j=1}^{a-1} N_j^p T_j^p = \sum_{j=1}^{a-1} N_j^p \frac{D_{j,j+1}^p}{V_j} \tag{5}
$$

where $D_{j,j+1}^p$ is the distance between the jth and the $(j + 1)$ thworkstation and V_j is the estimated velocity of movement of the material handling equipment at step j.

Therefore, the total time, T^p is given by:

$$
T^p = \sum_{i=1}^{a} T_j^p + \sum_{j=1}^{a} N_j^p \frac{D_{j,j+1}^p}{V_j} \tag{6}
$$

(6) will be generated for each product and the total daily time for all production processes in the plant can be obtained by summing thetotal time computed for each product.

For ease of analysis, T_i^p and V_j in (6) will be expressed in termsof T_u, the basic unit of production time.

3.4 Equation for Number of Units of a Product

A useful derivation from (6) is the estimated number of units of a particular product that can be manufactured in the plant within a duration of time. The number of units of a product 'a', U_a is given as:

$$
U_a = \frac{h_d \times d}{T^a} \tag{7}
$$

where h_d is the number of hours of work in a day, d is the number of work days in a week and T^a is the total time spent on product 'a' in a day as given by (6).

4. PLANT LAYOUT AND PROCESS FLOW IN EXAMINED FURNITURE PLANT: A CASE STUDY

4.1 Description of Plant and Production Processes

The case study is the Production area of a furniture manufacturing plant in Abuja, Nigeria. During inspection, data collected included Products manufactured, Machine positions & distance travelled, Materials Handling Equipment & Flow Paths, Storage space and Operations flow & process times. The threeproducts considered that are manufactured in the plant are Chairs, Beds and Cabinets. The total production area of the plant layout is approximately 1,110.4m^2. In the plant, two different types of materials, i.e.local wood and melamine faced chipboard (MFC) are used for production.

Plant Layout Measurements of the available space were made and setup to show the position of workstation locations as shown in Figure 1. This figure shows both the plant layout and process flows for the three products. The first product considered is theChair. The arrows show how the movements are carried out from one workstation to another in succession till the final storage point. First of all, local woods are taken to the drying section to dry out any water content in them and also betreated of pests. The woods are then taken to the cutting machine where they are cut into different sizes according to specifications, then to the planning machine where their surfaces are smoothened, flattened

and their thickness reduced. Next, they are moved to the thicknesser machine to add thickness to them if needed, then to the turning machine where they are carved into symmetrical objects and different shapes. They are next taken to the sandpaper section for spraying, are allowed to dry and then taken to the upholstery section and the final storage point.

The process description for beds is presented next. The MFC are taken from the warehouse to the cutting machine to be cut according to specifications, then to the edge banding machine to seal up the edges of the board. The next process is to drill holes on the boards at the drilling machine point, then the boards are taken to the coupling section where dowels are used. They are then moved to the local wood section where the inner part of the beds is made using local woods, then to the upholstery section where the local wood is padded for comfort. Finally, they are moved back to the cleaning section, where proper cleaning is done and then the fabricated bed is moved to the storage point, ready for dispatch.

The process of making a cabinet is similar to that of a bed because similar boards are used. In this case, MFC are taken to the cutting machine from the warehouse and cut according to specifications, then they are taken to the edge banding machine to seal up the rough edges. The next process is to drill holes on the boards at the drilling machine point, then the boards are taken to the coupling section where dowels are used at the joints, then to the cleaning section and finally to the storage point.

For each product, the number of movements between workstations are noted. Materials and parts in the plant are moved by trolleys, forklifts and by hands, which are presented in Table 1.

Table 1. Material Handling equipment and Dimensions

Equipment	Dimensions (m) (Length x Width)	Quantity
Forklift	4.50 x 1.40	1
Forklift	3.80 x 1.20	2
Hand		
Trolley	2.40 x 0.80	2
Trolley	2.70 x 1.20	3

4.2 Improved Layout

An improved production layout was designed generating processes where the distances between workstations are significantly reduced, thereby reducing the time taken to produce the different items. Based on the existing layout and the process flows for the three items considered, the following decisions are made to improve the existing layout in Figure 1: a) The door section is moved from the fourth compartment after the drying section to the first. b) The local wood section is moved from the third compartment after the drying section to the second. c) The sandpaper section and the spraying room are moved from the first compartment after the drying section to the third. d) The Upholstery section is moved from the second compartment after the drying section to the fourth.

Generally, the new layout arrangement was specifically carried out after careful consideration of the distances between workstations in the existing layout at use

in the factory. Since the production of chairs involved the highest movements between workstations, the new layout is developed to favour the reduction of connection lines for chair production with a careful consideration on the impact on production of beds and cabinets. The improved layout and process flow diagram is shown in Figure 2.

5. EVALUATION USING TIME-BASED METHOD

For analysis and comparison of the two layouts, the production process of the three products (Chairs, Beds and Cabinets) are analysed. This is based on the proposed Mathematical framework assessing their production time. The parameter considered is the time it takes to make a single unit of each product. This time parameter can be used to estimate the number of products that can be manufactured and by extension the amount of revenue that can be received. For each material movement in the process flow as shown in Figures 1 and 2 for the three products, the equipment used for movement as well as the number of movements in each step are shown in Table 2.
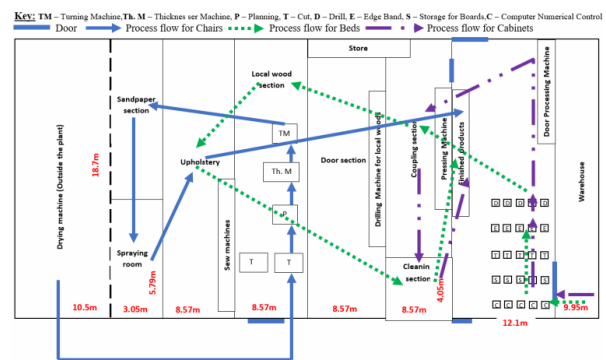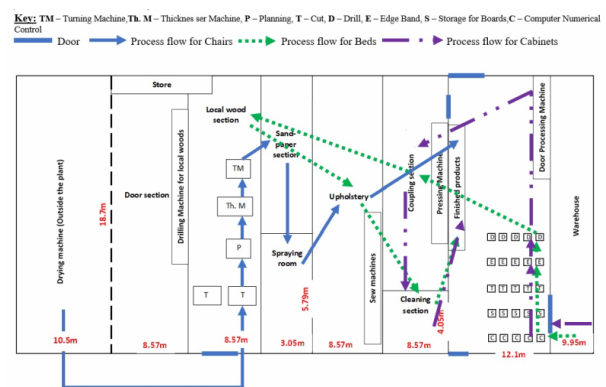

Figure 1. Current Plant layout and Process flows

Figure 2. Modified Plant layout and Process flows

Table 2. Equipment list for each Movement step and number of movements per step

Movement Step	Chair production	Bed production	Cabinet production
1	Forklift(1)	Forklift(1)	Forklift(2)
2	Hand(2)	Hand(3)	Hand(1)
3	Hand(1)	Hand(3)	Hand(1)
4	Hand(1)	Trolley(3)	Trolley(1)
5	Trolley(1)	Trolley(1)	Hand(1)
6	Hand(1)	Trolley(2)	Trolley(1)
7	Hand(1)	Trolley(2)	
8	Trolley(1)	Trolley(3)	

4.3 Production time for Chairs

Based on the description of (2), the time spent daily to produce a chair, T^c is given by:

$$T^c = T_w^c + T_m^c \qquad (8)$$

where T_w^c is the total daily time spent at all workstations used for the chair and T_m^c is the total daily time spent during movement.

To obtain T_w^c which is based on (3), the typical total time spent at any workstation in a day is considered as a basic unit of time given by T_u. For the production of chairs which has 9 workstations, the following were observed: 1 Chair is produced every week (6 working days). Therefore, the equivalent quantity of Chair produced in a day is $\frac{1}{6}$. All workstations apart from Upholstery take almost equal time equivalent to T_u, i.e eight workstations take time $8T_u$. Time for Upholstery, T_{us}^c takes three times the time in each of the other workstations, i.e $3T_u$. Therefore:

$$T_w^c = \frac{1}{6} \times \left(3T_u + 8T_u\right) = \frac{11T_u}{6} \qquad (9)$$

To obtain T_m^c, (5) requires that during production, the equipment used for each movement between workstations as well the number of movements in each step should be noted. These are obtained from Table 2. (5) also specifies the estimated velocity of moving each equipment as a parameter to compute the time of movement. The estimated velocity for each movement equipment (Forklift, Trolley and Hand) can be expressed in terms of T_u, derived based on current information from the plant, as follows:

- It takes approximately 50 times less than T_u (the time spent on one workstation) to move items in the forklift by 1m, therefore the velocity of movement with a forklift is $\frac{1}{T_u/50} = \frac{50}{T_u} m/s$

- It takes approximately 30 times less than T_u to move items in the trolley by 1m, therefore the velocity of movement with a trolley is $\frac{30}{T_u} m/s$

- It takes approximately 15 times less than T_u to move items by hand for 1m, therefore the velocity of movement by hand is $\frac{15}{T_u} m/s$

These are summarized in Table 3. T_m^c is computed from (5) by using these derived velocities, extracting the number of movements from Table 2. and using the distance between workstations obtained from Figure 1 (for the current plant layout) and Figure2 (for the improved layout).

Table 3. Velocity of Movement for Equipment

Equipment	Velocity(m/s)
Forklift	$50/T_u$
Trolley	$30/T_u$
Hand	$15/T_u$

4.4 Production time for Beds

This is derived using a similar process to the chairs. T^b, T_w^b and T_m^b represent the time spent daily to produce a bed, the total daily time spent at all workstations used for the bed and the total daily time spent in movement during bed production, respectively. To produce beds, 9 workstations are involved as shown in Figures 1 and 2. The following are noted from current production: 2 beds are produced daily, all workstations related to bed production take almost the same amount of time equivalent to $0.5T_u$ except coupling, i.e eight workstations take time equivalent to $4T_u$. Coupling time takes thrice the time in each of the other workstations, i.e $1.5T_u$. Therefore:

$$T_w^b = 2 \times \left(4T_u + 1.5T_u\right) = 11T_u \qquad (10)$$

4.5 Production time for Cabinets

Similarly, T^a, T_w^a and T_m^a are derived for the case of cabinets. To produce Cabinets, Figures 1 and 2 show that 6 workstations are involved. The following information is noted: 6 cabinets are produced daily. All workstations related to Cabinet production take almost the same amount of time equivalent to $0.5T_u$, except Coupling and Cleaning, i.e four workstations take $2T_u$. Coupling time takes twice the time in each of the other workstations, T_u and Cleaning time, takes 1.5 times the time in each of the other workstations, i.e. $0.75T_u$. Therefore:

$$T_w^a = 6 \times \left(2T_u + T_u + 0.75T_u\right) = 22.5T_u \qquad (11)$$

4.6 Analysis of Time for movement between workstations

T_m^c, T_m^b and T_m^a are defined as the total movement time during the processes of making chairs, beds and cabinets respectively. This refers to the three movement paths shown in Figure 1 (for the current layout) and Figure 2 (for the modified layout). Recall that T_u is the basic time unit that relates both time spent at workstations and during movements. The value of T_u is considered to depend on factors like the number of staff at a workstation and quality of equipment. For example, if the number of staff at a workstation increases or if more sophisticated equipment are used at a workstation, then T_u will likely decrease. However, the scope of this research does not cover analysis of the impact from labour and equipment quality. Rather, the focus is to investigate the effect of T_u on T, (total time of daily production activities defined in (1).Consequently, the basis for analysis in this work is to vary T_u and study the resulting effect on T. First of all, the realistic range of values for T_u is calculated. From (1), T for this plant is:

$$T_m^c, T = \left(T_w^a + T_m^a\right) + \left(T_w^b + T_m^b\right) + \left(T_w^c + T_m^c\right) =$$
$$= \frac{11T_u}{6} + 11T_u + 11T_u + T_m^a + T_m^b + T_m^c \qquad (12)$$

Let $T_m = T_m^a + T_m^b + T_m^c$. Therefore:

$$T = 35.33T_u + T_m \qquad (13)$$

T, the total time spent daily on production in the factory is 9 hours (9 × 60) minutes excluding a 1hour break. Therefore the range of possible values for T_m are:

$$T_m = T - 35.33T_u = 9 \times 60 - 35.33T_u \qquad (14)$$

Figure 3 shows two plotsgenerated from (14) as T_u is varied according to the range $2 \le T_u \le 18$.
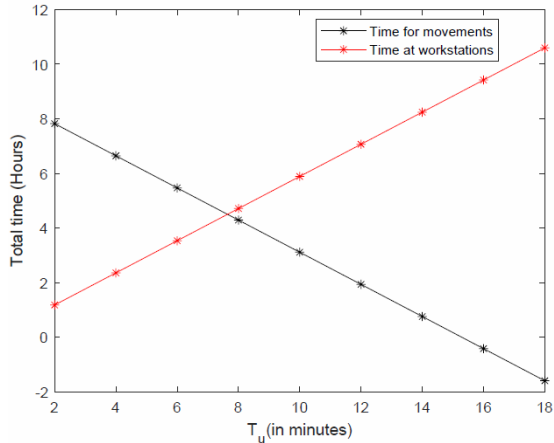

Figure 3. Total time for activities at workstations & during movements based on available working time in a day

The first plot is of $35.33T_u$ in hours versus T_u in minutes to show the relationship between total time spent at workstations and T_u. The second plot is of T_m in hours versus T_u in minutes which gives the result for time spent in movement between workstations. The plots have different slopes because both parameters plotted are constrained by the fixed daily time for work (T), hence the more time is spent at workstations, the less time is spent during movements and vice versa. For analysis and optimization, it is important to select a realistic range of values for T_u. From the above graph, the realistic range of T_u is obtained when $T_m > 0$. Therefore, the selected range of T_u for analysis in this research is $2 \le T_u \le 14$.

6. RESULTS AND DISCUSSION

Having isolated the realistic range for the unit of time (T_u), (13) is expanded based on (6) as:

$$T = 35.33T_u + \sum_{j=1}^{8} N_j^c \frac{D_{j,j+1}^c}{V_j^c} + \sum_{j=1}^{8} N_j^b \frac{D_{j,j+1}^b}{V_j^b} + \\ + \sum_{j=1}^{6} N_j^a \frac{D_{j,j+1}^a}{V_j^a} \qquad (15)$$

where $D_{j,j+1}^c$, $D_{j,j+1}^b$, $D_{j,j+1}^a$ refers to the distance between the jth and $(j + 1)$ th workstations in sequence for the manufacturing processes of chairs, beds and cabinets respectively as obtained in Figures 1 and 2. $T_{existing} = 51.73T_u$, N_j^b, N_j^a are the number of movements at step $j$during the production of chairs,

beds and cabinets respectively as outlined in Table 2. V_j^c, V_j^b, V_j^a are also the velocities (from Table 3) of equipment at step j during the production of chairs, beds and cabinets respectively as outlined in Table 2. For the current layout in the plant shown in Figure 1, the total time for the three products is:

$$T = T_{existing} = 35.33T_u + T_u \left[\frac{35.6m}{50m/s} + \frac{2 \times 3.12m}{15m/s} \right] + \\ + \frac{3.12m}{15m/s} + \frac{3.12m}{15m/s} + \frac{14.38m}{30m/s} + \\ + \frac{9.36m}{15m/s} + \frac{10.9m}{15m/s} + \frac{32m}{30m/s} \right] + \\ + T_u \left[\frac{21.38m}{50m/s} + \frac{3 \times 9m}{15m/s} + \frac{3 \times 3m}{15m/s} + \\ + \frac{3 \times 15.4m}{30m/s} + \frac{17.4m}{30m/s} + \\ + \frac{2 \times 17.92m}{30m/s} + \frac{2 \times 35.4m}{30m/s} + \\ + \frac{3 \times 21.97m}{30m/s} \right] + T_u \left[\frac{2 \times 21.38m}{50m/s} + \\ + \frac{9m}{15m/s} + \frac{3m}{15m/s} + \frac{15.4m}{30m/s} + \\ + \frac{20.19m}{15m/s} + \frac{21.97m}{30m/s} \right.$$

$$T_{existing} = 54.72T_u \qquad (16)$$

For the modified layout for the plant as depicted in Figure 2, the total time for the three products is:

$$T = T_{existing} = 35.33T_u + T_u \left[\frac{32.57m}{50m/s} + \frac{2 \times 3.12m}{15m/s} \right] + \\ + \frac{3.12m}{15m/s} + \frac{3.12m}{15m/s} + \frac{5.81m}{30m/s} + \\ + \frac{9.36m}{15m/s} + \frac{5.81m}{15m/s} + \frac{14.85m}{30m/s} \right] + \\ + T_u \left[\frac{21.38m}{50m/s} + \frac{3 \times 9m}{15m/s} + \frac{3 \times 3m}{15m/s} + \\ + \frac{3 \times 15.4m}{30m/s} + \frac{20.19m}{30m/s} + \\ + \frac{2 \times 11.62m}{30m/s} + \frac{2 \times 14.34m}{30m/s} + \\ + \frac{3 \times 21.97m}{30m/s} \right] + T_u \left[\frac{2 \times 21.38m}{50m/s} + \\ + \frac{9m}{15m/s} + \frac{3m}{15m/s} + \frac{15.4m}{30m/s} + \\ + \frac{20.19m}{15m/s} + \frac{21.97m}{30m/s} \right.$$

$$T_{existing} = 51.73T_u \qquad (17)$$

Figure 4 gives a plot of the total time spent at workstations, for movement in the current layout and movement using the modified layout, all plotted against T_u. This was generated from (16) and (17). It can be

observed that more time is spent at the workstations than during movement. There is also a significant time gain using the modified process over the current process. This result shows the proposed layout modifications will generally shorten the time required to manufacture products in the plant. The benefit is that within the time available for work in a day, more furniture can be produced and more revenue earned.
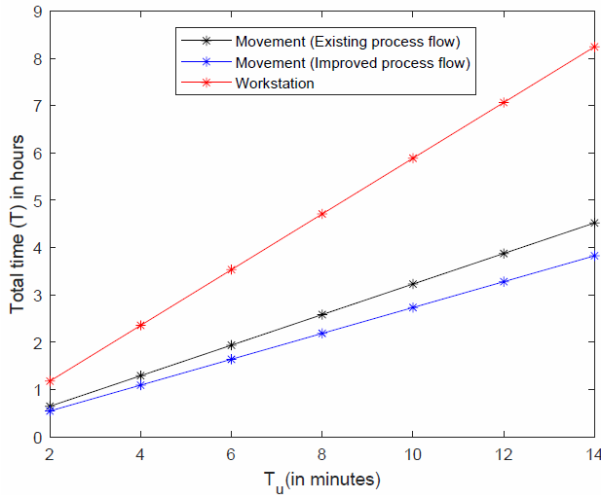

Figure 4. Comparison of time spent in movement and time spent at workstation processes
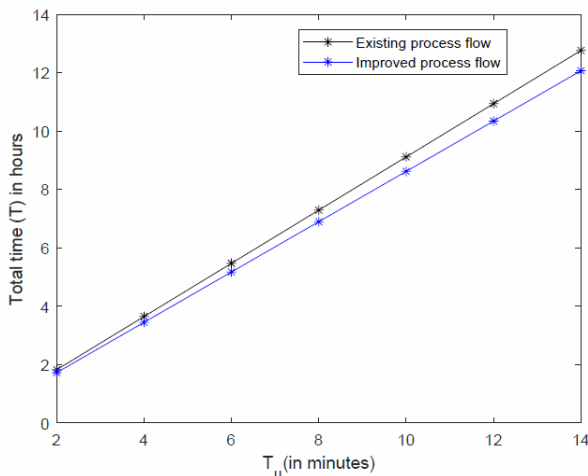

Figure 5. Comparison of total time spent according to current and improved layouts
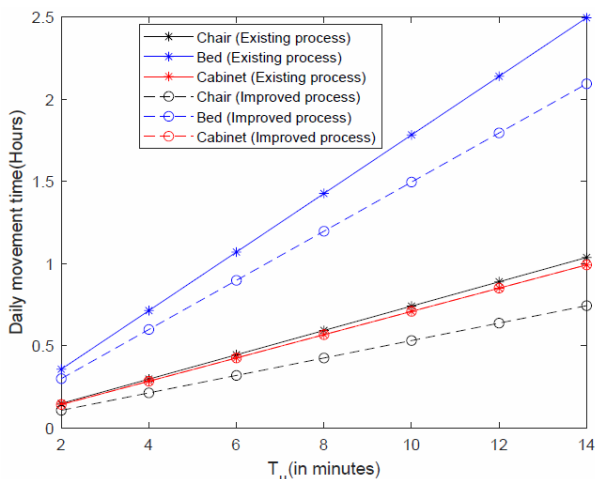

Figure 6. Comparison of time spent to make each product

Figure 5 shows the plots when the combined time at workstations and movements using the two layouts. Contribution from the improved movement in the new layout improves production efficiency. Figure 6 gives a comparison of the improvements obtained for the three products. Whilst there was no difference in the time in manufacturing cabinets, the times for producing chairs and beds were shortened significantly in the new layout.

Finally, (7) was applied to compute the estimated number of units of each product manufactured in a week, which is presented in Table 4. h_d was set as 9 (i.e. for 9 hours of daily work), d was set as 6 (i.e. for 6 days of work weekly). In all cases of T_u, the new layout gives a higher production for both chairs and beds with the maximum gain obtained when T_u =14 where 37% and 17% more units are made for Chairs and beds respectively.

Table 4. Estimated units of products made weekly.

T_u	Chairs		Beds	
	Old layout	New layout	Old layout	New layout
2	302	395	100	111
4	165	222	60	69
6	113	154	43	49
8	86	118	33	39
10	70	96	27	32
12	58	80	23	27
14	50	69	20	23

6.1 Comparison between Distance matrix and proposed Evaluation method

In this paper, presentation has been made on the evaluation of the current layout at a furniture plant and a new layout designed. The evaluation was carried out using a developed time-based technique.

This technique is able to provide useful information about which layout is more efficient.

This research has shown that in practical manufacturing activities, the information for distance alone is not sufficient to accurately describe the efficiency of operation.

This methodology therefore provides the following benefits in layout and process analysis over the methodology of distance matrix presented in [8,9,26]:

- Showing how time is related to the distance between workstations.
- Considering the effect of material handling equipment on the time of production by considering the speed of each equipment.
- Considering the time spent at a workstation in the analysis.
- Considering the time spent in moving between workstations.
- Showing how the time spent in production can be analysed and enhanced.
- Shows how to compare different layouts based on how many products are manufactured.
- Generally, the new method provides more information and deeper analysis about the key factors affecting production in a plant.

7. CONCLUSION

This research has presented a new technique for analysing production plants that captures the time to manufacture products in a holistic way. Furthermore, details of how this technique was applied to a case study furniture plant was shown. An initial visit was made to the plant and data of the production process was obtained including the current plant layout, the products fabricated and the detailed processes for fabrication of each product. This information was detailed using graphs, tables and discussed. Afterward, a new layout was designed for the plant based on some inefficiencies observed in the old layout. Finally, the new evaluation technique was also applied to the improved layout and result graphs show how improvement is achieved pictorially using the basic unit of time spent at each workstation.In addition, the estimated number of units for each product is computed, revealing as much as 37% more units of a product with the new layout.The limitation of this evaluation technique is that some other important parameters affecting production have not been considered in the mathematical model, but have been assumed. This includes the impact of labour and quality of equipment at workstations on the production time. A thorough cost analysis has also not been captured in the scope of this work. However, the mathematical model presented herein is scalable and all these parameters can be incorporated in future research.

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ТЕХНИКА ПРОЦЕНЕ ВРЕМЕНА ПРОИЗВОДЊЕ КОД МАЛИХ ПРОИЗВОДНИХ ПРЕДУЗЕЋА

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Мала производна предузећа најчешће се суочавају са изазовима неефикасности и малим приходима од производње. Овим проблемима истраживачи су се раније бавили изменом просторног распореда погона и смањењем међусобне удаљености радних станица. Процена перформанси просторног распореда погона вршила се методом матрице удаљености машина. Међутим, овакве методе имају ограничења. У раду се приказује нови модел који зовемо модел процене времена производње за процену ефикасности посторног распореда производних погона. Модел обухвата израчунавање процене времена производње у радним станицама, времена потребног за кретање производа између станица и број делова готовог производа. Модел је примењен код предузећа за производњу намештаја. Издвојен је просторни распоред погона и приказан је процес производње три производа. Израђен је пројекат новог распореда и упоређен са постојећим коришћењем методологије производног времена. Утврђено је да скраћење времена производње и повећање капацитета производње на дневном нивоу доводи до унапређења производње производа за 37%.