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Process mapping and optimization of the process flows of a furniture manufacturing company in Zimbabwe using machine distance matrices

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Abstract

Appropriate arrangement of machinery in a manufacturing environment can have a positive impact on the productivity of a company. A detailed work study carried out at a furniture manufacturing company revealed that parts travelled long distances before the final product is produced owing to the positions of machinery and crisscrossing process flows. This paper looks at how the plant layout was re-organized by mapping process flows and regrouping of the machinery according to their functions and products using machine distance matrices. Challenges relating to the plant layout, process flows, materials handling and transportation as well as assembly procedures were established, coupled with grouping machines according to functions and the least distance between interacting workstations. Using the machine distance matrices, processes were mapped and equipment re-organized to allow for continuous flow of production, resulting in significant reductions in transportation distances among interacting workstations and elimination of crisscrossing process paths.

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Keywords: Machine distance matrix; optimisation; plant layout; process flow; process mapping

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1. Introduction

A complex or multi-stage manufacturing system must follow a clearly defined path with very little or no backtracking to produce high quality products within the shortest possible time [1, 2, 3]. The more different products are made at a company, the more process flows there are and it is therefore vital to ensure that the manufacturing plant and process flows are arranged properly, in sequence and logical orders in order to reduce transportation distances and to eliminate backtracking which usually makes the products costly. Adequate documentation facilitates good production planning that include stock records, production/process flow charts, purchases and sales documents, and product knowledge and plant layout [4]. Most manufacturing companies have realized the need to invest in new manufacturing techniques to enhance profitability, competitiveness and efficiency. However those in Zimbabwe have evidently lagged behind in the acquisition of new hardware and systems because of limitations in financial capacity. This was compounded by the global recession that affected many economies from 2008 especially in Sub-Saharan Africa because of weak global linkages [5]. Most companies in Zimbabwe at that time were faced with closures and liquidations with the few remaining, operating below capacity. A work study carried out at one of these companies in Harare revealed a number of flaws in the manufacturing plant such as crisscrossing and backtracking of process flows resulting in long distances travelled by parts during production, old and obsolete equipment, some of which were still in use and thus creating bottlenecks in production and excessive use of certain machines leading to frequent breakdowns. In view of the lack of financial capacity to invest in new machinery or systems such as Automated Guided Vehicles (AGVs), a simple and affordable but unique technique of machine distance matrices was developed to assist in the rehabilitation of the company following the 2008 recession. This paper reports on the work undertaken at the company with the aim of reorganizing the plant layout and related process flows in order to reduce the distances that parts travelled and thereby eliminating backtracking, ultimately resulting in the effective utilization of space and machinery, simplification of the production processes and improvement in throughput times.

2. Process mapping and optimization literature review

The positions of machinery in a manufacturing environment have to be arranged in accordance with well-documented and single direction process flows to avoid any backtracking and crisscrossing of process paths, hence the need to map processes and their respective flows. Sometimes it is difficult and complex to visualize an entire system in a manufacturing environment because of the proximity of the individual processes. Understanding what a business does and how it does it, requires documenting the inputs, processes, outputs and resources [6]. Process mapping is an analysis of a process flow by distinguishing how work is actually done from how it should be done, and what functions a system should perform from how the system is built to perform those functions [7]. Using this method, the relationship, interconnections and process flows are grouped as a collection of elements to enable visualizing the entire operations and processes together and can conveniently make required adjustments to optimize the flows, an approach commonly employed in systems thinking. Process mapping enables manufacturers to easily identify the sequence of activities through processes that cut across the functional boundaries [8]. Three primary stages in mapping processes are usually followed, i.e. identifying sequences of activities, diagnosing the activities for bottlenecks and redundancies as well as considering a course of action to enhance the production processes and flows [9]. Process mapping techniques also need to support users to decide whether one or several service components can substitute a product component and how this can be achieved [10]. There are several case studies that reveal the success of process mapping such as Kraft Maid Cabinetry, America's second largest cabinet manufacturer. Prior to reconfiguring production, drawer parts would travel a total of 208 miles, crisscrossing throughout the company's 1.2 million square foot plant. Components were cut in one area, holes drilled in another, joints machined in another area and finishing occurring far from where the drawer components would be assembled [11]. Process flow mapping has also been widely used for manufacturing optimization where it allows the user to observe the 'as is' scenario and use the information to benchmark for improvements in the manufacturing environment [12]. Process mapping allows for capturing materials and subsequently waste from manufacturing processes e.g., as a value stream mapping tool that enables organizations to work towards eliminating waste, maintaining inventory control, product quality improvement and financial and operation control [13]. Increasing global competition has compelled many manufacturing organizations to relook at their manufacturing systems in order to produce at the shortest possible time in efficient ways and reduced cost while coping with demand fluctuations in the market [14]. This trend has pushed some to redesign their systems resulting in techniques such as Value Stream Mapping (VSM), an important tool for lean manufacturing [15]. Similar research was carried out where a future state map was developed over a current state map leading to the design of a lean process flow through the elimination of the root causes of waste and finally process improvements [16]. However both researches were limited to single product lines whereas this research was for multi-product manufacturing where the technique of machine distance matrices is generic and can be applied to different lines of production at the company. A model was developed to cater for a multi-product manufacturing system where its application was tested through simulation and proved to be quite useful for the control and analysis of design of process layouts [17]. However the model did not have the capability of scheduling individual jobs as this would require incorporation of parameters such as fixed machine utilization rates, machine setup, blocking and waiting times.

Plant layout design involves planning an optimum arrangement of industrial facilities, including personnel, equipment, storage space, materials handling, along with the design of the best structure to contain these facilities through product, process or fixed position layouts [18]. From time to time, plant layouts in a manufacturing environment are altered to satisfy production requirements such as product design changes that may result in the sequence of process changes while the same machines are maintained for production. The acquisition of new machines may also require reorganizing the plant layout to meet space requirements or changes in production flows. Optimization in general involves finding alternative ways with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones. One of the most commonly employed techniques in optimization is modelling and simulation where different alternatives are experimented on by evaluating and solving business problems using linear programming as the foundation technique [7]. This paper looks at both the quantitative and qualitative techniques but dwells more on the quantitative technique by experimenting on physical locations of machines and the transportation distances among interacting workstations. Owing to product complexities and market turbulences, manufacturing firms are continuously exploring new methodologies and tools that support and assist in their decision-making to radically and holistically enhance resource efficiency for more sustainable design of products, processes and production systems [19, 20].

3. Work study and as-is-analysis at case study company

The case study company is located in the heavy industrial sites of Harare in Zimbabwe and specializes in the manufacture of a wide variety of domestic and commercial furniture as well as industrial timber products using both soft (pine) and hardwood (teak and mahogany) as shown in the sample products in Fig. 1. As evidenced by the number of parts and accessories on these products, parts go through various stages and workstations until a product is complete.

(a) (b) (c)

Fig. 1. Some of the company's timber products (a) bunk bed (domestic); (b) office desk (commercial); (c) pallet (industrial).

A work study was carried to establish the operational setup, machines available and their arrangement, process flows and sequences of operations, documentation available and skills and expertise in each unit. Understanding why a particular process is performed in a particular way will permit the elimination of non-value added work during production [9]. The factory layout for the entire complex at the inception of research is given in Fig. 2 showing the production flow for bunk beds from the timber yard to dispatch. The figure shows the various numbered workstations and the key to the numbered machines and their functions is provided in Table 1.

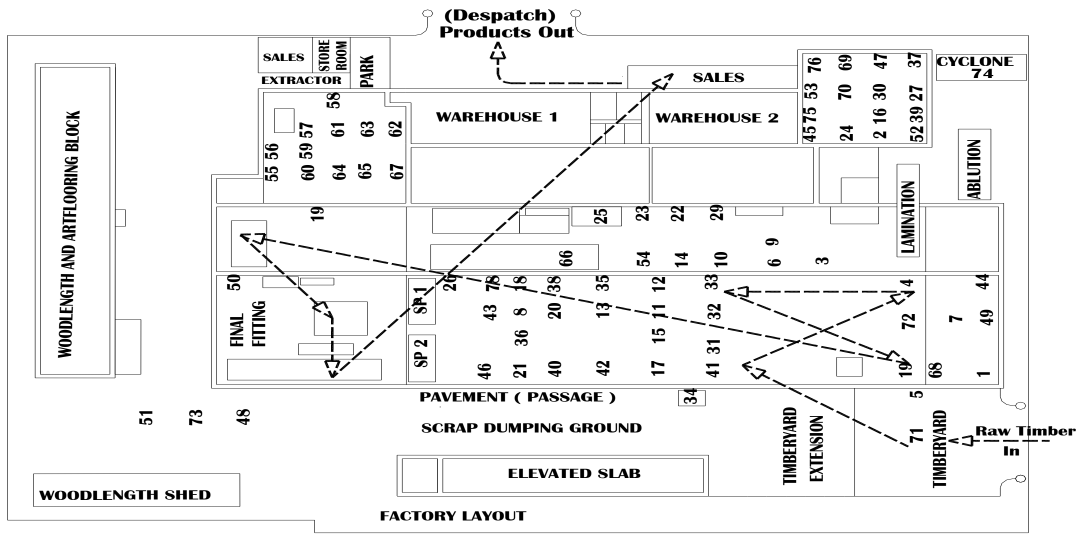

Fig. 2. Factory layout at inception of research.

Table 1. Key for machines in Fig. 2 and their functions

Machine number	Machine name	Machine functions
1, 2 & 9	Ripsaw	Ripping
3 & 7	Surfacer	Edging/planing/surfacing
4	Thicknesser	Thicknessing/planing/
5, 12, 23, 39, 41, 43, 50, 65 & 71	Cross cut saw	Cutting/Sizing
6	4 cutter	Planning/t&g/f-joins
8	Precision saw/cross cut saw	Ripping/cutting/shaping
10, 64 & 70	Radial arm saw	Bevelling/cutting/trenching
11	Multiborer	Boring
13, 14, 15 & 29	Spindle moulder	Rounding/rebeting/tennnoning/trenching
16, 40 & 55	Bendsaw	Cutting/Shaping
17 & 59	Router	Mortising
18	Doweling machine	Dowelling
19, 35 & 36	Drum sander	Sanding
20	Tennoner	Tennoning
21, 42, 62 & 66	Drilling machine	Drilling
22	Cross cut saw(small)	Cutting
24	Disc sander	Sanding
25	Sewing machine	Upholstery
26	Dowel moulder	Doweling
27	Grinder	Grinding
28	Press table	Joining/pressing
30, 49, 52, 60 & 68	Ripsaw/precision saw	Ripping/cuttin/shaping
31	Dimension saw	Cutting
32	6 cutter	Planing/surfacing/thicknessing/ripping/t&g/f-joins
33	5 cutter	Planing/surfacing/thicknessing
34	Dust extractor	Extraction of dust
37	Mortiser	Mortising
38 & 74	Centre Lathe	Shaping/turning
44	Planer/Thicknesser	Cutting
45	Surfacer	Planing/thicknessing
46, 54 & 58	Belt sander	Planing/surfacing
47 & 53	Surfacer/Thicknesser	Sanding
48 & 73	Press machine	Press Fitting
51	Web saw	Cutting/bevelling
56	Mortiser	Mortising
57 & 63	Spindle	Moulding
61	Louvre machine	Shaping
67	Press	Press Fitting
69	Laminating machine	Laminating
72	Multi cutter	Planning
75 & 76	Ingersol rand compressor & Standby compressor	Provision of compressed air

The 'as-is-analysis' involved establishing the company's procurement process, plant layout, manufacturing and assembly operations, process paths and flows, product groups and analysis of problems that the company was facing over and above the backtracking and crisscrossing of process paths. Obsolete and old machines that frequently broke down contributed to poor quality products and delays in meeting customer orders. The final fitting area was originally located adjacent to one of the machine shops and was thus exposed to dust which spoiled some of the vanished products, requiring further polishing before dispatch to customers. The spray shop was also originally located close to the other machine shops and was not completely covered, thus posing a health hazard to workers because of fumes.

4. Research methodology and plant layout analysis

4.1. Product assembly trees

Having established the plant layout and processes the next task was to develop product assembly trees for the company's main products. A method of front to back (dispatch warehouse to timber yard) was used by picking a product and in consultation with the production and costing departments, a detailed bill of materials was drawn up, including the quantities for each component that make up the product. A typical product assembly tree is illustrated in Fig. 3, showing the components for the assembly of a bunk bed as well as the quantities for each item in {}.

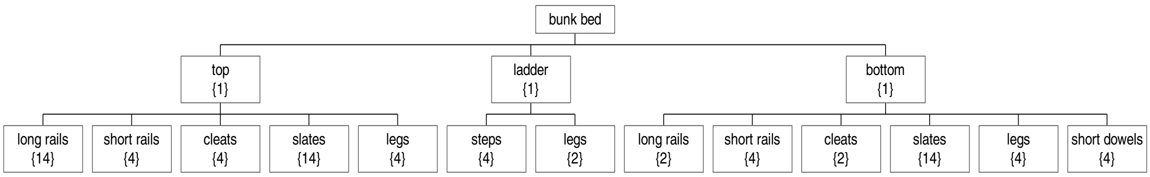

Fig. 3. Product assembly tree for a bunk bed.

4.2. Plant layout and process flows

The approach taken in the layout and process flows involved constructing a model incorporating the relative positions of all machines in the factory. Using the product assembly trees, the process paths through which each component travelled were traced, noting the distances from the Timber Yard through the various workstations until it is fitted to another component, at which point it assumes a new identity, the process path of the subassembly of which was also traced through the next stage until all the parts were accounted for in the final product. Bottlenecks observed at machines such as the multi-borer, 11 and drum sander, 35 were due to the high demand for the two machines, pointing to insufficiency in their numbers. The long transportation distances among interacting workstations were the major drawbacks that needed to be addressed through reorganization of the plant. The various activities were broken down into sub-processes to enable a close analysis at each workstation. Movement of materials between workstations was largely dependent on their bulkiness, with forklifts and trolleys being used at the beginning and manual handling in the assembly areas. A typical production flow process for the machining of the bunk bed legs is illustrated in Fig. 4.

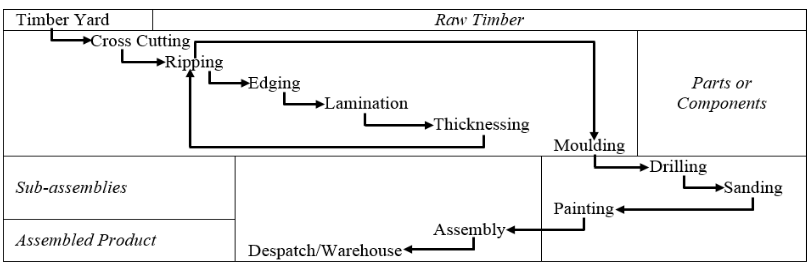

Fig. 4. Production flow process for bunk bed legs.

4.3. Machine distance matrix for interacting workstations

Transportation distances among interacting machines were measured and recorded in the form of a matrix such as shown in Table 2 after reorganization. Reducing the distances among interacting machines enabled parts to be shifted from one workstation to another without having to wait for a full trolley, although the least time in these segments was the transportation time.

Table 2. Machine distance matrix (transportation distances (m) among interacting workstations) – reorganized layout

W.S.A.	T.Y.	1	7	9	11	12	13	14	16	20	26	29	31	35	46	53	55	60	63
T.Y.		11.01	19.01																
1	11.1		3.2																
4	29.6	13.2	4.2	3.5		30.6					37						53.9		
6	29.4	15.8		15.8		31.7		17.8											
7	19.0	5.8				42.2													
8			18.5			22.8				22.7				30.1					
10				2.6								6.9		13.2					
11						6.3	2.6												
12			34.9		6.9		3.2		13.2	5.3									
15						12.1	6.9		4.22	6.9									
17							3.2							14.3					
18					9.5	9.5	7.9		9					12.1	16.9				
21					13.2		8.5							2.6	5.3				
35							7.9			5.3					5.3				6.9
38					19.5	7.9													
41	2.6	7.9	14.6											5.3				6.9	
46					23.2		18.5							5.3					
53																		2.6	
55						58.2	56.5									13	11.6	5.3	
65																5.3	6.9	5.3	
H.S.							22.1					2.6			5.3				
F.F.																	23.8		
W.T.																			
C.B.								7.4						18.5					
F.A.							7.4							18.5	40.7				

Key: T.Y. – Timber Yard, H.S. – Hand Sanding, C.B. – Cross Buttons, L – Lamination, F.F. – Final Fitting, W.T. – Water Treatment, W.S.A. – Workstation or Area

5. Process mapping and optimization

Based on the transportation distances and the frequency of interaction among certain workstations, the plant was reorganized using functional departments and machine positions. Machines that were used for secondary processes such as the spindle molder, 13 and multi-borer, 11 were grouped together to form the core of the machine shop while the cross-cutters were also grouped for products such as pallets. The storage area for boards was centrally located close to the assembly of domestic furniture where the products utilized plywood, bison boards and Masonite. The cross cut saw, 41 and multi-cutter, 6 were relocated close to the Timber Yard. The orientation of the multi-cutter, 72 was placed parallel to the other multi-cutters, 32, 33 and 6 to allow for free movement of the trolleys without interferences. The transportation distances were recomputed and compared to the original matrix. An example of such comparison is illustrated in Table 3 for the main components of the bunk bed. The comparisons were carried out for the components of the company's main products and showed an average of 43% reduction in transportation distances, an improvement in the overall production process, implying an improvement in throughput time, productivity and efficiency. Fig. 5 is a schematic of the reorganized plant showing the functional groups and products.

Table 3. Comparison of component travel distances (m) for bunk beds

Component	Top	Bottom	Ladder	Slates	Rails	Legs
Original layout	253.3	220.3	50.7	57.0	92.4	85.0
New Layout	125.2	130.4	26.4	25.9	63.4	58.1
% Reduction	50.6	40.8	47.9	54.5	31.4	31.7

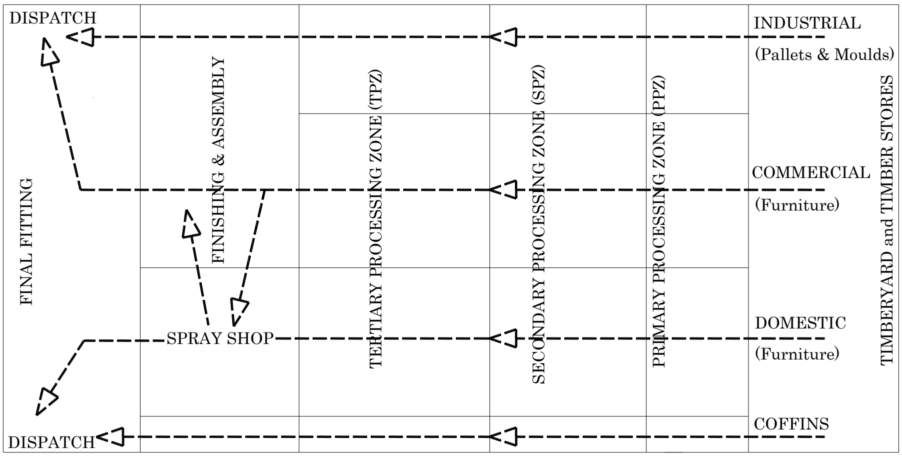

Fig. 5. Reorganised plant in functional groups

6. Discussion and recommendations

The implementation of the reorganized layout required cooperation and commitment from all stakeholders, particularly management as they always attached costs to changes. The tendency from artisans demonstrated some form of resistance initially but with time, they realized that the reorganized plant was a much more comfortable setup and they were able to produce more than before. The reorganization and removal of obsolete and non-functional machines also reduced the amount of backtracking and crisscrossing of process flows and created a safe working environment. The transportation distances for the components were calculated from the machine distance matrices and compared. The sanding, assembly, finishing and final fitting regions were placed close to each other. The 4 spray paint shops were decentralized to the different departments of the company for easy access while each department was allocated a spray paint shop specifically for its products, thereby reducing congestion at the painting area. A number of recommendations were made along with the reorganized plant. These included; the improvement in the dust extraction system since some of the machines like multi-cutter, 33 and thicknesser, 44 produced a lot of dust and noise, thus the need to fit effective dust suction pumps and noise dampers. Machines that were used for cable drums e.g. drilling machine, 36, and the mortising machine, 37 can be repositioned for use by other departments. These can be connected parallel to the drill machine, 17 in the machine shop core to serve as an alternative. All redundant and obsolete machines such as the radial arm saw, 70 can be disposed of thereby creating more space in the plant. Machines that break down frequently, presumably because of overuse, such as the multi-cutters may need to be augmented by additional ones while a proper planned maintenance is prioritized for these. The use of these machines, being equipped with the cutters required, can replace operations carried out by the rip saw, 1, thicknesser, 4 and surfacer, 7 thus saving a lot of production time. Material transportation by hand can be minimized by acquiring more trolleys, which should be allocated to various departments accordingly, also in view of the cleared gangways. Adequate workbenches may be set on various workstations to avoid too much work in progress on the floor and gangways so that processed parts are quickly removed from the workstations. Most assembly and final fitting tools were inadequate and the operations in these areas were mostly manual. The company could consider automating some of the operations in these areas by investing in modern machines as well as acquiring more hand tools.

7. Conclusions

The relocation of various departments ensured a continuous production flow, improving the production throughput times and hence meeting customer orders on time. The relocation of various machines and disposal of obsolete and redundant equipment cleared the gangways leading to reduced interferences and a safe and free working environment. Materials movement can be improved by acquiring more trolleys or investing in an automated conveyor system. There is an expected reduction in assembly time due to in-line quality control and purchase of more assembly tools. The layout proposed is inclined to the product layout approach where components are cut in one area, machining operations carried out in another area (machine shop), while finishing and assembly is done in areas close to the dispatch. The transportation distances were reduced by an average of 43%, resulting in a reduction in transportation costs through the reorganized plant, using machine distance matrices among interacting workstations.

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