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A STRUCTURED APPROACH TO DESIGN A HYBRID CELLULAR LAYOUT FOR JOBSHOP

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Abstract

Facility planning is a strategic issue in manufacturing planning. A well-designed facility layout will facilitate the production flow, simplify handling of materials, and ensure product flexibility. In production environment, where product mix changes and demand volumes fluctuates, a hybrid cellular layout that includes cell layout and functional groups is probably the most appropriate. Designing a hybrid layout however is a complex problem. This article presents a structured approach to choose appropriate design for a hybrid cellular layout. The approach is a combination of tools and algorithms that covers the whole facility planning process from data collection, cell formation (Family formation), cell layout and shop layout. One case study where the approach was successfully applied to improve material flow is also introduced.

I. INTRODUCTION

Facility planning is defined as a process to determine the physical organization of manufacturing system. Facility planning is considered a strategic issue in manufacturing industry as it directly affect material, work and information

Key words: jobshop, facility planning, layout, cellular manufacturing, cell formation, hybrid manufacturing system, hybrid cellular layout.

flow through the manufacturing system. Many studies have shown that from 20 to 70 percent of the total operating expenses in production are attributed to materials handling costs and effective facility planning could reduce these costs by 10 to 30 percent annually [1,2].

The main output of facility planning is a block layout that specifies the relative location of each facility. In practice, there are 4 main types of layout design in production system: process (functional) layout, product layout, fixed-position layout and cellular layout [3]. In past decades, due to the emphasis on lean practice throughout the world, facility planning using cellular design increasingly becomes popular [4]. Manufacturing systems that are based on cellular layout have shown to help in reducing the material handling, work-in-process, setup time, and lead time and improve productivity, operation control, etc. [5].

Cellular manufacturing system however does not perform well in every situation. When the variability and uncertainty of demand is high such as in jobshop environment, the use of pure cellular layout may not be favorable. In this situation, a hybrid cellular layout, where there is a coexistence of a process layout and a cellular layout, could be a better choice. In the past 50 years, facility planning with cellular layout has been the subject of extensive research. Most research has been focused on finding the best algorithm for cell formation (to identify machines and part families)[6,7], or inter-cell layout (to assign cells on the shop floor) [8]. Hybrid cellular layout, despite its widespread usage in practice, has been addressed only in limited past studies [9,10,11].

In this paper, a structured approach is proposed for designing a hybrid cellular layout. The approach is a combination of tools and algorithms that covers the whole facility planning process from data collection, cell formation, shop layout and cell layout. An algorithm is also suggested for identifying cases for hybrid cellular layout. One case study where the approach was successfully applied to improve material flow is introduced.

II. METHODOLOGY

The method for designing hybrid cellular layout consists of 7 steps as summarized in Figure 1.

Step 1 - Data Collection: First, data is collected for layout analysis. 3 main types of data are collected: product data, machine data, and floor plan data. The information for product includes: product type, quantity, price, routing. The information for machine includes: machine type, area requirements, quantity, price, mobility. Floor plan data could be in a form of CAD drawing or sketches drawing showing space availability. In case of redesigning, information on current locations of all manufacturing workcenters/machines and support services is also collected.

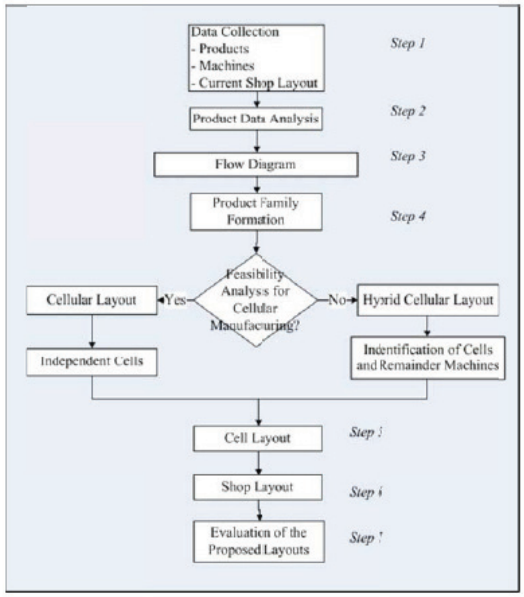

Fig. 1. Structured approach to design a hybrid cellular layout

Step 2 - Product Data Analysis: The objective of this step is to simplify the complexity of the product mix. This step is very important when planning facilities for a jobshop with high mix of product. This will help identify critical product types that should be considered in the process of planning. One of the tools could be used at this step is Pareto analysis [12]. According to the Pareto principle, only 20% of the total product types will account for 80% of the total revenue of operating expense of the manufacturing system, therefore, any layout planning should give priority to this subset.

Step 3 - Flow Diagram: Flow Diagram, which shows the flow lines of all products, is used to evaluate the current layout [12]. Flow Diagram is a good tool to assess visually the complexity of materials flow on shop floor. In this study we use Flow Planner [13], a commercial software that allows working in with CAD drawing, and provides statistics on transportation distance, time and cost.

Step 4 - Product Families Formation: Product families formation is a core issue in facilities planning with cellular layout. Many models and solution approaches have been developed to identify product families and groups of machines to assigned to the cell [6,7]. However, there are only a few studies that considers hybrid case [9,10,11]. In this method, in order to form product families, Production Flow Analysis (PFA) matrix [14] is used with the combination of heuristics (Greedy and 2-Opt) by permuting the rows and columns

PFA matrix to create final matrix [15]. The final PFA matrix is analyzed to determine product families, identify shared machines, Cells, eliminate inter-cell movements, and Non-movement machines. The final PFA matrix is also used as the input for selecting an appropriate design for the final layout. There are two cases:

- *Cellular Layout:* If all cells are independent, or there is no shared machines that could be additionally acquired or split to cells, or there exists no unmovable machines.

- *Hybrid Cellular Layout:* There are a high diversity of product, demand uncertainty, or non-movement machines that can not be placed inside any cell, or expensive equipments that must be shared by many cells.

Step 5 - Cell Layout: In both cases, cellular and hybrid cellular layouts, machines layout for each cell, this layout is performed for cells. A layout of L, U or S shape could be used for cells. The choice of shape is based on the product families assigned to cells. The locations of machines are set using routing information with the objective of minimizing material and operator travelling. This step is facilitated using a software, developed on Quadratic assignment problem and Simulated annealing [15].

Step 6 - Shop Layout: This step provides the location of cells, shared machines and other non-cell machines on the floor plan. Constraints such as available space, shape, the boundaries of shop floor, storage of raw materials, finished products, tool room, space for maintenance, and other support services should be considered. In addition, the size and locations of the input/output points for cells, the transport of materials between cells, and limitation on structural foundation, material handling system should also be taken into account. Software that facilitate cell layout planning in step 5 could be used here.

Step 7- Evaluation of Proposed Layout: The proposed layout is evaluated on total material movement distance, material handling cost, and space saved.

III. CASE STUDY

The proposed methodology is applied to re-arrange the machining shop that is specialized in providing spare parts for a wide range of equipments including engines, agricultural equipments etc. Its products include large-size parts such as drive pulley, main shaft, etc as well as small-size parts such as gears, chains, sleeves etc.

A. Analysis of Existing Layout

The original floor plan is shown in figure 2. The area for planning is 19 x 38 m2. Facilities are functionally arranged, and divided into 5 main areas (marked by a letter on Figure 2). Area A is for large lathing and milling machines. Small milling and grinding machines are located at area B. Area C

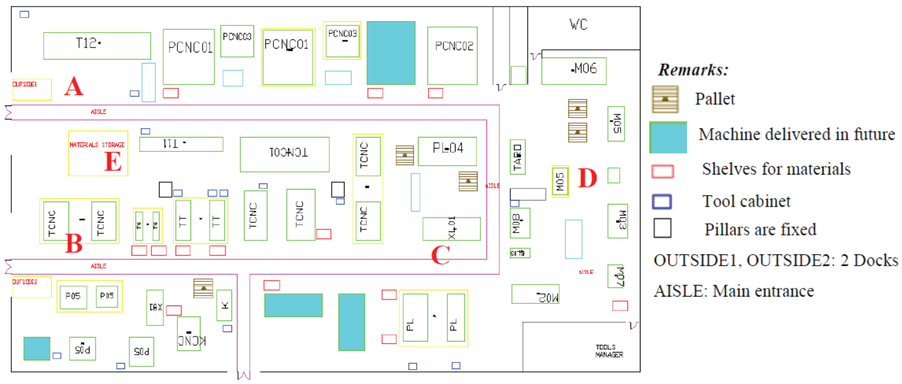

Fig. 2. Current layout

TABLE I. INFORMATION ABOUT EQUIPMENTS

No.	Machine Code	Description	Quantity	Purchase Price
1	T11	Lathe	1	
2	T12	Large Lathe	1	
3	TCNC	CNC Lathe	6	EXPENSIVE
4	PCNC01	Large CNC Milling	2	EXPENSIVE
5	PCNC03	CNC Milling	2	EXPENSIVE
6	TN	Small Lathe	2	
7	TT	Average Lathe	2	
8	TCNC01	Large CNC Lathe	1	EXPENSIVE
9	P05	Milling	4	
10	X01	Slotting	1	
11	XL01	Slotting roller teeth	1	
12	M02	Large Grinding	1	
13	M03	Small Axis Grinding	1	
14	M05	Small Axis Grinding	2	
15	M06	Large Axis Grinding	1	EXPENSIVE
16	M07	Small Axis Grinding	1	
17	M08	Small Grinding	1	
18	PL03	Small Roll Milling	1	
19	PL04	Large Roll Milling	1	EXPENSIVE
20	PL	Roll Milling	2	
21	K	Drill	1	
22	KCNC	KCNC Drill	1	
23	TARO	Cooling Table	1	
24	Outside	Heat, Aluminum, Paint	-	
25	PCNC02	CNC Horizontal Milling	1	EXPENSIVE
26	Crane	Material Handling	4	

(Note: machine 8 and 15 are constrained on non- movement)

has roller mills and slotting machines. Cylinder grinder and tapping machines are kept at area D while area E stores raw materials and finished products. Materials and finished products are transported by cart for small products and large products transported by crane. Details on machines are shown in Table I. Data on 257 product types of the manufacturer is also collected, including production quantity in last 6 months, manufacturing routing, and revenue.

B. Designing shop layout

Pareto analysis is applied to select the critical product types. A subset of 85 product types that accounts for 80.2% of the total revenue of the machining shop. A performance evaluation for the existing layout is carried out using Flow Diagram (Figure 3), we used Flow planner software to generate. Figure 3 shows the complex web of flow lines by 85 main products passing machining routing. The thickness of the flow lines is corresponded to the total values of products.

It is evidently the tangling of flow lines in the existing facility plan. Many

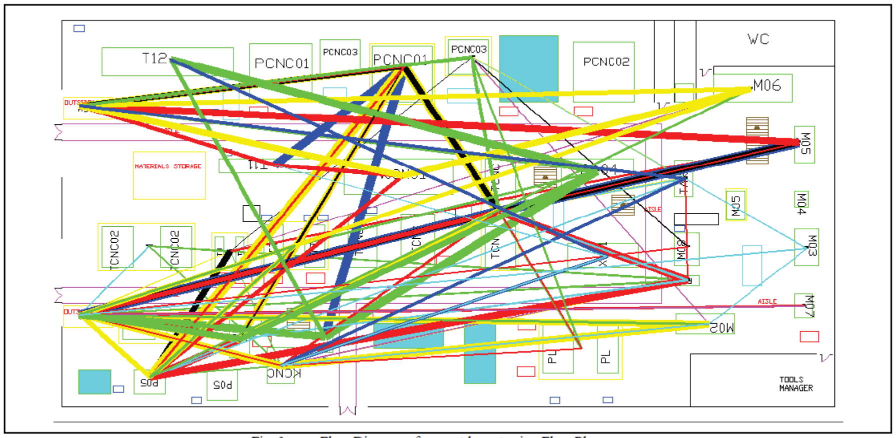

Fig. 3. Flow Diagarm of current layout using Flow Planner

lines are inter-crossed, double-flowed or cut through transportation isles. It is mainly due to the separated location of machines that are consecutive on machining routing. For example, T12→PL04, K→T12, PCNC01→K, M06→Outside, these two consecutive machines are not located near each other, and the products have to move from one area to another area for processing. Moreover, there are many high-revenue flow with long-distance.

To improve the material flow, cellular layout is used for facility preplanning. Step 4 is applied for determining product families and machine groups. Figure 4 displays a part of the final PFA matrix for 85 products. The matrix shows that there are sharing and overlapping between machines: red columns mark no-movable machines, and green columns signify shared machines. By using diagonal block of marker "1" we can identify independent blocks. Each block is defined by a set of consecutive rows and consecutive columns, representing a family of products that could potentially be processed by grouping appropriate machines into a cell.

Step 4 results in grouping product types into six product families and one special group of products that could not completely allocated to any family. This step also identify shared machines, non-movable machines, cells and inter-cell movements. The grouping of machines are:

- Shared machines: TARO, KCNC, TCNC, X01.
- Non-movement machines: M06, TCNC01.
- Cell 1: TCNC, PL03, M08,TN, P05
- Cell 2: M05, TCNC
- Cell 3: M03, PCNC03, TCNC, P05
- Cell 4: K, PL04, T12
- Cell 5: T11, TCNC01
- Cell 6: P05, M06, TT, M02, PCNC01, TCNC.

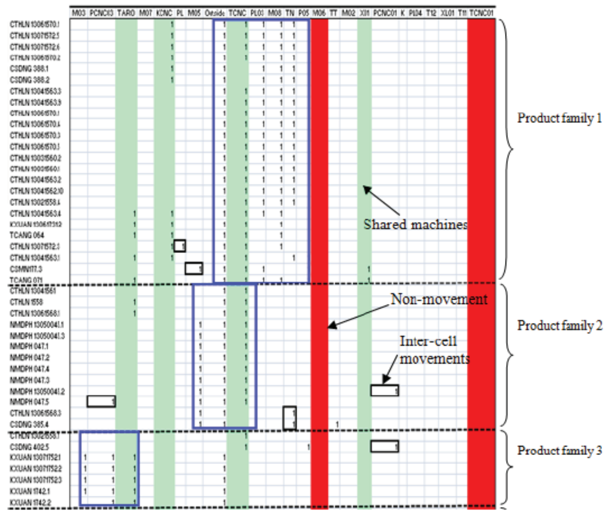

Fig. 4. Final PFA matrix. (Note: only a few families are shown)

- Remainder machines: PCNC03, TCNC, XL01, PL.

- Inter-cell movements: CTHLN13071572.3; CSMN177.3; NMDPH13050045.2; NMDPH047.5; CTHLN13061568.3; CSDNG385.4; CSDNG402; TCANG065.4; CSMN177.2 and CSDNG402.7.

Due to the presence of shared machines and non-movable machines, hybrid cellular layout is used for the shop facility planning. After product families and cells identified, cell layout is implemented. Table II is a typical from-to chart generated from the routing/processing sequence of products and revenue where the aggregate flows between pairs of individual machines were shown for Cell 1.

This chart is the input for finding the optimal location of machines in cell (step 5). Figure 5 gives an example of locating machines in Cell 1. Similarly, machines in cells 2,3,4,5,6 are arranged using Step 5.

After cell layout, shop layout are arranged with locating cells and shared machines on the shop floor. Before allocating cells, constraints and limitation are considered. These constraints include available floor area, built-in aisles, non-movement machines, prescribed location of machines (such as large machines T12, T11, TCNC01 should be arranged near material storage), cell size and the locations of entrances and exits. It results in a primary layout shown in Figure 6.

The arrangement of cells on the floor is implemented in steps. First, Cell 1, Cell 2, Cell 3, Cell 4, Cell 5 and Cell 6 are allocated on the layout. Then, the

TABLE II. FROM- TO CHART TO DESIGN CELL 1

	TN	P05	M08	PL03	Outside	TCNC
TN	x	693,000			35,000	576,068
P05		x			711,500	
M08			x		47,000	
PL03		320,000		x	643,268	
Outside	75,000	66,000	788,268		x	769,560
TCNC				749,868	823,060	x

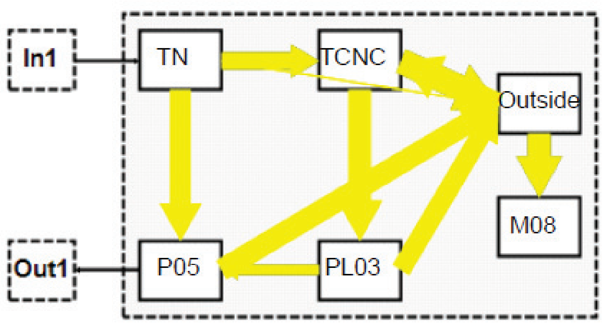

Fig 5. U-shaped layout for Cell 1

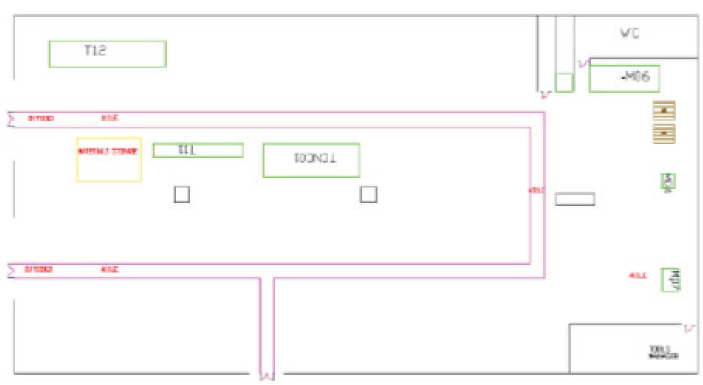

Fig. 6. Floor layout with constraints

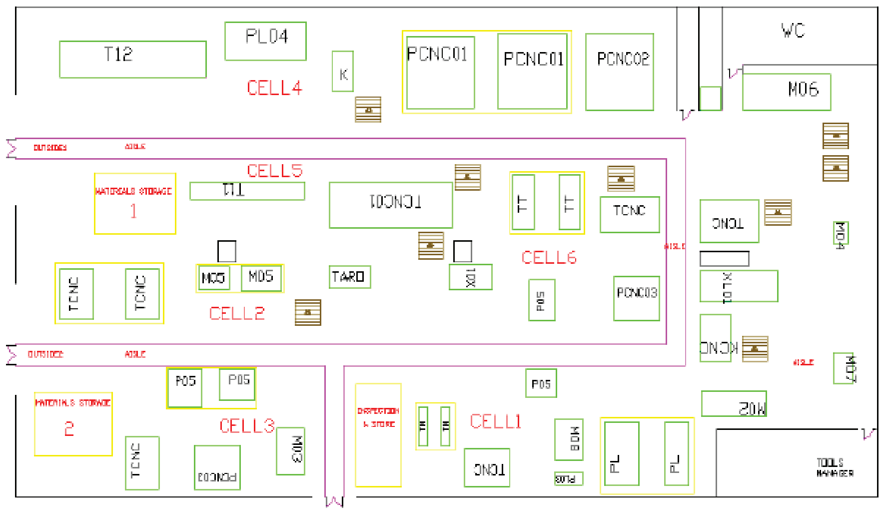

Fig.7. Proposed layout

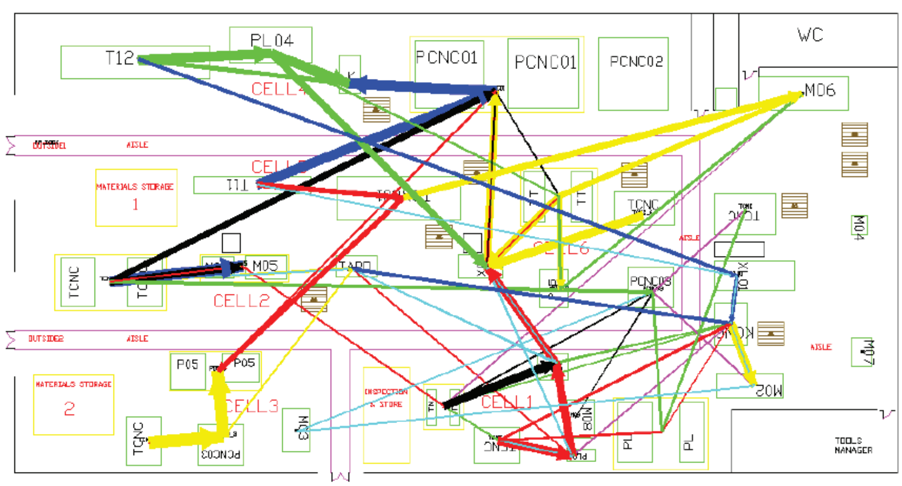

Fig. 8. Flow diagram of the proposed layout using Flow Planner

shared machines and remainder machines are arranged in a particular area in a functional layout. Final, based on flows of inter-cell movements are between cells and this functional group of machines which adjust their positions appropriately on shop floor to transportation distance is the shortest. The proposed layout is shown in Figure 7.

C. Evaluation of the proposed layout

The proposed layout is evaluated by Flow Diagram. Figure 8 is the flow diagram for the new layout. It displays a substantial improvement of material flow. The number of flow lines is reduced with less inter-cross, and thick flow lines are shortened. The performance of the new layout is also assessed quantitatively using the total distance score. The total distance score is calculated by multiplying the matrix of flow and distance between machines. The result of total distance score is as follows:

- Total distance core - Current layout: 426,827,233.24
- Total distance core - Proposed layout: 298,734,755.80
- Reduction in material handling: 30.01%.

Moreover, the new layout utilizes the available space more efficiently by allowing additional material reception area (MATERIALS STORAGE2 is 2.5x3.5 m2 in Figure 7) before Cell 3, and adding an inspection and finished products area (INSPECTION & STORAGE is 4x2 m2 in Figure 7) before Cell 1.

IV. CONCLUSION

This paper proposes a structured approach for designing a hybrid cellular layout for jobshop production. The approach consists of sequential steps from data collection to performance evaluation. The tools utilized in the steps include commercially-available and custom-designed ones. Its main advantage is providing a simple but practical way of facility planning, which is especially needed by the people on the shop floor. It was applied to redesigning facility plan for one jobshop. The result has shown significant improvement of material flow and space usage.

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