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Development of flexible manufacturing system

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Abstract: The focus of this project is the development and analysis of a Flexible Manufacturing System (FMS) for the production of a range of tables. Tables are typically used in homes and offices, where different variants are selected for different environments and uses. By implementing a flexible manufacturing system, different versions of tables can be produced in the same factory to fulfil different customer needs and preferences. This project designed and evaluated four different variants in the FMS, demonstrating aesthetic and functional differences while maintaining core similarities; this demonstrates FMS's flexibility and adaptability and provides insights into the trade-offs between design choices and manufacturing considerations. The article uses Mejabi and Solberg analysis for detailed FMS design and analysis. This analytical approach allows for thoroughly examining the FMS design, including factors such as productivity, efficiency and cost-effectiveness. The analysis further helps understand and optimise the implementation of the FMS to ensure that it effectively meets the production goals. This paper paves the way for enhancing productivity, increasing product range and improving customer satisfaction in the furniture manufacturing industry.

Keywords: Construction Projects, Schedule Optimisation, Market Prospects.

1. Introduction

In this project, a Flexible Manufacturing System (FMS) is developed and analysed for the production of a family of discrete products. The family of products chosen for this project are tables. Tables are a common furniture piece for household and office spaces. Different variants for tables are preferred for different settings and use cases. Therefore, developing a Flexible Manufacturing System (FMS) for manufacturing these will allow for the same facility to produce different variants of the same product to better suit the needs and preferences of the customers.

For this projects purpose, four different variants are designed and analysed for manufacturing in the FMS. The four variants generated vary in overall aesthetics and functionality whilst being similar to each other at the core. In figures 1.1–1.4 below, each variant is depicted with a brief description and difference between each variant. In the subsequent sections of this report, a detailed FMS design is provided alongside analysis of this proposed FMS using Mejabi and Solberg analysis.

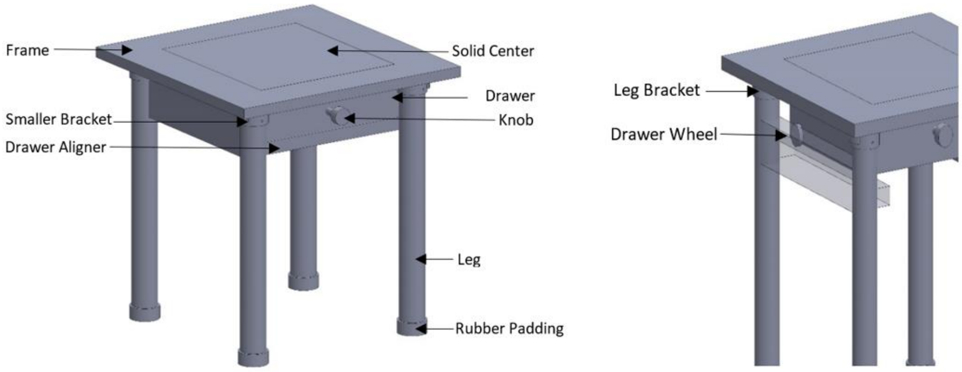

Figure 1. First variant with labelled components.

As can be observed in figure 1, the first/base variant is a square table with four legs and a drawer. The tabletop consists of a solid centre piece and the four legs have rubber paddings attached to them to increase friction and stability. Furthermore, the drawers also include a knob and ball-bearing drawer runners to allow for ease in using the drawers.

Figure 2. Second variant with additional components labelled.

Figure 2 above depicts the second variant of the table with the main variance being in the material of the table-top centre. The centre piece of the table in this variant is now a tempered glass panel which gives a fancier appearance to the table and also allows the contents of the drawers to be visible without opening the drawer.

Figure 3. Third variant labelled with additional components.

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Figure 3 above depicts the third variant and highlights the key differences between it and the second variant. The third variant builds on the previous one through inclusion of a storage base structure housed over base brackets mounted on the table legs. This provides an additional storage surface for the table.

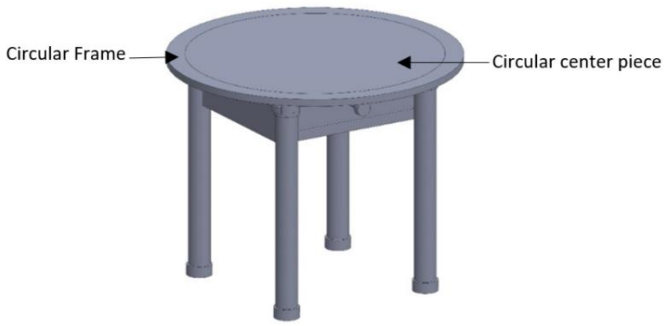

Figure 4. Fourth variant with labelled additional components.

Figure 4 above depicts the fourth variant which consists of a circular solid table top instead of a square top. This is a significant variance in the shape of the table and a circular table is more suitable for some customers who are working with confined spaces.

Table 1. Table of all the components utilised in product manufacture and their presence in corresponding product variants.

All Components		*Variant 1*	*Variant 2*	*Variant 3*	*Variant 4*
1	Square Frame	✓	✓	✓	
2	Square Solid Centre	✓			
3	Drawer	✓	✓	✓	✓
4	Knob	✓	✓	✓	✓
5	Bracket (small and leg)	✓	✓	✓	✓
6	Drawer Aligner	✓	✓	✓	✓
7	Drawer Wheel	✓	✓	✓	✓
8	Leg	✓	✓	✓	✓
9	Rubber Padding	✓	✓	✓	✓
10	Square Glass Centre		✓	✓	
11	Storage Base			✓	
12	Base Bracket			✓	
13	Circular Solid Frame				✓
14	Circular Solid Centre				✓

1.1. Market Information

The four product variants discussed above belong to the ‘table’ product family. Within the overall annual market demands for tables, the demand for specific variants only slightly varies. The second table variant which consists of a glass centre mainly attracts customers for decoration purposes for domestic or office use. Variant three of the table is mainly attractive for customers for domestic and office use due to additional storage whereas variant four is appealing for office use cases or domestic where spaces are confined, and overall aesthetic is valued.

The bar chart below shows sales of tables made from wood and metal, the two most used materials. It can be inferred that the annual demand has decreased across the years, and the sales volume in 2021 was 79,730,000. Therefore, for the purpose of this project and the development of a FMS, 80,000 tables is a good approximate assumption for the total annual demand [1].

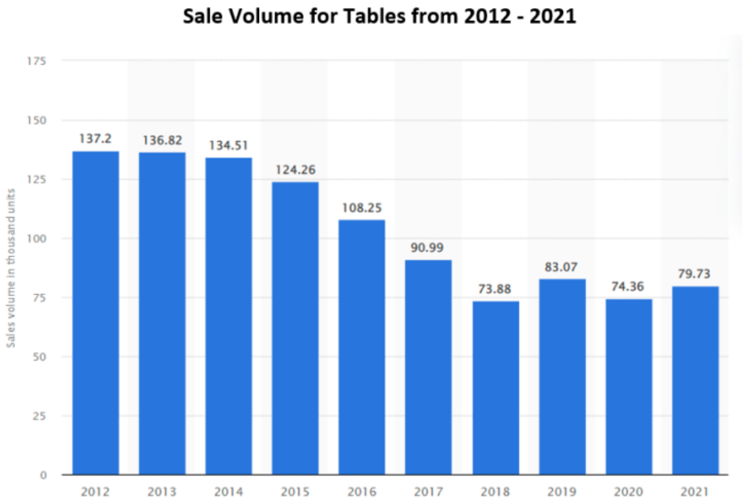

Figure 5. Sales volume for tables made out of wood or metal in the UK across the years [1].

Further research into the use cases for tables highlighted that 36% of tables were utilised in residential environments, whereas 32% and 31% of the tables were used in offices and mixed-use case scenarios respectively [2]. In light of these findings, project variant 1 will account for 40% of the total tables produced. Variants 2 and 4 will account for 20% and 30% respectively, whereas variant 3 will account for 10% of the production.

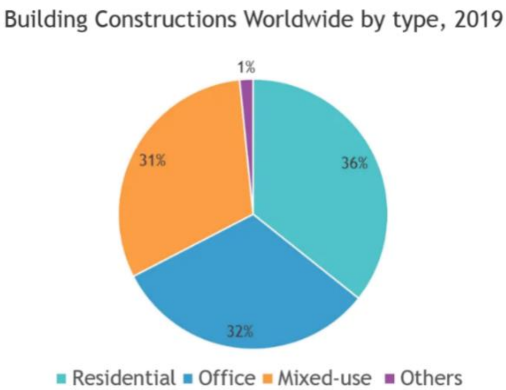

Figure 6. Proportions of use cases for tables [2].

2. Manufacturing System Design

2.1. FMS Design Details

Table 2. Table detailing the FMS design details.

FMS Design Details				
Variant 1	Variant 2	Variant 3	Variant 4	Demand Total Units
32000	16000	8000	24000	80000
Time Available for Production		7 hours x 5 days per week x 4 weeks in a month x 12 months = 1680 hours = 100800 mins		

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2.2. Line Balancing

After acquiring the product and marketing information, one of the strategies to design an FMS is through Line Balancing. Line Balancing is the process through which tasks are assigned to workstations.

The type of line balancing problem solved in this section is the Mixed Product Assembly Line Balancing Problem (MPALB). It involves the solution of the line balancing problem for Mixed Model Assembly Lines [3].

This problem also involves the Type 1 Simple Assembly Line Balancing Problem (SALBP-1). The SALBP-1 is derived from the Bin Packing Problem (BPP), in which tasks are viewed as objects, and cycle times are viewed as containers into which the objects are placed [3].

2.3. Methodology for solving the MPALB

2.3.1. Identify the tasks.

Table 3. Table depicting the tasks involved in producing the tables in the FMS.

Task	Description
1	Insert paddings to legs
2	Assemble leg brackets to legs
3	Attach base brackets to legs
4	Connect store base to base bracket
5	Attach small bracket to leg bracket
6	Combine square frame to brackets
7	Place square centre into square frame
8	Place glass centre into square frame
9	Combine circular frame to brackets
10	Place circular centre into circular frame
11	Assemble drawer aligner to frame
12	Assemble drawer to drawer aligner
13	Place drawer wheels into drawer aligner
14	Attach knob to drawer

2.3.2. Determine the task-precedence relationships.

Table 4. Table showing the task – precedence relationships for each of the four product variants.

Task	Variant 1		Variant 2		Variant 3		Variant 4	
	Task times [min]	Predecessors	Task times [min]	Predecessors	Task times [min]	Predecessors	Task times [min]	Predecessors
1	0.3	-	0.3	-	0.3	-	0.3	-
2	0.4	1	0.4	1	0.4	1	0.4	1
3	-	-	-	-	0.2	1	-	-
4	-	-	-	-	0.1	3	-	-
5	0.4	2	0.4	2	0.4	2	0.4	2
6	0.5	5	0.5	5	0.5	5	-	-
7	0.2	6	-	-	-	-	-	-
8	-	-	0.2	6	0.2	6	-	-
9	-	-	-	-	-	-	0.3	5
10	-	-	-	-	-	-	0.1	9
11	0.4	6	0.4	6	0.4	6	0.4	9

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Table 4. (continued).

12	0.4	11	0.4	11	0.4	11	0.4	11
13	0.3	12	0.3	12	0.3	12	0.3	12
14	0.2	12	0.2	12	0.2	12	0.2	12
Mix Ratio	0.4		0.2		0.1		0.3	

Figures 7 – 11 below depict the precedence diagrams for each variant produced in the FMS and an overall combined precedence diagram.

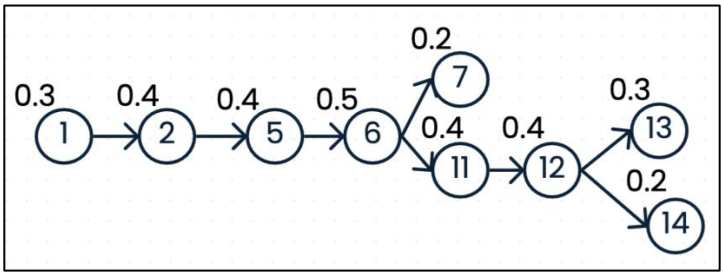

Figure 7. Precedence diagram – variant 1.

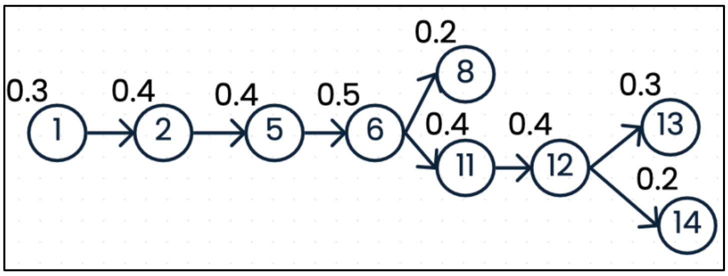

Figure 8. Precedence diagram - variant 2.

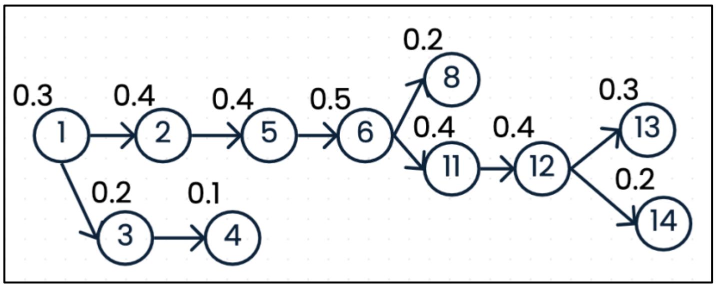

Figure 9. Precedence diagram - variant 3.

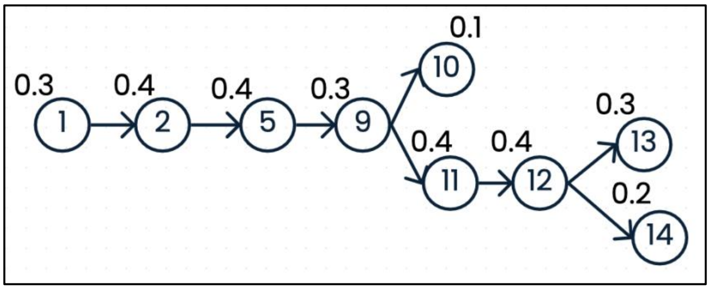

Figure 10. Precedence diagram - variant 4.

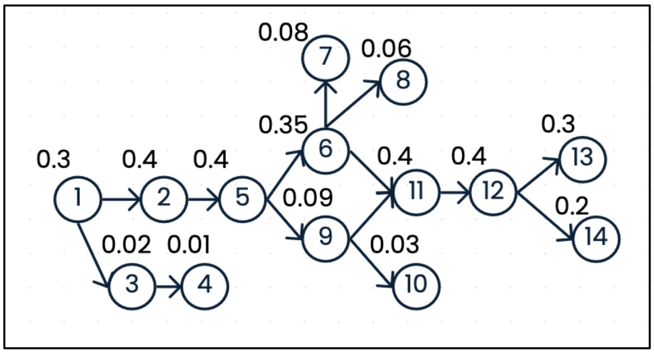

Figure 11. Combined precedence diagram - product family.

Precedence groups were formed which can be observed in figure 12 below.

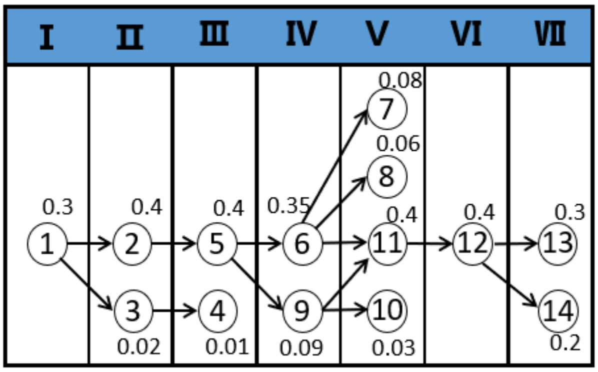

Figure 12. Precedence groups.

Table 5. Rank order tasks.

Task	Precedence Groups	$t_{k\ [min]}$	Predecessor
1	I	0.3	
2	II	0.4	1
3	II	0.02	1
5	III	0.4	2
4	III	0.01	3
6	IV	0.35	5
9	IV	0.09	5
11	V	0.4	6,9
7	V	0.08	6
8	V	0.06	6
10	V	0.03	9
12	VI	0.4	11
13	VII	0.3	12
14	VII	0.2	12

2.3.3. Compute the cycle time.

$$T_c = \frac{T_a}{D} = \frac{100800}{80000} = 1.26\ minutes$$

$$\frac{3.04}{1.26} = 2.41 \approx 3\ Workstations\ (minimum)$$

2.3.4. Solve the SALBP-1 by assigning tasks to workstations. Place the tasks in workstations based on rank making sure it does not exceed the cycle time, and the **final FMS design configuration** through line balancing is acquired as below:

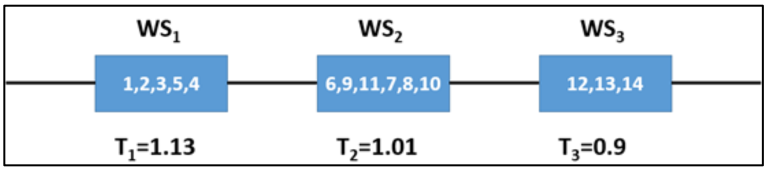

Figure 13. FMS tasks placed in workstations.

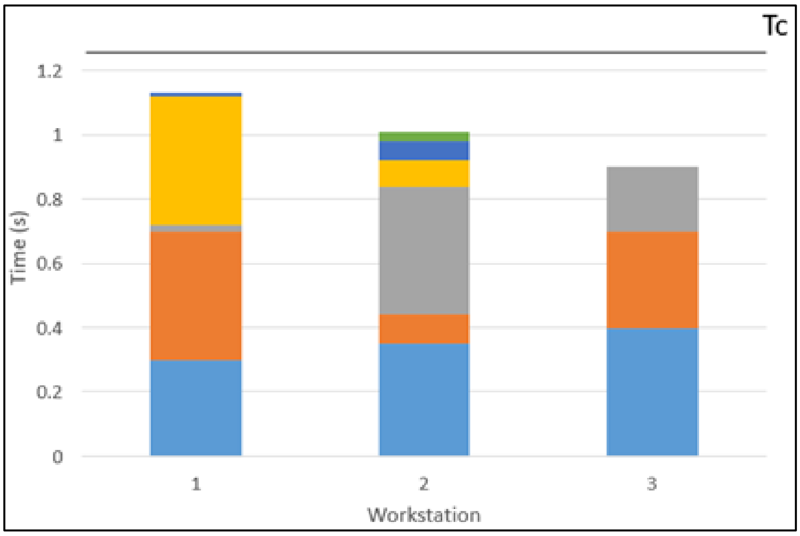

Figure 14. Time(s) against workstation bar chart.

2.4. Model/Product Sequencing

One other method of obtaining an FMS design is through model sequencing. There are two approaches to model sequencing but in this report the Variable Rate Sequencing method will be used [4].

The Variable Rate Sequencing approach is focused on assigning all product variants required to meet the demand in a planning horizon into the available time slots in order to achieve an even production schedule [4].

In this section, the product rate sequencing algorithm will be used, and the steps/methodology will be shown along with its results below:

Step 0: Initialization

Create List A by calculating the required values as shown below:

$$NS = \sum_{j=1}^{V} NS_j = NS_1 + NS_2 + NS_3 + NS_4 \quad (1)$$

$$NS_j = D_j / d \quad (2)$$

$$d = GCD(D_j, j = 1,4) \quad (3)$$

Figure 15. Required values formulae for the algorithm [4].

Table 6. Table consisting of variants and their demands.

Variant	1	2	3	4
Demand	40, 000	20, 000	10, 000	30, 000

where, d=10,000

$$NS_1 = \frac{40,000}{10,000} = 4\ ;\ NS_2 = \frac{20,000}{10,000} = 2\ ;\ NS_3 = \frac{10,000}{10,000} = 1\ ;\ NS_4 = \frac{30,000}{10,000} = 3$$

From Eq (2):
$NS = 4 + 2 + 1 + 3 = 10$ periods

Table 7. List A.

List A (j)	1	1	1	1	2	2	3	4	4	4

Step 1: Assign Product Variants
From List A, create List B of all product variants that do not violate the constraints:

Constraint 1: $\sum_{h=1}^{NS} y_{jh} = NS_j \qquad \forall\, j = 1, \cdots, V$

- This constraint is implicitly satisfied by the algorithm

Constraint 2: $\sum_{h=1}^{s} \sum_{j=1}^{V} tp_j^* y_{jh} \le sT^* \qquad \forall s = 1, \cdots, NS$

Figure 16. Constraint equations to create list B [4].

Table 8. tp^*_j (mins).

j	1	2	3	4
tp^*_j (mins)	1.1	1.1	1.4	1.1

$T^*\ (bottleneck\ ws\ time) = 1.13\ min$
For s = 1
Constraint 2 is expanded as follows:
$tp^*_1 y_{11} + tp^*_2 y_{21} + tp^*_3 y_{31} + tp^*_4 y_{41} - sT^* \le 0$
For j = 1: $y_{11} = 1;\ y_{21} = y_{31} = y_{41} = 0$
$tp^*_1 y_{11} - sT^* = (1.1)(1) - (1)(1.13) = -0.03 \le 0\ (hence\ C_2\ is\ satisfied)$
For j = 2: $y_{21} = 1;\ y_{11} = y_{31} = y_{41} = 0$
$tp^*_2 y_{21} - sT^* = (1.1)(1) - (1)(1.13) = -0.03 \le 0\ (hence\ C_2\ is\ satisfied)$
For j = 3: $y_{31} = 1;\ y_{11} = y_{21} = y_{41} = 0$
$tp^*_3 y_{31} - sT^* = (1.4)(1) - (1)(1.13) = 0.27 > 0\ (hence\ C_2\ is\ not\ satisfied)$
For j = 4: $y_{41} = 1;\ y_{11} = y_{21} = y_{31} = 0$
$tp^*_4 y_{41} - sT^* = (1.1)(1) - (1)(1.13) = -0.03 \le 0\ (hence\ C_2\ is\ satisfied)$
From results obtained, create List B (j) using the variants that satisfy the constraints:

Table 9. List B.

List B(j)	1	2	4

Step 1.2: Select variant that minimizes objective function.

Objective Function: $\min \max_{1 \le s \le NS} \left| \sum_{h=1}^{s} \sum_{j=1}^{V} tp_j^* y_{jh} - sT^* \right|$

Figure 17. Definition of objective function [4].

For $s = 1$

The **objective function** is expanded as follows

$\min \max_{1 \le s \le NS} |tp_1^* y_{11} + tp_2^* y_{21} + tp_3^* y_{31} + tp_4^* y_{41} - sT^*|$

Figure 18. Expansion of the objective function [4].

For j = 1: $\left|tp^*{}_1 y_{11} - sT^*\right|$ = $|(1.1)(1) - (1)(1.13)|$ = 0.03
For j = 2: $\left|tp^*{}_1 y_{21} - sT^*\right|$ = $|(1.1)(1) - (1)(1.13)|$ = 0.03
For j = 4: $\left|tp^*{}_1 y_{41} - sT^*\right|$ = $|(1.1)(1) - (1)(1.13)|$ = 0.03
Either j=1, j=2 or j=4 can be chosen; j=1 is selected
Step 1.3: Add j to the s^{th} position in the sequence
Hence, add j = 1 to position s = 1

Sequence(s)	1									

Step 1.4: Remove j from List A

List A (j)	1	1	1	1	2	2	3	4	4	4

Step 1.5
All steps are repeated for s = 2, 3, 4…10
The final sequence determined:

Sequence(s)	1	1	1	1	2	2	4	4	4	3

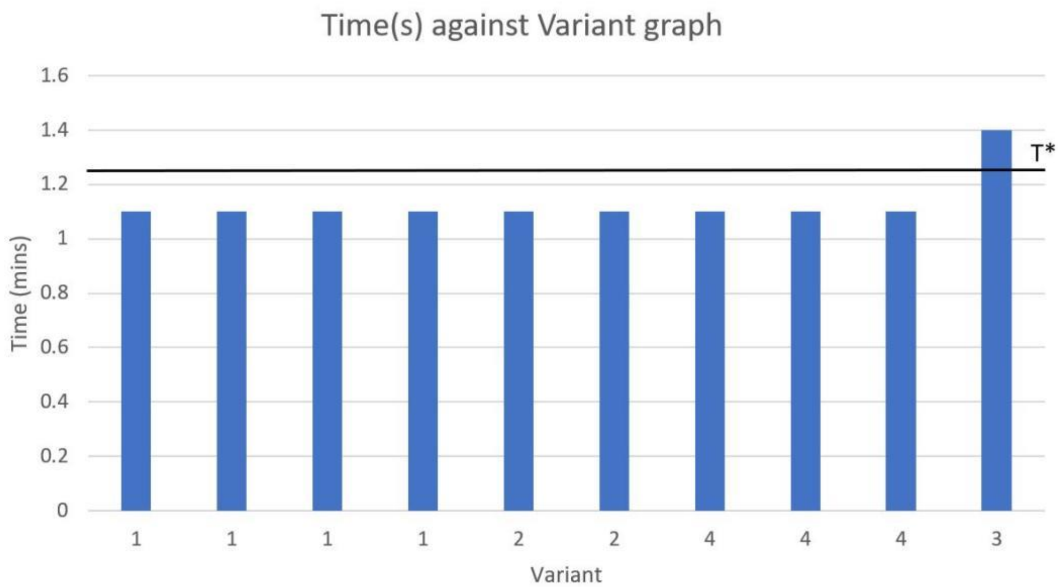

Figure 19. Time against Variant graph.

3. Manufacturing System Performance Analysis

3.1. Performance Analysis Methods

In this section, two types of performance analysis methods will be used: Solberg analysis and Mejabi analysis.

The FMS design/configuration that this analysis will be used on is based on the design determined from the line balancing method in section 2, however a loading and unloading station is added. The sequencing used in this design is also from the one obtained from section 2. Additionally, it is determined that each work station only has one server/machinery (this is calculated in the Solberg analysis) [5]. The stations are connected by a part handling system that has one work carrier and a mean transport time = 0.1 min. Below is the representation of the FMS configuration used in the analysis:

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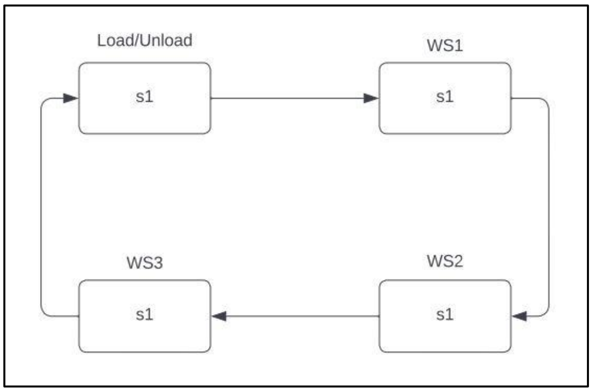

Figure 20. FMS design.

3.2. Solberg Analysis

This section will now perform the Solberg analysis whilst also detailing its required steps. Firstly, the details of the design required for the analysis are stated in the table below:

Table 10. Table consisting of the details of the FMS for performing Solberg analysis.

Variant	Mix ratio	Task	Station i	Process time[min]	Frequency
1	0.4	Load	0	0.3	1
		1	1	0.3	1
		2	1	0.4	1
		5	1	0.4	1
		6	2	0.5	1
		7	2	0.2	1
		11	2	0.4	1
		12	3	0.4	1
		13	3	0.3	1
		14	3	0.2	1
		Unload	0	0.3	1
2	0.2	Load	0	0.3	1
		1	1	0.3	1
		2	1	0.4	1
		5	1	0.4	1
		6	2	0.5	1
		8	2	0.2	1
		11	2	0.4	1
		12	3	0.4	1
		13	3	0.3	1
		14	3	0.2	1
		Unload	0	0.3	1
3	0.1	Load	0	0.3	1
		1	1	0.3	1
		2	1	0.4	1
		3	1	0.2	1
		4	1	0.1	1
		5	1	0.4	1
		6	2	0.5	1

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Table 10. (continued).

		8	2	0.2	1
		11	2	0.4	1
		12	3	0.4	1
		13	3	0.3	1
		14	3	0.2	1
		Unload	0	0.3	1
4	0.3	Load	0	0.3	1
		1	1	0.3	1
		2	1	0.4	1
		5	1	0.4	1
		9	2	0.3	1
		10	2	0.1	1
		11	2	0.4	1
		12	3	0.4	1
		13	3	0.3	1
		14	3	0.2	1
		Unload	0	0.3	1

To perform the analysis, the values below need to be calculated:

First, we need to calculate the Station Workload ($\boldsymbol{WLi}$), which is formally defined as the weighted average time required to complete all tasks at a machine/center/server.

$$WL_i = \sum_{i=1}^{V} \sum_{k=1}^{O} t_{ijk} f_{ijk} p_j \ \forall i, \dots, 4$$

Substituting all the values from the table:

$$WL_i = (0.3 \times 0.4 \times 1) + (0.4 \times 0.4 \times 1) + (0.4 \times 0.4 \times 1) + (0.3 \times 0.2 \times 1) + (0.4 \times 0.2 \times 1) + (0.4 \times 0.2 \times 1) + (0.3 \times 0.1 \times 1) + (0.4 \times 0.1 \times 1) + (0.2 \times 0.1 \times 1) + (0.1 \times 0.1 \times 1) + (0.4 \times 0.1 \times 1) + (0.3 \times 0.3 \times 1) + (0.4 \times 0.3 \times 1) + 0.4 \times 0.3 \times 1 \dots.$$

Table 11. Station Workloads.

Workstations	WL_0 (min/pc)	WL_1 (min/pc)	WL_2 (min/pc)	WL_3 (min/pc)
Quantity	0.6	1.13	1.01	0.90

Then we will calculate the Workload of the Material Handling System ($\boldsymbol{WLM+1}$), and its value is the product of the average transit time and the Total Number of Transports ($\boldsymbol{nt}$). where the Total Number of Transports is the total number of times each product is operated at the workstation on average.

$$n_t = \sum_{i=1}^{M} \sum_{i=1}^{V} \sum_{i=1}^{O} f_{ijk} p_j - 1$$

Substituting:

$$nt = 11.2 - 1 = 10.2 \ transports$$

Assuming the stations are connected by a part handling system that has one work carriers and a mean transport time = 0.1 min.

$$WL_{3+1} = WL_4 = n_t t_4$$

Substituting:

$$WL4 = 10.2 * 0.1 = 1.02 \ min/pc$$

Sizing the FMS:

$$s_i = \frac{WL_i}{T_c}$$

T_c = 1.26 min (from section 2), and substituting values:

$s_0 = \frac{0.6}{1.26}$ = 0.476 = 1 server

$s_1 = \frac{1.13}{1.26}$ = 0.897 = 1 server

$s_2 = \frac{1.01}{1.26}$ = 0.806 = 1 server

$s_3 = \frac{0.9}{1.26}$ = 0.714 = 1 server

$s_4 = \frac{1.02}{1.26}$ = 0.810 = 1 server

Each workstation only has 1 server, because the tasks were already balanced beforehand.

Next, we can calculate the Workstation Time ($\boldsymbol{T_i}$) for each workstation, which is the average time a workstation takes to complete each product. Each workstation only has one server:

$$T_i = \frac{WL_i}{s_i}$$

Substituting:

$$T_0 = 0.6 \div 1 = 0.6\, min/pc$$

$$T_1 = 1.13 \div 1 = 1.13\, min/pc$$

$$T_2 = 1.01 \div 1 = 1.01\, min/pc$$

$$T_3 = 0.9 \div 1 = 0.9\, min/pc$$

$$T_4 = 1.02 \div 1 = 1.02\, min/pc$$

Then determine which one is the Bottleneck Station, and the Workstation Time at the Bottleneck Workstation (T^*):

$$T^* = maxT_i, i, \ldots, 4$$

Substituting:

$$T^* = max\ (0.6, 1.13, 1.01, 0.9, 1.02)\ = 1.13\, min/pc$$

Finally, we can calculate Production Rate (R_p):

$$Rp = \frac{1}{T^*}$$

Substituting:

$$Rp\ = 1 \div 1.13\ = 0.885\, pcs/min$$

The corresponding production rates of each product:

$$R_{pj} = R_p p_j \quad j = 1, \cdots, 4$$

Substituting Values:

$$Rp_1\ = 0.885 \times 0.4\ = 0.354\, pcs/min$$

$$Rp_2\ = 0.885 \times 0.2\ = 0.177\, pcs/min$$

$$Rp_3\ = 0.885 \times 0.1\ = 0.089\, pcs/min$$

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$$Rp_4 = 0.885 \times 0.3 = 0.266\, pcs/min$$

The utilization of each workstation, where i=0, …, 3:

$$U_i = \frac{T_i}{T^*}$$

Substituting Values:

$$U_0 = 0.6 \div 1.13 = 53.1\%$$

$$U_1 = 1.13 \div 1.13 = 1 = 100\%$$

$$U_2 = 1.01 \div 1.13 = 0.894 = 89.4\%$$

$$U_3 = 0.9 \div 1.13 = 0.796 = 79.6\%$$

The overall utilization of the FMS:

$$\overline{U_s} = \frac{\sum_{i=1}^{M} U_i S_i}{\sum_{i=1}^{M} S_i}$$

Substituting Values:

$$\overline{U_s} = \frac{0.531(1) + 1(1) + 0.894(1) + 0.796(1)}{4} = 80.5\%$$

3.3. Mejabi Analysis

This section will now perform the Mejabi analysis whilst also detailing its required steps.

Table 12. Station Workloads.

Workstations	WL_0 (min/pc)	WL_1 (min/pc)	WL_2 (min/pc)	WL_3 (min/pc)	WL_4 (min/pc)
Quantity	0.6	1.13	1.01	0.90	1.02

Manufacturing Lead Time (MLT_1) here is the sum of each workpieces spend:

$$MLT_1 = 0.6 + 1.13 + 1.01 + 0.9 + 1.02 = 4.66\, min$$

Little's Law determines total number of workpieces (L) within a manufacturing system:

$$L^* = Rp^* \times MLT1 = 0.885 \times 4.66 = 4.1241\, pcs$$

If we set $L = 3$:

$$Rp = \frac{3}{4.66} = 0.644\, pcs/min < Rp^* = 0.885\, pcs/min$$

And for $L < L^*$:

$$MLT = MLT1 = 4.66\, min$$

Meaning that at this time, the arrival speed of the material so slow that maximum production rate has not been reached.

If we set $L = 5, L > L^*$:

$$Rp = Rp^* = 0.885\, pcs/min$$

$$MLT = \frac{L}{Rp} = 5.85\, min$$

$$Tw = MLT - MLT_1 = 5.85 - 4.66 = 1.19\, min$$

It illustrates that the material arrival speed is too fast where material accumulation occurs before the bottleneck process.

The best solution here is setting the Little's Law $L = L^* = 4.1241$ pcs, because the production line reaches the maximum production capacity as well as no material queuing.

4. Conclusion

To summarise, all steps required for the FMS design and analysis were completed. Firstly, tasks were successfully assigned to each component and detailed individual and family group precedence diagrams were created. From there, the line balancing technique (MPALB) was used in which the final FMS design was determined, it included 3 work stations and the final graph of the findings.

From the bar chart, is shows that the processing times for workstations 2 and 3 are considerably much lower than the cycle time. This could be bad cost-wise as not all the time and workers are being used effectively. Hence to improve efficiency, it may be best for the system to operate only 6 hours or 5 hours per day to reduce the cycle time and eventually costs as each work station would still be able to operate under those conditions. After line balancing, the variable rate model sequencing technique was also performed.

Finally, by using the Solberg and Mejabi techniques, the performance of the FMS design (including load/unloading stations) were determined.

Firstly, for the Solberg analysis, the Workstation Load (WL) was calculated for each workstation and from this, the Workstation Time (T) for each workstation. By comparing these times, the maximum time amongst the workstations can be determined, thus identifying the bottleneck process time.

From this, the production rate was calculated to be 0.885 pcs/min, and the production rate of each of the four variants was calculated based on the mixing ratio of each product. The utilisation rate of each workstation was also calculated. Based on the calculated utilisation rates, it can be seen that the utilisation rate of all three workstations is approximately 80% or more, and the average utilisation rate is 80.5%, which is a good balance for the line.

For the Mejabi analysis, the appropriate material arrival rate can be calculated based on the Workstation Load (WL) of the four workstations including the transport system. The line reaches maximum productivity when the material arrival rate is equal to the critical value L*. When the material arrival interval is less than L*, the material arrival rate is too fast, and the production line will create a queue in front of the bottleneck process. When the logistics arrival interval is greater than L*, the material arrival rate is too slow, and the line cannot reach maximum productivity as it needs to wait for material at the bottleneck workstation. In this analysis, the material arrival rate can be represented by the number of workpieces in the line (L). It was determined for an ideal case L=L*=4.1241pcs.

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