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Cellular Manufacturing and Teamwork Concepts in Garment Manufacturing

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Abstract: *Typical layout of a garment manufacturing line includes on average about 30 machines arranged in a straight line configuration. Normally one skilled operator works on one machine and semi skilled operators are employed at some machines to help the skilled operator. This arrangement hinders work sharing and team work, as no communication is possible between operators in this long line. Work sharing in manufacturing cells and teamwork concepts are indispensible in lean manufacturing environments. Further, balancing of lines for one-piece-flow or near one–piece–flow is only possible with a large balancing loss or impossible due to large variations between cycle times of operations. The new layout proposed in this research facilitates work sharing and team working concepts and proved dramatic improvement when implemented. An algorithm to balance the cell based on the garment type and the skill matrix of operators too is proposed.*
Keywords: *Cellular manufacturing, group technology, garment manufacturing, line balancing, sub-cell, teamwork*

I. Introduction

Garment manufacturing in comparison to most other manufacturing industries use light weight machineries which are easily movable during a changeover. Therefore the present practice is to rearrange the garment manufacturing line when a garment style needs to be changed. The same machine arrangement may prevail for several years for large order quantities or it may last only few hours as the order quantities can be as small as 10 . As the fashion is changing rapidly, today's trend of the garment industry is to move towards small order quantities. Hence the garment manufacturing lines should react fast for rapid changeovers.

II. Literature Review

Cellular systems have been core strategy in process improvement initiatives in some manufacturing companies. Dramatic improvements have been achieved by exploiting the features of cellular concept. Team working and work sharing are features of most cellular systems. Following is a review of cellular manufacturing and team working concepts.

2.1 Group Technology and Cellular Manufacturing

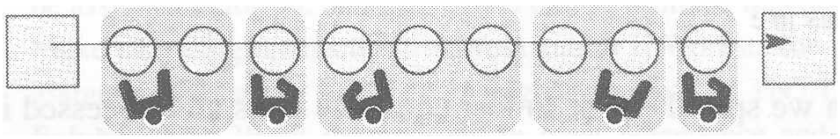
The Group Technology (GT) approach originally proposed by Mitrofanove in 1966 and Burbidge in 1971 has projected the philosophy that exploits the proximity among the attributes of given manufacturing resources [1]. GT is identified by many researchers as dividing the manufacturing facility into small groups or cells of machines; each cell is being dedicated to a specific set of part types and it is called cellular manufacturing [2, 3, 4]. Singh [1] depicts cellular manufacturing as an application of GT in manufacturing while Mahesh and Srinivasan [5] mention Cellular Manufacturing as one of the primary applications of GT principles, where parts with similar process requirements are placed together into groups called part families. In Japan, the term 'Group Production' and 'U-shaped Lines' appear to dominate. In Scandinavia the term 'Flow Manufacturing' and 'Flow Groups' are used. The term 'Production Islands' is commonly used in Germany and in Britain the term 'Group Technology' and 'Group Technology Cells' dominate. The term 'Group Technology Cells' is widely used in America [6]. Thus Group Technology and cellular manufacturing are often refers to similar production environments and cellular manufacturing is considered to be one of the main techniques towards a lean environment.

It is evident of 'U' and 'L' shaped layouts in cellular manufacturing systems [7]. In a U-shaped layout the operators are allowed to work across both legs of the line. The fundamental difference between a traditional straight line and U-shaped layout is illustrated in Fig.1, where operator 4 can perform task 1 on the front side of the U-line and then move to the back side and complete task 8.

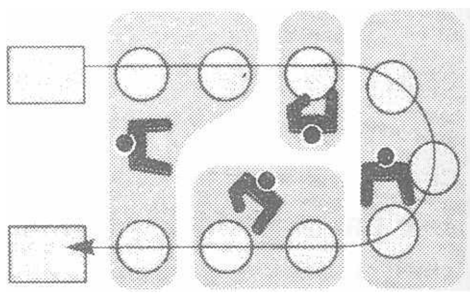
The operators in a U-shaped assembly line move between the two legs of the U-line and perform different tasks that are not possible in straight-line layouts. This flexibility enables to reduce the total number of operators and thereby allows creating a more efficient facility layout [8]. The labour productivity is significantly improved when switching from straight line layouts to U-shaped lay outs in most cases but not in all cases [8]. Most U-shaped assembly lines are not large and consist of less than 30 tasks and 10 stations [9].

Benefits achieved GT and Cellular manufacturing –

The benefits of implementing GT is identified by many researchers as to minimise the Through Put Time (TPT), improve the quality of the product, reduce the Work In Progress (WIP) levels and stocks and thereby the cost, improve the deliveries, reduced set-up times and improve productivity level [10, 11]. Askin & Standridge [3] explained the set up time reduction as an important aspect of GT. As a consequence of set up reduction the labour cost and the TPT are reduced. Thomopouulos [12] explains the objective of cell formation as to minimise the inter cell part movements and to allocate the work equally across all machines on a style basis thus making the flow smooth. One of the major advantage of GT is that it creates a better human relations [13] as the cells consists of only a few workers who form a small work team. Burbidge, [10] claims that GT makes a climate to increase the job satisfaction, motivation and the industrial relations. Wemmerlov & Hyer [11] identifies that working in cells naturally encourages team work and motivation for process improvement.



(a). Straight line assembly system



(b). Cellular assembly system

Figure 1 – (a) Straight and (b) U-shaped assembly line layouts (Chase et.al, 2003)

A mail survey carried out in United States on different aspects on manufacturing environment and the results were published in 1989. Of the 53 companies, 32 have indicated that they are using manufacturing cells. The range of end products was very large spanning from 3 to 80,000. The number of cells ranges from 3 to 40. The results revealed that the five most common reasons for establishing cells were to reduce work in progress inventory, set up time, TPT and material handling, and to improve output quality [14]. The operators in cells, in addition to their traditional tasks performed material handling and also simple maintenance tasks. They claimed that both the cell labour and the equipments are more efficiently used as the labourers move between work stations. The operators are multi-functional and can assist several processes and the mobility of the workers within the cell was high [14]. In order for the cells to be effective, everyone must learn every job in the cell and rotate jobs to retain this knowledge [7].

When the machines are dedicated to cells, the balancing of the cell has been found to be difficult. It has been reported that the average annual utilization of the machines in some companies is as low as 5%. The highest utilization has been found to be 92% [14]. The main benefits gained by shifting to cellular manufacturing are the reduction in TPT (average 45.6%), reduction in inventory (average 41.4%) and the reduction in material handling (39.3%). A study of ten British firms revealed that the average reductions in WIP and TPT are 62% and 70% respectively [14]. Although it can be expected a great resistance when shifting to cellular manufacturing, only a little evidence on this was found. In fact the average improvement of operator job satisfaction was 34.4%.

The research jointly carried out by the London Business School, Salford and Bradford Universities on GT revealed that the reduction of WIP and the TPT are 62% and 70% respectively and the output per employee increased by 33% in best companies [10].

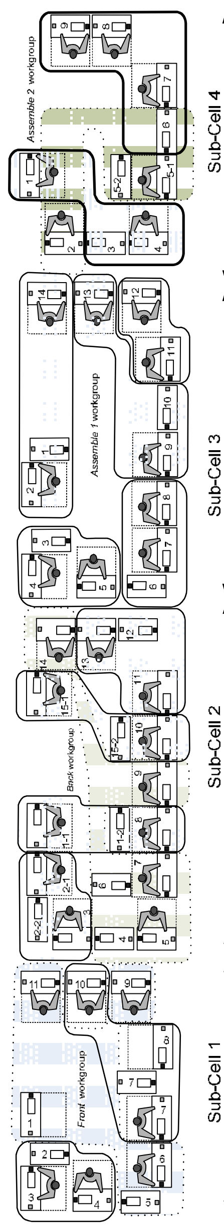


Figure 2

The difficulty in part handling, the part classification system and the coding systems, labour rules, the existing incentive systems and the changing the company structure are highlighted as reasons for not implementing Group Technology by a survey carried out by London Business School to find out the reasons for implementing and not implementing the Group Technology [10].

2.2 Teamwork

A team of employees would achieve better results than individuals working within confined job roles and responsibilities [15]. As long as 1933, Elton Mayo observed that the synergy of the team members produces an energy and creativity beyond that of its individuals and the effectiveness of workgroups resides in the degree of motivation, co-ordination and unity of purpose [16]. Thus employing effective teams pave the way to a successful business and improvement in many areas of an organization. Batt [17] has found that the team allocation is related to reduce employee turnover and increase the sales growth in telecommunication service sectors. The human resources practices such as team work, information sharing, performance based pay, participation, team work, empowerment etc., are associated with reduce employee turnover and increase productivity, financial performance and market rates [18]. Trainers of creativity have found that teamwork is a splendid instrument of innovation and innovation can be practiced in all teamwork as different persons with different backgrounds can find something new [19].

The term 'teamwork' has defined by many researches and writers in several ways, but all and all most of the definitions put forward a similar thought. Stoner et. al. [20]. defines a team as two or more people who interact and influence each other towards a common purpose. The requirement of coordination of activity among the members of the team for its attainments of goals is added to the above in another definition [21]. Kuipers [22] defined the team as a permanent group of people with a defined number of members. These members are committed and they hold a joint responsibility for a common purpose, set of performance goals and approach. These goals are based on customers´ demands. The team performs in all areas with a degree of independence and with continuous focus on improvement.

A team must understand the goals and they must exhibit loyalty and dedication to the team. The members of the team must possess the necessary skills to achieve the desired goals and mutual trust, good communication and negotiation skills are indispensable. It is essential to have a good and effective team leader to facilitate the team members by motivating, supporting and guiding [23]. The most fundamental problem that teams confront is the existing work structure. The traditionally structured organizations could not be free of problems when implementing teams [21]. Common problems experience in implementing teams is lack of support and the commitment from the top management [21]. Lack of training is one other common reason why the teams fail. The vision of team may blur with individualism.

III. Methodology

A 'true' cellular system has four major characteristics as discussed below. The applicability of all the characteristics of a cellular system in garment manufacturing is analysed and the possibility of applying a 'true' cellular system is investigated. A concept that can use most features of cellular manufacturing system and a system that encourages work sharing and team working to reduce TPT and to reduce WIP is proposed and implemented. The resources in the garment manufacturing line is formed into small cells termed as 'sub cells' as shown in Fig.2 and an algorithm is designed to balance the work between sub cells.

3.1 Definition of Cellular manufacturing

Several definitions for cellular manufacturing are introduced by several authors [24]. Nancy Hyer and Urban Wemmerlov [14] in their book on' Reorganizing the Factory' defines cellular manufacturing as follows. A cell is a group of closely located work stations where multiple, sequential operations are performed on one or more families of similar raw materials, parts, components, products or information carriers. The cell is a distinctive organizational unit within the firm, staffed by one or more employees, accountable for output performance, and delegated the responsibility of one or more planning, control, support, and improvement tasks. The characteristics of a cellular manufacturing system can be described in four perspectives [14].

1. Resource perspective – A cell is a group of resources (human and equipment) dedicated to process a set of similar products or components.
2. Spatial perspective – A cell is a group of resources located in close proximity within clear physical boundaries.
3. Transformation perspective – a cell system is designed to perform multiple and consecutive process steps on a family of objects.
4. Organizational perspective – A cell is an administrative unit within the firm. The resources are allocated and the material is supplied, used as a planning and control point, and accountable for performance and improvement. The operators are empowered to solve production and customer problems and to work on process improvement.

In garment manufacturing the machine layout is changed from style to style depending on the operation sequence. The machines are arranged close to each other to perform the operations in a sequence. Thus the machines are not permanently set; their positions are changed from style to style. The change of the layout depending on the product is possible due to the use of movable, comparatively small and light weight machineries used in sewing lines. The moving of the machines is required in order to keep the sequence of operations to avoid back tracking. The analysis of the operation breakdown of few garments shows that the cycle times are varying largely and therefore setting each operation to the 'takt' time is difficult ('takt' is the speed at which the company should be producing in order to meet the customer demand). Combining of two or more operations to be performed by a single operator is frequently happening, but it is not happening in an effective way. The analysis of WIP of a large number of garment manufacturing lines revealed that although the manufacturing lines are balanced, the WIP and its fluctuation is remarkably high.

3.2 Sub-cell concept (Proposed cellular manufacturing system)

As the cycle times are vastly changing, balancing the operations for each worker or levelling the operations is not possible without heavy backtracking. Therefore this research suggests a cellular manufacturing system. This resembles to the phantom cells in definition [14]. The operations for manufacturing each garment are divided into few groups. These groups of operations are performed by a group of operators in close proximity. The number of such sub-cells within a production line is determined by the type of garment. However, for most garment types 4 sub-cells would be more justifiable so as to perform the front operations, back operations, assembly operations and finishing operations of a garment. The operators are expected to move between predetermined workstations for self balancing the sub-cell. Thus the machines in a sub-cell are arranged in such a way that the operators' movement within the sub-cell is facilitated with a minimum disturbance. The shape of a sub-cell is similar to a miniature U-shaped cell. This facilitates easy communication, minimized operator movement and more importantly team concepts and the human empowerment within the sub-cell. The incentives for achievement of the set targets can now be based on the performances of the sub-cell unlike considering one manufacturing line as one entity, which is the most commonly practiced system.

3.2.1 Definition of the proposed sub-cell

A sub-cell is a group of closely located work stations where a **sequence of operations** is performed to complete a part of a product. The sub assemblies of the product move through few sub-cells in order to complete all the operations required for a product. These cells only **exist until the order is completed**, thereafter the operators and the machines dedicated to the sub-cell and the layout may marginally be changed to suit for the next product. The **resources are generally dedicated** to the sub-cell, but not very strictly. The operators are empowered to solve the problems and to make improvements on the methods. The sub-cell is only **accountable for the operations (output and quality) carried within the cell** and is motivated for its performance by empowerment and a cell oriented incentive scheme. The operators need to be multi-skilled.

3.3 Developing workgroups

As the Garment Industry is more people involved process it is critical to obtain the positive commitment of the people in the implementation of lean techniques and creating a lean environment. The most effective way of obtaining positive contribution from the people is through workgroups [25]. The ideas of the workgroups can be used for continuous improvement, while this will help them to have a better life at work. According to John Allen et.al., [25] workgroups are essential for a successful implementation of lean. Researches and on the job experience has concluded that when the workgroups are properly installed, trained and used, they improve individually, collectively and cooperate performance through productivity improvement [25].

The performance of the sub-cell is accounted for the sub-cell, not for the individual operators. Therefore the operators are motivated to share work and to reduce accumulating WIP in work stations. The machine layout need to be arranged in such a way that the operator movement and share of work is facilitated. The operations too are grouped to be performed by two or more operators when a need arises.

3.4 Algorithm for balancing the operations in sub-cells

The following algorithm suggests a method of balancing the operations in proposed sub-cells. The Standard Minute Values (SMV) shown in Table 1 are arbitrarily selected, but these cycles times are in the range of the practical cycle times in garment manufacturing. Instead of takt time the term 'pitch time' is used in sub-cells. The pitch time is the time between the two successive sub assemblies out from a sub-cell. The calculation of the pitch time is based on the takt time, but considers the number of operators in a sub-cell and the total

$$Average\ Operator\ Pitch\ Time = \frac{Total\ SMV\ assigned\ to\ the\ garment}{Number\ of\ Operators\ assigned} \cdots (1)$$

SMVs of the operations carried out within a sub-cell (1).

The operations assigned to each sub-cell are determined by considering the operations sequence of the whole garment. Although this depends on the type of garment, operations of most garments fit into three/ four sub-cells as front operation, back operations, assembly/ final assembly. Once the operations for each sub-cell is assigned the operator requirement for the sub-cell is calculated by dividing the total SMV of the sub-cell by the average operator pitch time mentioned above (2).

Table 1 Arbitrarily Selected SMVs

Operation	SMV
A	0.57
B	0.28
C	1.2
D	0.5
E	0.7
F	0.5
G	1.25
H	0.87
I	0.56
J	0.3
K	0.45
L	1.4
M	0.6
N	1.32
Pitch time =1 min	

$$Number\ of\ Operators\ required\ to\ a\ sub\text{-}cell = \frac{Total\ SMV\ assigned\ to\ the\ sub\text{-}cell}{Pitch\ time} \cdots (2)$$

If this number is a non integer, it is either round off or round up considering skill inventory of the operators in the sub-cell. The skill inventory is the document indicating the skill levels of operators for different operations. As an example, if the calculated number of operators is 7.4, it will be round off to 7 if the average skill levels of the operators in the sub-cell are high and will be round off to 8 if average skill level is low.

3.4.1 Step 1 of the Algorithm – Combine consecutive operations with small SMV

Combine any two or more consecutive operations that can be performed by the same operator if these operations are on the same garment piece and the combined SMVs are under the pitch time. As these operations generally have less SMVs, this step will reduce handling times by avoiding the same garment piece being handled several times for several operations, especially if the same machine is to be used. These operations may sometimes need more than one machine and therefore these machines are arranged closer to the operator. The number of different machine types for these operations should not be more than three, which otherwise would restrict the operator movement. Thus, when the operator is working on one machine, another machine is idle and any operator who can work on this machine can sew in case of an emergency (machine break downs, absenteeism etc.).

3.4.2 Step 2 of the Algorithm – group two operations to be performed by two operators

When the SMVs are above the pitch time, the particular operation cannot be performed by one operator. Though a second operator with a SMV well under the pitch time is grouped with the first operator, the second operator is unable to assist the first operator as the first operator is always busy on his machine. Therefore it is recommended to use an extra machine to perform the first operation. [26] has well demonstrated the benefits of keeping the operators busy in contrast to sewing machines). Thus both the operators can perform both operations if they are multi-skilled. When combining operations greater than the pitch time and less than the pitch time, if the number of operators allocated to a team is an odd number ‘n’, always the number of dual operator combination should $\langle \frac{n}{2}$ -1

The operations that satisfy the above conditions are traced as follows. The operations with SMVs higher than the pitch time is placed on a column of a table and the SMVs less than the pitch time is placed on a row of the same table as shown in Table 2. The sum of values in columns and the rows are represented in the other (middle) cells of the table. If two operators are grouped they together must perform two operations, where the combined SMV lies in the range either side of twice the pitch time, i.e. the combined SMVs between 2 X Pitch* f_1 % (f_1 =95 is considered for calculation) and 2 X* Pitch* f_2 % (f_2 =105 is considered for calculation) are selected. Defining this range is for two reasons. If a single value is defined (e.g. twice the pitch time) sum of the two values rarely match with this value. The second reason is the skill variation of the operators, with in a sub-cell. Usually most garment manufacturers keep a record on each operator's skill level and when assigning operations the skill range from 90% to 110% from the average operator's efficiency level is practiced. Therefore the range of the combined operators' pitch time (f_1 and f_2 values) can be decided with the average skill needed by an operator in a cell.

$$\textit{The average skill needed by an operator in a cell} = \left(\frac{\textit{Calculated number of operators}}{\textit{number of operators assigned}} \right) \times 100 \cdots (3)$$

Accordingly following operations can be combined (the cells in Table 2 with values within the specified range are hatched). However it is required to select operations which are close in the operations sequence. The closeness of the operations depends on the machine layout.

Table 2 – SMVs of Operations and Sums of SMVs

SMV <Pitch (Pitch=1 is assumed)												
SMV >Pitch			**B**	**J**	**K**	**D**	**F**	**I**	**A**	**M**	**E**	**H**
			0.28	0.3	0.45	0.5	0.5	0.56	0.57	0.6	0.7	0.87
	C	1.2	1.48	1.5	1.65	1.7	1.7	1.76	1.77	1.8	1.9	2.07
	G	1.25	1.53	1.55	1.7	1.75	1.75	1.81	1.82	1.85	1.95	2.12
	N	1.32	1.6	1.62	1.77	1.82	1.82	1.88	1.89	1.92	2.02	2.19
	L	1.4	1.68	1.7	1.85	1.9	1.9	1.96	1.97	2	2.1	2.27

Table 3 shows the combined operations and the combined pitch times.

Table 3 – Possible Operations to be Combined Under Step 2 of the Algorithm

Possible operation combinations	Combined pitch times within the specified range
CE	1.9
CH	2.07
GE	1.95
NM	1.92
NE	2.02
LD	1.9
LF	1.9
LI	1.96
LA	1.97
LM	2.0
LE	2.1

Each of these groups performs two operations by two operators and dedicated more than two machines. Out of the above combinable groups, the selection of the operations to be combined mainly depends on the shortest distance between the workstations where these combined operations are carried out. The operations to be shared by the operators in the group too can be considered where important. The distance between the workstations depends on the machine layout. However the final decision on which operations are to be combined is drawn after reconsidering other possible combinations available. As example, if the combinations having shortest distances are selected initially, there is a possibility that the remaining machines/ operations grouped by the following steps of the algorithm are relatively distant from each other. Therefore reconsidering all available combinations are essential and finally select the combinations having shortest average distances as the best set of combination for the sub-cell.

3.4.3 Determining the suitable machine layout that gives the optimum results

Different manufacturing units practice different layouts. Following are some of the common machine layouts used in the garment industry.

Straight-line layout - The layouts in garment manufacturing are generally straight. The straight line layouts have several versions, more common being the zig-zag layout [27]. Fig. 3 to Fig. 7 illustrates the few straight line layouts and U-shaped cells.

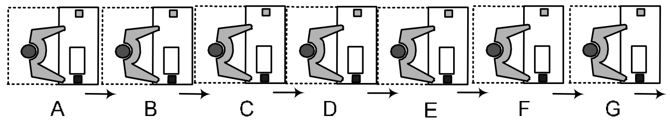


Figure 3 – Straight line layout

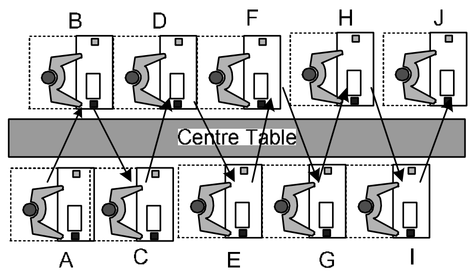


Figure 4 – Zig-Zag layout with the centre table for material handling

The Zig-Zag layout with the centre table is very common in the garment industry. The centre table is used to transport the subassemblies of garment between the work stations. The centre table restricts the movement of the operators if they are to work in teams and share work.

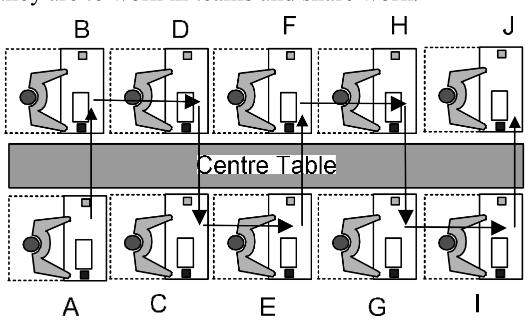


Figure 5 – U-shaped material flow layout with centre table for material handling

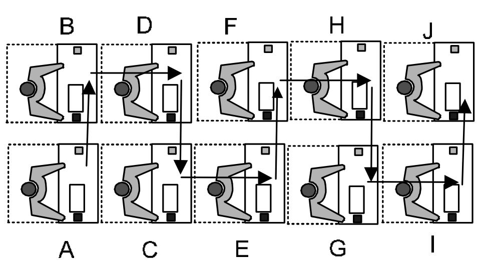


Figure 6 – U-shaped material flow layout with no centre table

In the absence of centre tables, the machines should be positioned in such a way that the layout facilitates the movement of the garment sub assemblies between workstations or use means of transporting sub assemblies between workstations.

The U-shaped machine layouts shown in Fig.7 too are used in garment manufacturing.

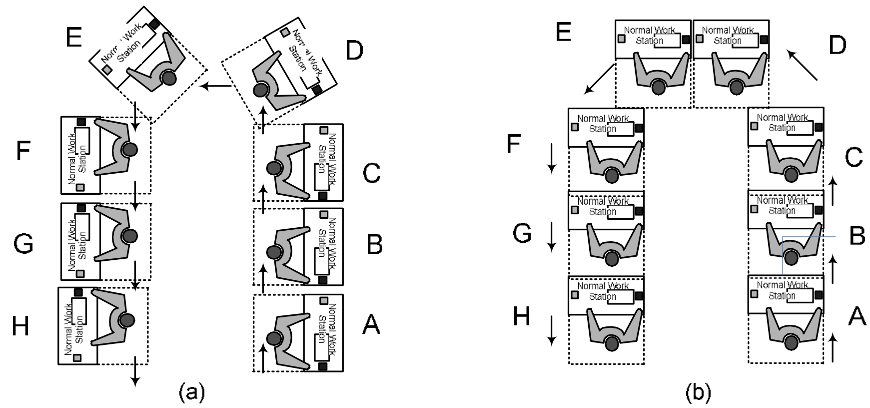


Figure 7 – U-Shaped Layouts

3.4.3.1 Calculation of distance between the sharable workstations and the time to move

The calculation of the distance between sharable workstations and the time to move between workstations are required to determine grouping of which operations (workstations). Following calculations of distances between workstations are based on actual physical dimensions of different layout and the values used are mentioned below.

Following arbitrary observations are made from an average production line in a garment factory.

1. Width of a sewing machine = 1.75′
2. Length of a sewing machine = 3.5′
3. Distance between two sewing machines = 4′
4. Distance between two legs in U shaped lay out –Fig.7- (a) = 5′
   & (b) = 4′

The calculation of time to move between workstations require the body movements of the operator such as stand up, side step, turn, walk, sit etc. The International Labour Organization (ILO) has standardized and documented the times required for each of these operator movements [28].

3.4.3.2 Calculating the time in walking between workstations

Pre-determined Motion time System (PMTS) method is used to find the walking time between work stations. The motions in carrying out any operation are divided into body motions and hand motions in the Motion Time Measurement (MTM) system. The MTM times for foot, leg, hand and body movements are presented in Table 4 (MTM Association for standards and Research, 1969). All the predetermined times are given in Time Measurement Units (TMU).

100000 TMU = 1 Hour

After calculating the times of a given activity, the allowances are added depending on the nature of the activity and the environment in which the work is performed. Table 5 shows the allowances and the percentages added.

Table 4 - MTM times for foot, leg, hand and body movements

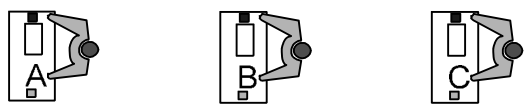
Description			Symbol	Distance	Time TMU
Foot motion	Hinged at ankle		FM	Up to 10 cm	8.5
	With heavy pressure		FMP	Up to 15 cm	19.1
Leg or fore leg motion			LM	Up to 15 cm Each additional 1cm	7.1 0.5
Sidestep	Case1	Complete when leading leg contacts floor	SSC1	Less than 30 cm 30 cm	Use reach or move time 17
				Each additional 1 cm	0.2
	Case 2	Lagging leg must contact floor before next motion can be made	SSC2	30 cm	34.1
				Each additional 1 cm	0.4
Bend, Stoop, Kneel on one knee			B, S, KOK		29
Arise			AB, AS, AKOK		31.9
Knee on floor Both knees			KBK		69.4
Arise			AKBK		76.7
Sit			SIT		34.7

Stand from sitting position	STD		43.4
Turn body 45 to 90 degrees			
Case1 – Completes when leading leg contact floor	TBC1		18.6
Case2 – Lagging leg must contact floor before next motion can be made	TBC2		37.2
Walk	W-M	Per meter	17.4
Walk	W-P	Per pace	15
Walk obstructed	W-PO	Per pace	17

Table 5 – Allowances added and their percentages depending on the work environment and complexity of working

Activity	Allowance points
Sitting easily	0
Standing or walk freely	4
Monotony	0
Eye strain (normal factory work)–	0
Noise – No distraction noise, light assembling factory	0
Side step	2
Temperature (less than 23.8^{0}C) , Humidity Up to 75	0
Temperature (less than 23.8^{0}C) , Humidity 76-85	1 - 3
Temperature and humidity More than 24^0 C	6

3.4.3.3 Calculation of walking times (Using MTM database)



A, B and C are three workstations.

Assumptions - Sitting easily, Standing or walk freely, no monotony, no eye strain, no distraction noise and the factory temperature is around 23^{0}C.

Motion from B to A –

Table 6 Motions and times when moving from B to A

Sequence	Motion	MTM code	Time (TMU)
1	Stand from the sitting position	STD	43.4
2	Sidestep (42 cm)	SSC2	38.9
3	Walk 4 steps (path is interrupted to the first step and the path is not interrupted to the other 3 steps)	W1PO+W3P	65
4	Sidestep (42 cm)	SSC1	19.4
5	Sit	SIT	34.7
SMV including allowances			0.128

Movement from A to B-

Table 7 Motions and times when moving from A to B

Sequence	Motion	MTM code	Time (TMU)
1	Stand from the sitting position	STD	43.4
2	Sidestep (42 cm)	SSC2	38.9
3	Turn to the opposite side	2TBC2	74.4
4	Walk 4 steps (path is not interrupted)	W4P	64
5	Turn to the left hand opposite side	2TBC2	74.4
6	Side step(42 cm)	SSC2	19.4
7	Sit	SIT	34.7
SMV including allowances			0.221

Using the procedure explained above the times to move from one workstation to another when sharing work is calculated for all the possible sharable operations (determined using the Step 2 of the algorithm presented above) and for different machine layouts mentioned in section 4.3.3. Table 8 illustrates the distance between work stations and the time taken to move between workstations for a straight line layout shown in figure 3.

Table 8 Distances and times between workstations for straight line layout

Possible combinations	Distance (feet)	Path	Time (min)	Path	Time (min)	Average time (min)
CE	8	C→E	0.128	E→C	0.252	0.19
GE	8	G→E	0.252	E→G	0.128	0.19
NM	4	N→M	0.221	M→N	0.128	0.174
LD	32	L→D	0.401	D→L	0.309	0.355
LF	24	L→F	0.352	F→L	0.259	0.305
LI	12	L→I	0.261	I→L	0.178	0.219
LA	44	L→A	0.485	A→L	0.389	0.437
LM	4	L→M	0.128	M→L	0.221	0.174
CH	20	C→H	0.234	H→C	0.278	0.256
NE	36	N→E	0.431	E→N	0.334	0.383
LE	28	L→E	0.382	E→L	0.284	0.333

Movement between ‘LM’ has the lowest average time, followed by ‘NM’ and ‘CE and GE’ as shown in Table 8. Table 9 presents these values when the layout is set in for zig-zag with a centre table for material movement.

Table 9 Distances and times between workstations for zig-zag with the centre table

Possible combinations	Distance (feet)	Path	Time (min)	Path	Time (min)	Average time (min)
CE	4	C→E	0.201	E→C	0.294	0.25
GE	4	G→E	0.294	E→G	0.201	0.25
NM	12	N→M	0.274	M→N	0.274	0.27
LD	16	L→D	0.324	D→L	0.230	0.28
LF	12	L→F	0.283	F→L	0.200	0.24
LI	24	L→I	0.354	I→L	0.354	0.35
LA	26.25	L→A	0.374	A→L	0.374	0.37
LM	14.25	L→M	0.284	M→L	0.284	0.28
CH	22.25	C→H	0.349	H→C	0.349	0.35
NE	22.25	N→E	0.324	E→N	0.324	0.32
LE	26.25	L→E	0.374	E→L	0.374	0.37

The lowest time to move between the workstations when the layout is zig-zag with the centre table, is in the order ‘LF’, ‘CE and GE’, ‘NM’, ‘LD’ etc. Thus it is clear that the sharable operations are determined by the machine layout

Once the sharable operations are determined using the above procedure the next step is to determine the sharable operations when three operations are performed by two operators. The operations ‘G & E’ and ‘L & M” are selected to share work determined by the rules of the Step 2 of the algorithm and therefore they are opt-out for the next step of the algorithm.

3.4.4 Employing Step 3 of the Algorithm – Combine three operations to be performed by two operators

If the remaining number of operators (n_{r1}) is an odd value limit the number of allocations to $\langle \frac{n_{r1}}{2}$ -1

The combined pitch times lie between 2 X Pitch X 95% and 2 X Pitch X105% are traced in this step. There are remaining 10 operations to be grouped (for this example) with three operations in each group. Thus there are 120 ($^{10}C_3$) combinations possible. All the combinations possible are shown in the following table and the combinations lie in the specified range are separately marked.

Table 10 Combined pitch times when three operations are grouped

Operations	Possible combinations										
A	2.05	2.27	1.57	1.94	2	1.43	1.32	2.27	2.64	2.33	2.07	1.63
B	1.98	1.28	1.65	1.71	1.14	1.03	2.05	1.65	1.34	1.08	1.23	1.08
C	2.2	2.57	2.63	2.06	1.95	2.97	3.09	2.26	2.0	2.15	3.02	2.52
D	1.87	1.93	1.36	1.25	2.27	2.39	1.35	1.67	1.82	2.69	1.94	2.38
F	1.93	1.36	1.25	2.27	2.39	1.35	1.98	1.51	2.38	1.63	1.34	1.37
H	1.73	1.62	2.64	2.76	1.72	2.35	2.57	2.49	1.74	1.45	2.37	1.6
I	1.31	2.33	2.45	1.41	2.04	2.26	1.56	1.58	1.29	2.21	1.51	3.08
J	2.07	2.19	1.15	1.78	2	1.3	1.67	1.9	2.82	2.12	2.12	1.37
K	2.34	1.3	1.93	2.15	1.45	1.82	1.88	2.22	1.52	1.52	1.89	1.23
N	2.17	2.8	3.02	2.32	2.69	2.75	2.18	2.1	2.1	2.47	2.16	3.39

Combinations outside the range   Combinations within the range

The operations that can be grouped according to the rules of the STEP 3 of the algorithm are represented in Table 10. The last rule applies to all the steps is the proximity rule. The grouped operations should be as close as possible. The same procedure is used in calculating the times to move between the combined operations suggested by the STEP 3 of the algorithm for different layouts. Table 11 presents the MTM times in moving between the three workstations for all the sharable operations suggested by STEP 3 of the algorithm for few selected machine layouts.

Table 11 Distances and times required to move within a group for different layouts when three operations are combined

Combination	Walking time in different lay out systems (min)					
	Straight line	Zig-zag layout with centre table	Zig- zag U with centre table	Zig- zag U without centre table	U-shaped layout (a)	U-shaped layout (b)
BCD	0.361	0.578	0.545	0.518	0.307	0.398
FHI	0.390	0.708	0.668	0.642	0.308	0.361
DHI	0.462	0.717	0.587	0.574	0.373	0.501
KBC	0.606	0.713	0.462	0.462	0.331	0.461
AFH	0.529	0.602	0.664	0.638	0.547	0.595
AHI	0.577	0.724	0.589	0.576	0.509	0.527
CJK	0.577	0.664	0.463	0.463	0.331	0.433
JCD	0.544	0.664	0.628	0.621	0.331	0.496
FBC	0.430	0.607	0.361	0.361	0.360	0.471
JNF	0.569	0.420	0.420	0.420	0.437	0.588
CFA	0.226	0.649	0.545	0.518	0.487	0.505
DIN	0.526	0.696	0.664	0.678	0.500	0.534

After the STEP 3, if there are remaining operations they can be combined using STEP 4 of the algorithm or STEP 2 and 3 can be reconsidered.

3.4.5 Employing step 4 of the Algorithm - Combine four operations to be performed by two operators or three operators

The remaining operations (if more than four) are tested to find whether they can be grouped together by the same way as explained under STEP 3 of the algorithm. If the remaining operations are far away (or the remaining number of operations are less than 4), the STEP 2 and STEP 3 can be reconsidered with the grouping possibilities proposed but discarded by the STEP 2 and 3 of the algorithm.
Fig. 8 illustrates the algorithm in balancing the operations within a sub-cell.

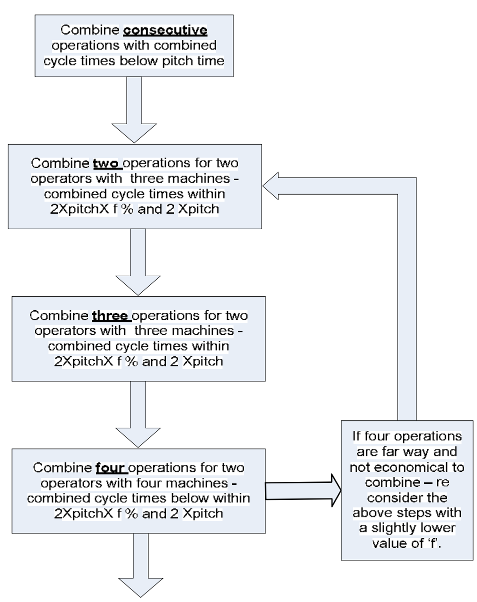


Figure 8 – Flow chart of the algorithm for balancing operations of sub-cells

Once the WIP is accumulated in one place other operators helped the respective operator to make them. Thereby WIP is minimized

IV. Discussion

The addition of value for a garment mainly happened in the sewing department. Thus the sewing department, hence the sewing operators, can be considered as the heart of any garment manufacturing factory. Lean practitioners identify that the most important of any manufacturing process is where the value is added to the product [29]. According to Allen et.al, [25] the workgroups are the most effective way of obtaining positive contribution from the people. The workgroups in the proposed sub-cells are expected to share work. Sharing of work although reduces the opportunity of mastering a single operation and that is the key component addressing the problem of excessive amounts of WIP.

The accumulation of WIP increases the defect percentage by concealing any defect for an excessive period of time and hinders the smooth flow of material. The proposed sub-cell concept motivates the operators to share work and to organize themselves to achieve the cell performance.

Balancing a garment manufacturing line with 100% operator utilization is not practically achievable as the cycle times of operations widely different. Thus the algorithm proposed to balance a garment manufacturing line is formulated with some preset conditions and assumptions. The industrial engineer/ work-study officer will have to consider the capacities of the operators and to know the average operator capacity of the operators in each sub-cell. Thus it is presumed that the skill levels of the operators vary in a range and this range is used in the grouping operation as discussed above. When the operators of a group (within the sub-cell) are relatively distant (this may probably happen towards the last steps of the algorithm) the industrial engineer may have to reconsider the already grouped operations (by the initial steps of the algorithm) to find the optimum solution. When the number of operators within a sub-cell is high, the number of grouping possibilities is high and therefore converging to the optimum solution will be difficult without a computer programme. Therefore it is essential to develop a software solution to find the best balancing solution for the sub-cell concept.

The validation of the sub-cell concept is demonstrated by implementing the concept on a selected garment manufacturing unit with 20 production lines. It returned dramatic improvements (Vijitha, 2009) in reducing the WIP and improving the factory efficiency.

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