CELLULAR LAYOUT IN MANUFACTURING AND SERVICES

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Abstract: *Cellular layout, also known as cellular manufacturing or group technology layout, is a strategic arrangement of workstations into groups or cells, each of which is dedicated to the manufacture of a particular product family or the provision of a range of related services. The principle of group technology underlying cellular processes is simple: when multiple products need to undergo similar operations, production can be more efficient if these operations are grouped together in a single work cell. The cellular layout is a combination of the efficiency resulting from the product layout and the flexibility of the process layout type. This type represents a good compromise between volume and variety; it is a hybrid solution. The cellular layout is an attempt to bring some order to the complexity of flow that characterises the process layout. This chapter examines the principles, design considerations, and applications of cellular layout in both manufacturing and services, highlighting its advantages and disadvantages as well as examples from practise.*

Key words: *Cellular layout, Manufacturing, Services, Part families, Binary sorting*

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1. Introduction

Layout planning is a critical aspect of operations management in both manufacturing and service industries. It involves the strategic arrangement of physical facilities – such as machines, equipment, workstations, and service areas – to optimize workflow, minimize costs, and enhance productivity. An effective layout aligns with the organization's goals, supports efficient resource utilization, and contributes to a smooth and streamlined process flow (Buchmeister, 2024).

Among the various types of facility layouts, cellular layout has gained prominence due to its unique ability to combine the efficiency of product layouts with the flexibility of process layouts (Attia et al., 2023). A cellular layout organizes workstations or machines into cells, each dedicated to producing a family of similar products or handling related services. These cells function like mini-production lines, enabling a more focused and efficient workflow.

This layout strategy is grounded in Group Technology (GT) principles, which identify and group similar products based on shared characteristics or processing requirements (Ramesh et al., 2021). By minimizing material handling, reducing work-in-process inventory, and enhancing communication among team members, cellular layouts foster a leaner, more responsive operational environment.

The application of cellular layouts extends beyond traditional manufacturing settings to various service industries, where they help streamline customer-facing processes, reduce wait times, and improve service quality.

1.1 Brief history of cellular manufacturing

Cellular manufacturing is not a recent innovation. The concept was first envisioned by Flanders in 1925, who proposed reorganizing manufacturing processes into small, manageable units to enhance efficiency and flow. In the 1930s, the idea gained traction when Mitrofanov published a seminal book that laid out the theoretical underpinnings of group technology – a principle closely tied to cellular manufacturing. His work influenced the structuring of production systems in Russian factories, emphasizing the grouping of similar parts and processes to improve coordination and reduce unnecessary motion (Kuuse, 2023).

However, it was not until the 1970s that cellular manufacturing began to be more widely recognized and systematically applied. During this period, the global manufacturing landscape was undergoing significant change, with increasing interest in improving productivity, reducing waste, and enhancing responsiveness to customer demands. These concerns were especially pressing in Japan, where resource constraints and competitive pressures spurred innovation. There, cellular manufacturing became a cornerstone of what would later be known as the lean movement. As Japanese manufacturers, particularly Toyota, developed and refined lean methodologies, cellular manufacturing was integrated into key operational strategies, including just-in-time (JIT) production, standardized work, and continuous improvement (kaizen). The core idea of organizing workstations and equipment into efficient, compact production cells – with an optimized ergonomic footprint – helped reduce motion, transportation, and waiting time, all of which are considered forms of waste in lean thinking.

By breaking down large-scale production into smaller, more agile units, companies were able to improve quality, enhance worker ownership, and respond more flexibly to changes in demand (Rodriguez et al., 2023). This approach also facilitated better communication, faster problem-solving, and more efficient training. Over time, the principles of cellular manufacturing have been adopted globally across a wide range of industries, contributing to ongoing efforts to create more responsive, sustainable, and human-centred production environments.

1.2 Characteristics of the cellular layout

Cellular layout is an approach to lean production and service delivery that aims to improve efficiency, flexibility and overall performance. By identifying a subdivision of the entire range of products and services based on processing similarities, machines and other resources are grouped into what are known as cells to improve workflow and shorten lead times. The philosophy behind the cellular layout is to organise similar tasks or products together to exploit similarities and minimise variations (Fig. 1). A cell capable of accommodating product variations is equipped with specialised machinery (and customised tools and fixtures) as well as highly skilled employees who can work as a team (Groover, 2010).

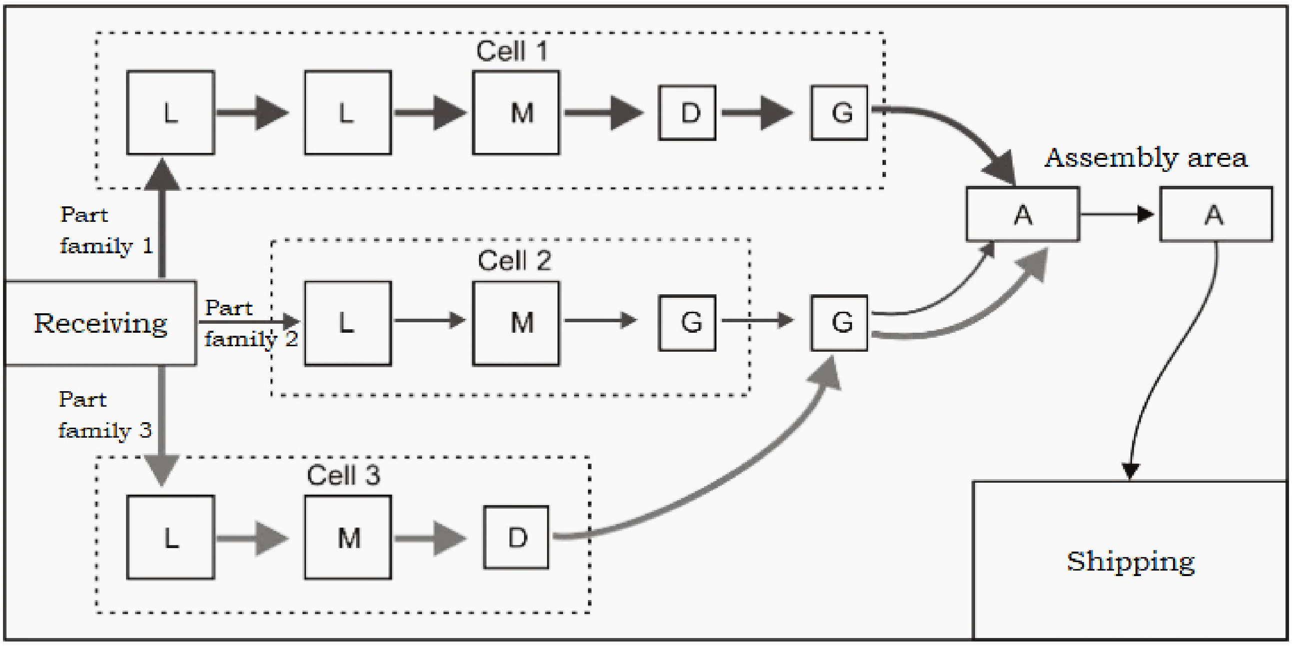

Fig. 1. Cellular layout.

The main difference with a product layout is that in a cellular layout the operation sequence and flow direction can be varied. In terms of unskilled labour, a cellular layout draws on one of the features of the fixed-position approach (Slack & Lewis, 2006). The arrangement of machines and equipment ensures a smooth, uninterrupted flow of work resulting in a seamless transition from raw materials to semi-finished or finished products. It is important to balance cycle times both inside and outside the manufacturing cell. A major problem in manufacturing cells is the arrangement of machines within the cell: movements between cells must be minimised, while the utilisation of machines within the same cell must be maximised.

The factory layout is created by placing the consecutive machines as close together as possible. When designing a cell, one has to consider the product, the process, the logistics, and the layout.

Advantages of cellular layout:

1) Increased efficiency: Cellular layout increases efficiency by minimising movement and transport between workstations. This lowers material handling costs, enables faster feedback on potential quality issues, reduces work-in-process inventory, simplifies scheduling and shortens lead time. Space requirements are reduced. Each cell becomes a factory within a factory.
2) Flexibility: The ability to adapt quickly to changes in the product mix or service requirements is a significant advantage. A well-designed cell is able to minimise set-up operations throughout the whole facility by subdividing processes based on their similarities. This allows batches to be reduced in size.
3) Specialisation: Cellular layout enables specialised attention to specific products or services, resulting in improved quality. Cell teams better understand the entire process of making parts/assemblies. Communication between workers is improved. Understandable, logical participation leads to a feeling of empowerment. Employees have a common production goal and are accountable for achieving it. Continuous improvement is ingrained within cellular manufacturing as each production cell seeks to optimize its processes and reduce waste.
4) Standardisation: Group technology promotes standardisation of tooling, fixturing, and set-ups.

Disadvantages of cellular layout:

1) Implementation challenges: Creating effective cells requires careful analysis and planning, and implementation can be a challenge. Rearranging machines in the factory to the appropriate cells is a problem, and the machines do not produce during the changeover.
2) High initial investment: The initial set-up of a cellular layout may require significant investment in reorganising facilities and training staff. Cellular layout can require more equipment.
3) Imbalance of utilisation of machines and labour: some machines in a cell could be more utilised than others. It is not uncommon for the cell to contain one specific type of machine. If that single piece of equipment breaks, the line is down, and production may bottleneck.
4) Not suitable for all products or services: Cellular layout may not be suitable for industries with highly customised products or services. It must be well designed, fully process-mapped, and constantly improved to produce benefits. Not enough groups or operations are critical for this layout type. However, modern computerised models are quite capable of using product data to determine whether a cellular layout is a suitable choice.

1.3 Cellular layout in manufacturing

Cellular manufacturing can be implemented using manual or automated machines. In manufacturing, the cellular layout is particularly effective when dealing with a variety of products that are similar in their production processes. A part family is a group of parts that have similarities in geometric shape and size, material and processing steps used in their manufacture (Baudin & Netland, 2023). The key characteristics of cellular layout in manufacturing include:

1) Grouping by similarity: Machines and workstations are organised according to the similarity of tasks or processes, which enables a more concentrated and efficient production process.
2) Flexibility and autonomy: Cellular layout promotes flexibility and enables rapid adaptation to changes in production volume or product mix.
3) Reduced lead times: By minimising the distances between workstations and concentrating on specific product families, the cellular layout helps to reduce throughput times.

1.4 Cellular layout in services

Although the cellular layout is more commonly associated with the manufacturing industry, its principles can also be applied in the service sector. In the service sector, cells are created to fulfil specific types of services or customer needs. Key features of cellular layout in services include:

1) Specialisation: The service providers organise the workstations or service areas according to the type of service offered so that they can adapt to the needs of each customer.
2) Customer-centric approach: Cellular layout in services emphasises a customer-centric approach by tailoring the delivery of services to specific customer requirements.
3) Improved service quality: By grouping similar services together, companies can streamline their processes, resulting in higher service quality and customer satisfaction.

2. Application of cellular layout in different industries

Cellular layout is used in various industries and proves its versatility in manufacturing and the service sector. Let's examine its use in a few key areas:

1) Manufacturing

<u>Machining and fabrication</u>

In the machining and fabrication industries, cellular layout is often used to group machines that perform similar operations. This approach increases efficiency by minimising the time and distance required to move materials between workstations. It is very useful for companies that produce a variety of parts in small batches to take advantage of the benefits and economics of product layout (Kumar & Suresh, 2008). In an automotive assembly line different production cells are responsible for specific tasks such as engine assembly, chassis assembly, or interior installation.

Aerospace manufacturing

Aerospace manufacturing often involves the production of diverse components. Cellular layout is applied to organise workstations based on the type of components being manufactured, allowing for more efficient and specialised production processes.

2) Services

Healthcare

In healthcare, the cellular layout is used for organizing patient care teams around specific treatment types (units) or departments, such as emergency care, radiology and surgical services. Each cell is designed to meet specific medical needs, enabling efficient and specialised care.

Banking

Banks use the principles of cellular layout to organise service areas according to customer needs, transaction types or customer segments, e.g. counter services, loan processing and financial advice. This approach increases service quality and efficiency, and improve customer satisfaction.

3. Identification of part families

The classification of cell formation approaches was introduced, for example, by Offodile et al. (1994) and Irani et al. (1999). There are several ways by which part families are identified in the industry (Groover, 2010). One method involves visual inspection of all parts produced in the factory (or photos of the parts) and categorising them into appropriate families based on best judgement. These product groupings may be parts of a similar design that only vary in size, shape, or functionality.

The second approach is called production flow analysis (PFA). In the 1970s and 80s, John Burbidge (1961) developed a technique to transform job shops into flow shops using the group technology (Fig. 2). His PFA method is used worldwide, regardless of industry and factory size (Burbidge, 1989). The PFA method uses the information contained on the route sheets to classify parts. In effect, parts with similar manufacturing steps are grouped into the same family. During data collection, the sequence of operations and the machine routing for each part are taken into account. The parts are displayed in the part-machine incidence matrix. We use cluster analysis to group parts with similar routings; each machine group represents a machine cell. The initial PFA normally assigns products to groups based on the operations to be performed, regardless of sequence. It is necessary to determine how many cells will be formed, which production sources are in the cell and which part should be produced in which cell (Kagnicioglu, 2019). Sometimes it is possible to perform a further, more detailed PFA based on individual products or subgroups that take into account the sequence of operations. All parts assigned to a cell are processed almost exclusively in that cell itself. The aim here is to minimise movement between cells (Kumar & Suresh, 2008). PFA leads to a cellular layout with independent production cells that often form the unit for capacity planning and production allocation.

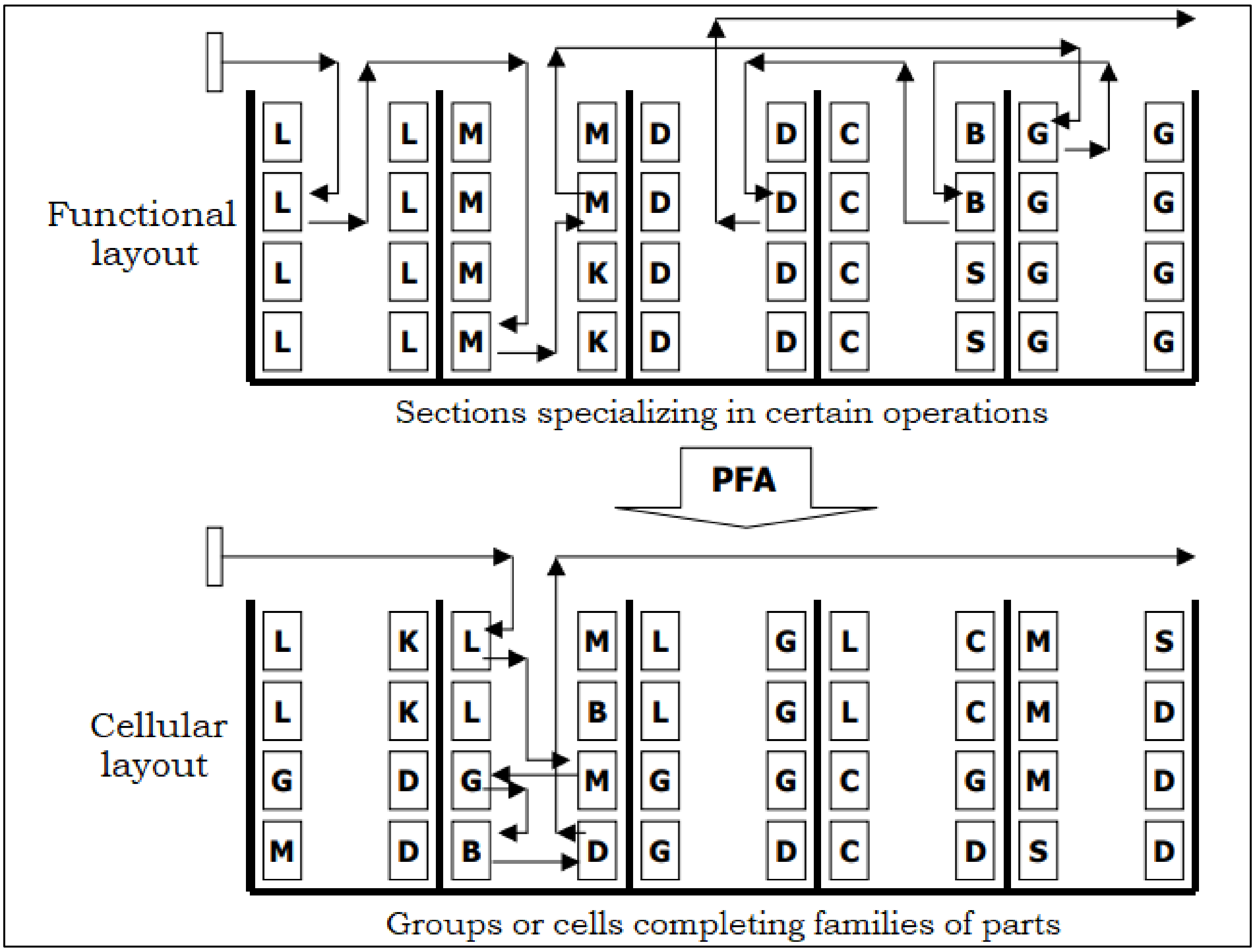

Fig. 2. Transformation of functional layout into a cellular layout.

A third method, which is usually the most expensive but also the most useful, is the classification and coding of parts. Part classification and coding (based on design and manufacturing characteristics) involves identifying similarities and differences between parts and relating these parts using a numerical coding scheme. Each company must design its own coding scheme. The design characteristics of a part include: main dimensions, basic external shape, basic internal shape, length/diameter ratio, material type, part functional tolerances, surface finish. The attributes of part production include: main process, operation sequence, batch size, annual production, machine tools, cutting tools, material type.

Over the last four decades, research in the field of cellular manufacturing systems has mainly focussed on production-oriented approaches (Modrak & Semanco, 2012) with the aim of applying the principles of assembly line production to other types of production (the PFA-based methods).

Deciding how many operations to put in a cell is complicated by two conflicting factors (Martinich, 1997):

- The more operations are performed in a flow cell, the greater the efficiency gain from its use, but the fewer products can normally be accommodated in the cell.
- The more operations are contained in a group cell, the more different products can be processed, but the less efficient the processing of the individual products is on average.

In the detailed design phase, information is needed on the processing times and expected production volume for each product (in terms of cell capacity). The layout of the entire cellular system is normally treated as a functional layout. Since the group cells must allow a variety of routings within the cell, they must be configured and connected in such a way that a free flow of materials and labour is possible (a U-shaped layout meets these requirements well).

4. Binary sorting method

This method is one of the cluster analysis methods and is also known as the array-based method. It rearranges the order of the rows and columns to find a block-diagonal structure of a part-machine incidence matrix, which is represented as a binary (zero-one) matrix. The rows of the matrix are the machines and the columns represent the parts. The entries in the matrix are '1's and '0's, which indicate whether a part requires that machine for production or not.

In the first step, we convert the individual rows of the matrix into the decimal system and sort the machines in descending order of the decimal values. We also sort the rows in the new part-machine matrix in the same way.

In the second step, we repeat the calculation (conversion from binary to decimal numbers) for the columns. We sort the parts in descending order of the decimal values and rearrange the matrix in the same way (sorting the columns).

The block-diagonal structure is a basis for the definition of cells. Its aim is to minimise the number of exceptional elements (minimising the cost of material transport between cells). Exceptional elements represent movements between cells, which in practise means that they represent unwanted movements of parts to machines between individual cells (Buchmeister, 2023). This method is known as the Rank Order Clustering (ROC) algorithm. The fact that it uses binary values limits the size of the matrix that can be solved.

Other production-oriented cell formation methods are: descriptive methods, graph partitioning methods, mathematical programming methods, heuristic methods, meta-heuristics and artificial intelligence methods, and hybrid methods.

4.1 Cell formation example

An overview of the routings for the 10 parts gives the following machine requirements (8 types of machines):

P1: B, D, G	P2: A, F, H
P3: A, C, F, H	P4: B, G
P5: D, E, G	P6: A, C
P7: B, E, F, G	P8: A, B, C, H
P9: A, C, H	P10: A, F

Group parts into families and design machine cells!

First, we form a part-machine matrix:

Part / Machine	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
A		1	1			1		1	1	1
B	1			1			1	1		
C			1			1		1	1	
D	1				1					
E					1		1			
F		1	1				1			1
G	1			1	1		1			
H		1	1					1	1	

We present the individual rows in the matrix as binary numbers and convert them to the decimal system (8 calculations):

A: $0110010111_2 = 2^0 + 2^1 + 2^2 + 2^4 + 2^7 + 2^8 = 407_{10}$

B: $1001001100_2 = 2^2 + 2^3 + 2^6 + 2^9 = 588_{10}$

C: $0010010110_2 = 2^1 + 2^2 + 2^4 + 2^7 = 150_{10}$

D: $1000100000_2 = 2^5 + 2^9 = 544_{10}$

E: $0000101000_2 = 2^3 + 2^5 = 40_{10}$

F: $0110001001_2 = 2^0 + 2^3 + 2^7 + 2^8 = 393_{10}$

G: $1001101000_2 = 2^3 + 2^5 + 2^6 + 2^9 = 616_{10}$

H: $0110000110_2 = 2^1 + 2^2 + 2^7 + 2^8 = 390_{10}$

We sort the machines in descending order of decimal values (from 616 to 40): G – B – D – A – F – H – C – E and sort the rows in the new part-machine matrix:

Part / Machine	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
G	1			1	1		1			
B	1			1			1	1		
D	1				1					
A		1	1			1		1	1	1
F		1	1				1			1
H		1	1					1	1	
C			1			1		1	1	
E					1		1			

Now, we repeat the calculation (number conversion) for the columns (10 calculations):

P1: $11100000_2 = 2^5 + 2^6 + 2^7 = 224_{10}$

P2: $00011100_2 = 2^2 + 2^3 + 2^4 = 28_{10}$

P3: $00011110_2 = 2^1 + 2^2 + 2^3 + 2^4 = 30_{10}$

P4: $11000000_2 = 2^6 + 2^7 = 192_{10}$

P5: $10100001_2 = 2^0 + 2^5 + 2^7 = 161_{10}$

P6: $00010010_2 = 2^1 + 2^4 = 18_{10}$

P7: $11001001_2 = 2^0 + 2^3 + 2^6 + 2^7 = 201_{10}$

P8: $01010110_2 = 2^1 + 2^2 + 2^4 + 2^6 = 86_{10}$

P9: $00010110_2 = 2^1 + 2^2 + 2^4 = 22_{10}$

P10: $00011000_2 = 2^3 + 2^4 = 24_{10}$

We sort the parts in descending order of decimal values (from 224 to 18): P1 – P7 – P4 – P5 – P8 – P3 – P2 – P10 – P9 – P6 and sort the columns in the new part-machine matrix:

Part / Machine	P1	P7	P4	P5	P8	P3	P2	P10	P9	P6
G	1	1	1	1						
B	1	1	1		1					
D	1			1						
A					1	1	1	1	1	1
F		1				1	1	1		
H					1	1	1		1	
C					1	1			1	1
E		1		1						

We see that machines A, C, F and H should form one cell with the parts P2, P3, P6, P8, P9, P10. For better display we move the last row (for E) above A:

Part / Machine	P1	P7	P4	P5	P8	P3	P2	P10	P9	P6
G	1	1	1	1						
B	1	1	1		1					
D	1			1						
E		1		1						
A					1	1	1	1	1	1
F		1				1	1	1		
H					1	1	1		1	
C					1	1			1	1

Cell 1 has machines B, D, E and G machining parts P1, P4, P5 and P7. **Cell 2** has machines A, C, F and H machining parts P2, P3, P6, P8, P9 and P10.

In this case, the solution with two cells is not ideal. We have two exceptional elements (circled). Part P7 must travel to Cell 2 to be machined on machine F; part P8 is moving to machine B in Cell 1.

Performance evaluation of the cell formation (Garbie et al., 2008) includes the calculation of machine utilisation (*MU*), grouping efficacy (*GE*), and grouping capability index (*GCI*). We expect all three indicators to be between 0,6 and 1.

$$MU = \frac{N_1}{\sum_{c=1}^{C} m_c \cdot n_c} = \frac{28}{4 \cdot 4 + 4 \cdot 6} = 0{,}70 \tag{1}$$

where:
N_1 – total number of ‘1’s in the diagonal blocks of the part-machine incidence matrix,
C – number of manufacturing cells,
m_c – total number of machines in the c^{th} cell,
n_c – total number of parts in the c^{th} cell.

$$GE = \frac{1 - \frac{N_2}{N_3}}{1 + \frac{N_4}{N_3}} = \frac{1 - \frac{2}{30}}{1 + \frac{12}{30}} = 0{,}67 \tag{2}$$

where:
N_2 – total number of ‘1’s in the off-diagonal blocks of the part-machine incidence matrix,
N_3 – total number of ‘1’s in the part-machine incidence matrix,
N_4 – total number of ‘0’s in the diagonal blocks of the part-machine incidence matrix.

$$GCI = 1 - \frac{N_2}{N_3} = 1 - \frac{2}{30} = 0{,}93 \tag{3}$$

These results show that the system needs some duplicate machine types to minimise or eliminate intercellular movements. We need two machines B and two machines F. In this case, we will eliminate exceptional parts, intercellular movements and bottleneck machines.

4.2 Discussion about group technology and cellular layout

Group technology has proven to be very successful when implemented properly. Prior studies (Pullen, 1976; Wemmerlow & Hyer, 1989) have shown the following improvements:

- Throughput time (5–90 %).
- Work-in-process inventory (8–80 %).
- Material handling (10–83 %).
- Job satisfaction (15–50 %).
- Set-up time (2–95 %).
- Quality (5–90 %).
- Finished goods (10–75 %).

All these advantages essentially reduce production costs and lead to higher product quality. The simplified operations planning requirements of cellular manufacturing systems leads to improved operating efficiency. Cellular manufacturing teams should have a high degree of autonomy. Teams should be accountable for their performance and have the authority to influence performance. It is believed that employee control and empowerment is an important aspect of cellular manufacturing.

There are a number of potential limitations to the introduction of cellular manufacturing. Some argue that cellular manufacturing can lead to a reduction in production flexibility. Cells are usually designed to maintain a certain flow volume of parts produced. If demand or the required volume decreases, the cells may need to be reorganised to meet the new requirements. This is a costly process that is usually not necessary with other manufacturing concepts.

5. Machine cell designs

Cell design impacts cycle time, waste, fatigue, and many other considerations and allows process improvement. Because units may be in quantities as low as one and remain efficient, it reduces work in process and space requirements often overwhelmed with batching (Kuuse, 2023).

There are many design objectives that must be achieved during cell formation. These objectives are to minimise lead times, minimise set-up times, minimise inventory levels, minimise movement of parts within the cell and between cells (minimising material handling costs), minimise machine relocation costs, minimise variation in machine utilisation, minimise operating costs, minimise capital investment, maximise resource utilisation (machines and labour) and maximise production. Some of these objectives can conflict with each other (Selim et al., 1998).

5.1 Types of cell layouts

There are many types of layouts for configuring cellular manufacturing (Fig. 3). These include (Kuuse, 2023):

- Linear: Linear cells (also called “I” cells) are like mini assembly lines. Work proceeds in order, with each machine adding value to the part until it is finished. Linear cells require access to both sides of the layout for optimization. However, it is also possible to configure it with labour on one side and point-of-use raw materials or components on the other.
- Cage: A cage configuration consists of a rough circle or square, usually with one operator inside the “cage.” Products may require multiple passes or repeat passes on each machine several times before completion. In a cage configuration, equipment utilization may be low, and machine use is intermittent based on part design.
- U-shaped: One of the most common cell designs is the U-shaped cell. Here, all staff and process steps are included within the inside of the “U”. This optimizes cross-training and reduces the time required to produce the part. It also alleviates fatigue and improves communication and collaboration.

- T-shaped: T-shaped cells are used for production that requires multiple sources of raw materials. Subassemblies are produced on the arm of the "T" and converge into a final leg for final assembly and finish. T-shaped cells work well for semi-finished goods and when different product lines are serviced concurrently.
- S-shaped and Z-shaped: S- and Z-shaped cells are often used to work around obstructions. This may be a beam or girder in an older facility with eclectic space to consider. It may also be configured around a heavy machine such as a CNC or metal bending machine where moving it is impractical or impossible. Once in place, S and Z-shaped cells may act like a U or linear cell, depending on the product.

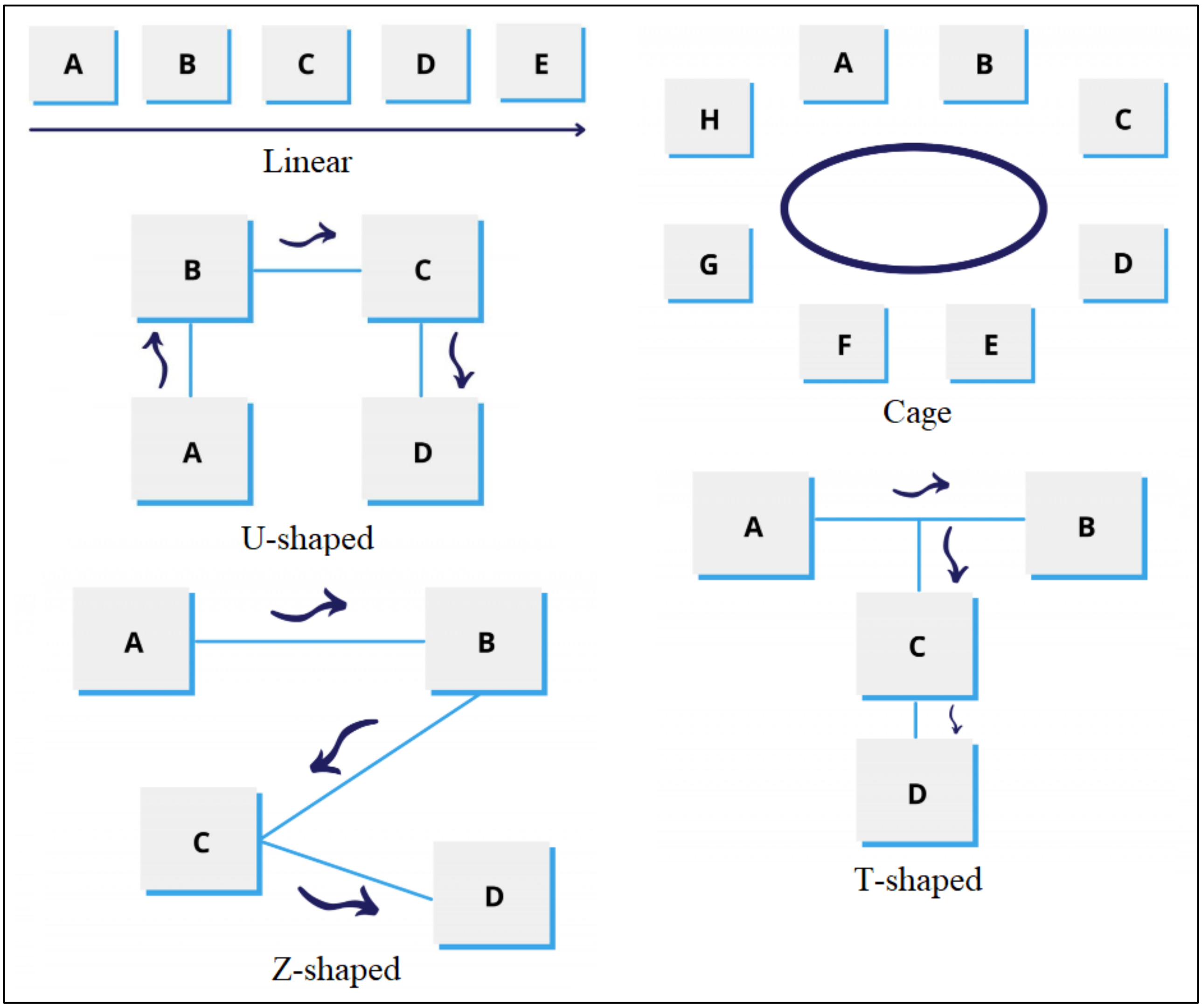

Fig. 3. Types of cell layouts.

Machine cells can be classified according to number of machines and level of automation. The possibilities are: single machine, multiple machines with manual handling, multiple machines with mechanised handling, flexible manufacturing cell, or flexible manufacturing system.

The single machine cell has a machine that is operated manually. The cell would also include fixtures and tooling to allow for variations of features and size within the part family produced by the cell.

Multiple machine cells have two or more manually operated machines (Fig. 4). These cells are distinguished by the method of workpiece handling in the cell, manual or mechanised. Manual handling means that the parts are moved within the cell by workers, usually the machine operators. Mechanised handling means that the parts are transported from one machine to the next using conveyor systems.

Flexible manufacturing cells and flexible manufacturing systems consist of automated machines with automated handling. Parts moves in the cell could be: in machine sequence, in the opposite direction, or with by-passing a machine (a mixed-flow line).

Alternative way of forming machine cells are virtual machine cells – dedication of certain machines in the factory to produce part families, without physical relocation of machines.

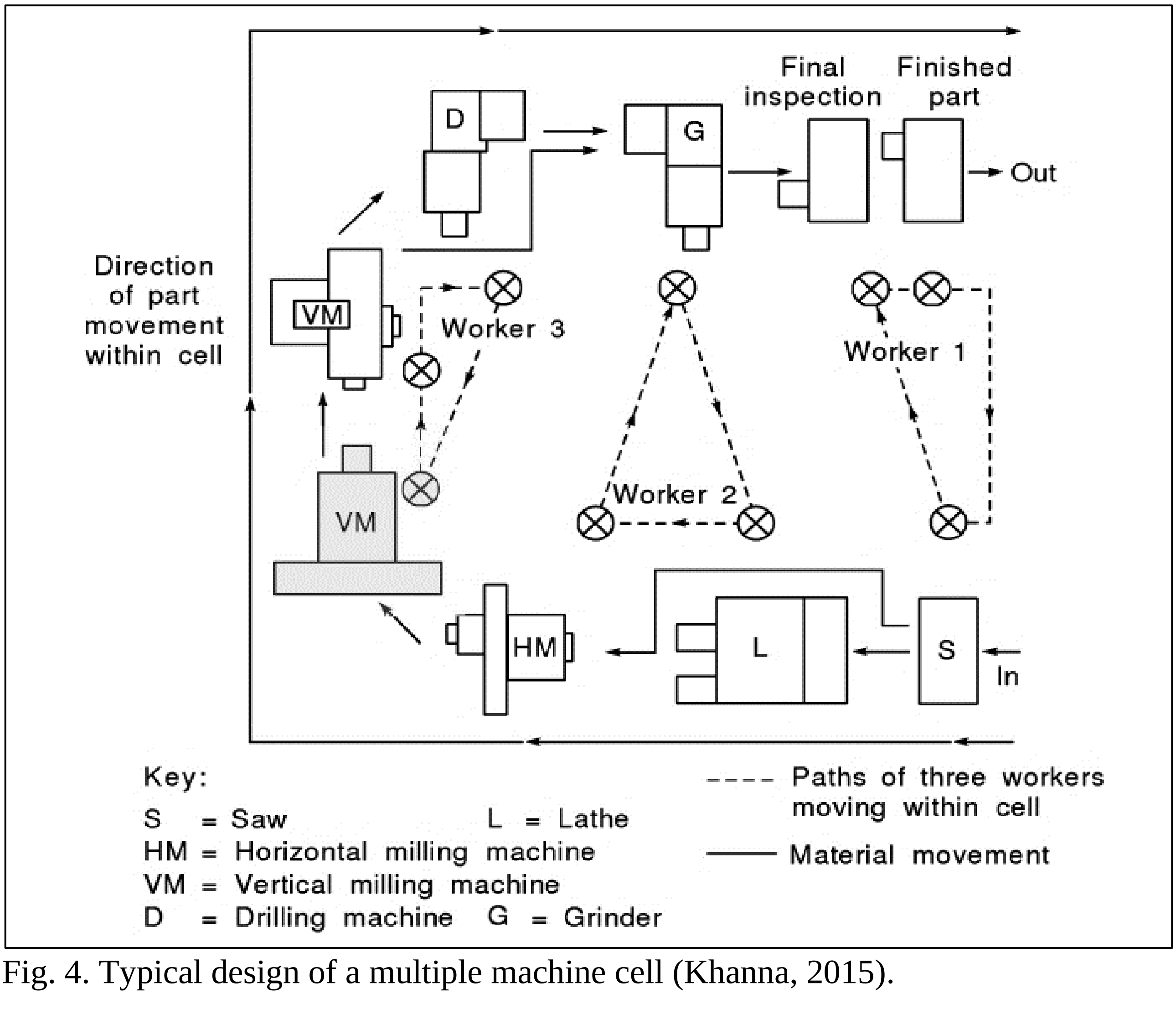

Fig. 4. Typical design of a multiple machine cell (Khanna, 2015).

6. Conclusion

Cellular manufacturing is a production organization method that consists of arranging the shop floor in a way that would accommodate the greatest efficiency. A cellular layout is actually a hybrid arrangement of facilities based on the combination of some of the principles of fixed-position and product layouts.

Cellular layout, whether in manufacturing or in the service sector, offers a strategic approach to increasing efficiency and flexibility. It is a response to the growing complexity and diversity of products and services in today's markets. By grouping machines, equipment, or service resources into cells dedicated to families of similar products or service types, organisations are able to reduce material handling, shorten throughput times, and improve quality consistency. Beyond operational improvements, the adoption of cellular layouts also fosters greater ownership among employees, since teams working within a cell are more directly accountable for performance outcomes. Whilst implementation can be challenging, the benefits of increased efficiency, flexibility and improved service quality are a valuable strategy for organisations looking to remain competitive. Considerable effort is required in the planning phase, particularly in the identification of product families, the balancing of workloads, and the allocation of resources. In addition, changes in demand, product variety, or service requirements can undermine the initial benefits if the system lacks sufficient flexibility. For this reason, continuous monitoring and improvement, as well as integration with lean principles, remain essential to sustain performance over the long term. As industries continue to evolve, the cellular layout remains a relevant and adaptable approach to meet the dynamic demands of the market.

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