Cellular manufacturing against relocation:
the most efficient way to transform plants

Lluís Cuatrecasas-Arbós*, Jordi Fortuny-Santos, Jordi Olivella Nadal

Business Management Department. Technical University of Catalonia (UPC)1-3, Jordi Girona Street, Barcelona, 08034, Spain * Corresponding author: Tel.: +34 934 016 813;   Fax: +34 934 015 629; E-mail: lluis.cuatrecasas@upc.edu

ABSTRACT

This paper presents a methodology to help decide whether a process-oriented plant would become more competitive by relocating its facilities in a low-cost country or by transforming it into an efficient plant by means of the implementation of a cellular layout with production driven by demand, managed in accordance with the principles of lean manufacturing. In this paper, our methodology is applied to an existing process-oriented production system A set of key magnitudes and cost data attributed to the production plant and the way it is managed are calculated. These key magnitudes, related to production cycles and inventories, are easily calculated by means of an Operation-Time diagram. Fourteen types of manufacturing and distribution costs are considered including those costs due to the relocation strategy, which are mostly related to logistics. The paper includes the necessary calculations to transform the original plant by implementing three U-shaped flexible cells and to quantify the number of employees that are necessary, taking into account global takt time and cycle time of individual processes. Key production magnitudes and production and distribution costs are then calculated for the cellular implementation. Final conclusions show that an efficient implementation of cellular production processes pursuant to the lean management principles (low resource consumption, elimination of activities that do not contribute to value creation, maintenance, on-time deliveries, high quality…) is able to offset, at least in the studied case, the improvement in costs attributed to relocation strategies in process-oriented plants managed in a conventional style.

1 INTRODUCTION

There is a vast literature on the benefits of lean or cellular manufacturing in certain companies but many times we wonder if those improvements are really due to the operation of a new manufacturing strategy or maybe to the commitment of people because "something is changing in the factory" or even due to external factors like market demand. In this paper, a methodology to change the plant layout is described and its physical effects are monitored in an Operation-Time diagram to ensure that other events do not affect the outcome.

Nowadays, to have a method to study costs and competitiveness is very important. The topic "Global Relocation" has become very usual because companies are moving their production plants from Western European countries to Central and Eastern European countries or from the Unites States to India and Eastern Asia. This relocation strategy seems to be increasingly applied because more and more companies discover that they are not competitive since their production plants in developed countries involve high costs, and therefore they decide, in search of a higher degree of competitiveness, to move to foreign countries, where costs, and specially labor costs are lower (Eenennaam and Brouthers, 1996; Tuselmann, 1999; Pennings and Sleuwaegen, 2000; Manzon, 2005).

Therefore, the aim of this research must be to determine if relocation is the only way to cut costs or maybe transforming the traditional process-oriented plant into a cellular plant can be a feasible –and even better option. In our attempt, our methodology to control cycles, inventories and costs involved in each alternative will be necessary.

Our preliminary hypothesis contend that a cellular layout, with one piece flow, according to the principles of lean management must be a good choice since process-oriented plants with differences amongst operations' cycle times involve big production and transfer lot sizes, whereas inventories are an important aspect to improve competitiveness through cost reduction in the design and implementation of a production system.

In the lean manufacturing framework, it is said that the existing level of work-in- process (WIP) inventories in a production process is a direct measurement of the incompetence of the system and its management while stock reduction is a direct result of the gradual removal of all kind of activities that can be seen as waste.

Stocks, indeed, act as a "protective shield" against the effects of a bad management in its numerous variants: failure to forecast real demand and its changes, incompetence to suitably schedule operations in processes, inability to make or buy with the appropriate quality, etc. Stocks mean an addition resource consumption to be managed, controlled, handled and, of course, to be produced. An excessive amount of work-in-process (or WIP) inventories, in short, comes to hide the deficiencies of a badly managed production system because it helps the system to keep on working (that is why stocks are considered a protective shield). High levels of WIP allow achieving the necessary flexibility to operate with an extensive range of products under conventional style production management at the expense of efficiency

Therefore, not only will a reduction in work-in-process inventories make a more efficient system, but also it will help to mend many other sources of inefficiency that constitute one or another kind of waste. Cost due to operations with excessive work-in-process inventories turns out to be higher than what can be assumed: transportation, storage, handling and wait costs are usually undervalued. In fact, process improvements are closely related to stock reduction, as is going to be seen further on. It's not for nothing that well designed balanced processes, with minimal lead times, operating under minimum production and transfer lot sizes, i.e. efficiently managed processes, result in minimal work-in-process inventories.

2. ANALYSIS OF A PROCESS-ORIENTED PLANT

To develop our methodology, the process to manufacture DVD-players is analyzed. It has been chosen because the electronic industry has experienced many cases of relocation. If we look around us we will realize most electronic devices have been assembled in South-Eastern Asia. The overall process includes three processes: one of them, labeled P, makes printed circuit boards; another, D, is the pre-assembly of certain control devices, and the last one, M, is the final assembly. Process P includes three operations P1, P2 and P3. Process D also includes three operations D1, D2, D3, related to different mechanical and electric devices. Finally, M has three operations M1, M2 and M3 referred to the assembly of the parts coming from P and D as well as other pieces bought to external suppliers. Operations are carried out in a job shop plant. Some of them are performed at same time in more than one workplace. As usual in this functional arrangement, parts flow from operation to operation in groups (containers). Operation time per unit, transfer batch size and number of workplaces for each operation are shown in Table 1.

Table 1: Operation time per unit, transfer batch size and number of workplaces for operations in a process-oriented plant to manufacture DVD players

Operations and processes	Time (s)	Workplaces	Batch size
P1	180	3	100
P2	90	1	250
P3	120	2	150
D1	60	1	200
D2	48	1	250
D3	84	2	250
M1	60	1	10
M2	84	1	5
M3	108	2	10

A possible layout for this process-oriented factory is shown in Figure 1. It's a classical layout that can be found in the majority of manufacturing plants in any industry.

The precedence relations among operations causes P2 wait till a transfer batch comes from P1 (as P3 has to wait for P2). For this reason, if the cycle time of an operation is shorter that the cycle time (see Table 1) of the previous one, the last operation will finish up a container and will have to wait till a new batch arrives. That is the case of P3, which depends on P2 (also D3 and D2, D2 and D1 or M3 and M2).

Next thing necessary to allow comparisons between this and other production systems is to know something about plant capacity, average work-in-process (due to process configuration) and cycle-times. This can be done by means of an Operation-Time diagram (a new version of the classical Gantt chart) (Cuatrecasas, 2002):

P1 and D1 can start at time zero because they do not depend on previous processes. When P1 will have finished the first lot (according to Table 1, each worker in operation P1 (there are 3) needs 180 seconds per unit and there are 100 units in a transfer lot), P2 will start. The same philosophy applies to P3 and the operations in D. The final process M can start when all previous operations (P3 and D3) have finished and, in the present case, it is only possible after P3 completes a batch of 150 units.

Operation P2 (and consequently process P) is the bottleneck of the manufacturing system. P2 has a cycle time of 90 seconds, the highest of all, affecting P3 and thus, process D. Ninety seconds is the cycle time of the whole process (cycle time to obtain a finished product).

According to this, forty units is the hourly capacity of the production system. If we represent the flow of all transfer lots to complete a production batch of 500 units, we find that the first transfer lost is finished at 40,000 seconds while the last one reaches the end of M3 at 85,000 second. That is the total lead time needed to finish a production order. We can also estimate the average number of heterogeneous units in process by adding the median inventory (half the maximum) for every operation except the final D3.
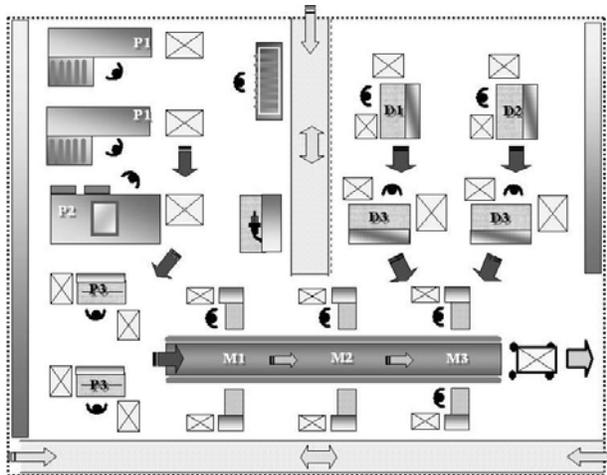
Figure 1: Layout of the process-oriented production plant

3. TRANSITION TO A CELLULAR LAYOUT

Plant layout for a lean strategy includes processes in flexible cells to make possible a quick product flow, the elimination of all kind of waste and the introduction of the necessary flexibility (Sekine, 1992). Figure 2 shows a possible cellular layout for a well balanced system.
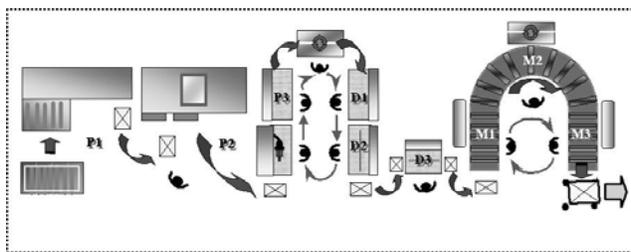
Figure 2: Cellular layout for a lean plant

Processes P and D could be placed together, except operation D3, in a cell with 6 people, with a resulting cycle time of 83 seconds. In Figure 2, we can see operations P1 and P2 taking an L shape with an employee moving around in charge of the supervision of the machines. Operation P3 together with D1 and D2 constitute a U-shaped cell with manual operations and

five employees inside it. Nagare has been considered instead of dividing up the tasks in the cell.

Then the product would be transferred to an isolated position in charge of operation D3, with a cycle time of 84 seconds. This arrangement can be modified if takt time changes, integrating D3 in a workcell.

Finally, M1, M2 and M3 can be carried out around a roller conveyor taking a U shape, with three workplaces, being two of them in Nagare in charge of operations M1 and M3 (The "U"-shaped layout would make it easier), with a cycle time of 84 seconds while the last one is in charge of operation M2, with a cycle time of 84 seconds.

As a whole, ten employees are necessary in this flexible design, provided workers are trained to be multiskilled, allowing different workplace distributions, assigning different tasks to the workers in the same cell or in another one in order to achieve a leveled flow with either longer or shorter cycle time.

Furthermore, we suggest that production is been carried out in batches of 150 units, with transfer lots of 10 units between the first cell and D3, lots of 5 from D3 to the assembly cell (M), where transfer between operations would be done unit by unit. Table 2 summarizes key data of this cellular layout.

Table 2: Key data in a cellular layout

Operations and processes	Number of workers	Cycle time (sec.)	Transfer lot
P1			
P2			
P3	6	83	10
D1			
D2			
D3	1	84	5
M1 + M3	2	84	1
M2	1	84	1

Furthermore, each process in the production flow in a cell needs only two containers, one at the beginning and one in the end, to move material between processes that, in all cases, are very close together, allowing the very small lot sizes that are used to transfer products in this implementation.

If we depict the production flow in an Operation-Time diagram, we realize that total lead-time diminishes to 14,200 seconds, yielding the first batch in 1,600 seconds. In addition, the flow regularity and the workload balance amongst posts, reduce the work-in-process amount, to 9 units.

Table 3 gives results for the key performance indicators in the cellular implementation, beside those achieved in a conventional process-oriented

implementation, a comparison between values in both implementations. Parameters in the cellular manufacturing system have been calculated for a lot size of 150 units and for a lot size of 500 units to assure a better comparison between both implementations. The column evaluating improvements has been calculated for values achieved with a lot size of 500 units, for both the conventional and the lean systems.

Table 3: Outline comparing key magnitudes between both production strategies

M a g n i t u d e s	Process-oriented	Total change (%)
Total Lead time *(LT)* (hours)	23.6	- 48%
Lead time for 1st unit (hours)	11.1	- 96%
Average stock in process (u.)	885	- 99%
Waiting time in posts (hours)	11.6	- 99%
Cycle time range (seconds)	90-42 = 48	- 98%
Number of workplaces *(N)*	14	- 29%
Productivity (units per hour)	40	+ 7,5%
Flexibility	Non-existent	+100%

M a g n i t u d e s	Cellular manufacturing	
	Batch = 150	Batch = 500
Total Lead time *(LT)* (hours)	4	12.2
Lead time for 1st unit (hours)	0.4	0.4
Average stock in process (u.)	9	10
Waiting time in posts (hours)	0.1	0.08
Cycle time range (seconds)	84 – 83 = 1	
Number of workplaces *(N)*	10	
Productivity (units per hour)	43	
Flexibility	Very wide	

4. COST ANALYSIS

Now we can analyze the costs involved with the process-oriented layout and the cellular layout. As stated in our previous hypothesis, we are supposing that the conventional plant is located abroad, far from the natural market of the product in order to achieve lower production costs. The cost elements to study are:

1. Cost of purchased materials and components, including regular transportation cost (Cp). Materials, in a plant under conventional management, are obtained from cheap suppliers close to the production plant.

2. Charges for rush courier services (Cc), allocated to finished product that must be send far away from the production plant. They are estimated as a proportion of the basic production cost.

3. Charges, as a proportion of the unitary costs, for the time lost in activities that do not give rise to finished goods or, otherwise, manufactured products are faulty (Ct). Such costs have been analyzed in the study of the attainable productivity and they are:

4. Hourly labor cost (L) of each of the production associates (N) is an important account, which decides many times the relocation of production plants. When needed, L can be split between low salaries and high salaries (Ll and Lh)

5. Wages of indirect workers, (Iw) as a proportion of direct labor costs. Usually there are more of them in plants under conventional management where employees are specialized in certain operations and they need indirect workers to carry out quality control tasks, maintenance or internal logistic activities, among many others than in lean plants.

6. Indirect labor is also needed for external logistics and physical distribution to the market. Moreover, if we assume the possibility of relocated manufacturing, if the market is not near the plant, some of the employees in charge of distribution activities must be based in a country with high salaries (Ieh) while the rest are in the low salary country (Iel).

7. Finally, indirect employees are needed in post-sales service and to deal with claims and customer guarantees (Ich, Icl).

8. Costs due to equipments, machines, systems and facilities, and other cost that can be allocated to the product (Co). They will probably be higher when using a relocation strategy because of the duplicity of overhead expenses created by an economic activity split between two distant locations.

9. Real state costs (Cr). Depreciation costs are higher in non relocated facilities.

10. Daily costs due to stocks (Cs). Most important costs come from handling and transportation activities, as well as the room taken up. They are clearly higher for the lean implementation because it does not benefits from relocation. With these figures, the cost of work in process inventories can be calculated, because average inventories values (WIP) have been previously quantified.

11. Stocks of finished product in transit from the production plant to the market must also be considered. Their volume can be quantified as the production amount (P) dispatched per time unit (T) multiplied by the time the journey takes (J).

12. Safety stocks (SS) for urgent deliveries can be estimated as a percentage of the total lead-time that it is enough for safety purposes (ts).

13. We must take into account the stocks of finished product (Sf) in the production plant, due to the time lag between production and sales (tl).

14. Cost of stocks of unsold products (Cu). A certain percentage (U) of the total stock of finished goods will finally become obsolete, unmarketable or just unsold . We can consider it as a monthly percentage of the total amount of finished product inventories.

Equation 1 determines the basic cost (CB) of every DVD player produced.

$$CB = Cp + \frac{L \cdot N \cdot T}{P} + Co + Cr +$$
$$+ \frac{T}{P} \cdot \left[(Iw \cdot N + Iel + Icl) \cdot Ll + (Ieh + Ich) \cdot Lh \right] \quad (1)$$

The total production and distribution cost (CT) for every unit can be found according to equation 2.

$$CT = CB \cdot (1 + Cc + Ct) + Cwip \cdot WIP \cdot LT +$$
$$+ Cs \cdot \frac{P \cdot J}{T} + Cs \cdot SS \cdot ts + Cs \cdot Sf \cdot tl + Cu \quad (2)$$

Some of the previous parameters, like N or WIP are already known with the aid of the Operation-Time diagram., many others (like Cp, Cc, Cf, Iw, Ie, Ic…) must be fixed according to the reader's experience, but some must be obtained from the day-to day running of the plant:

The production plant operates 2,400 hours per year (T) -8 hours a day and 300 working days per year. With a cycle time of 90 seconds in the process-oriented layout, the capacity of the plant is 96,000 units a year but effective net production can be estimated in 86,400 units per year (P) or 7,200 units per month, assuming a constant production rate. With a demand like Table 4, sales will be lost because the system cannot react to changes in the market while stocks keep on growing when production is not sold.

Table 4: Monthly demand, stocks and lost sales (in units of finished product)

Month	Demand	Stock	Lost sales
January	8,500	-	1,300
February	8,000	-	800
March	8,000	-	800
April	7,500	-	300
May	6,000	1,200	-
June	8,000	400	-
July	6,500	1,100	-
August	6,000	2,300	-
September	5,000	4,500	-
October	6,500	5,200	-
November	7,000	5,400	-
December	8,000	4,600	-

A cellular implementation operating 2,400 hours per year would keep monthly production rate tracking real demand, with an effective net production of 85,000 units per year (7,083 units per month on average). If we admit that times losses, including quality rejections, do not exceed 1.5%, gross production should be 86,329 units. With a cycle time of 84 seconds, the system has a 16.1

percent extra capacity. Table 5 summarizes costs and profits for both strategies.

Table 5: Production, cost and profit values for both production strategies

Magnitude (unit)	Process-oriented	Cellular manufacturing
Cp (Euro)	28.00	36.00
T (hours)	2,400	2,400
N (associates)	14	10
L (Euro/hour)	1.20 (Ll)	12.00 (Lh)
P (units/year)	86,400	85,000
Iw (proportion)	0.60	0.25
Ieh (people)	2	1
Iel (people)	2	0
Ich (people)	2	0
Icl (people)	1	0
Co (Euro/unit f.p.)	4.00	2.50
Cr (Euro/unit f.p.)	0.50	2.00
CB (Euro/unit f.p.)	34.70	44.60
Urgent deliveries (proportion)	0.15	0.0075
Cc (proportion)	1.5 x 0.15 = 0.225	10 x 0,0075 =0.075
Ct (proportion)	0.10	0.015
Cwip (Euro/day unit)	0.002	0.025
WIP (units)	885	9
LT (days)	3	0,5
Cs (Euro/day unit)	0.0003	0.005
J (days)	8	1
In transit (units)	2,184	283
SS (proportion)	0.20	0.20
ts (days)	2.1	0.3
SS (units)	597	85
Sf (units)	2,058	0
tl (days)	7.1	0
U (proportion)	0.085	0.011
U (units/year)	4,936	49
Cu (Euro/unit f.p.)	2.10	0.00
CT (Euro/unit f.p.)	63.30	50.30
CT (Euro/year)	5,466,797	4,273,344
Sales (units)	81,800	85,000
Price (Euro/unit)	85	85
Sales (Euro/year)	6,953,000.00	7,225,000.00
Profit (Euro/year)	1,486,203.00	2,951,656.00
f.p. = Finished product		

5. CONCLUSIONS

In this paper we have seen the procedure to transform a process-oriented layout into a balanced cellular layout for a specific case. We have presented a general methodology, based on an Operation-Time diagram and on cost accounting to analyze whether to transform a conventional process-oriented plant into a cellular lean plant can compete with the advantages of relocation.

Relocation has several advantages like very low labor costs but it also has some disadvantages related to logistics. In the studied case, the basic production unitary cost is still lower in the traditional relocated plant than in the lean one.

Nevertheless, when the costs of inventories are considered, they are bigger in the process-oriented plant, with the result that total cost is lower in the lean plant time where stocks are very small.

The cellular management system, based on the lean management philosophy, achieves a better service level, because production is tracking monthly demand, and generates smaller inventories. As a result of a lower costs and higher sales, higher profit figures are achieved in the lean company.

It is possible to go more deeply into our comparison with a sensibility analysis of the different costs in Equations 1 and 2, to deduce to what extend results favor the lean implementation strategy, by changing parameters within a certain range.

To end this evaluation, we can consider another important saving in the cellular layout It is the saving in room taken up due to the lesser space needed for processes, especially when u-shaped work cells are used, and to the removal of stocks. This saving hasn't been considered in previous calculations, but it's important because the costs of land and industrial buildings are usually reasons for relocation strategies. However, it would favor the lean implementation.

As a final conclusion, we can state that an efficient implementation of processes, pursuant to the principles of lean management, can compete (and win) against the improvement in costs derived from a relocation strategy that a business managed in a conventional style could undertake.

REFERENCES

Cuatrecasas, L., 2002, Design of a rapid response and high efficiency service by lean production principles: methodology and evaluation of variability of performance, International journal of production economics, No. 80, pp. 169-183.

Eenennaam, F., Brouthers, K.D., 1996, Global relocation: High hopes and big risks!, Long Range Planning , Vol. 29 No.1, pp. 84-93.

Manzon, G. B., 2005, Halsey-Evans relocation of operations, Journal of Business Research, No 58, pp. 981-988.

Pennings, E., Sleuwaegen, L., 2000, International relocation: firm and industry determinants, Economic letters, No. 67, pp. 179-186.

Sekine, K., 1992, One-Piece-Flow, Productivity Press.

Tuselmann, H.J., 1999, German direct foreign investment in Eastern and Central Europe: relocation of German Industry?, European Business Review, Vol. 99, No. 6, pp. 359-367.

Hyer N., Wemmerlöv, U., 2002, Reorganizing the factory. Competing through cellular manufacturing. Productivity Press.

Askin, R., Goldberg J. 2002. Design and analysis of Lean Production systems. John Wiley & Sons

Suzaki K., 1993. The new manufacturing challenge. The Pree Press.

Womack, J., Jones, D., 2003. Lean Thinking. The Free Press.