# MOVING FROM JOB-SHOP TO PRODUCTION CELLS WITHOUT LOSING FLEXIBILITY: A CASE STUDY FROM THE WOODEN FRAMES INDUSTRY

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## ABSTRACT

Cellular production is usually seen as a hybrid approach between job-shop and flow-line paradigms, reducing the major disadvantages of these two paradigms: the low productivity of job-shops and the low flexibility (in terms of products' variety) of the flow-lines. This paper describes the implementation of a production cell in a production unit of wood-framed pictures and mirrors, which was originally configured as a traditional job-shop, without losing the necessary flexibility to face market demand and simultaneously increasing the production unit's performance. By implementing a highly flexible cell, very significant improvements were expected for the system's overall performance and the quality of the products. These expectations were met, and the implementation was successful, as demonstrated by the results presented.

## OPSOMMING

Sellulêre produksie word gewoonlik gesien as 'n kombinasie van werkswinkel en vloeilyn benaderings en in die proses word die groot nadele van beide die benaderings, naamlik die lae produktiwiteit van werkswinkels en die lae aanpasbaarheid (in terme van produk variëteit) van vloeilyne, verminder. Die implementering van 'n produksie sel in 'n houtraamvervaardigingsaanleg, wat aanvanklik as 'n tradisionele werkswinkel uitgelê is, word beskryf. Hierdie implementering vind plaas sonder om die aanleg se aanpasbaarheid te beïnvloed terwyl die produktiwiteit verhoog word. Deur 'n hoogs aanpasbare produksie sel te implementeer word noemenswaardige verbeteringe in die sisteem se algehele verrigting en gehalte verwag. Hierdie verwagtinge is inderdaad bereik en die implementering is dus as suksesvol beskou.

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## 1 INTRODUCTION

Job-shop organisation is highly flexible in terms of the variety of products, because the location of the machines does not depend on the products' requirements. Machinery and other resources are grouped according to the nature of the process, and the products travel freely from resource to resource as needed. The system is always ready to produce any product, as long as the existing technological resources are available and can provide the product's technological processing needs. Despite being excellent in producing a high variety of products, the job-shop layout is very weak in productivity, level of work-in-process (WIP), and throughput time [1]. Also, this type of layout is difficult to schedule [2].
It is generally considered that moving from a job-shop configuration to a cell configuration brings benefits in productivity and throughput time [3], but also brings disadvantages through loss of flexibility and machine use. In fact, most traditional literature dedicated to operations management states that the job-shop is the most appropriate solution for production that requires a high variety of products [1,4,5].

This study was performed in a production unit that manufactures wood-framed pictures and mirrors, and that was originally organised as a job-shop. This production unit was losing competitiveness in European markets, mainly because of its low labour productivity. Thus, the main objective of this study was to improve the production unit's performance by increasing its productivity and reducing the throughput time, WIP inventory, and occupied area. To achieve this aim, this study proposes that the original job-shop should be transformed into a highly flexible production cell.

In this project, which took place in an industrial environment, the authors were involved directly in the design and implementation of the cell. A team of seven people were assigned to the project: the authors, the production unit supervisor, the production manager, the plant manager, and an industrial engineering trainee. The tasks of the project team included all the planning, training of workers, data collection, workplace design, material supply planning and design, performance evaluation, interviews, and any other tasks needed for the project. The authors visited the production unit once a week (for four hours each week) during the entire project, which took four months. During these visits, the project's progress on the shop-floor was monitored and team meetings were held, during which the authors were responsible for setting the guidelines for the next steps.

This paper is structured into six sections. After this initial section, which includes the motivation and objectives of the work, Section 2 presents a literature review on production systems' layouts, including classification and comparison, and focusing on the production cells. The third section characterises briefly the family of products to be produced in the cell, and analyses the corresponding production process, using Value Stream Mapping (VSM). Section 4 describes the design and implementation of the production cell, and Section 5 provides the analysis of the results achieved. Finally, in Section 6, some concluding remarks and future research directions are outlined.

## 2 LITERATURE REVIEW

The most common classification of production systems is based on their organisational structure or layout. Production systems are usually grouped into three main classes: job-shop layout, flow-shop layout, and cellular layout. Typically, job-shops are production systems where machines of the same type are grouped into functional sections to manufacture the full range of products demanded by the market. As a functional section usually includes more than one machine, the pooling synergy effect occurs [6]. Hence, each functional section executes one type of transformation process or function (e.g., machining, turning, and milling) in the entire production process. For this reason, the job-shop layout has been considered to be the most adequate (because flexible) in dealing with demand changes and a large product variety. A job-shop layout also has less positive aspects, such as the long throughput time and poor productivity. These problems are a consequence of the production flow's high complexity (reverse and cross flow) and high levels of WIP, due to batch and queue practices. Job-shops are normally recognised as using equipment efficiently, due to the pooling effect referred above. Nowadays, however, rather than a higher use of equipment, it is more important to produce the products that clients want, in the exact quantities and at the time that they want them – i.e., in a just-in-time production contextualised in a lean production environment [7].

Flow-shops are designed to produce a particular product (i.e., they are product-oriented layouts). Machines are organised in a linear sequence (corresponding to the product's sequence of operations) near each other, and are often linked by a conveyor, thus ensuring a continuous and direct flow. The machines and/or equipment are complementary in their processing functions, and ensure all the necessary operations. The whole flow-shop layout is designed to optimise throughput time. This allows high levels of productivity and quality, due to the complete focus on a particular product. The main disadvantage of flow-shop layouts is their configuration inflexibility, which constitutes a major problem when market demand changes.

Many companies have substituted, or are substituting, job-shop and flow-shop layouts with cellular layouts. The cellular layout is considered a hybrid approach, having the flexibility of the job-shop and the productivity of the flow-shop. Over the last twenty years, production cells have been adopted in different types of industries that produce quite distinct products. Publications such as [11, 22-30] mainly describe cases from the metal-mechanics industry. Others examples of industries where production cells have been implemented include: tractor industry [14], missile components and subassemblies industry [18], ferrite parts for electronics industry [31] and forging industry [43].

The important concepts associated with cellular layout, according to Hyer and Brown [8], are the flow and the closeness in terms of time, space, and information. The flow is one of the five principles of the Toyota Production System [9], which is now known as the 'Lean Principle' [10]. These factors play a key role in the context of this work, since they are the main reasons for the considerable performance improvements achieved by production cells.

The implementation of cellular production has a beneficial impact on an enterprise's manufacturing operations [11-15]. It is also recognised that cellular production is the preferred production system when implementing lean production [7,16-19].
At the operational level, the improvements typically occur in:

1. reduced WIP and consequently throughput times;
2. increased productivity;
3. increased quality of products and processes;
4. reduced amount of required space;
5. reduced absenteeism; and
6. simpler management.

As the parts are completely (or almost completely) produced inside the cell, the distance they must travel decreases (due to the machines' proximity). and thus also the amount of transport needed. Besides these benefits, many intangible improvements are also achieved, such as higher involvement, motivation, commitment, and responsibility in the cells' operators, which also increases the products' quality and reduces costs [14,20,21].

## 3 INDUSTRIAL SETTING

The industrial environment in which this project took place is a company in the decoration sector whose core business is the production of wooden mouldings. Besides the production units associated with the production of mouldings (e.g., carpentry and painting), there was a specific production unit where this project was conducted that is dedicated to the manufacturing of three families of products:

- Family 1: customised wood-framed pictures and mirrors assembled in batches. These products follow a make-to-order strategy, and the main clients are hotels and companies (for marketing purposes);
- Family 2: customised one-of-a-kind wood-framed pictures. For these products, the strategy is similar to engineering-to-order, and the main clients are individuals, bars, and restaurants (for decorative purposes);
- Family 3: canvases for painting. These products follow a make-to-stock strategy. Products for sale are kept in stock, and customers choose from a catalogue of alternatives. Production orders are created as stock levels reach replenishment levels.

The production unit dedicated to those three families of products was originally organised in a job-shop or functional layout (or process-oriented; see the initial layout in Figure 4). This layout had an area for the cutting machines, followed by an area for the underpinning machines, the manual assembly work stations (MAWS), the wrapping machines, and finally the packing area, which was located away from this production unit.

### 3.1 The existing production system

This project was focused on the assembly of products for Family 1. The variety of these finished products results from the combination of the following variables:

- Moulding profile: customers can choose a moulding profile from about 2,000 designs. In some cases, customers can supply their own mouldings.
- Dimensions of the wooden frames: the customers define the height and the width of the wooden frame, in any combination of sizes varying from under 10 cm to more than 120 cm.
- Picture or mirror: the clients may choose to put mirrors in the frame or use pictures supplied by the company.

Figure 1 illustrates two examples of the products mentioned. Usually the products are ordered in small quantities of between 50 and 500 units.

**Figure 1: Wood-framed mirror (left) and picture (right)**

In order to obtain a final product, the normal set of components that need to be assembled include these:

- Moulding: main support of the final product.
- Mat board: enhances visibility (only for pictures).
- Mount board: supports the picture or mirror and forms the back of the frame.
- Glazing: protection made from glass or acrylic (only for pictures).
- Other small components (e.g., gummed paper for the back of the picture frame, clips, hanging devices, labels, cardboard for protections, and other elements).

The family of products follows the route described in the VSM, as presented in Figure 2.

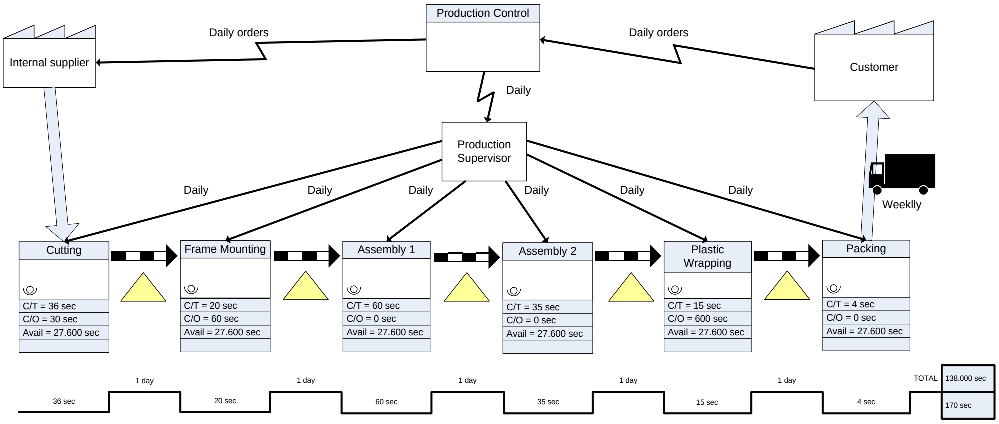


**Figure 2: VSM of Family 1: Wood-framed pictures and mirrors**

The cutting machine, which is supplied with three-metre-long mouldings, cuts two pairs of parts (top and bottom elements of the frame plus left and right elements of the frame) for each product. All of these parts (frame elements) are stored in pallets and later transported to the underpinning machine.

In the underpinning machine, each set of four parts is assembled as empty frames that are stored in pallets and transported to the first assembly area.

In the first assembly area (Assembly 1 workstation), the empty frame and the mirror, or the glass and picture print, are assembled manually and fixed with the help of an air-stapler gun. These semi-finished products are stored in pallets and transported to the second assembly area.

In the second assembly area (Assembly 2 workstation), other components are manually added to the product: the protecting corners, gummed paper, labels, and any additional gadgets. The final product is then stored and transported to the plastic wrapping machine, where it is wrapped with plastic film for protection.

The finished and wrapped products are stored in pallets and transported to the packing area, which is located more than 50 meters away (inside the finished products warehouse), where, finally, they are packed for delivery to the customers.

### 3.2 Performance of the existing production unit

In this production unit, there was a strong focus on processes performance and not on flow performance, resulting in push production, where the products had to wait in queues for the next operation. The focus on process performance is also related to the fact that each worker was specialised predominantly in only one process (cutting, assembling, etc.). Each worker was concerned only about the local processes and not about the whole system. This company did not keep any detailed records of production indicators until this project started, but the managers were already stating that production costs per unit always stayed above the forecasts and that the company was continually losing market share.

The most important performance indicators of the existing production unit in this family of products are shown in Table 1. The throughput time (or flow time), which was measured from the moment when all components become available until the delivery of the final products, was around one week (five working days, 460 minutes per day). During the longest part of this period, products were either waiting to be processed or to be moved from one production area to another (see initial layout in Figure 4). This production unit was hiding a wide range of wasted production, resulting in a poor production performance. The most common types of waste identified were transportation (moving pallets of products between production areas an average distance of 100 m) and inventory (average of 1,385 units between processes).

**Table 1: Main performance indicators in the existing production unit**

| Indicator | Existing production unit |
|---|---|
| Occupied area | 880 $m^2$ |
| WIP | 1385 units |
| Throughput time (average batch) | 1 working week (5 days) |
| Production rate | 277 units/day |
| Workers | 8 |
| Productivity | 35 units/day*worker |
| Value-adding time / Throughput time | 0.12% |
| Distance travelled by products | 100 m |

One important indicator that becomes clear after the VSM analysis was the extraordinary difference between throughput time (one work week, or 138.000 seconds) and the time used on value-added operations (170 seconds). The value-added ratio is only 0.12 per cent, while the typical value is 5 per cent [44].

## 4 DESIGN AND IMPLEMENTATION OF THE PRODUCTION CELL

Based on the benefits of implementing production cells, which were described in Section 2.1, the decision was made to design a production cell for the selected family of products (Family 1).

Many algorithms have been developed for the layout design problem, including approaches based on mathematical programming, simulation, and artificial intelligence [45]. As layout design depends on a lot of variables, it is considered a complex problem requiring combinatorial optimisation approaches. For this particular project, the Computerised Relationship Layout Planning (CORELAP) method [46] was chosen because it is able to provide good solutions in a short period of time. It is a sub-optimal method that constructs the layout by positioning the elements (departments, sections, or workstations) one by one, and involves two stages: (1) determining the elements' positioning sequence; and (2) determining the elements' placement. The positioning sequence and the location of each element are obtained based on the so-called closeness relationships between the elements.

The CORELAP method was applied using the following criteria to establish the closeness relationship: the number of the workers' movements between equipment and between equipment and input/output zones. Then, after making a few practical adjustments (e.g., the positioning of the cutting machine was constrained by the location of the central vacuum inlets), the solution, which is presented in Figure 3, was reached.

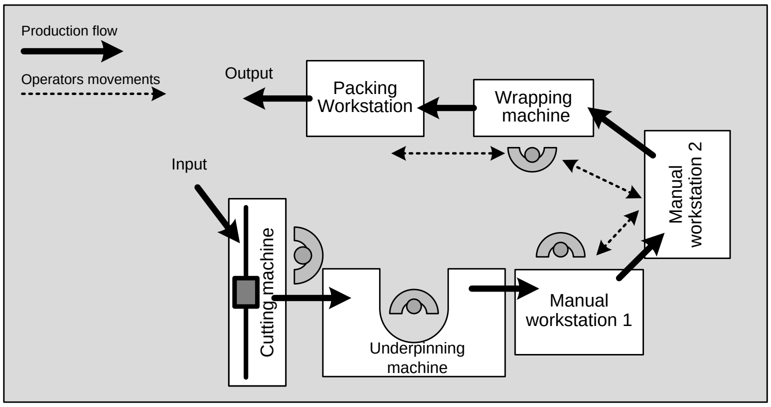


**Figure 3: Proposed U-shaped production cell**

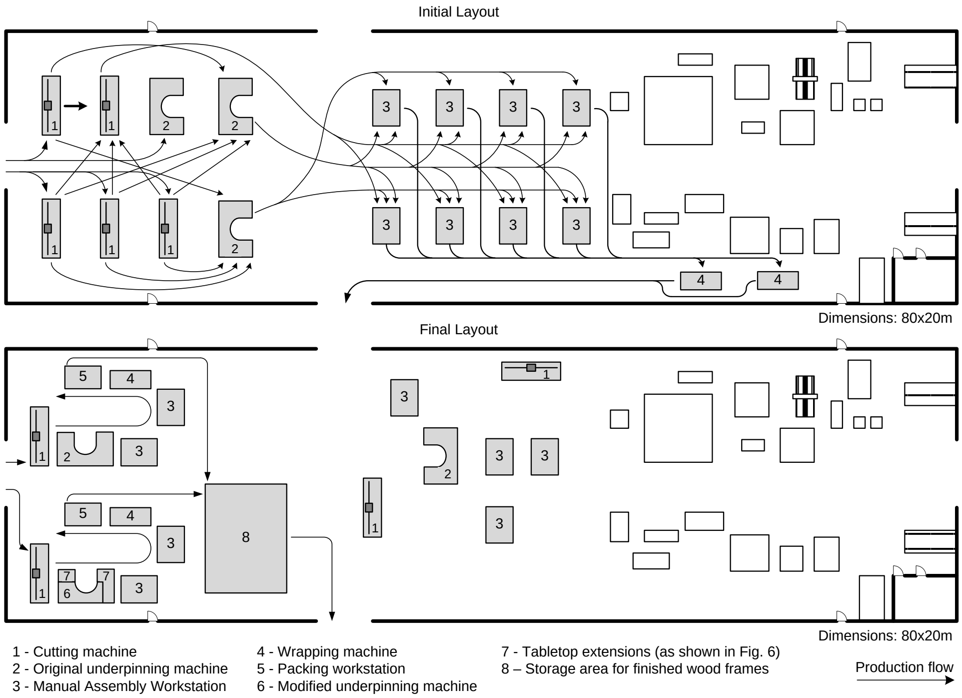


**Figure 4: Initial and final layout of the wooden frames' production unit**

The proposed cell was then implemented in the production unit, as can be observed in the bottom part of Figure 4. The second cell appearing in the same figure was created to deal with eventual peaks in capacity requirements.

The shaded elements (numbered) in Figure 4 are the machines or equipment involved in this work. In the initial layout, the packing workstations (5) were installed in a different location (shipment area). One of the five cutting machines (1) and one of the MAWS (3) were dispensed with in the final layout and moved to an adjacent building. Finally, a storage area (8) for finished wooden frames was created near the cells.

## 4.1 Standard operating solution

The major challenges faced in this cellular layout design were variability in demand and the diversity of the products within the product family. The variability in demand is expressed both in terms of the batch size of each customer's order (varying from 50 to 500 units per batch) and in terms of production per day (typically from 100 to 500 units). As the ability to respond rapidly to customer demand is a key competitive edge in this type of market, the designed system must deal effectively with the described variability in demand. It is easy to lose potential orders if the customer feels that the lead time is too long. The ability constantly to adapt the production capacity to market demand is crucial to maintain competitiveness. Thus, the cell must be able to adapt rapidly to significant changes in production demand (i.e., required capacity).

For this study, the decision was made to start with the design of a cell that could manage the most common conditions. This designated 'standard version' of the cell could manage a demand of 400 units per day, which is the typical daily demand. The planned production time for the cell was 460 minutes. In order to determine the takt time (TT) for the cell, the average time spent in changeover operations, which is around 20 minutes, is subtracted from those 460 minutes. Based on these calculations, the TT is 66 seconds (440 min / 400 units). This means that the operations assigned to each worker in the cell cannot last more than 66 seconds. One possible and feasible solution for balancing the operations by the workers is presented in Table 2. The operation times presented in the third column of the

**Table 2: Operations assignment to workers in the cell**

| Equipment | Operations | Op. time (sec) | Equip. effic. | Worker | Time (sec) |
|---|---|---|---|---|---|
| Cutting machine | Cut the top, bottom, left, and right elements (dimensions are defined by the customer) from moulding sticks (3 meters long on average). | 36 | 60% | Worker 1 | 56 |
| Underpinning machine | Assemble an empty frame from the top, bottom, left, and right elements. | 20 | 33% | | |
| Manual Assembly Workstation (MAWS) | Place the mirror and the mount board, and fix the set with the help of an air stapler gun. | 60 | 100% | Worker 2 | 60 |
| MAWS | Place protecting corners and glue the gummed paper and labels. | 35 | 58% | Worker 3 | 54 |
| Wrapping machine | Wrap each product with a thin layer of plastic to protect against dust. | 15 | 25% | | |
| Packing workstation | Pack the products into cardboard boxes (ready for shipping) | 4 | 6.7% | | |

table, which were supplied by the production planning and control personnel, are the company's official standard times for those operations.

According to the results presented in Table 2, the expected cycle time for the cell is 60 seconds. The projected equipment efficiency is very low for the packing workstation (6.7%) and very high (100%) for the bottleneck (first MAWS); despite this, the average efficiency is around 47 per cent.

### 4.2 Cell layout adaptability

For technical reasons, the cutting machine and the underpinning machine cannot be moved easily. All the other workstations, however, were equipped with wheels and could therefore be moved around rapidly and easily.

As already mentioned, the main difficulty with producing a diversity of products was dealing with a range of sizes (from less than 10 cm to over 120 cm), which has direct implications for the cell, especially the underpinning machine. This was a critical issue: if the cell were designed to suit large sizes, it would perform very badly for small sizes. On the other hand, if the cell were designed to produce small sizes, it would not be able to produce large sizes (because of area limitations).

To help deal with this problem, the underpinning machine was redesigned by the researchers and modified so that its table top could be changed as needed to accommodate different frame sizes better. The original table top was just one piece; so it was necessary to divide it into three removable parts: Tabletop Main, TabletopExt_1, and TabletopExt_2 (Figure 5). The removable table tops are in fact full tables with wheels that can be moved in and out as needed.

When assembling small frames (sizes below 70 cm), the area of the table top is reduced to its smallest size by removing TabletopExt_1 and TabletopExt_2. This change reduces wasted movements and transportation because the worker and the materials now travel a smaller distance. To deal with all aspects of variability, the cell was designed to allow considerable changes in its organisation whenever significant variations occurred in the products' physical size, complexity, and/or demand. The need for these reconfigurations, which may occur five or six times per day, can include layout changes (moving workstations around, in, or out) and/or workers' re-allocation (increase or decrease). Thus, as explained next, several configurations are possible.

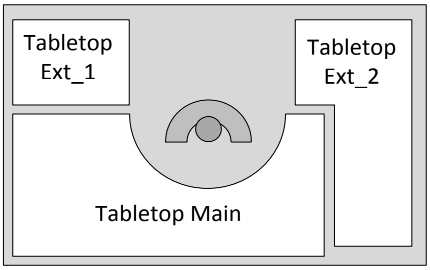


**Figure 5: Underpinning machine with table top adaptability**

The number of workers required for the cell depends on the TT, which is determined by the incoming orders, and also on the products' complexity (evaluated through the necessary total processing time (PT)). The number of workers assigned to the cell is determined initially by:

$$Minimum\ number\ of\ workers = (Total\ processing\ time)/(Takt\ time) \qquad \textit{(Equation 1)}$$

Special action must be taken by the supervisor, as the cell cannot perform well when more than five workers are needed. In these cases, another similar cell is activated.

For defining the cell layout, it was important to determine the adequate number of MAWS; this depends not only on the number of workers assigned to the cell, but also on the frame size (Fs) (Table 3). As the frame shape is either a square or a rectangle, the Fs considered in the table is the larger side of the rectangle.

**Table 3: Number of MAWS**

| Frame Size FS (cm) | Tabletop Ext_1 and Tabletop Ext_2 | Number of workers | | | |
|---|---|---|---|---|---|
| | | 1 or 2 | 3 | 4 | 5 |
| $F_S < 30$ | No | 1 MAWS | 1 MAWS | 2 MAWS | 2 MAWS |
| $30 < F_S < 70$ | No | 1 MAWS | 2 MAWS | 2 MAWS | 3 MAWS |
| $F_S > 70$ | Yes | 1 MAWS | 2 MAWS | 2 MAWS | 3 MAWS |

When one of the dimensions of the frame is larger than 70 cm, TabletopExt_1 and TabletopExt_2 are included in the underpinning machine. The larger the frame, the more working space is required, and so more MAWS are assigned to the cell. Note that when MAWS are included or removed, the wrapping machine and the packing workstation need to be moved to a different location in the cell in order to reduce movements.

Figure 6 illustrates another possible cell layout – in this case, for the smallest possible cell size. This layout is adequate for small-sized frames (below 70 cm) with no more than two workers; with more workers, the cell's performance is reduced.

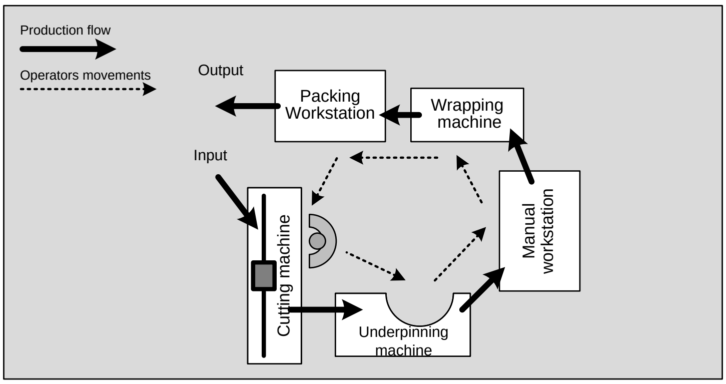


**Figure 6: 'Small version' of the production cell**

When the total processing time is lower than the TT (i.e., only one operator is needed; see Equation 2), he or she performs all the operations [47]. This operating mode is adopted frequently by workers, even when two or three are assigned to the cell. In general, the workers were very pleased with this operating mode, experiencing less fatigue and more productivity.

### 4.3 Management

According to the production orders released by the production planning and control system, the cell supervisor establishes the detailed schedule for the day. Due to poor planning and problems in the logistics system, causing frequent failures in the supply of materials to the cell, little room is left for the supervisor to decide on the assembly sequence for the day. The sequencing decisions are made very often throughout the day, according to the availability of the materials for each existing production order. The supervisor also assigns workers to the cell or to other areas of the same production unit, as required by demand.

Based on the required quantities and sizes of frames for the next batch that needs to be assembled, the supervisor assigns the workers needed for the cell and settles the number of workstations required for each production order (Table 3). For every production order associated with a specific batch of frames, the cell must be reconfigured in order to serve the size of the frames and production rates better. The experienced supervisor rapidly removes or includes workstations every time a different product must be assembled.

Setting up the cell requires the physical rearrangement of workstations, setting up machines for the new product, relocating some devices and tools, and including or removing workers (the most difficult aspect). This setup normally takes between 3 to 10 minutes, and includes the ramp-up time. Sometimes the supervisor needs to deal with another tricky restriction, such as the availability of workers. In some cases, the availability of workers determines the cell design, not the other way around. The workers move in and out of the cell according to the cell needs, but also according to other production needs within the same production unit.

The responsibility and autonomy assigned to the production cell required new organisational paradigms in the company, such as the lean production paradigm, as well as new performance measuring systems. These issues were discussed over several months, with the direct involvement of a large number of key workers. Thus the final implementation was the result of a lot of discussion and negotiation. A system following these principles may not be easy to create, but once it is running smoothly, it is self-sustaining.

## 5 RESULTS OF CELL’S IMPLEMENTATION

All the necessary elements were developed or made available for the success of the cell’s implementation. The workers were cross-trained and were given autonomy and responsibility. This section presents the most important results achieved by the implementation of the production cell for wood-framed pictures and mirrors, along with the workers’ perceptions about the new production paradigm. These perceptions were gathered from interviews that were conducted by the authors, with seven of the eight workers who were involved in the project. These seven workers were the same people who worked in the previous job-shop production unit.

### 5.1 Improvements achieved

The cross-training of the workers, and the rapid adaptability of the cell in the number of both workstations and workers, played a key role on the results achieved. Table 4 shows the improvements obtained for the main aspects of production performance. The occupied area was reduced largely because the storage areas next to the machines were eliminated, and also because in this new layout, machines were very close to each other (Figure 4). Since the machines were positioned close to each other and according to the required sequence of operations, the distance travelled by the products was reduced.

**Table 4: Main results achieved with cells**

| Indicator | Job-shop | Cell | Improvement |
|---|---|---|---|
| Occupied area | 880 $m^2$ | 360 $m^2$ | 59.1% |
| Distance travelled | 100 m | 12 m | 88.0% |
| WIP | 1385 units | 38 units | 97.3% |
| Throughput time (average) | 1 week (5 days) | 49 min | 97.8% |
| Production rate | 277 units/day | 360 units/day | 30.0% |
| Number of Workers | 8 | 3 | 62.5% |
| Productivity | 35 units/day*worker | 120 units/day*worker | 242.9% |
| Detection of quality-related problems | Difficult to detect | Easy to detect | - |

The reduction in manpower from eight workers to three, with a consequent productivity improvement of 242.9 per cent, resulted from the elimination of many non-value-added activities that were performed by each worker. The five workers who were freed as a result of these transformations were assigned to other production units in the company. Two of them were moved to the painting section, as this section was already short of manpower. The other three workers were assigned to a family of products that need a great deal of manpower and whose market is growing consistently. These products, referred to earlier as Family 2, are customised one-of-a-kind wood-framed pictures.

The common examples of a reduction in the wasteful use of manpower included transportation and movement waste, although the waiting and defects waste were also reduced. The major examples of non-value-added activities that were using labour hours and were no longer necessary are:

- Transporting materials from one storage area to another.
- Handling products from machines to pallets and from pallets to machines.
- Handling and transporting empty pallets.
- Handling and transporting pallets with products in process from storage areas to places next to machines or workstations.
- Searching for the pallet-truck.
- Workers waiting for a supervisor's decisions about batch sequencing.
- Reworking due to previous operation errors.

On the other hand, as a result of reducing the distances that products travelled, important improvements were achieved in production flow and inventory. The significant reduction observed in throughput time is a direct consequence of the drastic reduction of WIP, which in turn was possible because of the one-piece-flow approach applied in the cell (see transfer batch size in Table 5). The one-piece-flow approach became feasible with this cell layout, once the distances between workstations had been greatly reduced.

**Table 5: Comparison of important production parameters**

| Indicator | Job-shop | Cell |
|---|---|---|
| Setup time (average) | 2-3 minutes | 3-10 minutes |
| Processing time | 170 seconds | 170 seconds |
| Batch size | 50 to 500 units | 50 to 500 units |
| Transfer batch size | 50 to 500 units | 1 unit |

Some production parameters, such as processing time and batch size, did not change at all with the cell implementation (Table 5) since the machines and operation procedures were kept the same, and the batch sizes were defined by customers, as before. A negative aspect of the change was that the average setup time increased because more setup operations were needed in the cell. Examples of setup operations that were not needed in the job-shop layout include the removal or the inclusion of MAWS and changes to the underpinner table top.

A very positive and direct result of the decrease in throughput time was the reduction in delivery time to customers, which represents a major asset in terms of competitiveness. Additionally, the adoption of a unitary transfer batch (one-piece-flow) made production monitoring and management much easier because there is only one production order in the system at any one time. On the other hand, the detection of unbalanced work also became much easier.

Another substantial advantage was the early detection of quality problems. The company had no records on quality, in terms of number of defects, which inhibited the possibility of a quantitative comparison of results. However, the authors' observations revealed an improvement after the cell was implemented. These observations were confirmed by a situation in the previous job-shop: due to an error in the cutting section, the mouldings were cut to the wrong dimensions. When this problem was detected (in the mirror assembling operation), the entire batch of mouldings had already been cut and underpinned, which lead to an enormous waste of materials and work. This is one of the problems of large WIP units. After implementing the cell, the dramatic reduction of WIP (Table 4) can prevent the occurrence of similar situations because the detection of defects is almost immediate.

Although many improvements were already expected, the results achieved in terms of productivity were remarkable: from 35 units per day per worker in the job-shop approach, to an average of 120 units per day per worker in the implemented cell. Productivity is probably the most important indicator for managers, since it directly influences the production cost per unit. The reason that this indicator improved so impressively was thatthe workers were now able to spend most of their working hours in value-adding activities instead of using their time in non-value adding activities such as transporting materials from one place to another, reworking, waiting for orders or for components, moving around, looking for tools or for the pallet truck, and so on.

## 6 CONCLUDING REMARKS

The transformation of the production unit of wood-framed pictures and mirrors from the original job-shop layout to cellular production, preserving the necessary flexibility, was successful. All the defined objectives were accomplished.

The large diversity of products (due to frame types and, mainly, to size variation) was a serious problem for this cellular production implementation because the cell had to be reconfigured frequently (five or six times a day). In fact, the ability to reconfigure rapidly, both in layout and in the number of workers, was the main distinctive and innovative characteristic of the proposed cell.

Although some reductions were expected in terms of occupied area, in the cases of WIP, throughput time, and travelled distance, the achieved results (-59.1%, -97.3%, -97.8%, and -88.0%, respectively) exceeded expectations. However, the most unexpected result was the dramatic increase in productivity: from 35 units per worker per day to 120 units per worker per day. Amazingly, the workers were not aware of this remarkable improvement, apparently because they did not realise that they were working much more efficiently than before; they were not wasting time and effort in performing non-value-added activities such as moving around, transporting materials, waiting for something, and so on.

Two main conclusions emerged from this project: (1) product-oriented approaches are serious alternatives to the traditional process-oriented production units, leading to great improvements in production performance; and (2) human factors (such as objectives redefinition, motivation, cross-training, teamwork, autonomy, and responsibility) are crucial to the successful implementation of cellular production. It was also shown that with a proper design, the transformation of a job-shop layout into a production cell did not imply, necessarily, a loss of flexibility.

The main future research directions are: (1) further improvements in the assembly cell developed and presented in this paper, and (2) designing a new cell for the products of Family 2 (customised one-of-a-kind wooden framed pictures). The improvement of the existing cells can be achieved by more effective operating modes, by experimenting with different inclinations of table tops, in order to facilitate assembly operations, improving the ergonomics of workers, and by improving the border of line, in order to facilitate the supply of material and handling of materials by operators. Such research into the better design of a new cell for Family 2 products is very important because the company faces an ever-growing demand for these customised one-of-a-kind wood-framed pictures. These products are very attractively profitable, and the company feels the need to create a competitive production cell that is specially designed to produce this family of products. Designing a production cell that is able to produce such a wide variety of products in a one-of-a-kind fashion is already a major challenge; but an even bigger challenge is related to the supply of its material and the management of the very specific requirements. As each product requires specific components (such as frame type, glass dimensions, and other components), a critical issue is trying to ensure that all the right components are available in the cell at the right time and with the minimum WIP. In terms of future developments, the goal is to design a new cell that is able to cope with the new demand pattern and product typology, with performance values close to the ones achieved in the current cell.

## REFERENCES


[1] **Heizer, J. and Render, B.** 2013, *Operations management*. 11th edition. Prentice Hall.
[2] **Baker, K.R.** *Introduction to sequencing and scheduling*. John Wiley & Sons.
[3] **Johnson, D.J. and Wemmerlöv, U.** 1996. On the relative performance of functional and cellular layouts: An analysis of the model-based comparative studies literature. *Production and Operations Management*, 5(4), pp. 309–334.
[4] **Phillips, E.J.** 1997. *Manufacturing plant layout.* Society of Manufacturing Engineers.
[5] **Hitomi, K.** 1979. *Manufacturing systems engineering*. Taylor & Francis, Ltd.
[6] **Suresh, N.C.** 1998. Evaluation of functional and cellular layouts through simulation and analytical models. In: Suresh, N.C. and Kay, J.M. (eds.), *Group technology and cellular manufacturing.* Kluwer Academic Publishers.
[7] **Womack, J., Jones, D.T. and Roos, D.** 1990. *The machine that changed the world: The story of lean production.* New York: Rawson Associates.
[8] **Hyer, N.L. and Brown, K.A.** 1999. The discipline of real cells. *Journal of Operations Management*, 17. pp. 557–574.
[9] **Ohno, T.** 1988. *Toyota production system: Beyond large-scale production.* Productivity Press.
[10] **Womack, J.P. and Jones, D.T.** 2003. *Lean thinking: Banish waste and create wealth in your corporation.* Free Press.
[11] **Wemmerlöv, U. and Hyer, N.L.** 1989. A cellular manufacturing in the U.S. Industry: A survey of users. The International Journal of Production Research, 27(9), pp. 1511-1530.
[12] **Suresh, N.C. and Kay, J.M.** 1998. *Group technology & cellular manufacturing: Updated perspectives*. Kluwer Academic Publishers.
[13] **Irani, S.A.** (ed.) 1999. *Handbook of cellular manufacturing systems.* John Wiley & Sons.
[14] **Shayan, E. and Sobhanallahi, A.** 2002. Productivity gains by cellular manufacturing. *Production Planning and Control*, 13(6), pp. 507-516.
[15] **Hyer, N. and Wemmerlöv, U.** 2002. *Reorganizing the factory: Competing through cellular manufacturing.* Productivity Press.
[16] **Black, J. and Hunter, S.** 2003. *Lean manufacturing systems and cell design.* Society of Manufacturing Engineers.
[17] **Bhat, S.** 2008. Cellular manufacturing: The heart of lean manufacturing. *Advances in Production Engineering & Management*, 3(4), pp. 171-180.
[18] **Pattanaik, L.N. and Sharma, B.P.** 2009. Implementing lean manufacturing with cellular layout: A case study. In*ternational Journal of Advanced Manufacturing Technology*, 42, pp. 772–779.
[19] Hod**ge, G.L., Ross, K.G., Joines, J.A. and Thoney, K.** 2011. Adapting lean manufacturing principles to the textile industry. *Production Planning & Control: The Management of Operations*, 22(3), pp. 237-247.
[20] **Olorunniwo, F. and Udo, G.** 2002. The impact of management and employees on cellular manufacturing implementation. *International Journal of Production Economics*, 76, pp. 27-38.
[21] **Bhat, S.** 2008. A strategy for implementing the idea of cellular manufacturing in small-scale industries. *Production Planning and Control*, 19(6), pp. 547 555.
[22] **Fix-Sterz, J., Lay, G., Schultz-Wild, R., & Wengel, J. (1990).** Flexible manufacturing systems and cells in the Federal Republic of Germany (pp. 191-212). Wiley, Chichester.

[23] **Slomp, J., Molleman, E. and Gaalman, G.J.C.** 1993. Production and operations management aspects of cellular manufacturing: A survey of users. In: Pappas, I.A. and Tatsiopoulos, I.P. (eds.) *Advances in production management systems.* North-Holland: Elsevier Science Publishers B.V.
[24] **Olorunniwo, F.O.** 1997. A framework for measuring success of cellular manufacturing implementation. *International Journal of Production Research*, 35(11), pp. 3043-3061.
[25] **Marsh, R.F., Meredith, J.R. and McCutcheon, D.M.** 1997. The life cycle of manufacturing cells. *International Journal of Operations & Production Management*, 17(12), pp. 1167-1182.
[26] **Marsh, R.F., Shafer, S.M. and Meredith, J.R.** 1999. A comparison of cellular manufacturing research presumptions with practice. *International Journal of Production Research*, 37(14), pp. 3119-3138.
[27] **Wemmerlöv, U. and Johnson, D.J.** 1997. Cellular manufacturing at 46 user plants: Implementation experiences and performances improvements. *International Journal of Production Research*, 35(1), pp. 29-49.
[28] **Wemmerlöv, U. and Johnson, D.J.** 2000. Empirical findings on manufacturing cell design. *International Journal of Production Research*, 38(3), pp. 481-507.
[29] **Johnson, D.J. and Wemmerlöv, U.** 1998. Cellular manufacturing feasibility at Ingersoll Cutting Tool Co. In: Suresh, N.C. and Kay, J.M. (eds.) *Group technology & cellular manufacturing: Updated perspectives.* Kluwer Academic Publishers.
[30] **Johnson, D.J. and Wemmerlöv, U.** 2004. Why does cell implementation stop? Factors influencing cell penetration in manufacturing plants. *Production and Operations Management*, 13(3), pp. 272-289.
[31] **Levasseur, G.A., Helms, M.M. and Zink, A.A.** 1995. A conversion from a functional to a cellular manufacturing layout at Steward, Inc. *Production and Inventory Management Journal*, 36(3), pp. 37-42.
[32] **Kumar, A. and Motwani, J.** 1998. Case study: Reconfiguring a manufacturing system for strategic advantage: A real-world application. *Logistics Information Management*, 11(4), pp. 244-256.
[33] **Shayan, E.** 1998. Cellular design for injection molding shop. *Computers and Industrial Engineering*, 35(3-4), pp. 487-490.
[34] **Süer, G.A.** 1998. Operation and control of cellular systems at Avon Lomalinda, Puerto Rico. In: Suresh, N.C. and Kay, J.M. (eds.) *Group technology & cellular manufacturing: Updated perspectives*. Kluwer Academic Publishers.
[35] **Sohal, A.S., Fitzpatrick, P. and Power, D.** 2001. A longitudinal study of a flexible manufacturing cell operation. *Integrated Manufacturing Systems*, 12(4), pp. 236-245.
[36] **Dawson, P.** 2001. Contextual shaping in the origination, implementation and uptake of manufacturing cells. *Integrated Manufacturing Systems*, 12(4), pp. 296-305.
[37] **Dawson, P.** 2005. Changing manufacturing practices: An appraisal of the processual approach. *Human Factors and Ergonomics in Manufacturing*, 15(4), pp. 385–402.
[38] **Gunasekaran, A., McNeil, R., McGaughey, R. and Ajasa, T.** 2001. Experiences of a small to medium size enterprise in the design and implementation of manufacturing cells. *International Journal of Computer Integrated Manufacturing*, 14(2), pp. 212-223.
[39] **Park, K.S. and Han, S.W.** 2002. Performance obstacles in cellular manufacturing implementation: Empirical investigation. *Human Factors and Ergonomics in Manufacturing*, 12(1), pp. 17-29.
[40] **Molleman, E., Slomp, J. and Rolefes, S.** 2002. The evolution of a cellular manufacturing system: A longitudinal case study. *International Journal of Production Economics*, 75, pp. 305-322.
[41] **Durmusoglu, M.B. and Nomak, A.** 2005. GT cells design and implementation in a glass mould production system. *Computers & Industrial Engineering*, 48, pp. 525–536.
[42] **Kulak, O., Durmusoglu, M.B. and Tufekci, S.** 2005. A complete cellular manufacturing system design methodology based on axiomatic design principles. *Computers & Industrial Engineering*, 48, pp. 765–787.
[43] **Hung, K-T. and Maleki, H.** 2014. Applying group technology to the forging industry. *Production Planning & Control: The Management of Operations*. 25(2), pp. 134-148.
[44] **Productivity Press Development Team.** 1998. *Just in time for operators.* Portland: Productivity Press.
[45] **Heragu, S.S.** 2008. *Facilities design*, 3rd edition. Clermont, FL: CRC Press.
[46] **Lee, R.C. and Moore, J.M.** 1967. CORELAP: Computerized relationship layout planning. *Journal of Industrial Engineering*, 18, pp. 195-200.
[47] **Miltenburg, J.** 2001. U-shaped production lines: A review of theory and practice. *International Journal of Production Economics*, 70, pp. 201-214.