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U-Shaped Cells Operating Modes: a Review and a Hands-on Simulation Comparison

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Abstract

Increased demands of different products put some challenges to the production system layout that are not well addressed by the job-shop neither flow-lines layout. Cellular production is a production system layout that enables higher productivity than job-shop and greater flexibility than flow-lines and it is appointed as a better layout to face the product and volumes changes occurring in the companies. The cells design involves the operating mode selection for the U-shaped cell. Operating modes are the way the operators are organized inside a cell. This could take the form of working balance, baton touch, rabbit chase, bucket-brigades or Toyota Sewing System (TSS). This paper reviewed these U-shaped cells operating modes attending to the literature and also using some industrial case studies from real implementations in companies working with cells. For comparing the operating modes a hands-on simulation was performed by student teams in the classroom. This method was used so that it could be possible to simulate aspects related with operators: skills, teamwork, cross-training or motivation. The operating modes were compared through some performance measures like production output, productivity, efficiency, WIP and defects. The operating modes have some similarities and dissimilarities and knowing them it is possible to select an adequate operating mode for a specific production environment. This research could be very useful for companies implementing cells and having difficulties in selecting operating modes.

Key words: *U-shaped cells, types of operating modes, hands-on simulation*

1. INTRODUCTION

Cellular production is a production system layout that groups and organizes machines, workers, tools and/or handling devices to produce a product or a family of products, with identical or similar manufacturing requirements. Frequently, cellular manufacturing is based on the concept of Group Technology (GT) [1] that is defined by Gallagher and Knight [2] as "… a technique for identifying and bringing together related or similar components in a production process in order to take advantage of their similarities by making use of, for example, the inherent economies of flow-production methods.".

The GT objective, according Burbidge [3], is "to form small organizational units which complete all the set (or family) of products or components which they make, through one or a few major processing stages, such as metal founding, machining and assembly, and are equipped with all the machines and other processing equipment they need to do so." The GT concept emerged in the metal-mechanic industry as a technique to simplify the materials flow and achieve higher productivity, requisites not addressed by the job-shop, or functional, layout traditionally adopted in this industry [2]. Hyer and Wemmerlöv [4] advised reorganizing the factory through cellular manufacturing to achieve competitive advantage.

Like the job-shop configuration, normally, a cell has operators attending various machines but the similarity ends here because the operators in the cell will perform different tasks in complementary (different) machines necessary to complete the product.

Additionally, operators are central to cell discipline and are connected in terms of time, space and information [5]. Usually, they are cross-training or multi-skilling in the different processes inside the cell or, at least, they perform well in more than one process. Having cross-training, the number of operators in a cell and the correspondent allocated tasks can vary, according to the necessary cell output and operators' skills.

The benefits of the operators cross-trained are fully achieved when combined with the well-known and popular U-shaped physical layout configuration [6–8].

Furthermore, these two characteristics of cells allow different cell operating modes, i.e., internal organization and distribution of the operators by the workstations (related to how people work and how they flow inside a cell). Cells operating modes explore strategies like teamwork and tasks rotation, and the main types are: rabbit chase, Toyota sewing system, working balance, bucket-brigades and baton-touch. These operating

modes had similarities and dissimilarities, more or less adequate to different production environments, which will be explored in this paper.
Therefore, the objective of this paper is to explore the five most common cells operating modes highlighting the differences and similarities between them, based on a hands-on simulation.
This paper also presents a brief review of the operating modes based on the literature and in some industrial cases that adopt different modes according to the demands needs. Then, this paper will show the results of hands-on simulation of teams of students trained in each operating mode and compare the operating modes against quantitative and qualitative measures.
The structure of this paper includes five sections. After this initial section, which includes the motivation and objectives of the work, section two presents a literature review about production cells and its benefits as well the organization of people in the cells. Section three describes the hands-on simulation of the operating modes. Section four makes some comparisons between the operating modes and finally, some concluding remarks are outlined in fifth section.

2. LITERATURE REVIEW

This section presents a brief literature review about cellular production and related concepts and benefits brought by cellular production.

2.1 **Cellular Production and related concepts**

In Cellular Production (CP), a product or family of products are manufactured and/or assembled in a cell. A cell is a production system that groups and organizes the production factors, e.g., people, machines, tools, buffers, and handling devices necessary to manufacture the product (or the family), with identical or similar manufacturing requirements. The objective of CP is to attain economies of scale through economies of scope, by increasing the diversity of products manufactured within the same system.
The focus of the Cellular Production is the product or a family of products, being a product-oriented manufacturing system (POMS) [9] in opposition to the process organization (or job-sop) that, already in 1992, Burbidge [10] said that was becoming obsolete. An assembly line is also considered a POMS but an assembly line could easily also become obsolete due to the diversity of the markets demand needs.
In a broad sense, POMS concept becomes the concept of the focused factory introduced by Skinner in 1974 [11]. According to this author, a company works better and becomes more competitive when dedicated or focused on the execution of a specific task, process or product, increasing its productive competences or its quickness to answer to the market demands. Other concepts like Plant Within a Plant (PWP) [12–14] or Mini-Company [15] promoted product oriented groups inside the companies, attending a specific external market or internal clients (seeing the next process as a customer and the previous process as a supplier). So, a POMS is a concept that implies a cell structure but evolves according to the needs of demand, i.e., it is a reconfigurable structure that could change to face the new demands requirements in terms of a number of operators and equipment. It is very similar to a seru production system concept, defined in Kaku et al. [16] as a mini-assembly unit resultant from an assembly line conversion into cells, mainly in Japanese electronics industry, that it distinguish in different types according to the number and organization of people in the cell [17–21].
Like these authors advocated, a configurable, instead of a fixed system, is a preferable approach to deal with the dynamic environment with high product variety and low product volume. Even so, the decision-making to redesign the production system could be very hard [22].
These concepts are totally aligned with the need to create value for the customer, focusing on the quick delivery of the product.
This is the first of the five principles of Lean Thinking [23] derived from the well-known Lean Production model [24], a designation for the Toyota Production System [7,25]. These five principles are: 1) create value for the customer, 2) identify the value stream, 3) create flow; 4) produce only what is pulled by the customer; and 5) pursuing the perfection by continuous identification and elimination of waste (*muda*, in Japanese). The most common wastes found in companies can take seven forms: 1) overproduction; 2) waiting; 3) inventory; 4) handling and transportation; 5) over processing; 6) defects and 7) workers movements. Additionally, creative thinking of workers is considered as the eighth waste and it has been neglected by some companies.
Additionally, there are authors, namely, Black & Hunter [26], Black [27] and Black & Phillips [28] that advocate a model of production system capable of reconfiguring faster and cheaper, that favours: (i) manufacturing cells instead of job shops (ii) U-shaped subassembly cells in opposition to linear subassembly lines (iii) mixed model final assembly systems to level the demand on their suppliers instead of final assembly of large batches. Additionally, others like Bhatt [29] considered Cellular Production as the “heart” of Lean Production. Also Alves et al. [30] showed using the Analytic Hierarchy Process (AHP) method the appropriateness of POMS, particularly, cells to a Lean context.

2.2 **Benefits of Cellular Production**

All the wastes referred in the previous section could be reduced and/or eliminated by changing the layout to production cells. This reduction/elimination is achieved because the product (or family) is completely (or almost completely) produced inside the cell, which results in a decrease of the travelled distances (due to the machines’ proximity) and,

obviously, the transport effort and workers movements also.
The required space is also decreased, which reduces the WIP (inventory) and, consequently, the throughput times and promoting an increase in quality of products and processes because everyone in the cell is able to see the entrance and exit of a final product, i.e., the whole product value stream, not only a part of the value stream. This is also promoted by the team responsibility and empowerment that “owns” a specific product value stream. This responsibility will contribute to a reduction of the absenteeism and simplification of management and production control, knowing exactly what (mix and quantity) to produce, when to produce and for whom.
Besides the benefits described, the implementation of Cellular Production can have a wider impact on the manufacturing operations of an enterprise – this fact is largely referred in the bibliography, namely in Wemmerlöv and Hyer [31], Nyman [32], Singh and Rajamani [33], Suresh and Kay [34], Kamrani and Logendran [35], Irani [36], Wemmerlöv and Johnson [37–39], Shayan and Sobhanallahi [40] and Hyer and Wemmerlöv [4].
It is possible to find cell implementations in almost every type of company and industry. Some examples of the last 25 years are: Fix-Sterz et al. [41], Slomp et al. [42], Harvey [43], Olorunniwo [44](1997), Slomp [45], Marsh et al. [46,47], Olorunniwo and Udo [48]; Johnson and Wemmerlöv [39,49], Levasseur et al. [50], Kumar and Motwani [51], Shayan [52], Süer [53], Sohal et al. [54], Dawson, [55,56], Gunasekaran et al. [57], Park and Han [58], Molleman et al. [59], Durmusoglu and Nomak [60], Kulak et al. [61], Pattanaik and Sharma [62], Oliveira and Alves [63].
More recent cases describe cellular applications as a need of design and/or reconfigure production system in a Lean context, namely, in Kruger [64]; Shaikh et al. [65]; Dinis-Carvalho et al. [66], Simões et al. [67] and Alves et al. [68]. This reconfiguration could be from an existent conveyor assembly line to a seru production system, for example, in electronics industry, as described early by Kaku et al. [16] or from a traditional job-shop as described in Alves et al. [68] where, at least, two companies reconfigure their job-shops in cells.

2.3 **Organization of people in the cells**

This section describes ways to organize people in the cells in order to perform the tasks to complete a product that is called here of operating modes. The five most know cells operating modes are described. Additionally, some industrial cases applying these operating modes are presented.

2.3.1 *Types of cells operating modes*

Arvindh and Irani [69] defined the cells process design as an integrated solution for different problems: formation of parts’ families and groups of machines, and, the design of the intracellular and intercellular layouts. Additionally, cells design implies another issue, maybe the more complex that is related with the grouping of the operators and their allocation and organization inside the cells [70]. Min and Shin [71], Molleman and Slomp [72], Askin and Huang [73], Norman et al. [74] and Yu et al. [20] developed mathematical and heuristic models to form the cells or the seru production system, which allow the simultaneous grouping of machines and operators and, subsequently, the correspondent allocation into the cells.
Moreover, it is well known that the attitudes, the motivation, the teamwork, the allocation strategies, the adequate skills identification, cross-training or multi-skilling needs, communication, remuneration systems, roles’ definition, and conflicts’ management are important factors to the cells success and must be considered when implementing cells [48,58,75–77].
Operators’ mobility and versatility are essential to allow the achievement of a new operational reconfiguration of the cell in the shortest possible time (to start the production of a different lot of products). The dynamic standing posture and the rotation of tasks will foster the operators’ mobility, and, simultaneously, reduces their fatigue and boredom [78,79]. Synergies resulting from the interaction between cells’ operators, based on their skills, mobility, and socio-psychological characteristics are explored in the operating modes, i.e. in the internal organization and distribution of the operators by the workstations. Different configurations for the cells could be designed but all should be evaluated due to their impact on ergonomics performance [80].
Different operating modes support a flexible allocation of tasks and gives the responsibility for the work in the cell to a team, no matter what the concept of team is implemented [19,81–87], and not to a single individual. Most common operating modes for cells are: 1) working balance; 2) baton-touch; 3) Toyota sewing system; 4) bucket-brigades; and 5) rabbit-chase. Fig. 1 shows a schematic representation of each operating mode implemented in a U-shaped layout.

2.3.1.1 *Working balance*

The working balance (WB) is probably the most intuitive and traditional operating mode adopted. It consists of an equal distribution of the workload by the operators and the allocation to each one, in an invariable and permanent way, a specific number of tasks or operations with similar accumulate processing times, resulting this in a workstation. Each operator will have a work zone or section considered as a sub-cell [88]. Fig. 2 highlights the working balance operating mode with three operators.

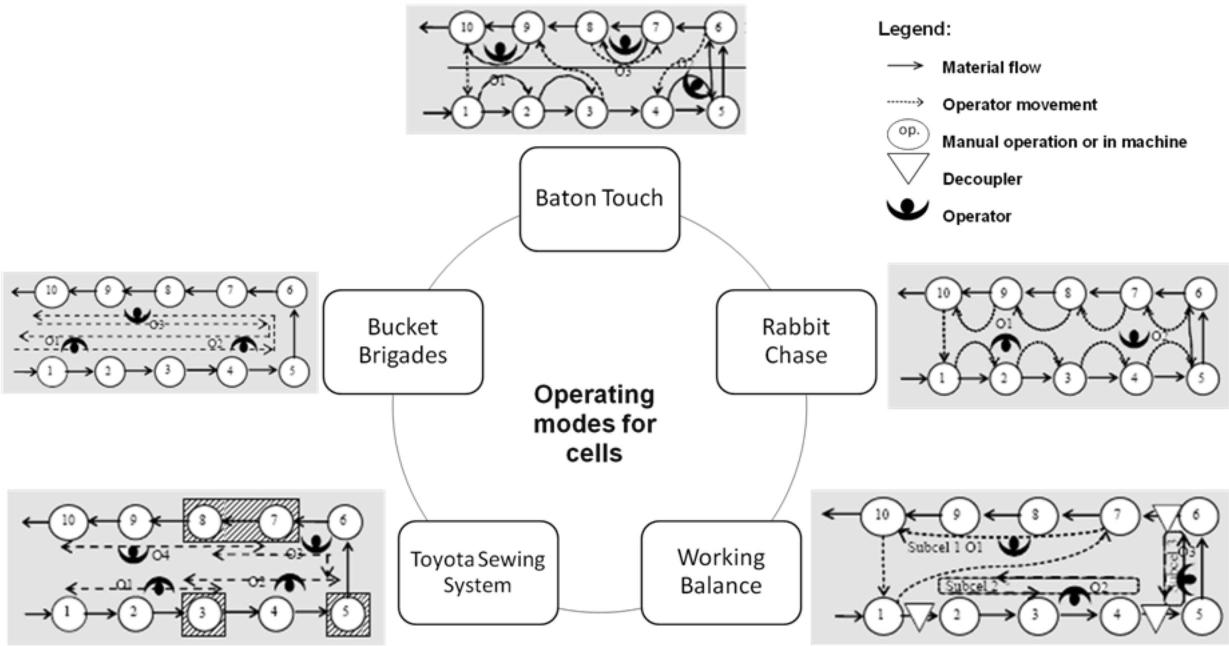

Figure 1. Schematic representation of operating modes for cells explanation

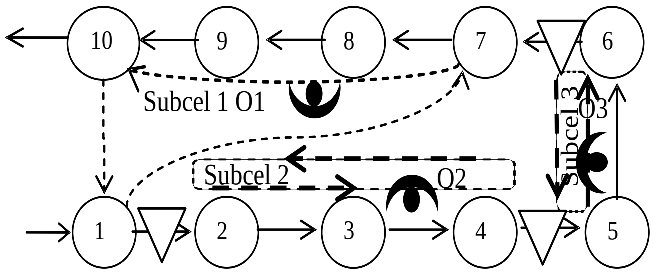

Figure 2. Schematic representation of Working Balance

Each operator has a work zone that is different from his neighbour and is responsible for processing all the operations allocated to him. This work zone could include operations from both sides of the cell, like the operator 1 (O1) that processes operations 1, 7, 8, 9 and 10, or only in one side, like the operator 2 (O2) that processes 2, 3 and 4. The U-shaped layout allows this to happen and also that the same operator easily controls the entrance and exit of the product. This is unquestionable in a linear layout because of the operators walking distance.

This operating mode shows some limitations: the perfect organization and balancing of the workload by the operators and the loss of flexibility. This could result in misbalancing and difficulties in reconfiguring the cells to face new demands.

The establishment of this mode could request a stable and repetitive situation that minimizes the difficulties referred. Another aspect that could attenuate the difficulties is the local buffer between the work zones that decouple the operations between the operators. It is for this reason that “decouplers” [89] are used.

The sub-cell starts a new product only when the product in the decoupler is removed in a pull control by the next operator.

2.3.1.2 *Toyota sewing system*

Typically in the Toyota sewing system (TSS) operating mode, a registered trademark of Aisin Seiki Co., Lta., a subsidiary of Toyota [90], there are three to five operators in the cell that, in a dynamic standing posture, work in ten or fifteen machines, i.e., more machines than operators [88]. Multi-skilling operators share the operators and pass the product between them like runners in a baton running (Fig. 3).

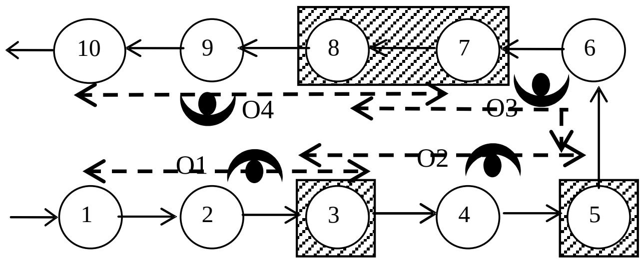

Figure 3. Schematic representation of Toyota Sewing System

The operators moved with the product in a counter clockwise direction, operating always in adjacent workstations. When they are blocked by the machine occupation by another operator and if decouplers exist in the cell, they put the product in the decoupler between the workstations. If decouplers do not exist, the operator will wait until the machine becomes available. Some authors like Bartholdi et al. (1995), Bartholdi and Eisenstein (1996) and Kalta et al. (1998) do not consider the existence of decouplers because the temporary buffering between workstation is not allowed. In both cases, when the operator does not have a product, he moves in a clockwise direction until he/she finds a product in a decoupler or in the hands of

another operator, taking the product off his hands and starting the movement following the product flow.
The allocation of operations to the operators is not fixed or permanent and the operators are not restricted to a work zone. They could develop work standards with specific operators taking the total responsibility for some operations in a workstation and sharing the responsibility of others operations in overlapping zones, as illustrated in Fig. 3 with the operations 3, 5, 8 and 7.
The advantages of this mode are the encouragement of autonomy and work responsibility and the promotion of self-organization. The disadvantages could be the nonexistence of decouplers that foster the delay of the work in the presence of a slow operator because it forces the other operator to wait. Another disadvantage is having different operators responsible for the first and last operation, not benefit from the fact of having the same operator controlling the entrance and exit of the cell. Additionally, the advantage of having the same operator doing operations on both sides of the cell is lost.

2.3.1.3 *Baton-touch*

Another operating mode that presents similarities with TSS but also with WB is the baton-touch [91]. Like the TSS, the operators could develop work standards. The differences are in the possibility of the operators to cross the cell, doing operations on both sides of the cell. The same operator could do the first and the last operation in the product. This operator will have the leader role performing other operations like supplying the cell, substituting other operators, filling the paperwork, among others.

The similarities with the WB has to do with the operators developing work in adjacent and opposite workstations (Fig. 4) and the differences are in affecting a work zone in the WB but inexistent in this mode. This inexistence allows flexibility to the operators in developing their work standards.

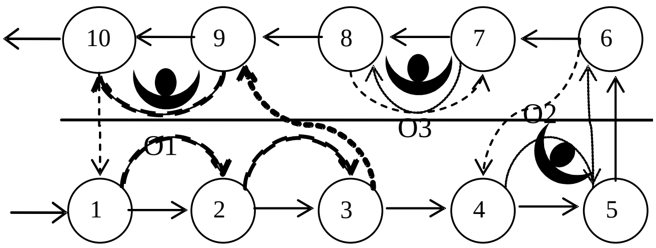

Figure 4. Schematic representation of Baton-touch (adopted from Baudin, [91])

2.3.1.4 *Bucket-brigades*

Bartholdi et al. [90] consider the TSS, described previously, as an implementation of bucket-brigades (BB). BB is a general approach presented by Bartholdi and Eisenstein [92] and Bartholdi et al. [93] that consists in the coordination of operators assembling progressively a product along with a flow line where there exist fewer operators than machines (Fig. 5).

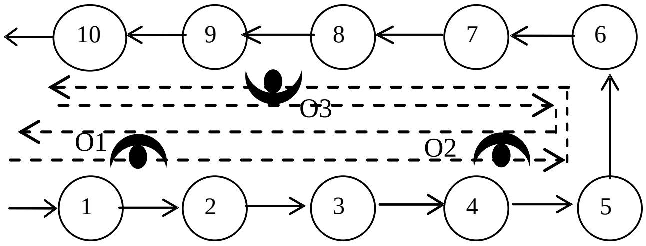

Figure 5. Schematic representation of Bucket-brigades

The operators are distributed from the slowest to the fastest along the product flow in the cell. They are moving along the cell and executing all the operations without restricted to a zone. If the operator reaches a workstation and is blocked, he must wait until the workstation becomes available. In the end of the process, the cell reconfigures and the operator walks backward, takes over the product from his predecessor that moves back and does the same. They follow a simple rule: “Carry work forward, from station to station, until someone takes over your work; then go back for more” [92].
The advantages of this operating mode are that the allocation of tasks is not fixed or permanent and doesn't need a perfect balancing because it is self-balancing. The time study is not necessary avoiding this cost. Additionally, a central planning and time to reconfigure the cell are not necessary because everyone knows what to do next. This behavior is inspired by the ants and bees behaviour [92].
The implementation of the simple rule makes the system a pull system where WIP is controlled, simplifying the management task [92,94–96]. The product manual handling avoids the use of another material handling system. This operating mode emphasizes teamwork and allows a motivate interaction and flexibility in the work execution. The production outputs are quickly adjusted by removing or adding more operators.
The main disadvantage consists in classifying the operators based only on one measure: their velocity, neglecting other measures. Another disadvantage could be the delay that could occur when the operator takes over the product from his predecessor.

2.1.3.5 *Rabbit chase*

The rabbit chase (RC) is an operating mode totally different from the others. In this mode, each operator will perform all the operations in the cell, from the first to the last operation, without bypassing the others. In a movement from operation to operation, they control all the transformation phases.
This mode allows the cell to be operated by only one operator if the output does not demand more. Of course, the mode name derives from the fact of having more operators because of each one “chases” the other, by executing successively the same operations in successive products (Figure 6).

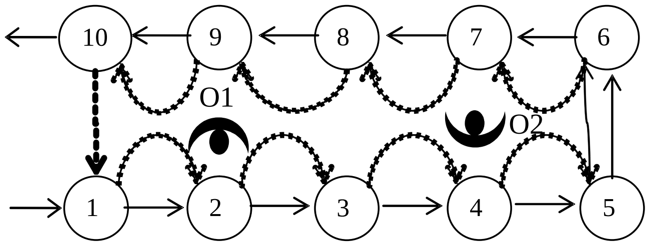

Figure 6. Schematic representation of Rabbit chase

This mode demands a total multi-skilling for all operators, with similar performance levels (Black e Chen, 1995). This is similar to the rotating seru defined in Yu et al. [17]; Stecke et al. [18]; Yin et al. [19]; Yu et al. [20]; Zhang et al. [21]. Because the product is constantly with the operator, it does not need decouplers or the operations distribution by the operators. The balancing workload issue does not exist. The production capacity is dependent on the operators' number in the system and is limited by the slower operator.Teamwork does not exist and conflicts could appear among the operators, which are a disadvantage of this mode. Other disadvantages are the production loss, difficulty in implementing reward systems and higher training costs, to obtain a maximum level of polyvalence.However, this mode has some advantages by being so different like the operator´s independence in the execution and control of operations, the capacity of easy adjustment by changing the operator´s number, easy quality control and imputing responsibility, no need for balancing and easiness reconfiguration.

Baudin [91] named this mode as caravan and considers that the cell must be limited to two operators but Black and Chen [88] do not restrict to this number and showed that the bottleneck is minor with three or fewer operators.

2.3.2 Some industrial case studies

The similarities and dissimilarities of the operating modes could also be seen in the companies that are implementing cells. For example, a company that manufactures hand tools has several cells for different products and employs operating modes like rabbit chase (Fig. 7), baton-touch or other. When demand varies they change the number of operators in the cells but could also change the operating mode.

Figure 7. Rabbit chase implemented in a cell of a hand tools company

Another company with assembly cells for controller's heat boilers adopted working balance or the rabbit chase operating modes (Fig. 8).

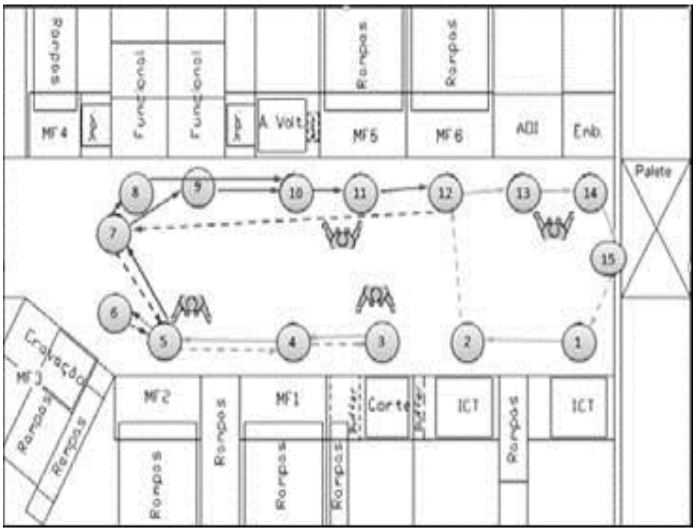

Figure 8. Layout of an assembly cell with working balance operating mode

Oliveira and Alves [63] studied these cells to understand the influence of the operating modes and their productivity. The paper also presented the difficulties when the cells are formed without careful in selecting and recruiting adequate and motivated people to form the team for operating the cells.

They showed that the factors of careless and others cause lower productivity in the cells.

In the same company, but for a different product, another project was developed in order to improve the cells teamwork performance.

Before a flow-line, this was reconfigured to new forms of work organization and relocation of tasks by operators integrated into a Lean implementation project. These new forms required rotation plans where the operator must rotate four times during his shift; in each shift the operator must rotate between two workstations; the rotation period must be, approximately, from 2 to 2 hours; the switch between workstation must be with different characteristics and workstations with high risk must rotate each other in successive periods.

The objective of these rotation plans was to prevent musculoskeletal disorders.

Additionally, it brings some advantages like operators satisfaction by changing from workstations during the shift, absenteeism reduction, productivity increase and improvement of product quality.

Apart from these changes, the change of operating modes for rabbit-chase was proposed (Fig. 9). The objective of this proposal was to reduce the empty movements of operators, i.e., without product and to improve the workload balance between the operators.

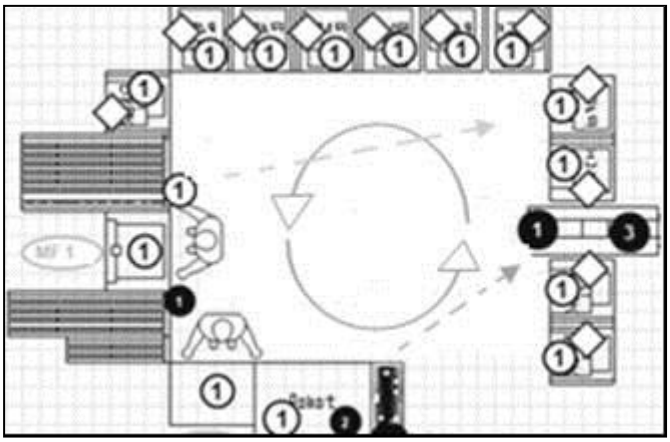

Figure 9. Rabbit chase in a cell of auto-radios

From the industrial case studies showed above, it is possible to conclude that reconfiguring cells is not a static process design. During the life cycle of a cell, it is expected to change many times the operating mode, adopting the most adequate, according to the demand, to the product or to the people's skills.
Another industrial case comes from an electronics company, where traditional assembly lines were converted in U-shaped cell adopting different operating modes. One assembly line was converted in an assembly cell with one single operator, operating as a yatai, as described by in Yu et al. [17]; Stecke et al. [18]; Yin et al. [19]; Yu et al. [20]; Zhang et al. [97]. Other examples could be seen in Alves et al. [68].

3. HANDS-ON SIMULATION

To simulate the operating modes and compare them, an assignment was given to the students of the 5th year of the Industrial Engineering and Management (IEM) Integrated Master degree. All students in different teams must simulate a different operating mode, using the same product – a torches kit (Fig. 10), to assembly in a hands-on simulation.
The hands-on simulation was the adopted method to simulate the modes because using another method or technique (e.g. software simulation) it is difficult to simulate aspects related with people, like motivation or confusion and to recognize some problems arising from the synergy (or conflicts) between the operators or difficulties in assembling the product.

Figure 10. Torches kit [98]

In this study, the product assembled in the cells was some torches with different colours (Figure 11). The students were involved in a specific activity that aimed to construct as many torches as possible with a specific operating mode.

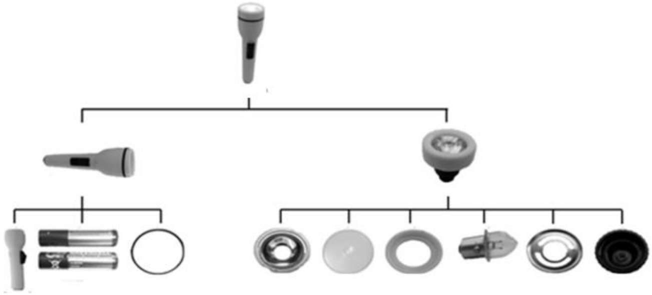

Figure 11. The torch and torch components (Bills of materials)

3.1 **Teamwork assignment**

The teamwork assignment was carried out by teams of three students and consisted in simulating the operating modes in a U-shaped cell. Five teams were formed (15 students), each team approaching a different operation mode: baton touch; bucket brigades; rabbit chase; working balance, Toyota sewing system.

3.2 **Sessions preparation**

The first task was to define the operations and standardize the operation times for all assemblies operations, defined by the teacher and students before the simulation sessions. Having these common operations (nine operations) and operations times, each team made some experiences and then sent the results to the teacher that found out an average that all teams could use in order to compare results.
The common material used by all teams was the torch kit, the torch kit manual, the operations and operation times (Table 1).

Table 1. List of operations and operations time

Operation	Average time (sec.)
1	2,8
2	2,9
3	1,7
4	2,8
5	3,4
6	3,2
7	2,3
8	5,7
9	1,2
Sum	**26,0**

The initial data for simulation was five minutes for simulation. Knowing that the longest operation time is 5,7 seconds, that was considered as the cell takt time, the expected demand was 53 torches (300 seconds/5,7 seconds). With this, it was calculated the initial theoretical number of operators that was 5, referring to the 26 seconds to complete a product. This was important to set-up in order to all teams start with the same values.
All sessions were video-taped and became available to the teams at the end of the sessions and the operating

modes photographed to discuss and understand the differences between the operating modes (Fig. 12).

Figure 12. Aspects of the operating modes simulation

The performance measures used to compare the operating modes were the cell output (good torches), the number of cells with defects, the WIP level, the productivity, the efficiency and the lead time for obtaining the first product.

3.3 **Simulation results**

After the five minutes of simulation, all measures were registered and the results obtained could be seen in Table 2.

Table 2. Results obtained from the simulation

	G1	G2	G3	G4	G5
Results	**BT**	**RC**	**WB**	**TSS**	**BB**
Cell output:	7	11	15	14	15
Torches with defects:	16	19	11	15	9
Work In Process:	27	4	10	2	4
Productivity [torches/minutes]:	0,28	0,44	0,60	0,56	0,60
Efficiency:	5%	2%	2%	3%	3%
Lead time for the first torch [seconds]:	74	37	33	38	42

Not discarding all the variables that such simulation involves (e.g. using an operation times average, different preparation of the students, different speed, different commitment, different motivation,…), all values were very different from the expected demand (53 torches). The maximum cell output was achieved for the WB and BB operating modes like the productivity. Surprisingly, the higher number of torches with defects was in the rabbit chase. As expected, the operating modes with buffers (WB, BT) had a WIP level higher than the others modes. The lead times for the first torch were also very dissimilar from the average of 26 seconds, the worst lead time was given by the BT operating mode.

3.4 **Discussion**

More important than the quantitative results, using the hands-on simulation, it was possible to recognize some problems that arose in such layouts and operating modes related with: the sort of the product assembled, the layout used and the people involved.
The product assembled in this simulation was a torch involving nine assembly operations, which implied different subassemblies. In the operating modes not having a buffer, it was difficult to pass in hands the small parts and the subassemblies. It was very frequent to see that some parts drop to the floor. For example, if this was done with software simulation, this kind of problem would never appear.

Also, the students recognized that a U-shaped cell, with all operators inside the cell, was not appropriate and proposed a different arrangement with two operators inside the cell and three operators outside the cell (Fig. 13).

Figure 13. A different arrangement for the WB operating mode

Not satisfied with this layout, they proposed a different layout with the same number of operators (five operators), in order to have a perfect balance (Fig. 14). All measures were improved, except the lead time for the first torch that was maintained.

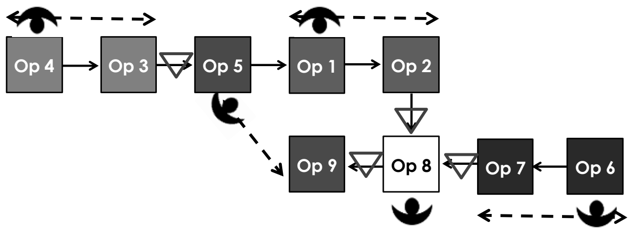

Figure 14. A different layout for the WB operating mode

The other teams also wanted to improve the results and because they noticed that five operators were an excessive number (they disturbed each other), they reduced the number of operators to three and the measures were improved or maintained.
Playing the role of operators' teams in companies, the students realized how important the interaction with others is, the teamwork, the mutual assistance, the personal involvement, the conflict when being delayed by others work, and so on. This fact led students to find out that some operating modes appeal to more mutual assistance or polyvalence than others.

4. OPERATING MODES COMPARISON

Based on the literature review, in the industrial cases and validated by the hands-on simulation, it was possible to compare qualitatively the operating modes, distinguishing them in regard to some characteristics like work and overlapping zones attributed to the operators, balancing, tasks allocation, mutual assistance, polyvalence and teamwork (Table 3). These characteristics could be compulsory, free (i.e. not conditioned) or not applied.

Table 3. Operating modes comparison (adapted from Authors, 2007)

Characteristics	WB	TSS	BT	BB	RC
Work zones	✓	✓	**O**	**O**	--
Overlapping zones	--	✓	**O**	**O**	--
Balancing	✓	**O**	**O**	**O**	--
Tasks allocation	✓	✓	✓	**O**	✓
Mutual assistance	**O**	✓	✓	✓	--
Polyvalence	✓	✓	✓	✓	✓
Teamwork	**O**	✓	✓	✓	--

✓: compulsory; **O**: free; not conditioned; -- not applied

Knowing the similarities and dissimilarities of the operating modes, the selection of an adequate operating mode for a production environment could be facilitated. For example, in a cell sewing system, the TSS is the most adequate, being easy to pass the cloth piece in hands to others. If the objective is to promote teamwork, RC is not appropriate but is very useful when the company has individualist type operators and wants to promote the operators independence and autonomy.
It is also important to refer that polyvalence or cross training competences should be total (i.e. all operators must perform all operations) in a rabbit chase but not for the others operating modes where the operators just need to be cross-trained in the set of operations they will perform. These operating modes are similar to the divisional seru referred by Yu et al. [17]; Stecke et al. [18]; Yin et al. [19]; Yu et al. [20]; Zhang et al. [21].
To face demand changes it is relatively easy to change the cell operating mode (even the cell system) to accommodate these changes, by removing or adding some operators and/or putting them working in a different operating mode. The flexibility of the U-shaped cells layout comes, largely, from this capacity. So, even in the operating modes not requiring total cross training, it is important that operators change between workstations.

5. CONCLUDING REMARKS

Cells are a layout type that organizes machines, people, tools and other production factors in order to produce a product or a family of products. Cells are product-oriented and are a superior alternative to the traditional process-oriented productions units. In the cells process design, many issues must be solved, being the difficult issues, the ones related to the people because of the social factors like the conflicts, teamwork, cross-training and/or motivation. People are crucial to the success of cellular manufacturing implementation and a proper design must address this, searching for the best internal organization and distribution of operators inside the cells, i.e., the operating modes.
In this paper the main operating modes for a U-shaped layout cell were reviewed: rabbit-chase, baton touch, Toyota sewing system, working balance and bucket-brigades. This review was complemented with a description of some industrial case studies. Then, this paper evaluated the operating modes through a hands-on simulation. This method was chosen because issues such as referred above are not easy to simulate in software. A final qualitative comparison according to some characteristics was made, allowing some concluding remarks, being the most important the need of a proper selection of an operating mode for a specific production environment. As many companies do not have access to a software, this research could also show that it is possible to evaluate different alternatives just using people to do the simulation.
Nevertheless, a software model could be used in a future research to compare with the results obtained here, or, at least, to show that the model could be very simplified to simulate the issues compared in this paper.

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Operativni režimi radnih jedinica prostorne strukture U tipa: Pregled literature sa fokusom na komparaciju simulacija

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Apstrakt

Povećani zahtevi za različitim proizvodima postavljaju određene izazove vezane za oblikovanje prostorne strukture proizvodnog sistema koja u velikom broju slučajeva nije adekvatno rešena što je takože slučaj is a tokovima proizvodnih linija. Ćelijska proizvodnja podrazumeva prostornu strukturu proizvodnog sistema koja omogućava veću produktivnost od radionice i veću fleksibilnost od protočnih linija zbog čega je okarakterisana kao bolja alternatva oblikovanja prostorne strukture kako bi se odgovorilo na promene samih proizvoda i fluktuacije u količinama koje se svakodnevno javljaju u proizvodnim sistemima. Dizajn ćelija (radnih jedinica) uključuje izbor načina rada za ćelije u uslovima prostorne strukture U oblika. Radni režimi su način na koji su operateri organizovani unutar ćelije. Na taj način moguće je obezbediti uravnoteženje procesa rada (baton touch, rabbit chase, bucket-brigades,Toyota Sewing System (TSS)). Ovaj rad predstavlja preged relevantne literature koja se odnosi na režime rada ćelija u prostornoj strukturi U oblika, kao i neke implementirane industrijske studije slučaja u proizvodnim sistemima ovog tipa.Upoređivanje načina rada, sa fokusom na simulaciju, izvodila je grupa studenata učionici. Ovaj metod je korišćen tako da je moguće simulirati aspekte vezane za operatere: veštine, timski rad, unakrsnu obuku ili motivaciju. Režimi rada upoređeni su preko određenih performansi kao što su proizvodnja, produktivnost, efikasnost, WIP i nedostaci. Imajući u vidu sličnosti i razlike identifikovanih režima rada, moguće je odabrati odgovarajući režim rada za određeno proizvodno okruženje. Ovo istraživanje bi moglo biti vrlo korisno za kompanije koje implementiraju ćelijsku proizvodnju, a imaju poteškoće u izboru načina rada.

Ključne reči: *Prostorna struktura U tipa, tipovi operativnih režima rada, praktična simulacija*