A simulation approach to traditional job shop manufacturing systems

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Abstract: Scheduling and organization of job shops and improvement of performances have been extensively researched over the last three decades and it continues to attract the interests of both academic researchers, practitioners and the industry managers as well. In the present paper a simulation model of an actual job shop organization was used to create a virtual representation of the production department of a company manufacturing mechanical components. This model has been used to evaluate the effect of different factors on the overall production performances, to define the best scenario and work organization. Shared vs. dedicated human resources and lot management policies are the main factors that affect the performance of job shops, in terms of saturation and efficiency of both machines and operators. The results of the simulation allow determine the optimal layout of the job shops, the way to share resources, the production scheduling and the lot management policy; the possibility to switch to scenarios based on cell manufacturing is evaluated as well.

Keywords: job shop manufacturing, simulation, group technology, work efficiency

1. Introduction

1.1 Background: job shop and cellular manufacturing

A job shop system consists in a manufacturing layout where machines are grouped together into homogeneous departments (Shafer and Charnes, 1993; Irani and Huang, 1998; Herage, 1994). Job shop layouts are typically adopted in industry when a large variety of products need to be manufactured and require different machineries. The job shop organization allows manufacturers the flexibility to produce small quantities of different products that the customer's request. It also allows the manufactures the flexibility to adapt to changes in customer's requirement; to quickly adjust to the manufacturing of new products and to cushion oneself when product have become obsolete (Bansee and Chowdary, 2007).

Today, the manufacturing sector has become increasingly competitive as markets more globalized. Consequently, there have been major shifts in the design of manufacturing systems using innovative concepts. The adoption of cellular manufacturing (CM) has received considerable interest from both practitioners and academicians. CM divides the manufacturing system into several subsystems that facilitate the management and control of the manufacturing flow. Traditionally, CM is based on the principle that similar things should be manufactured similarly, and therefore CM systems collect similar parts into groups (called families) and the related dissimilar machines into groups (called cells). This organization leads to get some benefits such as the reduction in the cost of materials, labour, manufacturing, machines, tools, and the reduction in the times of setup, throughput, lead, delivery, waiting, travelling. Furthermore, it typically simplifies materials flow, improve human relations, decrease work-in-process inventory, enhance the productivity and modify the quality.

It is evident that reorganizing a job shop manufacturing layout into a CM one to meet the changed customer's need could be time-consuming and costly. In addition, if changes in the production environment occur frequently, reconfiguration becomes impracticable or even infeasible. This is why work organization in job shops and CM scenarios has been extensively researched over the last three decades and it continues to attract the interests of both academic researchers and practitioners.

1.2 Context and contribution of the paper

This paper provides a simulation-based approach to this problem, by presenting a case study in an international company whose manufacturing department is actually based on a job shop layout. The company, based in Parma (Italy), manufactures homogenizer machines and is part of the GEA Group.

The current work organization grounds on a job shop manufacturing system, which is typically recognised as the best choice for manufacturing customized products in low volumes. The corresponding layout reflects the different group of process machines: more precisely, drill machines are located in one location, lathe machines in another location, shaping machines in another location and so on. The different jobs can move from one area to another in different ways. Therefore, the flow of materials is hard to recognize. This type of layout is suitable for an assemble-to-order or a make-to-order production environment, where the demand fluctuates, the customization is high and the volume of production is low. Since a wide variety of products is manufactured, workers with various skills and general-purpose machines are required in this type of manufacturing system.

The constant increase in the market demand for final products is forcing the company to improve the organization of its manufacturing department. To be more precise, to increase the overall equipment effectiveness (OEE) of its work centres, the company is currently evaluating alternative work organization approaches, mainly related to: shared vs. dedicated human resources; changes in the lot management policy; increase in the number of work shifts.

A customised CM approach is designed in evaluating the new work organization strategies. In fact, the organization of the company does not allow to consider a traditional CM scenario grouping dissimilar machines. Hence, a "hybrid" CM scenario is proposed, simulated and analysed. In this hybrid scenario, 2 or 3 similar machines are grouped in the same production cell and the number of resources required is reduced from one-per-machine to one (or two)-per-cell.

In the present paper, the performance of the two manufacturing systems (job shop and hybrid cellular manufacturing) is evaluated and compared. A simulation model has been built under Simu8™ professional software for Windows (Visual Thinking International Ltd.), to reproduce the functioning of both manufacturing layouts. Simul8™ makes use of dynamic discrete simulation and is commonly exploited to simulate systems that involve processing of discrete entities at discrete times (Concannon et al., 2007). The key performance indicators (KPIs) chosen for the comparison of the two manufacturing system are: average resources and machines efficiency, working and setup time, average number of output lots and products.

The remainder of the paper includes the review of the relevant literature, a brief description of the company under examination, a description of the simulation model, job shop and CM systems, the main results obtained and finally the conclusions.

2. Literature Review

Traditionally, a manufacturing cell has been considered as a system dedicated to the manufacture of a family of identical parts. A more comprehensive definition of a manufacturing cell points to a manufacturing system that groups and organizes the manufacturing resources, such as people, machines, tools, buffers, and handling devices, dedicated to the manufacture of a part family, or the assembly of a family of products, with identical or very similar manufacturing requirements. Therefore, important economies of scale can be obtained producing for economies of scope, i.e. for a variety of products. This approach of identical or very similar processing of similar objects is known as group technology (GT) (Gallagher and Knight, 1973). Typically, manufacturing systems based on cells are frequently associated with GT. To implement the GT in a firm, similar parts of different products are assumed as a part family and the machines related to that part family are located near together in cell. While GT production systems aim to arrange the machines in a way that the number of transits of the semi-manufactured products and the specialized experts of certain operations is minimized, job-shop production systems arrange the machines with the same process and purpose in a workshop.

There is consensus in the literature that conversion of job shop systems to CM results in reduced flexibility and uneven machine utilization, in terms of reduced availability of machines for part processing. Job shop systems are known to be more flexible in the sense that incoming parts can be processed by any machine from a group of similar machines grouped in one area. Flexibility is lower in CM systems, due to the configuring of manufacturing cells with a variety of dissimilar machines and dedicating them to process family of similar parts. Kannan and Gosh (1996) compared cellular manufacturing layout to process layout under different conditions and found that CM systems are in general rigid and inflexible. The advantage they bring do not always compensate its lack of flexibility. Gupta and Tompkins (1982) used simulation to study routing flexibility in response to product variation and suggested that an alternate routing allows parts to search for the least congested machine of the required type. Morris and Tersine (1990) explored various approaches available for identifying machine cells and stated that the major flaw in cellular layouts is the reduction in flexibility that is inherent in machine dedication process. Gaither (1990) argues that CM is relatively inflexible to change in product mix and volumes. Looking at the machine utilization issue, Sassani (1990) has reported that unbalanced workload distribution among cells can create problems in CM systems, mainly because of tendency to set up permanent cells. Kannan and Gosh (1996) have shown that a key issue of traditional CM systems is the uneven loads between cells, which can lead to low overall machine utilization. In this respect, Mahmoodi et al. (1990) examined the impact of several order releasing assignment policies in CM systems, with the purpose of reducing the load imbalance among the cells. A similar study by Okogbaa (1992) has proposed the use of alternate routing balances workload for machines of the same type, so that the long queues in front of the busy machines can be shortened significantly.

A number of simulation studies have been conducted previously by several researchers, in order to compare the performance of cellular and traditional layouts; a detailed review of these studies has been carried out by Chtourou et al. (2008). Among recent simulation studies, Bharamgude and Telsang (2014) have evaluated the production system of an automotive parts manufacturing company with the objective of implementing a CM system and design the cells effectively. A simulation model was developed to evaluate the performance of the current layout and to design a new layout according to cell formations. The results showed a 34% improvement in productivity of the CM system compared to the previous layout. In the same context, Bhangale and Mahalle (2012) have examined the key issues of CM systems implementation, using a simulation approach. Pan (2014) has instead looked at the implementation of CM in the apparel industry. The analysis carried out aimed at comparing four major cell production modes that are most frequently adopted in the clothing making industry, and at finding out the key factors that impact the overall performances of these different cell production modes.

3. Company description

GEA Mechanical Equipment Italia S.p.A. (GEA ME) manufactures and supplies high pressure homogenizers and plunger pumps for dairy, food and beverage, biotechnology, pharmaceutical, cosmetic, and chemical markets. GEA ME was formerly known as GEA Niro Soavi S.p.A. and changed its name to GEA Mechanical Equipment Italia S.p.A. in June 2001. The company was founded in 1947 and is based in Parma (IT). Homogenizers machines are manufactured on different assembly lines where operators (one in each station) assemble components brought from the main warehouse of the company after the picking process. The main warehouse stores all the components needed to assemble the full line of machines; according to the picking lists (about 8 for each machine) the operators prepare the mounting kits of sub-functional groups (compression head, mechanical transmission, etc.) and bring the kits to the relative station in which the specifies kit needs to be mounted on the machine. According to the nature of the specific parts/components, the main warehouse can be fed by purchase orders (for standardized parts, purchased to order) rather than production orders (for customized parts, most of which are standardized and thus kept in stock with some make-to-order exceptions).

These latter are sent to the production department of the company, and the scheduling consequently updated.

GEA ME manufactured in 2017 about 1,378 different components (SAP codes), each SAP code can be produced in one or more production lots according to the needs of assembly lines.

Table 1 shows SAP data extracted and imported in MS Excel for filtering and processing purpose.

Table 1: SAP data

Material	Work ctr	Qty	OP. Setup	OP. Labour time	OP. Machine time
9514-1724-012	29203	10	0,42	0,67	0,67
9514-4902-000	29203	1	0,33	0,33	0,33
9514-1287-000	29209	4	0,33	0,83	0,83
9514-1287-000	29209	4	0,33	0,33	0,33
9514-1629-010	29203	16	0,50	0,15	0,15
9514-1629-010	29197	16	0,50	0,15	0,15
9514-1630-010	29203	16	0,50	0,15	0,15
9514-1630-010	29197	16	0,50	0,15	0,15
9513-9156-000	29200	10	0,33	0,42	0,42
9513-9156-000	29203	10	0,25	0,17	0,17
9513-7989-000	29203	6	0,50	0,58	0,58
9514-6625-011	29209	5	0,58	0,67	0,67
9514-6625-011	29197	5	0,42	0,58	0,58
9514-6641-022	29200	2	0,25	0,25	0,25
9514-6641-022	29200	2	0,25	0,25	0,25
9514-6586-000	29208	30	0,33	0,36	0,36
9514-6586-000	29197	30	0,16	0,15	0,15

Each SAP code (Material) belongs to a specific product family and owns attributes like description and size/dimension (not shown in the table) which better define the part. Moreover, the manufacturing sequence (Work ctr), quantity, working time (OP Machine time) and setup time (OP Setup) are available for each machine.

Since data used for the simulation is the real production data related to 2017, the results of the simulation of the AS-IS scenario can be used to tune the simulation model comparing them with ex post production performances.

To evaluate the influence of different factors on the production performances, a simulation model is created in order to reproduce precisely the overall production of the 2017; all required data was available on SAP system of the company and thus it has been possible to calibrate and tune the simulation model of the AS-IS scenario. Once the virtual model of the production has been validated, it has been used to simulate new scenarios corresponding to different work organization. The simulation models of both systems and the obtained results are presented in the next sections.

4. Job shop and CM systems

The current layout and work organization of the selected factory is arranged as job shop, there are 40,045 parts of the chosen products under manufacturing in 3,494 lots. The average lot size is thus 11.5 parts/lot. The sequence of operations for each part on the seven machines under simulation (5 lathes and 2 mills) is available, machines are located in the AS-IS scenario in separated Job shops as presented in Table 2.

Table 2: process data of the AS-IS scenario

<table>
<tr><th>Work Center</th><th colspan="2">As-Is Job Shops and Resources</th><th colspan="2">To-Be Cells and Resources</th></tr>
<tr><td>29200</td><td>1</td><td rowspan="5">Lathe</td><td rowspan="3">2</td><td rowspan="3">Lathe 1</td></tr>
<tr><td>29206</td><td>1</td></tr>
<tr><td>29209</td><td>1</td></tr>
<tr><td>29207</td><td>1</td><td rowspan="2">1</td><td rowspan="2">Lathe 2</td></tr>
<tr><td>29208</td><td>1</td></tr>
<tr><td>29197</td><td>1</td><td rowspan="2">Mill</td><td rowspan="2">1</td><td rowspan="2">Mill</td></tr>
<tr><td>29203</td><td>1</td></tr>
<tr><td>Operators</td><td>7</td><td></td><td>4</td><td></td></tr>
</table>

For each machine and each part, process time and changeover time is defined, according to SAP data. Each machine has a dedicated resource; since the job shop scenario emulates the real one; thus 7 operators are required.

It has to be noticed that the simulation software doesn't allow the allocation of a resource on a machine only for the working time, thus the resource is assigned to the work centre for both working time plus change over time.

This is not corresponding to the real scenario, because the company has CNC centres so the operator is required only during the setup phase but has no operations to perform but supervising during the working time (the machine is processing the product according to the specified recipe and the operator is just supervising the manufacturing process). The operator can thus be released while the machine processes the parts, until next lot has to be processed.

To bypass this restriction of the software, each work centre has been split in two sub-work centres, namely (A) and (B). The first needs the resource and has change over time according to the part's production chart, but no working time; the second doesn't need the resource, has valid working time but no setup time. Each part, on each work centre, flows from (A) to (B) in sequence.

Table 3 reports the full resource matrix for the simulations.

Table 3: resource matrix

Resource Assignment Matrix

Activities - Operational | Pools

Activity\Resource	Risorsa rep tornit	Risorsa reparto C	Risorsa rep tornit
Input			
29200A			1
29200B			
29206A			1
29206B			
29209A			1
29209B			
29207A	1		
29207B			
29208A	1		
29208B			
29197A		1	
29197B			
29203A		1	
29203B			
Output			

OK · Cancel · Help

Once the job shops AS-IS scenario is simulated, the same simulation model is used to compute the performance parameters for 4 different TO-BE configurations, considering the influence of different factors. Table 4 reports a detailed summary of the simulations:

Table 4: simulation strategies

Simulation ID	**1**	**2**	**3**	**4**	**5**
Work centres layout					
Job shops (7 operators)	X				
Cell manufacturing (4 operators)		X	X	X	X
Lot size (40,045 parts)					
Big (1,378 lots – 29.1 avg parts/lot)			X		X
Small (3,494 lots – 11.5 avg parts/lot)	X	X		X	
Work shifts					
1 (105,600 minutes/year)	X	X	X		
2 (184,800 minutes/year)				X	X

Five different feasible and suitable configurations have been investigated, according to the possible combinations of different parameters:

- *Work centres layout*: refers to the layout of machines and usage of resources; "Job shops" is the current configuration using 7 operators (one per machine), "Cell manufacturing" implies a modified layout of machines and 4 shared resources (according to Table 2);
- *Lot size*: refers to lot management/scheduling policy; Big means production of every part in one big lot per year (thus a total amount of 40,045 parts produced in 1,378 lots), Small is the current work configuration manufacturing some parts in repeated smaller lots per year (thus a total amount of 40,045 parts produced in 3,494 lots);
- *Work shifts*: 1 is the current configuration (105,600 minutes per year), it can be set to 2 when some resources of the first shift are saved thanks to CM configuration, unused resources could be reallocated in a potential second shift (for a total manufacturing time of 184,800 minutes per year).

5. Simulation models of the two systems

The simulation models were built for both systems: job shop and cellular manufacturing according to Table 2. The only difference in the two simulation models is the number of resources allocated to machines: one per machine in job shops and one/two per cell in the other configuration.

Consequently, the proper set up is done in the resource matrix in Simul8™; such matrix, shown in Table 3, contains the different kinds of available resources (mill operators, lathe operators) and their relative amount (i.e. 1 mill operator, 2 lathe operators, etc.).

The transfer time between machines in each workshop in job shop system is less than 1 minute, so it is ignored in the current study. Simul8™ software requires, for each Work Type (Material, SAP code), the processing sequence, the work centre, working time and the change over time; the structure of the table is shown in Table 5.

Table 5: job matrix

Jobs Matrix

Work Type	Job	Location	Timing	Change Over
1	1	29203A	0	25.2
1	2	29203B	400.02	0
1	3	Output	0	0
2	1	29203A	0	19.8
2	2	29203B	19.98	0
2	3	Output	0	0
3	1	29209A	0	19.8
3	2	29209B	199.98	0
3	3	29209A	0	19.8
3	4	29209B	79.98	0
3	5	Output	0	0
4	1	29203A	0	30
4	2	29203B	144	0
4	3	29197A	0	30
4	4	29197B	144	0
4	5	Output	0	0

OK · Cancel · Help

As mentioned before, each work centre has been split in two sub-work centres, namely (A) and (B). The first needs the corresponding resource (mill operator, lathe operator) and has change over time according to the part's family, but no working time; the second doesn't need the resource, has valid working time but no setup time. Each part, on each work centre, flows from (A) to (B) in sequence.

Set up time is provided by the company according to the part's family, while working time has to be computed according to Lot size parameter.

When *Lot size* is set at *Big* the yearly consumption of each part is considered produced in 1 lot, thus working time is given by the working time of the single part multiplied by the number of parts required in one year (2017). This operation is done in Excel spreadsheet in order to prepare consistent data to be imported in Simul8™ job matrix. Set up time is considered only one time. If *Lot size* is set at *Small*, parts production simulation has been done according to the real production schedule taken in 2017, so a repeated multilot configuration is considered. Working time is given by SAP extraction and Set up time is repeated at the beginning of each lot.

The created Simul8™ model is shown in Figure 1.

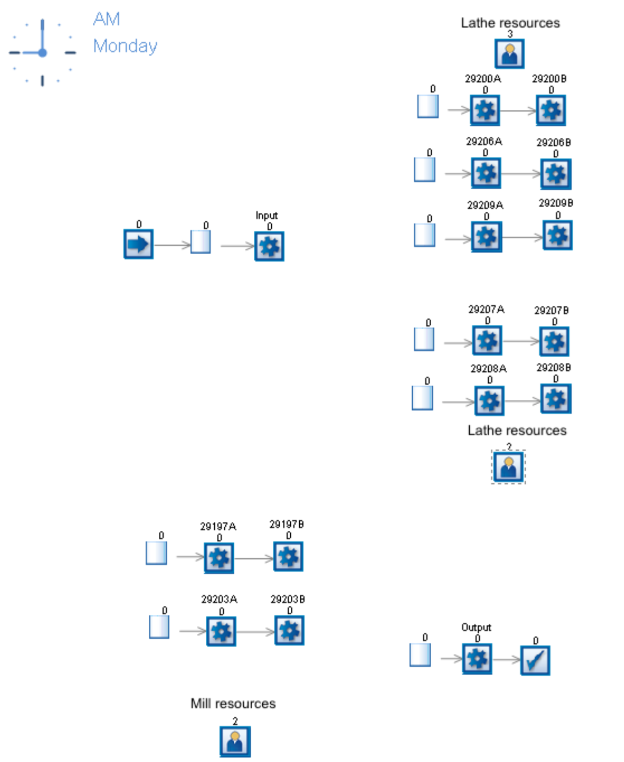

Figure 1: scheme of the simulation model in Simul8™.

Manufacturing machines are grouped into job shops; Input activity has a work time equal to zero and just assigns a random Work Item ID to each part leaving the Start point in order to characterize it, the route of the part is then taken from the Job Matrix.

Output activity has also work time equal to zero and it just collects all the processed parts to the End point.

The simulation model for job shop and cellular manufacturing system was built by Simul8™ software, using 10 replications for each Simulation ID.

6. Obtained results

Table 6 summarizes the detailed analytics obtained for each scenario; in particular, the table reports, for each work centre and for each scenario ID, the average saturation, number of employed resources and saturation of them.

It must be noticed (as previously stated) that every machine has been split in two (Machine A responsible of setup and Machine B responsible of main process), thus their saturation is separately reported in the table. This assumption implies that the operator can setup the machine while it is still processing the part under manufacturing; the company agreed with this behaviour.

Table 6: simulation results

		As-Is Job Shops ID 1				To-Be Cells Manuf. ID 2				To-Be Cells Manuf. ID 3				To-Be Cells Manuf. ID 4				To-Be Cells Manuf. ID 5			
Work Center		Resources	Resource efficiency	Setup	Machine efficiency	Resources	Resource efficiency	Setup	Machine efficiency	Resources	Resource efficiency	Setup	Machine efficiency	Resources	Resource efficiency	Setup	Machine efficiency	Resources	Resource efficiency	Setup	Machine efficiency
Lathe	29200	5	16,0%	18,48%	99,62%	2	23%	18,70%	99,66%	2	10%	8,41%	99,93%	2	23%	18,03%	99,66%	2	10%	8,07%	99,91%
	29206			15,65%	98,15%			14,77%	98,70%			6,17%	99,90%			14,52%	98,78%			5,81%	99,94%
	29209			15,03%	99,28%			13,52%	97,86%			5,38%	99,47%			13,75%	98,72%			5,54%	99,68%
	29207			18,99%	99,41%	1	33%	18,26%	98,57%	1	12%	7,15%	99,79%	1	34%	18,24%	98,80%	1	13%	7,42%	99,77%
	29208			14,26%	98,01%			15,11%	97,67%			5,28%	99,66%			15,76%	98,43%			5,40%	99,70%
Mill	29197	2	18,0%	19,34%	97,43%	1	35%	18,12%	96,24%	1	14%	8,03%	97,67%	1	36%	18,29%	96,91%	1	15%	7,77%	98,39%
	29203			17,62%	98,25%			16,71%	96,26%			6,35%	98,64%			17,63%	96,81%			7,44%	98,87%

Since the scenario ID 1 refers to the current work organisation, the results should be compared with productivity and overall performances along 2017.

The company gave some details about the saturation of resources (about 20% but not analytically determined) and about the productivity (40,045 components), which are comparable with the results of the simulation. The different simulated productivity can be explained considering some simplifications introduced in the simulation; in fact, no transfer time between machines has been considered and no failures and maintenance time as well. These factors may reduce the simulated productivity in order to make it closer to the real measured one.

It must be noticed that working on one shift and reducing the number of available resources (scenario ID 2) increases their saturation and does not significantly affect the productivity, probably because of the low saturation of resources in the current (ID 1) scenario. Increasing the lot size (ID 3) increases the overall efficiency of machines, reduces setup times but reduces the overall productivity, this behaviour can be explained considering the lower efficiency in lot scheduling and the higher waiting time for the machines due to higher working times for each processed lot.

Increasing the number of shifts (i.e. employing the 3 unused resources in the first shift to extend production in the second shift) leads to a higher productivity in both scenario ID 4 and ID 5.

Table 6 reports the main average KPIs for the different scenarios.

Table 7: KPIs for each simulated scenario

Simulation ID	1	2	3	4	5
Lots	3,853	3,715	1,407	6,598	2,492
Pieces	44,160	42,578	40,888	75,620	72,418
Resources	7 (1 S)	4 (1 S)	4 (1 S)	4 (1 S) 3 (2 S)	4 (1 S) 3 (2 S)
Resources saturation	17.0%	30.3%	12.0%	31.0%	12.7%
Setup (machine A)	17.1%	16.5%	6.7%	16.6%	6.8%
Working % (machine B)	98.6%	97.9%	99.3%	98.3%	99.5%
Working time (machine B - minutes)	104,114	103,331	104,855	181,661	183,812

7. Conclusions

This paper has proposed an analysis of a real job shop manufacturing system, with the aim to evaluating the implementation of a CM system. Simulation was used as the research methodology, due to its capability to evaluating the performance of modifications in the existing layout of a system without the need of implementing it. More precisely, five scenarios were analysed through simulation (the AS-IS scenario plus four TO-BE configurations). Every TO-BE scenario has been simulated in 10 runs, each of which considering one year of production. The TO-BE scenarios provided interesting outcomes: for instance, it was found that working on one shift and reducing the number of available resources increases their saturation but does not significantly affect the productivity of the system. Similarly, increasing the lot size enhances the overall efficiency of the machines and reduces the setup times; however, the overall productivity worsens slightly. As this study grounds on a real case study, the results obtained could be useful to the company when pondering the implementation of a CM layout; since the company is not interested in reducing resources, the most interesting outcome is the increased productivity obtained by adding a second work shift. In fact, unused resources in the first work shift may be employed in the second shift to increase both productivity and machine saturation.

Future research could address the improvement of the simulation model (i.e. considering transfer time, maintenance, production breaks due to the end of the shift, etc.) and the economic evaluation of the TO-BE configurations to quantify also their profitability and provide further useful insights to the company.

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