Decision System for Supporting the Implementation of a Manufacturing Section on an Automotive Factory in Portugal

A Case Study

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Abstract **- The main challenge of this work consists on finding an appropriate layout for a manufacturing section in the Trecar Company for producing a set of preheated molds, through thermoformation process on different batches of pieces. Thus, there are alternative scenarios, which are analyzed in order to realize which one may enable to obtain a better solution, based on makespan results, among other advantages, for processing the set of batches of pieces.**

Keywords- Decision support system, automotive manufacturing, alternative layouts, comparative analysis.

I. Introduction

Manufacturing systems include several distinct concerns, mainly regarding: the arrangement and operation of machines, tools, material, people, and information to produce a value-added physical, informational, or service product whose success and cost is characterized by measurable parameters.

While, manufacturing system design covers all aspects of the creation and operation of a manufacturing system, creating it includes a set of decisions to be made, regarding equipment selection, physical arrangement of equipment, work design (manual and automatic), and standardization. On the other hand, the operation of the system includes all aspects that are necessary to run the created factory (i.e., problem identification and resolution process, as stated by Cochran and Dobbs, in 2002 [1].

Major cause to low productivity is failure to utilize the resources due to poor management, organization, planning and layout. In order to try to overcome these problems, manufacturing cells (MCs) are manufacturing systems that many industrial sectors have used beneficially in recent years, as concluded by Tavakkoli-Moghaddam, et. al, in 2007 [2].

Different and independent surveys on the implementation of MC conclude that significant improvements can be achieved in areas such as lead times, set up times, work in process, quality, machine utilization and employee job satisfaction, as explained by Kaebernick and Bazargan-Lari, in 1996 [3].

This work aims at validating alternative manufacturing layouts for the implementation of a production section for producing a set of 12 different pieces. Therefore, the problem on hands consists on evaluating alternative production layout scenarios for producing the set of pieces, in order to minimize the average makespan. For accomplishing this, a set of alternative production flows, based on the alternative physical arrangements, mainly product oriented, like flow shops or manufacturing cells, are analyzed for further implementation on the Trecar Company.

For a better exposition of the main ideas underlying to this work, this paper is organized as follows. Next a brief literature review about some more or less closely related and similar problems found in the literature is presented. On section 3 the studied problem is described. Next, section 4 shows the main results obtained and presents a comparative analysis for the alternative scenarios considered. Finally, on section 5 a conclusion is presented, as well as intentions in terms of future work.

II. Literature Review

According to Sing [4] the design for manufacturing cells involves three stages as follows: (1) cell formation by grouping parts into part families and machines into cells, (2) layout of the cells within the shop floor (i.e. inter-cell layout), (3) layout of machines within each cell (i.e. intra-cell layout).

Although much research has been carried out over the last decades about manufacturing cells layout, MC layout problems have not yet always received adequate attention of researchers as much as cell formation in the past two decades. For this lack of information on layout issues, the benefits of MCs cannot always be easily validated, according to Salum [5]. Although this kind of research is intensifying over the last years, there is still room for much more improvements on industry, namely regarding the implementation of MCs. One such early experiment was carried out by Alfa et al. [6], were a model for solving an intra-cell layout problem was formulated.

Moreover, Das [7] also formulated a model for solving inter-cell layout problem and Wang et al. [8] formulated a model for solving both inter-cell and intra-cell layout with deterministic variable demands.

Moreover, Bazargan-Lari et al. [9] presented the application of an integrated approach to three phases of a design of cellular manufacturing systems to a white-goods manufacturing company in Australia.

Ho and Moodie [10] addressed a cell layout problem combining a search algorithm and linear programming models to design a cell layout and its flow paths.

Another interesting approach was proposed by Salum [5] based on a two-phase model to design a machine layout on a shop floor that reduces the total manufacturing lead time. Additionally, Tavakkoli-Moghaddam and

Shayan [11] solved a quadratic assignment problem (QAP) model by using genetic algorithms to generate a number of equal-sized facilities layout solutions.

Shore and Tompkins [12] studied four possible scenarios based on product demands.

Rosenblatt and Kropp [13] studied a stochastic single period for the QAP formulation.

Kouvelist et al. [14] also used the QAP model to study single and multi-period layout problems.

Norman and Smith [15] introduced a mathematical model of the block layout problem considering uncertainty in material handling costs on a continuous scale by the use of expected value and standard deviations of product forecast.

Tavakkoli-Moghaddam et al. [16] presented a new mathematical model of a cell formation problem (CFP) for a multi-period planning horizon where the product mix and demand are different on each period. They proposed a memetic algorithm (MA) with a simulated annealing (SA) based local search engine to find the optimal number of cells at each period as well.

Asef-Vaziri et al. [17] referred that between 20% and 50% of operating expenses in manufacturing can be attributed to facility planning and material handling. Thus any cost saving in this area can contribute to the overall efficiency of the production system. In their paper they model and solve the problem of optimally designing a material handling system in a factory. They refer the existence of several algorithms for the design of block layouts, namely a common one defined as BLOCPLAN [18]. Moreover, they also emphasize that the three principal and interdependent design decisions in the facility layout design problem are: (1) the conceptual design of the block layout including the shapes and locations of cells, (2) the determination of the locations of the pickup and delivery stations on the boundary of each cell, and (3) the design of the flow paths or aisles connecting the station points. Although these three problems are closely related, they refer that they have traditionally being solved sequentially due to the computational intractability of the integrated design problem, as stated by Kim and Goetschalckx [19].

Moreover, as described by Malmborg and Bukhari [20] the volume distance is also a widely used criterion for exact and heuristic plant layout procedures. So, they highlight that an important category of plant layout procedures involves line layout where the objective is to determine a linear sequence of work centers in a facility using a ‘process line layout’. They refer that their study is applicable to line layout cases where there is high product variation with relatively low volume. Special examples include cellular manufacturing systems as described in Liao [21], or flexible manufacturing systems as described in Langston and Morasch [22]. As with the more general case of block layout, most optimal procedures for line layout tend to be inefficient for problems of large to moderate size. As an alternative to optimal methods, heuristic methods can provide quality solutions at acceptable computational cost. The problem with heuristic methods lies on reaching an evaluation of relative quality, i.e. the quality of solution regarding the population of all possible solutions. This lack of context makes it difficult to specify criteria when applying heuristic layout procedures.

Lee et al. [23] considered the manufacturing layout problem in which a unidirectional loop material flow system was used for the material handling. The manufacturing system was used to process a group of parts on a set of specified workstations. Each part had a unique routing sequence, which was assumed to be complex and known. The workstations were configuring a layout in unidirectional loop manufacturing systems to be located along a unidirectional und cyclic path or loop, so as to minimize the material handling cost.

Moreover, Lee [24] on his paper addressed the layout configuration problems of a complex cellular manufacturing system. A three-phase interactive approach was outlined to determine the inter-cell layout, the location of transfer stations, and the machine layout for each cell. This approach was based on the decomposition strategy to partition the complex and large design problem into a subset of smaller problems with increasing details.

As a resume we may state that different approaches have already been put forward by a widened range of authors, for solving manufacturing system design problems, namely in the context of product oriented systems, like flow shops and manufacturing cells, which are being applied to the distinct industrial sectors and this paper also aims at providing a similar scenario, for solving the design problem about a manufacturing section within an automotive factory.

III. Problem Description

The Trecar Company is facing a new challenge. It is under an ongoing implementation of a new production section, which consists on using 12 different preheated molds for producing distinct kind of pieces.

The process is initiated through an injection machine, where foam is produced, which is further used on the produced pieces. The injection machine produces foam cubes of various types of sizes by means of a pre-existing formula composed of different materials. These cubes are subsequently to be transformed into plates.

The further processing stage performs an alignment of the sides of the cubes and, if necessary, they are divided into smaller ones. After this operation it is necessary that the cubes stand for approximately 6 to 8 hours.

The next operation consists on transforming the cubes on foam boards. It is executed on a machine for performing horizontal cuts, which makes the cut of the cubes into plates with the desired thickness, in order to obtain the desired different plates, which result from the different sizes of cubes.

On a next stage of the manufacturing process a manual operation is processed, which consists on joining an artificial tissue to the foam plate at the top and bottom of it, in order to provide protection and a different final aspect to the pieces.

The final operation of the manufacturing process consists on providing the final shape to the pieces, which is performed through a heating and cutting process called thermoforming. For performing this there are three heaters and three presses capable of executing all the required kind of thermoheating process.

Finally, with the pieces ready, they are packaged and shipped to the warehouse. Figure 1 resumes these main production processes.

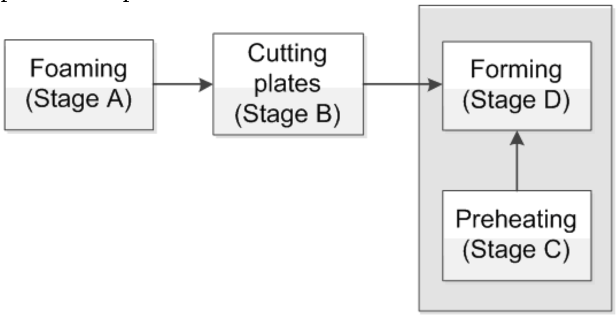

Figure 1. Main factory processes.

The entire production process described above seems to be quite simple; however it hides a quite complex scenario which led to the need for this study.

As was observed previously for the execution of the orders to fulfill each piece, they have to go through presses and the molds that form the pieces have to be preheated on a previous machine that supports it.

Along this manufacturing process the main concern focuses on that thermoforming process, as it is the stage where the bottleneck occurs.

Therefore, let us look at the data related to this particular stage for further analysis, which main underlying production data is shown on Table 1.

TABLE I. MODELS PROCESSING DATA

Mold	Pieces per mold	Dimensions (mm)		Operation 1 (min)	Operation 2 (min)	
				Heating mold	Pressing time	Total time
1	2	1338	1218	320 Min	1,50 Min	600 Min
2	4	1566	1176	320 Min	1,05 Min	210 Min
3	3	1428	1395	320 Min	1,50 Min	400 Min
4	4	998	723	230 Min	1,00 Min	200 Min
5	3	1396	890	280 Min	1,00 Min	267 Min
6	6	1222	1141	320 Min	1,25 Min	167 Min
7	3	1150	740	230 Min	1,00 Min	267 Min
8	6	1465	990	280 Min	1,10 Min	147 Min
9	8	1220	939	280 Min	1,50 Min	150 Min
10	4	1454	1012	300 Min	1,00 Min	200 Min
11	4	1083	788	230 Min	1,50 Min	300 Min
12	6	1380	632	230 Min	1,10 Min	147 Min

As we can realize there are twelve different molds, which enable to obtain different amounts of pieces.

The time for heating each mold varies depending on its size. Despite the daily quantities to be produced being equal for all the molds, the resulting time for the production time (per lot) is not equal due to the aforementioned different amount of figures or pieces that are obtain per mold.

For accomplishing the production of these models we consider three alternative layouts for the physical arrangement of the manufacturing section, for being analyzed, which are briefly described next.

A. *Scenario 1 (1+1+1)*

One scenario that we consider consists on a manufacturing layout that integrates three independent lines (i= 1, 2 and 3), each one composed by two kind of work centers: MCi and MDi, which are correspondingly a heater (MCi), from the Preheating stage C of the thermoforming stage, and a pressing machine (MDi), from the forming stage D of the thermoforming stage, as previously shown on Figure 1.

In this scenario if a mold was heated on a workstation MCi, for a given line i, it has to be processed next on the work center MDi, of the same line i and this kind of layout is illustrated through Figure 2.

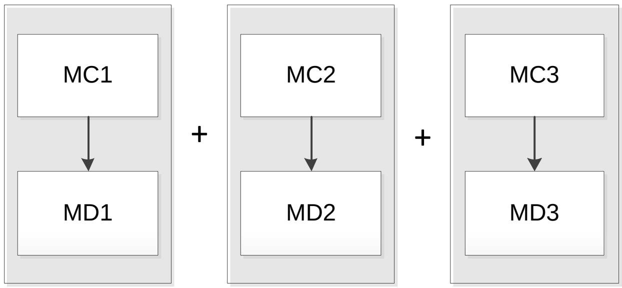

Figure 2. Schema of scenario 1.

B. *Scenario 2 (2+1)*

Another scenario considered consists of two sub scenarios, one integrating two lines, with work centers MCi and MDi (for i= 1 and 2), and where besides the flow of molds from each MCi to each MDi, on each line, also may occur two additional flows about molds that are preheated on the heater MCi of one line and subsequently go further for being pressed on the work center of the other one. In case of this last situation, the corresponding molds suffer a time penalization of 5 minutes, regarding transportation needed to pass the mold from one line to another. The other sub-section of this scenario consists on a third independent line, with machines MC3 and MD4, similar to the ones referred above on scenario 1, and this scenario is shown on Figure 3.

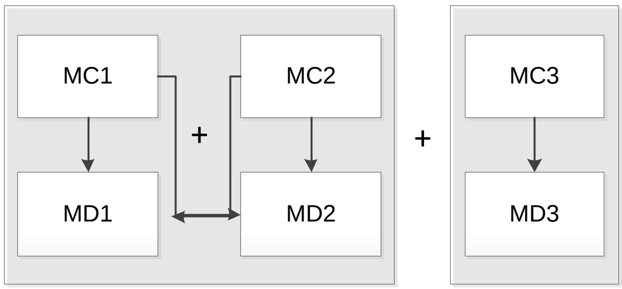

Figure 3. Schema of scenario 2.

C. *Scenario 3 (3)*

In the third scenario we consider that each mold can pass from each one of the three heaters (MCi) to any of the three available presses (MDi), accordingly to the first press available. As in the previous case when a mold is not allocated to the pressing machine (MDi) that is closer to the previously visited heater (MCi) of the corresponding line it suffers a time penalization of 5 minutes due to transportation requirements and this scenario is illustrated on Figure 4.

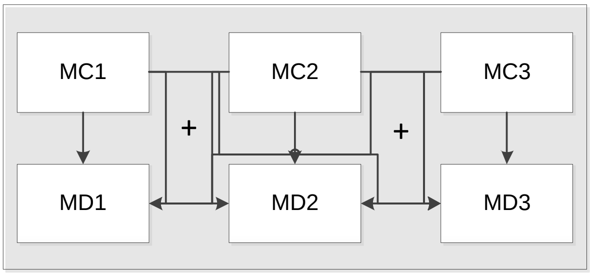

Figure 4. Schema of scenario 3.

D. *Alternative molds sequences considered for analysis*

Once defined the alternative scenarios in terms of manufacturing layouts, it turns out to be necessary to define the possible sequences of molds to be considered for production on those scenarios, for comparing them. Therefore, in order to obtain the most accurate conclusions about the three alternative manufacturing scenarios considered a set of 500 sequences were analyzed. Table 2 summarizes the first eleven of the 500 sequences of molds considered.

TABLE II. SAMPLE OF MODELS' SEQUENCES

	Heating 1				Heating 2				Heating 1			
	Mold	Mold	Mold	Mold	Mold	Mold	Mold	Mold	Mold	Mold	Mold	Mold
Sequence 1	1	2	3	5	6	7	10	11	4	8	9	12
Sequence 2	1	2	3	7	4	5	6	10	8	9	11	12
Sequence 3	1	8	9	12	2	3	4	10	5	6	7	11
Sequence 4	1	4	6	10	2	7	8	12	3	5	9	11
Sequence 5	1	6	8	11	2	3	7	10	4	5	9	12
Sequence 6	1	8	10	11	2	3	5	6	4	7	9	12
Sequence 7	1	5	6	12	2	4	7	11	3	8	9	10
Sequence 8	1	7	10	11	2	3	4	12	5	6	8	9
Sequence 9	1	2	4	12	5	9	10	11	3	6	7	8
Sequence 10	1	4	6	9	2	8	11	12	3	5	7	10
Sequence 11	1	6	8	12	2	3	9	11	4	5	7	10
...	1	7	10	12	2	3	5	9	4	6	8	11

All the 500 sequences of molds for being produced on the alternative three scenarios were analyzed, for comparing them in terms of total production time or makespan, which was the main performance measure used on this study, and on the next section the main results are going to be presented and briefly described.

IV. RESULTS ANALYSIS

According to the makespan criterion set out above for evaluating the production of the 12 molds, according to the 500 corresponding alternative sequences established for being applied for producing the molds based on each of the three scenarios defined, the results obtained are shown in Figure 5. As we can observe through this figure, they all correspond to not much different makespan values, and the minimum makespan obtained was of 1380 min.

However, a considerably wider range of better results regarding the makespan criterion, with a value below the average makespan value, were obtained for scenario 1.

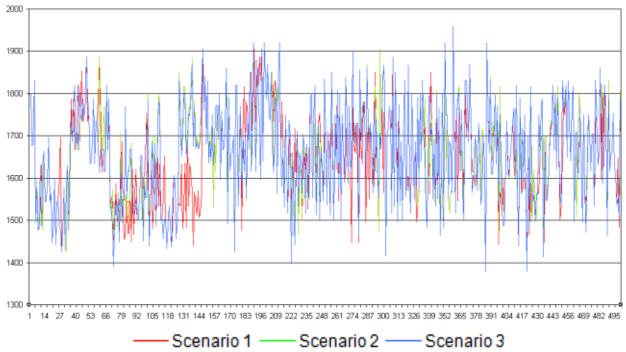

Figure 5. Makespan values obtained for each alternative situation (1 to 500) within each scenario (1, 2 and 3).

Therefore, by taking a closer look at the results obtained and summarized on Table II, it can be seen that 230 alternative sequences for the production of the 12 molds have obtained a lower makespan (below the average makespan value), which did occur for scenario 1.

TABLE III. MAIN ALTERNATIVE SCENARIOS' RESULTS

Values (min)	Scenario 1				Scenario 2				Scenario 3			
	M1	M2	M3	Cmax	M1	M2	M3	Cmax	M1	M2	M3	Cmax
Maximum	1960	1907	1830	1960	1960	1907	1830	1960	1960	1887	1830	1960
Minimum	1120	1143	1117	1380	1120	1137	1117	1380	1120	1137	1117	1380
Average	1572	1397	1367	1649	1580	1377	1367	1661	1578	1385	1365	1661
Standard Deviation	183	135	136	118	186	141	136	122	184	141	142	119
Below average	199	268	258	230	201	265	258	213	200	280	255	212

Thus, we may be able to conclude that, despite the best result (global optimum) was reached by the three scenarios, the layout that did provide an increased number of better makespan values, for the set of 12 molds considered was scenario or layout 1. Therefore, in terms of future work, this layout is going to be further studied in order to apply scheduling approaches for reaching more detailed data regarding a second step of this study for reaching the final physical implementation of this manufacturing section in the Trecar Company.

V. CONCLUSION

The main goal of this study was not to find the global optimum solution to the problem of selecting the physical configuration or layout that seems to be more appropriate in terms of trying to figure out the sequence of production of the molds considered, according to the three possible alternative layouts considered for their production, but, instead to try to find out which physical arrangement or layout that appears to be more favorable, on average, for the production of all 12 molds, according to a set of alternative sequences for their production, in order to achieve the best results in terms of total production time or makespan in a bigger number of occurrences.

Thus, through this study it was possible to conclude that the physical layout that is more advantageous in terms of minimizing more times the makespan value for the production of the 12 molds considered was scenario or layout 1, which consists on three independent lines, for performing the thermoforming process of those molds, integrating two work centers, a first for molds preheating and a second one for their pressing.

Moreover, through the results obtained through this study we may highline that several kind of advantages are also able to be reached throughout the implementation of the proposed layout on the Trecar Company about the thermoforming section. Those advantages are mainly related to WIP and inventory costs reduction, by decreasing the number of materials and work in progress (WIP) necessary, which is also an important aspect to be considered, under the scope of Lean and JIT production principles, with are being increasingly spread out through several different industrial companies over the last years, including in Portugal.

Besides that, even more important improvements can be obtained through this study, by enhancing the manufacturing system, by improving the production flow and consequently the production tasks management. Moreover, it is possible to simplify materials acquisition and storage. Therefore, material handling and control, can also be simplified as well as the whole production control process, enabling better tasks performance and enhanced productivity and production quality in the corresponding manufacturing environment, by reaching better work integration among operators, through a closer interaction and information and responsibility sharing, which is also a clear achievement through the proposed manufacturing section. As a consequence, reduced total production time and material and WIP flows are also reached, through the reduction of waste and distances between work centers within the manufacturing section, which is also visible by implementing the proposed manufacturing section.

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