ISSN 2683-345X
journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial Engineering and Management

Volume 12 / No 2 / June 2021 / 85 - 101

Original research article

A model for productivity improvement on machining of components for stamping dies

J. Silva [a], F. J. G. Silva [a,b] *, R. D. S. G. Campilho [a,b], J. C. Sá [a,b,c], L. P. Ferreira [a,b]

[a] *ISEP - School of Engineering, Polytechnic of Porto, Porto, Portugal;*

[b] *INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Porto, Portugal;*

[c] *IPVC - Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal*

ABSTRACT

The production of stamping dies requires the manufacture of numerous components, many of which have similar dimensions. However, because they are almost all different, this brings added problems in the acquisition of materials, and in their machining, the main process used in the manufacture of these components. Most SMEs do not have production systems properly organized to manage the machining of these components in the most cost-effective way. The purpose of this work is to provide a novel tool able to re-organize the machining operations in the production of dies for stamping operations, saving time and allowing an easy way to extend the autonomous machining time. This work follows an empirical approach resulting from the experience and attempts to optimize machining operations in the production of stamping dies. A flowchart was developed, acting as guidelines to select if the set of parts to be manufactured can integrate the approach designed. The approach is validated by two case studies presented in the paper.

ARTICLE INFO

Article history:

Received December 18, 2020
Revised March 28, 2021
Accepted March 31, 2021
Published online April 14, 2021

Keywords:
Machining; Manufacturing;
CNC milling equipment;
Productivity;
Tools and Dies;
Parts grouping;
Improvements in manufacturing

*Corresponding author:
Francisco J. G. Silva
fgs@isep.ipp.pt

1. Introduction

This work was developed regarding the difficulties felt by smaller tools and dies manufacturers, who have their production organized in a one-piece-flow system, and that are losing competitiveness due to more advanced approaches. The causes for poor machine tool performance are usually due to poor management policies. The predominant causes for low incomes sometimes relate to lack of internal organization, lack of work preparation, and lack of planning. The first action to take is to measure, and in this way the size of the problem is assessed, making it possible to create indicators that monitor the progress. It is very important to measure the actual working times of the CNC machining times, as well as all other non-productive times. All these non-productive but part of the work times must be performed while the equipment is working. This paper is presented a novel methodology to select the tool elements that should be considered for grouped machining, as well as a workflow to support this decision. To validate the effectiveness of this model, two case studies are presented, where the increase of the equipment availability is directly reflected on the growth of the company's OEE indicator.

Thus, this work is divided into six sections, starting with this Introduction, which is followed by the

DOI: http://doi.org/10.24867/IJIEM-2021-2-279

Literature Review in section 2, where the theoretical elements needed to support the development are presented. Section 3 describes in detail the methodology used throughout this work and section 4 presents the Results, using for the validation of the model developed two real case studies, proving by this way the usefulness of the model. Section 5 presents a discussion about the novelty of the work and compares the results obtained with others previously referred to in the literature, and Section 6 highlights the main achievements obtained through this work.

2. Literature review

The molds and dies industry represents a significant portion of the metalworking industry and needs its know-how, which is divided by the molds industry for plastics injection molding, high-pressure die-cast, forgings, sheet metal cutting, and sheet metal forming [1]. Both the manufacturing process and the durability of these tools have been a number of concerns for researchers [2]. In fact, the main concern of Castro et al. [3] was to develop a crimping tool for electrical terminals that was versatile, based essentially on standardized elements and that ensured adequate operating precision with the minimum necessary adjustments in the setup operations. The modular construction of this type of tool constituted a new step in its flexibility, allowing greater interchangeability between standard components and greater operational safety. Taking into account the hot stamping, Yun et al. [4] developed a new cooling system based on the use of Mixed Cooling Channel (MCC), which simultaneously uses Straight Cooling Channels (SCC) and Conformal Cooling Channels (CCC), thus improving the cooling of the parts and achieving an increase in productivity between 5.8 % and 9%. On the other hand, Maeno et al. [5] developed a direct cooling process for parts in ultra-high-strength steel, which saves time in cooling, since the parts have less mass, and their cooling is faster than all or part of the mold. With this cooling process, they managed to reduce the time needed to obtain the desired hardening of the part. The stamping tools have very specific characteristics, requiring high know-how to understand where to act in order to solve problems in the stamped parts. Today, the shapes demanded by customers are increasingly complex, being extremely challenging for materials, tools, and dies designers [6,7]. Silva et al. [8] studied the origin of the problems created by a progressive tool in the stamping of a complex part for the automotive industry, in Dual-Phase high-strength steel. Using the Autoform® software to simulate the behavior of the material during the different forming phases based on the Forming Limit Diagram and taking into account the Forming Limit Curves regarding the material in use, and comparing the experimental results with the simulation, and also taking into account the Hole Expansion Tests results to analyze the properties of the material used, it was possible to mitigate edge crack defects, through slight but effective die changes. Springback is a typical problem in most metals, and even more in high-strength steels [9]. Gomes et al. [10] carried out simulation studies to minimize the number of iterations necessary for the design of a tool that avoided spring back defects as much as possible when stamping Dual-Phase steels with UTS between 780 MPa and 900 MPa. The results achieved were quite interesting, leading to savings of 71% in the simulation time required to obtain the desired results. Another of the recurring problems with stamping tools and injection molds is their lifespan. To this end, several investigations have been carried out based on the application of hard and/or self-lubricating coatings, to reducing the friction of the plate to be stamped with the die, reducing the deterioration of the part surface, and preserving more effectively the die surface. Fernandes et al. [11-13] used different coatings to maximize the useful life of a die used to produce lids of butter cookie tins. In a comparative study between a hard B4C coating and a soft Mo coating [11], the authors concluded that the Mo coating had better characteristics to be applied in that type of application, because it presents a better surface texture and allows a better sliding of the plate to be stamped, while the B4C coating had droplets, which showed a strong tendency to stand out from the surface in service. However, the authors left the message that Mo coatings would still need a lot of research in order to find the best deposition parameters and specific microstructure for this application, mainly due to the Mo coating adhesion to the stamped parts and corresponding need to repair the coating after a few thousands of operations. In further work, Fernandes et al. [12] used WC and CrCN coatings, pointing out a better coating behavior in terms of hardness and less adhesion, expecting a better lifespan to the die. However, in further work it was used TiAlN regarding the same purpose and the results obtained were even better, improving the lifespan of the stamping die by 500% relative to the initial situation, reporting a well low friction coefficient. Other attempts have also been made by several authors to increase the life of molds for high-pressure die casting [14] or injection molding with reinforced plastics [15, 16].

Efforts to reduce costs are transversal to any type of company [17] and the metalworking industry is no exception [18]. The dies manufacturing process involves several machining operations, the cost of these machining processes being preponderant in the total cost. Hence, the machining processes have since very early, been the subject of numerous investigations, which can be focused on several aspects, from the optimization of CNC programming [19] to a correct selection of the tools to be used [20], not leaving to explore details related to the fixation of the parts [21] or the management of the machining process [22]. Most of the studies currently carried out on the optimization of machining processes are centered on problems related to environmental sustainability, namely energy saving. Li et al. [23] developed a model capable of integrating more correct planning of operations with the optimization of cutting parameters, which resulted in an energy-saving that was later validated through a case study. On the other hand, numerous tools have been developed, their geometry has been modified or coatings have been added that aim to reduce friction, saving energy, and trying to increase the useful life of the tools, both for environmental and economic sustainability issues. Gouveia et al. [20] carried out a comparative study between commercially available milling tools, showing that there are substantial differences in their behavior, is crucial to the coating they are provided with, as well as the cemented carbide which constitutes the substrate. In view of the compared coatings, it was clear that TiAlN behaves better than AlCrN when machining duplex stainless steels. Economic sustainability can also be improved by the faster and more precise fixing of parts on the CNC machining center table. Costa et al. [21] developed a hydraulic clamping system that made it possible to reduce the number of clamps required for machining a part with complex geometry, thereby reducing the machining time and improving the accuracy obtained in the different operations carried out. On the other hand, the jigs used to fix the parts in the machining processes can, in most cases, be optimized with a view to reducing the time required in their assembly or in the machining of the set. A study by Kumar et al. [22] in view of the series machining of parts for the construction industry, it has been possible to optimize a jig, which now comprises 50% more parts in each cycle, but which, through a careful machining strategy, only increased by 10% the cycle time of the set, compared to the initial situation. In addition, the jig was designed incorporating modularity concepts, thus allowing it to be used for other types of parts only with the replacement of some of the more specific components. These are just some of the examples that demonstrate that economic and environmental sustainability is widely studied, and in several aspects, there are still many opportunities for improvement, especially with regard to the use of more advanced tools and more effective lubrication systems [23-24]. However, also at the management level, it is possible to obtain significant gains [25, 26], provided the most appropriate tools are used and the most effective policies are applied considering these processes. The application of Lean methodologies to machining can allow, in many cases, greater economic sustainability [27]. Seifermann et al. [28], after finding that the one-piece flow cycle commonly used in assembly lines could not be directly applied in the industry that intensively uses machining processes, developed a model that intended to convert batch size-oriented machining into synchronous one-piece flow machining. To this end, a methodology was developed that consisted of six steps, starting from the beginning by understanding and eliminating all barriers that prevent a real flow of production, stabilizing the continuous flow through identification of which production cells are most suitable for each product, and creating the respective segmentation by process or type of machining required. The man-machine relationship was dissected, and flexibility was increased, in order to respond positively to changes in market demand. This methodology was validated in the laboratory and in the industry. In recent years there has been a growing tendency to associate Lean methodologies with concepts of environmental preservation, usually called Green. Thus, an association between terminologies was created: Lean-Green. The machining industry and the metalworking industry, in general, can take great advantage of this association, and researchers interested in studying this topic rapidly upsurged [29]. In the case of the work by Leme et al. [30], the association was made through the application of the SMED methodology, duly combined with the Carbon Footprint tool, in order to analyze the eco-efficiency of machining centers. These authors started by appealing the SMED methodology and, later, they went to verify what the implications in environmental terms were achieved. Indeed, after successfully eliminating around 88% of waste, they concluded that the resulting footprint had also been improved by around 81%. On the other hand, the joint application of Lean tools in the metalworking industry has gained adherents, as it allows relatively sharp gains in short periods of time. Rodrigues et al. [31] applied a set of Lean tools in a metalworking industry devoted largely to machining, in order to obtain a quick response in terms of results. In a short period of three months, through the application of this set of tools, he achieved a reduction in the costs of non-conformities in the order of 30% and an increase in worker satisfaction.

The subject addressed by the present work deals partially with manufacturing planning operations, but not in its strict term. In fact, what is sought in this work is to save machining time and material, using a new work preparation methodology that allows transforming the production of the one-piece-flow type in groups of parts, saving the cut initially made in the suppliers of raw material, and increasing the machining time of a part for a very wide group of parts, thus allowing to optimize the production time of the equipment, putting the equipment to work continuously, but without the company operating in more than a single shift. Nesting is a methodology widely explored and used in different mass production industries [32], but it can only be partially applied in this work, functioning as an integrated tool in the methodology now developed. However, the problem is similar: in additive manufacturing, the parts should fulfill the plate of the machine as much as possible, when in the machining, it will be needed to pay attention to the path of the tool and clearance between consecutive parts allowing the best tool trajectory. Moreover, it is easier to deal with nesting in additive manufacturing than in machining, because machining is more sensitive to the thickness of parts. The optimization of isolated parts production through greater integration between CAD and CAM has also been the subject of investigation [33]. Simulation has also been used to try to create models that allow the grouping of parts to be machined [34, 35]. The principles do not differ markedly from others used in the assembly lines [36], but they do not fully integrate the needs considered as main requirements in the problem now formulated. A very deep review of the literature revealed that there is a clear gap in this matter, which justified the accomplishment of this work.

3. Methodology

First of all, it is necessary that the designers of dies are aware that this tool will be used, taking the necessary care to standardize the thickness of the components as much as possible, so that the process can later be more easily streamlined.

After the development and design of the die have been approved for production by the customer, directly from the software, a list of all parts to be machined can be extracted. Depending on the tool size and complexity, they could be a few hundred. This list of materials provided in MS Excel® file will support the acquisition of the raw materials for machining, as well as the production planning for each CNC milling machine, establishing the priority elements to be machined, among other important features to produce the die. Figure 1 presents an example of a dies' components list.

COMPONENTS LIST

Desig.				Customer				Project
Dim.s	2490x1430x595mm			Band width	577			Step
Part		Step Nº	21	Internal Ref.	275			Thickness
	Priority	High	Medium	Minimal	TOOL/DIE Nº 275			
N.º	Designation	Dimensions (mm) X	Y	Z	Material	Qt	Gross Wheight (kg)	TT
1000	INF_PLATE	2490	1230	94	1.0570	1	2260	
1050	CUTTING DIE	106.5	40	35	1.2379	1	1.2	57~59HRc
1051	CUTTING DIE	21.9	34	20	1.2379	3	.1	57~59HRc
1054	CUTTING DIE	74.5	288.5	35	1.2379	1	5.9	57~59HRc
1055	CUTTING DIE	59.5	305	35	1.2379	1	5	57~59HRc
1056	CUTTING DIE	74.5	288.5	35	1.2379	1	5.9	57~59HRc
1057	CUTTING DIE	55.5	107.5	35	1.2379	1	1.6	57~59HRc
1058	CUTTING DIE	107.5	76	35	1.2379	1	2.2	57~59HRc
1310	STRIPPER PAD	30	25	16	1.1191	2	.1	
1312	STRIPPER PAD	19.5	23	42	1.1191	2	.1	

Figure 1. Components list regarding a specific die 275

This list contains all components that need to be machined, being assigned to the various existing equipment. Some of the parts need to be subjected to external subcontracted heat treatment (usually quenching and nitriding). The execution priority of components in production is defined in this list by the following color coding:

- Red: used for critical elements that are needed first in bench assembling, which have the longest production time in a given sector or go through several sectors;
- Orange: used for elements that have an average execution time, and which are required only at a final stage of the assembly process and workbench;
- Yellow: used for non-critical elements, which do not condition the due date of the first tryout.

After analyzing several lists of previously executed dies, various machining similarities could be found among the various components of the die, as follows:

1. Type of part and its functionality in the tool;
2. Type of base material;
3. Thickness or height of the part.

By filtering the MS Excel® file in the list of components for each of the above features, commonalities can be found, as can be seen in Figures 2 and 3.

By analyzing the images of the previous list, it can be realized that for the same type of tool elements,

COMPONENTS LIST

Desig.		Customer		Project	XPTO
Dim.s	2490x1430x595mm	Band width	577	Step	107mm
Part	Step Nº 21	Internal Ref.	275	Thickness	0.75mm

Priority: High | Medium | Minimal — TOOL/DIE Nº 275

N.º	Designation	Dimensions (mm) X	Y	Z	Material	Qt	Gross Wheight (kg)	TT	Liquid wheight (kg)
2613	PRESSER FOOT	85	155	22	1.2738	1	2.3	Nitruration	1.94
2614	PRESSER FOOT	85	155	22	1.2738	1	2.3	Nitruration	1.94
2615	PRESSER FOOT	156.5	131	22	1.2738	1	3.5	Nitruration	3
2616	PRESSER FOOT	156.5	337.5	22	1.2738	1	9.1	Nitruration	8.27
2617	PRESSER FOOT	156.5	126	22	1.2738	1	3.4	Nitruration	3.01
2618	PRESSER FOOT	52	150	22	1.2738	1	1.3	Nitruration	1.03
2619	PRESSER FOOT	52	155	22	1.2738	1	1.4	Nitruration	1.08
2620	PRESSER FOOT	118	46.5	22	1.2738	1	.9	Nitruration	0.78
2621	PRESSER FOOT	105	187	22	1.2738	1	3.4	Nitruration	3.04
2622	PRESSER FOOT	97	95	22	1.2738	1	1.6	Nitruration	1.35
2623	PRESSER FOOT	105	192	22	1.2738	1	3.5	Nitruration	3.13
2624	PRESSER FOOT	118	46.5	22	1.2738	1	.9	Nitruration	0.78

Figure 2. Presser foot components list for specific die 275

COMPONENTS LIST

Desig.		Customer		Project	XPTO
Dim.s	2490x1430x595mm	Band width	577	Step	107mm
Part	Step Nº 21	Internal Ref.	275	Thickness	0.75mm

Priority: High | Medium | Minimal — TOOL/DIE Nº 275

N.º	Designation	Dimensions (mm) X	Y	Z	Material	Qt	Gross Wheight (kg)	TT	Liquid wheight (kg)
1050	CUTTING DIE	106.5	40	35	1.2379	1	1.2	57~59HRc	0.92
1051	CUTTING DIE	21.9	34	20	1.2379	3	.1	57~59HRc	0.09
1054	CUTTING DIE	74.5	288.5	35	1.2379	1	5.9	57~59HRc	5.11
1055	CUTTING DIE	59.5	305	35	1.2379	1	5	57~59HRc	4.31
1056	CUTTING DIE	74.5	288.5	35	1.2379	1	5.9	57~59HRc	5.03
1057	CUTTING DIE	55.5	107.5	35	1.2379	1	1.6	57~59HRc	1.34
1058	CUTTING DIE	107.5	76	35	1.2379	1	2.2	57~59HRc	1.84
1059	CUTTING DIE	106.5	40	35	1.2379	1	1.2	57~59HRc	0.92

Figure 3. Cutting dies components list for specific die 275

there are a lot of these elements which use the same base material and thickness, as shown below:

- Cutting dies: 1.2379 steel as raw material, all the same thickness, usually 35 mm;
- Stripper pads: 1.1191 steel as raw material, have different thicknesses, but several components with the same thickness;
- Punch holder: 1.1191 steel as raw material, all of the same thickness, and typically with 35 mm;
- Scale guide: 1.2738 steel as raw material, all of the same thickness and usually with 18 mm;
- Presser foot: 1.2738 steel as raw material, all the same thickness and usually with 22 mm.

Thus, the novel methodology intends to group these parts with the main objective of increasing the machining time per program, thus reducing the setup time of the equipment and operator. The strategy is based on the selection of parts made of the same material and using the same raw material thickness (Z dimension), being these parts machined from the minimum number of raw material blocks necessary for each thickness. The CAM operator selects the components as previous conditions and organizes their disposition to decrease the raw material waste. The novelty of this approach relies in the following principles: (a) The machining process assumes cutting in contour, creating with the cutting process the shape of the part needed, thus, the part is not machined as a unique part, but being integrated in a series of parts having different shapes, but the same thickness (or similar, being adjusted by a further short operation); (b) The blocks are not purchased as a single block, but as a whole, avoiding to pay to the supplier cuts that can be made in a better way into the company; (c) A nesting software can be used to optimize the use of each plate, thus, the cutting process cuts the different parts from the plate in a near final shape and can produce two faces in each cut, because the milling tool will be removing the material between two consecutive parts in the same plate; (d) The execution of continuous tasks in the same CNC milling machine will help the production scheduling to plan activities those can be performed out of the usual working hours, increasing a lot the availability of the equipment and allowing to operate 24 hours over 24 hours, but having just one shift of collaborators, who can put the CNC machines working before the working day charged enough to work during the 16 hours between working days. This will depend on the production planning and control, trying to optimize the machining times within and without the collaborators working time. The accommodation of the parts made by the nesting software ("Define the group layout" in the flowchart of Figure 4), not only allows to avoid material waste but also allows to adjust the interval/clearance between parts, so that the same milling tool can work more consecutively, minimizing tool changes. This working methodology was not presented before in the literature and can be followed regarding the production of other products, namely in wood, for the furniture industry, among others.

The flowchart of the production process after launching the tool components list is illustrated in Figure 4. The first two decision blocks of the flowchart are made automatically. Using a home-made VBA application, the MS Excel® application will collect the BOM (Bill of Materials) of the complete stamping tool/die and will organize first the information as described in Figures 2 and 3, and taking also into attention the information presented in Table 1, will allocate the different parts to one or more plates of the same material and thickness, allowing the use of the nesting program to optimize their distribution into the plate, simplifying by this way the planning operation at the Production Planning and Control office. This will give rise to a list of plates to be purchased, which will allow the production of the groups of parts previously planned. Each of these plates will be clamped to the CNC milling machine and, with the help of the CAM software, an estimation of the machining time will be achieved, allowing to clamp plates able to be worked all-time between two shifts corresponding to two consecutive working days (about 15.5 hours), do not need the assistance of the operator during this time.

4. Results

The previously mentioned methodology was applied to the production of two different dies, one more complex and the other less complex, with a view to analyzing the feasibility of the application, validating the methodology, and analyzing the results. Thus, two dies were defined, one with manufacturing code 298, which is more complex, and the other with code 281, which is less complex, that is, a die with fewer components. This double-check made it possible to assess whether the model would apply only to more complex dies, or whether it could be taken as a more generic model, with a broader application. The first case study presents a part to be produced in a progressive tool within14 steps having the reference

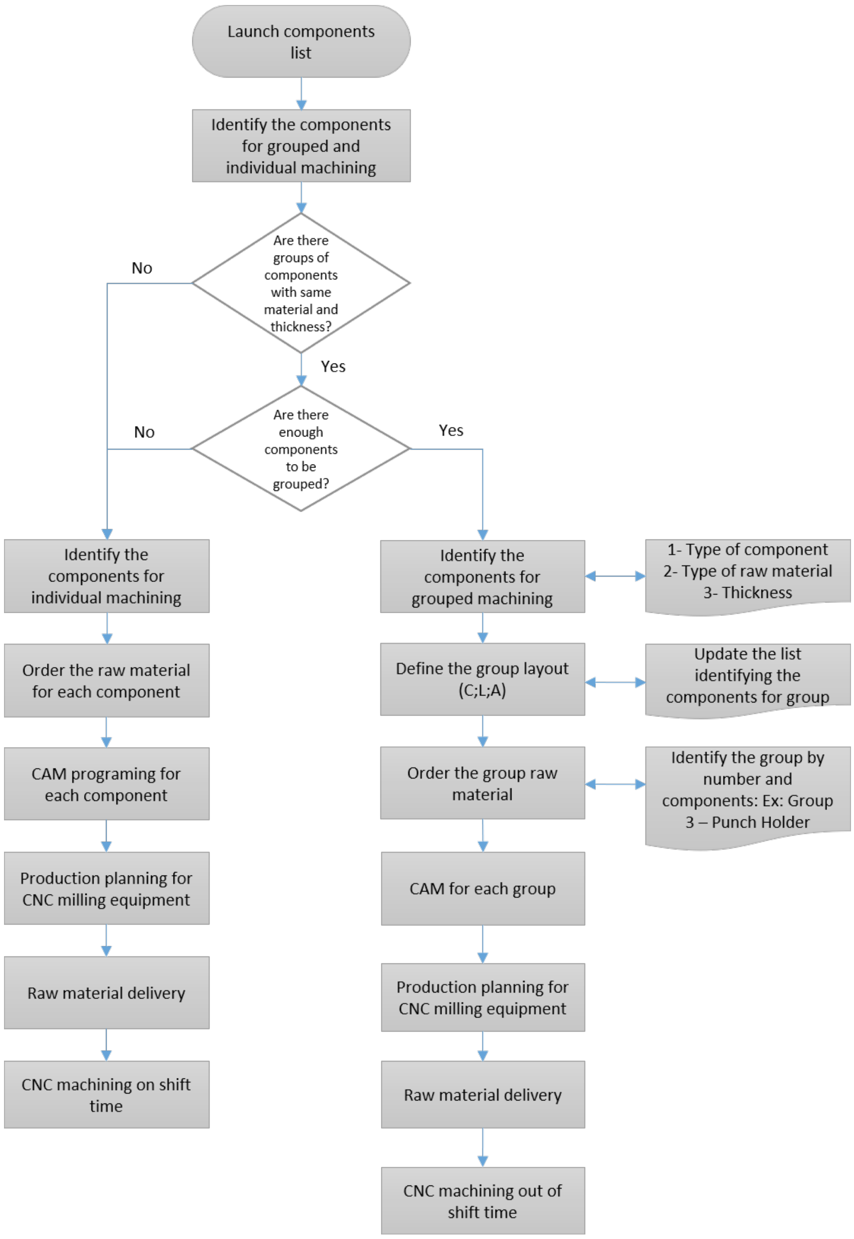


Figure 4. Production flowchart after releasing the components list of the sheet metal cutting and forming die

298. The raw material of the part is the DC01 steel and the thickness is 1 mm. This part connects the parabolic antenna to the frame pipe. In Figure 5, it is possible to see the final product.

Regarding this tool, it was possible to group 27 components for machining in 6 different groups as can be seen in Table 1, taking into account the Z thickness.

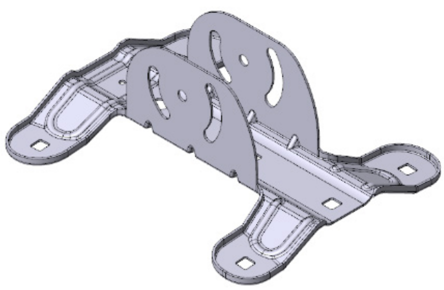


Figure 5. Parabolic antenna assembly holder

Table 1. Times and cost regarding the individual machining of parts for die 298

No.	DESIGNATION	X (mm)	Y (mm)	Z (mm)	RAW MATERIAL	NOTES	CNC (min)	SETUP (min)	ACCOUNT UNITS
1002	CRT STRIPPER	156	226	37	1.2379	GROUP 1	92	15	61
1003	CRT STRIPPER	143	70	37	1.2379	GROUP 1	39	15	23
1004	CRT STRIPPER	143	70	37	1.2379	GROUP 1	39	15	23
1005	CRT STRIPPER	162	110	37	1.2379	GROUP 1	48	15	35
1006	CRT STRIPPER	162	110	37	1.2379	GROUP 1	48	15	35
1007	EST STRIPPER	33	49	37	1.2379	GROUP 1	21	15	10
1008	EST STRIPPER	33	49	37	1.2379	GROUP 1	21	15	10
1014	LIFT	99	25	98	1.2378	GROUP 4	125	15	8
1024	LIFT	119	29	98	1.2378	GROUP 4	125	15	9
1034	LIFT	119	21	98	1.2378	GROUP 4	125	15	9
1601	SCALE GUIDE	360	55	17	1.2378	GROUP 5	35	15	16
1602	SCALE GUIDE	360	55	17	1.2378	GROUP 5	35	15	16
1604	SCALE GUIDE	169	58	17	1.2378	GROUP 5	19	15	10
1605	SCALE GUIDE	169	58	17	1.2378	GROUP 5	19	15	10
2029	PRT PUNCH	76	110	27	1.2378	GROUP 2	25	15	11
2030	PRT PUNCH	50	79	27	1.2378	GROUP 2	25	15	9
2031	PRT PUNCH	66	168	27	1.2378	GROUP 2	27	15	13
2032	PRT PUNCH	146	223	27	1.2378	GROUP 2	32	15	25
2033	PRT PUNCH	171	111	27	1.2378	GROUP 2	19	15	17
2034	PRT PUNCH	171	111	27	1.2378	GROUP 2	19	15	17
2035	PRT PUNCH	144	83	27	1.2378	GROUP 2	29	15	13
2036	PRT PUNCH	144	83	27	1.2378	GROUP 2	29	15	13
2048	PRT PUNCH	38	126	27	1.2378	GROUP 2	18	15	9
2600	PRESSER FOOT	300	149	17	1.2378	GROUP 6	44	15	26
2601	PRESSER FOOT	320	149	17	1.2378	GROUP 6	49	15	26
2604	PRESSER FOOT	149.6	122.3	20	1.2378	GROUP 3	39	15	14
2605	PRESSER FOOT	149.6	122.3	20	1.2378	GROUP 3	39	15	14
						TOTAL	1185	405	482

Table 2 depicts the setup and machining time of these components for each of the six groups defined.

Table 3 presents the layouts with the distribution of components on the board to be machined.

Table 2. Times and costs for machining groups regarding die 298

DESIGNATION	RAW MATERIAL	X (mm)	Y (mm)	Z (mm)	No. PARTS	SETUP (min)	MACHINING (min)	ACCOUNT UNITS
GROUP 1	1.2379	535	232	47	7	15	315	187
GROUP 2	1.2738	614	281	37	9	15	198	122
GROUP 3	1.2738	265	150	25	2	15	68	14
GROUP 4	1.2738	119	115	108	3	15	373	32
GROUP 5	1.2738	540	126	27	4	15	90	39
GROUP 6	1.2738	320	318	27	2	15	89	51
				TOTAL	27	90	1133	445

Table 3. Group layout of the components to be machined regarding die 298

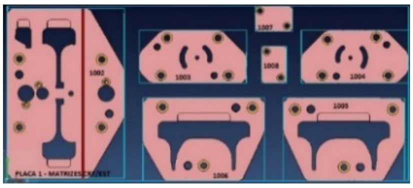
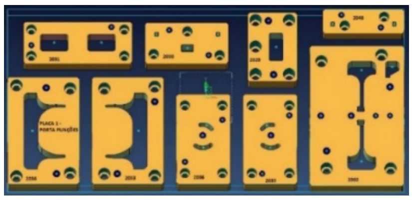
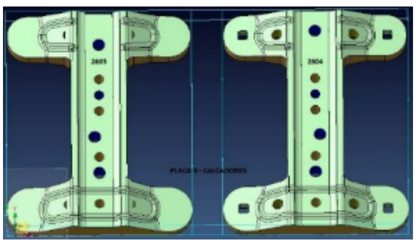
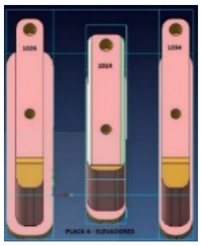
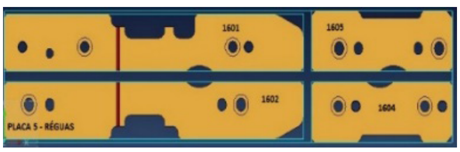
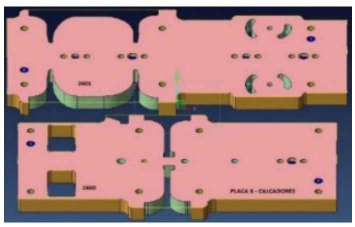
GROUP	LAYOUT	GROUP	LAYOUT
GROUP 1		GROUP 2	
GROUP 3		GROUP 4	
GROUP 5		GROUP 6	

Figure 6 shows a graph whit the profitability achieved in the machining of the grouped elements in relation to their individual machining.

Table 4 presents the time and cost reduction for the machining of the grouped components. For an average cost per hour of production for the CNC milling machines of 40 account units, and also considering the saving in the acquisition of the raw material, the gain achieved was 1.84% of the total machining costs for this tool.

The second case study presents a part to be produced in a progressive tool within14 steps having the reference 281. The raw material of the part is aluminum alloy and the thickness is 2 mm. This part supports an electronic device of an auto-radio. In Figure 7, it is possible to see the final product.

For this tool, it was possible to group for machining 27 components in 4 distinct groups as can be seen in Table 5.

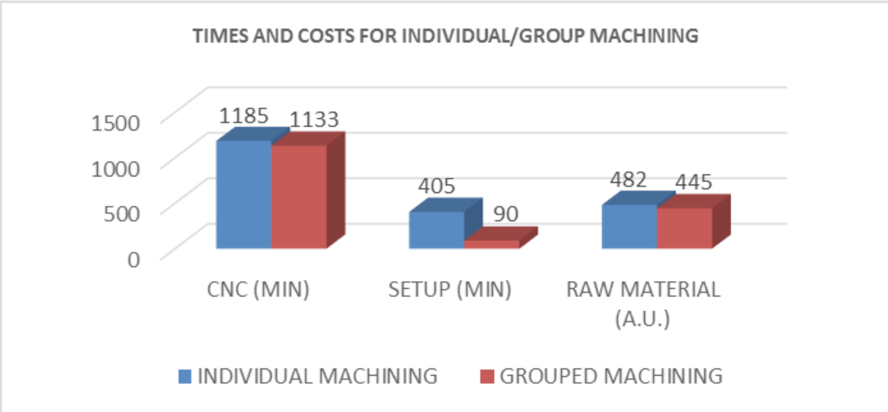


Figure 6. Times and cost for individual and grouped machining of the components regarding die 298. The raw material cost is in arbitrary units, due to confidentiality reasons imposed by the company that has supported this work

Table 4. Savings obtained through the utilization of grouping methodology in die 298 components production

	TIME (min)	MONETARY ACCOUNT UNITS
SETUP TIME REDUCTION	315	210
MACHINING TIME REDUCTION	52	34.66
RAW MATERIAL COST REDUCTION		37
	TOTAL	281.66

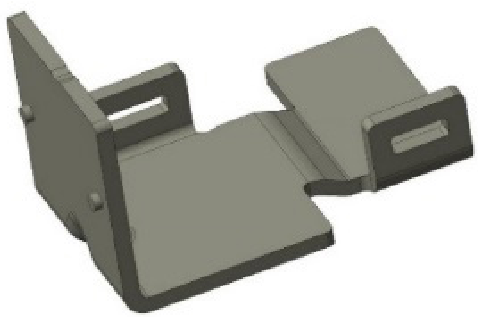


Figure 7. Electronic support part for auto-radio

Table 5. Times and cost for individual machining of the components regarding die 281

No.	DESIGNATION	X (mm)	Y (mm)	Z (mm)	RAW MATERIAL	NOTES	SETUP (min)	CNC (min)	ACCOUNT UNITS
2603	PRESSER FOOT	122	89.5	22	1.2738	GROUP 1	15	40	10
2604	PRESSER FOOT	88	82.5	22	1.2738	GROUP 1	15	36	10
2605	PRESSER FOOT	122	99.5	22	1.2738	GROUP 1	15	38	10
2606	PRESSER FOOT	98.2	73.5	22	1.2738	GROUP 1	15	33	10
2607	PRESSER FOOT	177	67	22	1.2738	GROUP 1	15	52	10
2608	PRESSER FOOT	171.5	66	22	1.2738	GROUP 1	15	52	10
2609	PRESSER FOOT	25.2	23	22	1.2738	GROUP 1	15	18	10
1602	SCALE GUIDE	251	17	18	1.2738	GROUP 2	15	14	10
1603	SCALE GUIDE	36	41	18	1.2738	GROUP 2	15	11	10
1604	SCALE GUIDE	68	36	18	1.2738	GROUP 2	15	14	10
1605	SCALE GUIDE	83.5	46	18	1.2738	GROUP 2	15	15	10
1608	SCALE GUIDE	192	36	18	1.2738	GROUP 2	15	19	10
1609	SCALE GUIDE	200	36	18	1.2738	GROUP 2	15	18	10
1610	SCALE GUIDE	177	36	18	1.2738	GROUP 2	15	20	10
2300	PRT PUNCH	54	63	35	1.1191	GROUP 3	15	17	10
2301	PRT PUNCH	54	73	35	1.1191	GROUP 3	15	18	10
2303	PRT PUNCH	83	134	35	1.1191	GROUP 3	15	28	10
2304	PRT PUNCH	67	134	35	1.1191	GROUP 3	15	27	10
2305	PRT PUNCH	42	61	35	1.1191	GROUP 3	15	15	10
2306	PRT PUNCH	105	52.5	35	1.1191	GROUP 3	15	22	10
2307	PRT PUNCH	79	49	35	1.1191	GROUP 3	15	18	10
1050	CRT STRIPPER	48	63	35	1.2379	GROUP 4	15	21	10
1052	CRT STRIPPER	35	51	35	1.2379	GROUP 4	15	17	10
1053	CRT STRIPPER	83	134	35	1.2379	GROUP 4	15	36	17
1054	CRT STRIPPER	95	51.5	35	1.2379	GROUP 4	15	26	10
1101	CRT STRIPPER	58	30	35	1.2379	GROUP 4	15	18	10
1103	CRT STRIPPER	29	26.5	35	1.2379	GROUP 4	15	13	17
						TOTAL	405	656	248

Table 6 presents the machining and setup time of these components for each one of the four groups defined.

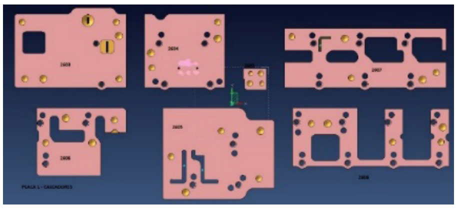
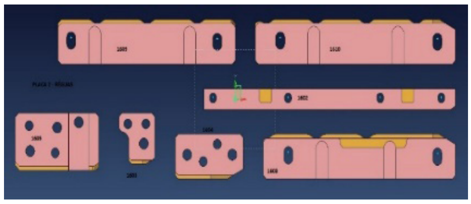
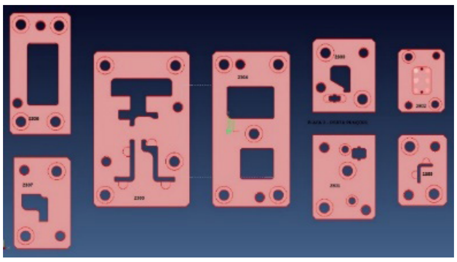
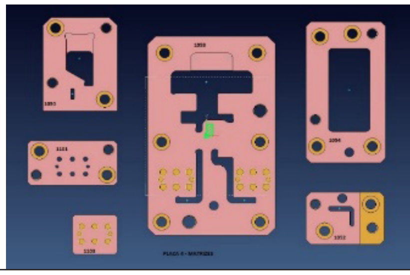
Table 7 presents the layouts with the distribution components in each plate to be machined.

Figure 8 depicts a graph, which shows the profitability achieved in the machining of the grouped elements in relation to their individual machining.

Table 6. Times and costs for machining groups regarding die 281

DESIGNATION	RAW MATERIAL	X (mm)	Y (mm)	Z (mm)	No. PARTS	CNC (min)	SETUP (min)	ACCOUNT UNITS
GROUP 1	1.2738	476	209	37	7	270	15	70
GROUP 2	1.2738	440	129	33	7	120	15	40
GROUP 3	1.1191	380	204	50	7	85	15	40
GROUP 4	1.2379	233	160	50	6	75	15	74
				TOTAL	27	550	60	224

Table 7. Plate layout of the components to be machined regarding die 298

PLATE	LAYOUT	PLATE	LAYOUT
GROUP 1		GROUP 2	
GROUP 3		GROUP 4	

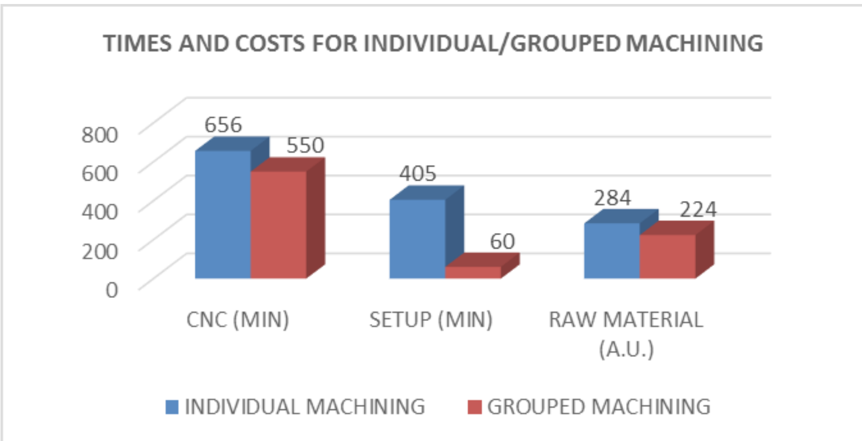


Figure 8. Times and cost for individual and grouped machining of the components regarding die 281

Table 8 shows the time and cost reduction obtained for the machining of the grouped components. For a medium-hour cost production of the CNC milling machines of 40 account units, plus the lower acquisition price of the raw material, the gain achieved in this model was 3.68% of the total machining costs for this die.

After analyzing the results taking into account different tools, and concerning the reduction of machining and setup times, it can be concluded that the machining of grouped components for sheet metal cutting and forming dies is a favorable process and it presents time profitability and reduction of production costs. It is in drastically reducing setup times that it is possible to observe the greatest advantage. With the machining of grouped components, it was possible to reduce the machining time for each setup, freeing the operators' labor for operating other CNC machines. In relation to the small savings in the cost of the raw material, this will always exist because the cutting cost of a steel plate for the machining of grouped elements will always be lower than the cost of several cuts for individual machining. Also, the more optimized the layout of the parts on the plate, the greater will be the benefit in the purchase.

Table 9 and Figure 9 show the improvement in OEE indicators which increased by an average of 21%, referring to the increased availability of the equipment (4 CNC three-axis machines) regarding this new machining model, relieves the worker of constantly assembling and disassembling parts on the machine table and monitoring production operations, which, being short, prevent the worker from being able to monitor equipment without losing effective productivity of each equipment.

Table 8. Savings obtained through the utilization of grouping methodology in die 281 components production

	TIME (min)	ACCOUNT UNITS
SETUP TIME REDUCTION	345	201.25
MACHINING TIME REDUCTION	106	70.66
RAW MATERIAL COST REDUCTION		60
	TOTAL	331.91

Table 9. OEE indicator before and after the model implementation

EQUIPMENT	AVAILABILITY (%)		PRODUCTIVITY (%)		QUALITY (%)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
CNC1	57.3	79.4	94.9	96.6	93.7	96.1
CNC2	62.9	83.4	95.0	96.7	94.1	96.3
CNC3	66.1	86.2	94.7	97.9	93.7	97.8
CNC4	72.9	86.3	96.3	98.1	95.7	98.0

5. Discussion

After intense searches in the literature, the dealt problem in this work does not have any previously established solution/model that allows its easy resolution. In fact, it is intended that the solution to the problem described is as simple as possible, for easy application in SMEs. Chan et al. [35] and oh et al. [32] have dealt with partially similar problems but following other restrictions. Thus, their models cannot be easily applied to the current problem, because the assumptions of this problem are different from the restriction present in other works, like [32, 35]. Indeed, the restrictions presented by this work are (a) the parts are made of the same material; (b) the parts possess similar thickness; (c) the parts complete as much as possible the area of the machine worktable; (d) the clearance between parts to be as identical as possible, in order to permit the separation of the parts in a single path. These conditions are not complied with by any of the models/methodologies presented so far. Thus, the development of this new methodology intends to fulfill that gap.

The methodology now developed presents savings of 1.84% and 3.64% on the total machining costs regarding the two examples used to validate the model. Also, the availability of the equipment increased a lot, rising the OEE (Overall Equipment Effectiveness) indicator by 21% for all equipment's, on average. The percentage of savings may appear to be small but, given that the commercial yields usually does not exceed 15% in this type of products,

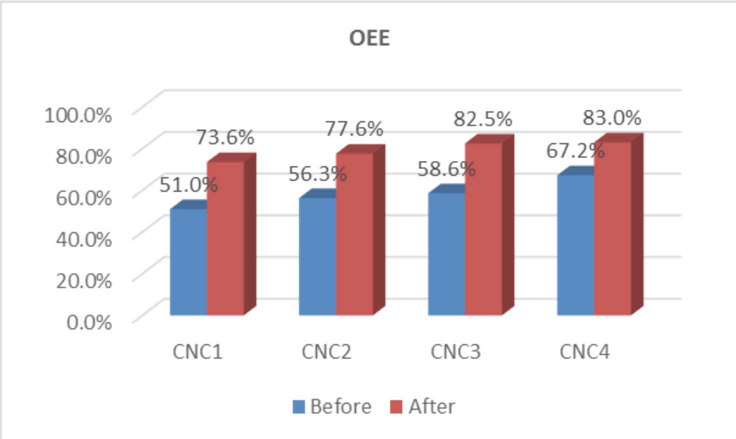


Figure 9. OEE indicator before and after the model implement

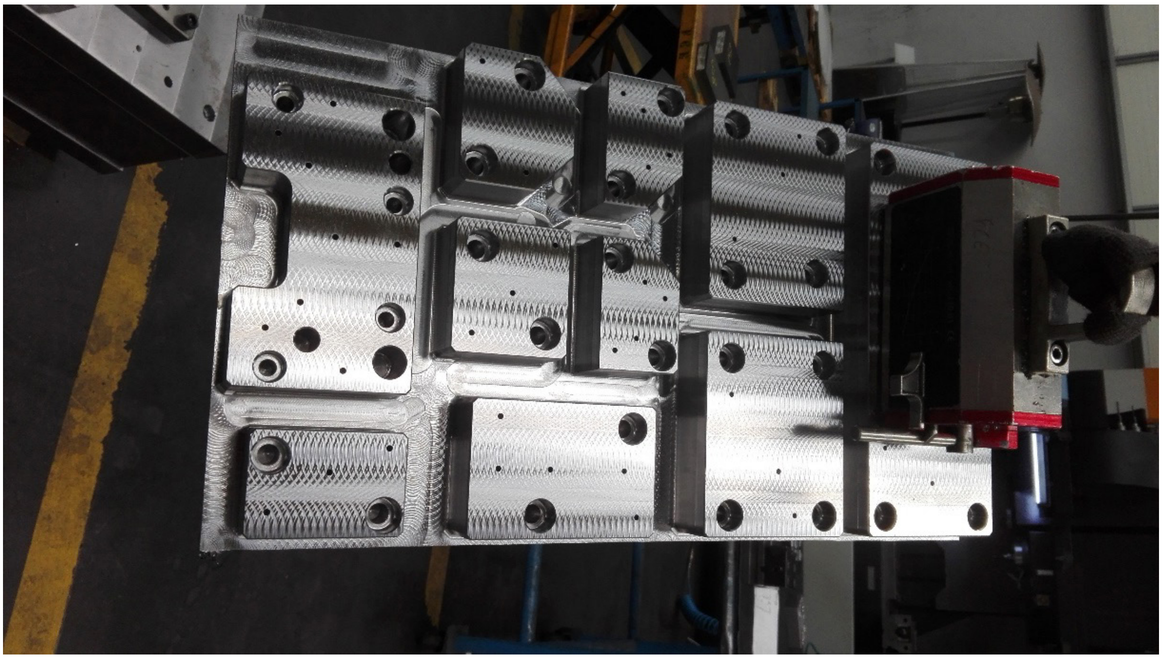


Figure 10. Group machining example

you can consider a very satisfactory gain, given that it allows gain between 10% and 20% of the gross profit yield of the product. The gains in terms of OEE are also not as significant as those achieved in other works developed in other types of industry, however, it is better than that achieved by Moreira et al. [17] in the printing industry, and similar to that achieved by Guariente et al. [37] (8%), although it is lower than those obtained by Antoniolli et al. [38] (16%), Pereira et al. [39] (15%) or Dias et al. [40] (21%), although these works were developed in the automotive industry, which is usually more competitive, but also where there are more effective techniques for eliminating redundancies. On the other hand, efficiency gains were not as high as those achieved by Kumar et al. [22] (32%), since the scope of the improvements introduced in the case of the present work does not include the optimization of jigs, due to the unique character of the parts required for each tool. However, as in the work presented by Costa et al. [21], the process has been significantly improved, leading to learning that can be taken into account in many other works developed.

6. Conclusions

The work here presented brings a new approach to machining planning operations, brings as a main novelty to take advantage of nesting computer applications and apply than in a new methodology able to group the parts with equal or similar thickness and made of the same material, to avoid the purchase of individual blocks of raw materials already cut, a practice very usual in the metalworking industry. Grouping the parts, the approach to the raw material purchase and machining planning can be significantly different, allowing important savings, which can make the difference in when budgeting is provided regarding a stamping tool. The novel approach allows getting the more quantity possible of parts from the same plate of material, which should fit as much as possible the useful area of the CNC machine worktable, prolonging the machining time and allowing to get the advantage of extended CNC programs that can run out of the usual working hours, allowing to make the equipment more profitable, reducing lead-times and making products more competitive. These factors can make a difference in terms of competitiveness in the market. Through the implementation of this machining model, it is possible to increase the sustainability and growth of the organizations. The main advantages can be summarized as follows:

- Easier production planning by grouping components for machining;
- Machining time is much higher, passing from the usual 8 working hours to 24 hours of service, allowing to make effective the CNC equipment over time, or if the machining occurs during the normal working schedule, relieves the operator to other functions;
- Dramatic reduction of setup times;
- Decreased likelihood of errors associated with CAM programming and setup. It will be more difficult to produce and do not detect eventual programming errors;
- Increased productivity and availability of the equipment, reducing the lead-times and shortening the delivery of the tools to the customers;
- Savings in raw materials consumption by reducing the individual cuts of each component by the supplier, making by this way the process more sustainable;
- The process is more sustainable, economically, and environmentally;
- Reduced purchased time of the raw materials because the previous cutting process usually performed in the supplier is excused.

Thus, applying this new machining planning methodology in the production of cutting and stamping dies, it is possible to reduce machining costs up to 5%, as well as increase the equipment availability, consequently, making the product more competitive, reducing the lead-time and improving the production capacity.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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