DEVELOPMENT OF A METHODOLOGY BASED ON A GENERATIVE SYSTEM FOR A CAD/CAPP/CAM SOFTWARE IN MACHINING $2^{1/2}$D

Hugo Marcelo Bezerra de Carvalho
Renault do Brasil – Av. Renault, 1300 – Borda do Campo – CEP 83070-900
hugombc@hotmail.com

Osíris Canciglieri Junior
Pontífica Universidade Católica do Paraná (PUCPR) – Laboratório de Automação e Sistemas (LAS) – Av. Imaculada Conceição,1155 – Prado Velho – CEP 80215-030
Osiris.canciglieri@pucpr.br

Abstract. *Nowadays, the Computer-Aided Process Plan (CAPP) is one of the tools that are used to define the CNC program, the optimal sequencing of manufacturing processes and the time reduction between the design and the production. CAPP is used to analyse the size, the shape and the location of geometric features in the part and translate these information into manufacturing operations instructions to convert a rough part to a finished one. This work aims the development of a CAPP methodology based on the graph theory for recognition of machining features to optimise the process sequence. Through this methodology it will be possible to define the manufacturing operations and the sequencing of machining 2 ½_D.*

Keywords: *CAD, CAPP, CAM, Machining, feature recognition*

1. Introduction

Process planning can be define as converting engineering drafts/3D model into manufacturing instructions that will give information about operations, machines that will be used, tools, cutting parameters and inspections details. Sadaiah et al.(2002).

Today, more and more companies have been searching the reduction of the time and the costs of machining of their products. In these companies there is a manufacturing engineer or a technician that is responsible to define the process planning. The process planning demands a lot of hours what increases the costs of the new part. The companies can buy the CAD/CAPP/CAM software, but they will need that the engineer/technician determinate how will be the machining planning, the tool path, the kind of tools, the cutting parameters and the type of the process. In machining 2 ½_D is possible to use the following machining process: milling, reaming, drilling, tapping and chamfering.

In general, the engineer/technician spent their time tin three items:

- Searching the data;
- Taking decisions;
- Preparing the documentations.

Statistically, 15% of the time of planning a new part is dedicated to technical decisions, while the other 85% is dedicated to acquire data, calculation and documentation which are repetitive work and can be done by computer. Thomas & Fischer (1996), Younis &Wahad (1997) apud Andrade (2001).

There are two kinds of process plan activities. One is a lean manufacturing, where does not have lots of modification between the part that has been machined and a new one. In this case the tools and the machining planning are basically the same as the machined part and there is the necessity of doing an enormous amount of part. In the other process plan a few part are done and generally not more than 3 machines are used to achieve the finished part. In this case, there is the necessity, almost daily, of planning a new part. One example is the cast industry.

The researches in Computer-Aided Planning Process (CAPP) started around 1960. During the decade of 1990, the Computer-Aided Design (CAD) and the CAPP have emerged as an effective means to improve productivity and efficiency, resulting in a widespread of researches works related to CAD and CAPP integration, hoping to achieve a data seamless, flowing among relevant computer systems. Lau el al. (2004).

Nowadays, there are three basic approaches in Computer-Aided Process Planning: Variant, Generative and Hybrid. Liu at al. (1999) and Chu et al. (2000). The difference among these methods is that the variant system helps the activities of the process planning and the new part is compared to a similar part that has been machined giving the data to machining the new one, while the generative system makes the process planning without comparison, following a logical procedure. The hybrid system uses both methodologies. Some authors like Xiang et al. (2002) consider that are only two systems: the variant and the generative. The majority of CAPP software use the variant system.

This work is an attempt to define a new methodology for a generative CAPP system. It is based on the graph theory for recognition of machining feature, reduction of the time of process planning of a new part and the interference of the process planner.

2. Methodology

Computer Systems such as Computer-Aided design (CAD) and Computer-Aided Process Planning (CAPP) are classified as automation islands and it is important that they can be linked to achieve the information exchange without taking on consideration their dissimilar format that are used by the various systems. Lau et al. (2004). The development of CAPP system consists in a module of feature recognition, modules for selecting machines, tools, machining parameters, a module of optimization of cutting conditions and tool path, and a module of CN generation. The development of a CAPP system is based on the CAD system. There are two kind of CAD system, one is based in feature and the other does not have feature, so the difference between them can be the program that generates the features. An example of CAPP system based on CAD system is described in Gao et al. (2004). The figure 1a and 1b, show the difference the CAPP system when it has an interface with the CAD system not based on feature and based on feature.

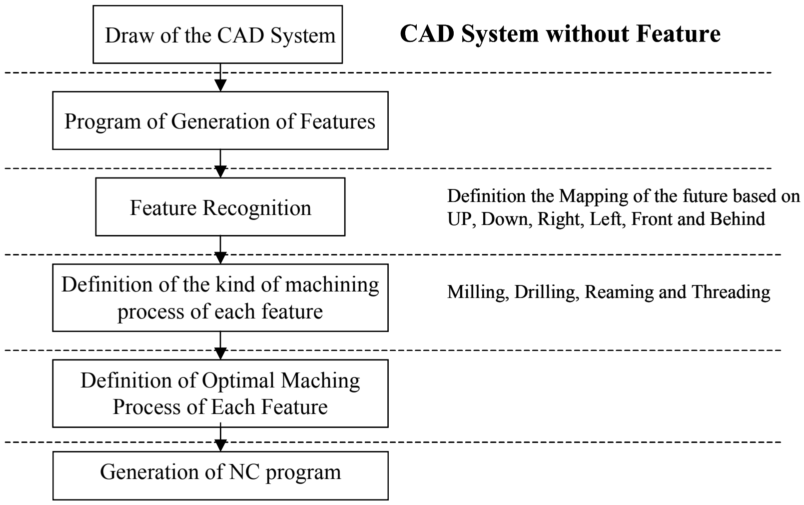

Figure 1a. Schematic Diagrams of CAPP System in related to CAD System without features.

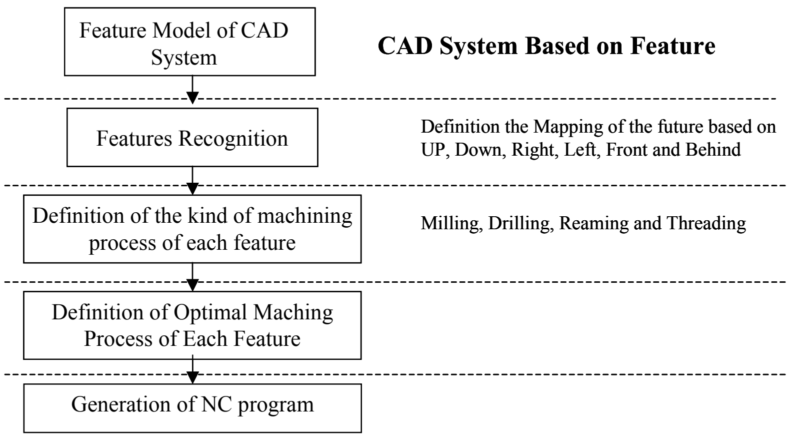

Figure 01b. Schematic Diagrams of CAPP System in related to CAD System based on feature.

In this work, the CAPP system takes on consideration the CAD system not based on feature when it gets information about size, points, edges and polygons of the rough and the finished part. After, the CAPP system creates the features that will be removed during the machining. The recognition of the machining features is made in sequence and the type of process machining is chosen to each feature or group of features through the tool path to the milling process and optimal cutting condition to drilling, reaming and tapping process. Finally, the CAPP system creates the NC program of the part relates to the machining process option.

2.1 Feature Recognition and Location of the Features

One of the major difficulties in extracting machining features is the lack of a systematic methodology to generate alternative ways to manufacture a machined part, Lee and Kim (1999). To implement an efficient methodology, this work has divided the part in 6 regions: Up, Down, Rigth, Left, Front and Behind “Fig. 1”. Then, the part will be machined up to 6 setups, one setup to each region. The part division makes an efficient feature recognition because is possible to define the location of the feature in any region.

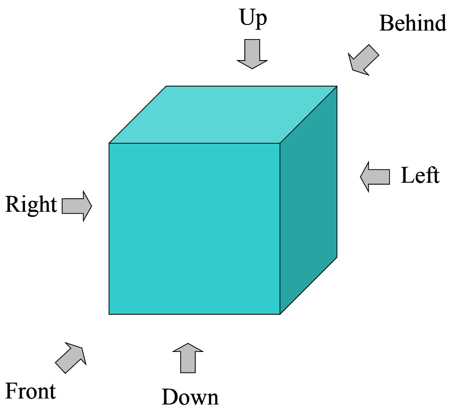

Figure 01. Schema of the division of a part

The feature location is identified using graph theory, where each feature is made of the polygons, each polygons is made of edges, and each edge is made of points, “fig. 2”.

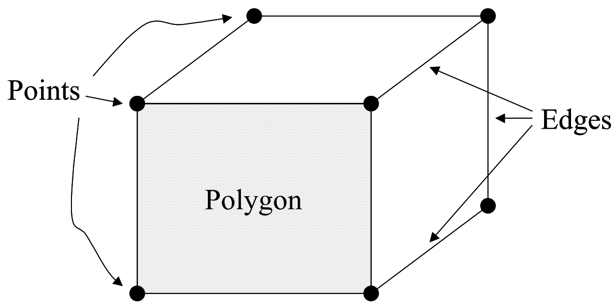

Figure 2. Definition of polygons, edges and points in a feature

An example of construction of the graph is shown in “figure 2”. In this example we can see that there are a lot of possibilities to machining a piece. “Figure 03”.

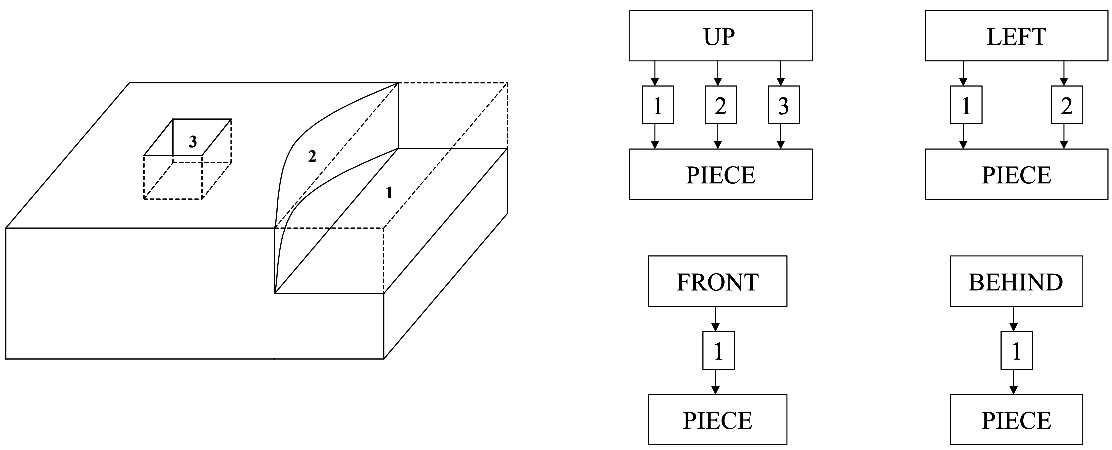

Figure 03. Na example of graph construction

After the construction of the graph, “fig. 3”, it’s possible to verify that the machining part can be divided in the following planning:

1. Machining feature 1,2,3 with UP setup;
2. Machining feature 1 with Front setup and feature 2 and 3 with UP setup;
3. Machining feature 1 with Behind setup and feature 2 and 3 with UP setup;
4. Machining feature 1 with Left setup and Feature 2 and 3 with UP setup.

In the planning 4, it isn’t possible machining the feature 2 with Left setup because in this work the analysis is to 2 $^{1/2}$D machining. After the analysis of the 4 setups, the feature recognition is defined, and the best planning can be find relating to the time of machining and the roughness of the part. The definition of the best process plan depends on the tool path and optimal cutting condition.

If the best setup is started with Left reference, it will be put in the machine with the Left face in UP position, because of this, it is possible machining all features with Left face in UP position. The machining planning option is defined for minimum number of setups.

2.2 Definition of the type of machining process

The kind of machining process of each machining feature or for a group of machining feature depends on where the feature is located. In this way, it is possible to classify the machining features related to the operation process. The rule for how the features are machined is described in “table 1”. The processes used in this work were milling, drilling, tapping, or reaming.

The “table 1” demonstrates the rule for the location of the feature. This rule is find through the parent tests, that make possible to know if the feature is son of UP, Down, Right, Left, Front and Behind. The answer can be 1 if the feature is son; 0 - if the feature is not a son; and x, if it is not important to do the test. Then, the feature can be machined with different process. In the table 1, we can see that the milling process is the most important machining process in the $2^{1/2}$D machining. It is defined without any test in 50 location of the feature in the part. The others machining processes are defined in others 9 location of feature. So, this methodology can define a smaller number of setup to machining the part and the type of machining that each feature or group of feature will be removed.

However, there are others tests to find the real operation process when the rule can not define. The tests are related to the form and size of the feature. An example is a hole with drilling, reaming and threading processes, “figure 4”. In this case, the sequence of machining is found because is not possible to do the reaming or tapping process before the drilling.

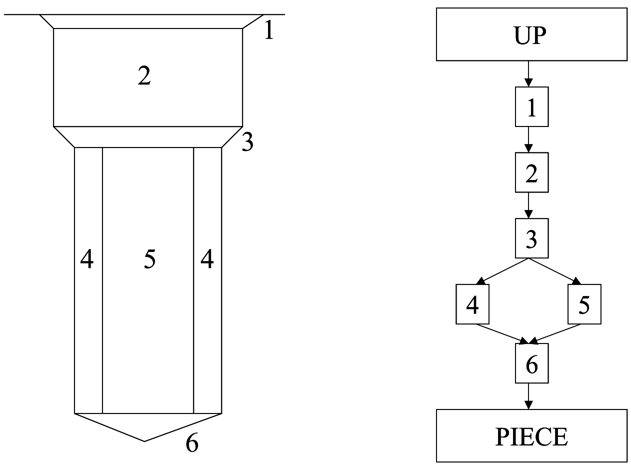

Figure 4. Features that represent the same finishing element

The graph of the hole is shown in “figure 4”. We can see that all features have the same parents, i.e., they are sons of UP like feature 2 and only this. However, there is a difference: the feature 1 can be defined as chamfer through of its dimension and if it is father of a cycle feature. The feature 2 is defined by the roughness. If the roughness is not possible by drilling, the reaming will be defined. The feature 4 and 5 are compared with the first father, feature 3, and if they have some points in common and the same son, it will define the tapping and drilling processes for them. A further information from the graph is that the diameter of the hole is equal of the diameter of the feature4. The data of the threading process can be defined by the thickness of the line.

Table 1. Rule of definition the machining process in related to the feature position

Up	Right	Left	Front	Behind	Down	Description of process
1	0	0	0	0	0	Milling, Drilling, Tapping, Reaming,Chamfering
1	0	0	0	0	1	Milling, Drilling, Tapping, Reaming,Chamfering
0	1	0	0	0	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	1	0	0	0	1	Milling
0	0	1	0	0	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	0	1	0	0	1	Milling
0	0	0	1	0	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	0	0	1	0	1	Milling
0	0	0	0	1	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	0	0	0	1	1	Milling
0	0	0	0	0	1	Milling, Drilling, Tapping, Reaming,Chamfering
1	1	0	0	0	0	Milling
1	1	0	0	0	1	Milling
1	0	1	0	0	0	Milling
1	0	1	0	0	1	Milling
1	0	0	1	0	0	Milling
1	0	0	1	0	1	Milling
1	0	0	0	1	0	Milling
1	0	0	0	1	1	Milling
0	1	1	0	0	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	1	1	0	0	1	Milling
0	1	0	1	0	0	Milling
0	1	0	1	0	1	Milling
0	1	0	0	1	0	Milling
0	1	0	0	1	1	Milling
0	0	1	1	0	0	Milling
0	0	1	1	0	1	Milling
0	0	1	0	1	0	Milling
0	0	1	0	1	1	Milling
0	0	0	1	1	0	Milling, Drilling, Tapping, Reaming,Chamfering
0	0	0	1	1	1	Milling
1	1	1	0	0	0	Milling
1	1	0	1	0	0	Milling
1	1	0	1	0	1	Milling
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1	1	0	1	1	0	Milling
1	1	0	1	1	1	Milling
1	0	1	1	1	0	Milling
1	0	1	1	1	1	Milling
0	1	1	1	1	1	Milling
1	1	1	1	1	0	Milling

2.3 Definition of the parameteres of the machining process

There are two different ways to machine a part. These ways are related to the different parameters of the machining process. In general, there are two groups of parameters:

- Cutting conditions;
- Path of tool;

2.3.1 Cutting Conditions

The machining parameters of cutting conditions are: depth of cut, feed, cutting speed, direction of cut, angles of tool and cut fluid, material of the part and material of the tool.

For optimal cutting conditions, is necessary to define the depth of cut, feed and cutting speed based on the material of the part, the insert and the process. The range of the cutting, speed, depth of the cut and the feed is related to the material of the insert, part and geometry of tool. Then, a database about the kind of part material and tools, and the geometry of tool can be done. In this database is, also, necessary to have parameters of Kienzle and Taylor related to this kind of part material and tolls, and the geometry of the tool. To determinate these parameters is necessary to do a lot of tests. An example of database integrated with CAPP was developed by Mesquita et al.(2002), they developed a database for turning. The advantage of a database integrated with CAPP is the facility to get tools from different companies in the same place. Other advantage is the fast access to the parameters of the tools in comparison to the catalogues.

The CAPP system, also defines the value of the depth of the cut, feed and cutting speed. These values can be modified during the analysis of the capability of the process, for instance, through the Gauss Curve of the process, meanly because of the problems of roughness and trouble shooting during the life of the tool. So, the CAPP system, roughly, defines de NC program butt some modification can be done during the machining of the part if the NC program is used in a lean manufacturing.

2.3.2 Path of Tool

The path of tools is related to the type of process that can be milling, drilling, reaming and threading. So that, each machining process has a sub-program that describes the path into the CAPP system. There are four steps to find the path of the tool. The first step, the CAPP system recognizes the pockets and features or group of features. The second analyses the kind of process that will be done in the feature selected. In the third step, the kind of tool is analysed through the database. In the fourth step, the CAPP defines the path of the tool by mathematics techniques. These mathematic techniques can be, for example, the Voronoi Diagram when the feature will be a pocket, and when the machining process will be the milling.

2.4. Generation of NC program

In the CAPP system, there is a module where the NC system is created. This step is the last step of the CAPP software. Generally, the CAPP system takes a particular command of NC program into consideration when creates it. On the other side, the proposal of this work is just the use of the NC commands based on the ISO 6983. The advantage is that the program can be used in different machine without necessity of a post-processor for each NC program.

3. Case study

The part in the figure 05 demonstrates the 12 features and the finished part. So, the CAPP system creates the 12 features from the CAD system, independently, if the CAD system is based on feature or not. In this case, the rough part is a rectangular block but it can have any shape. After the CAPP creates the features, it recognizes the location of them related to UP, Down, Rigth, Left, Front and Behind, figure 6.

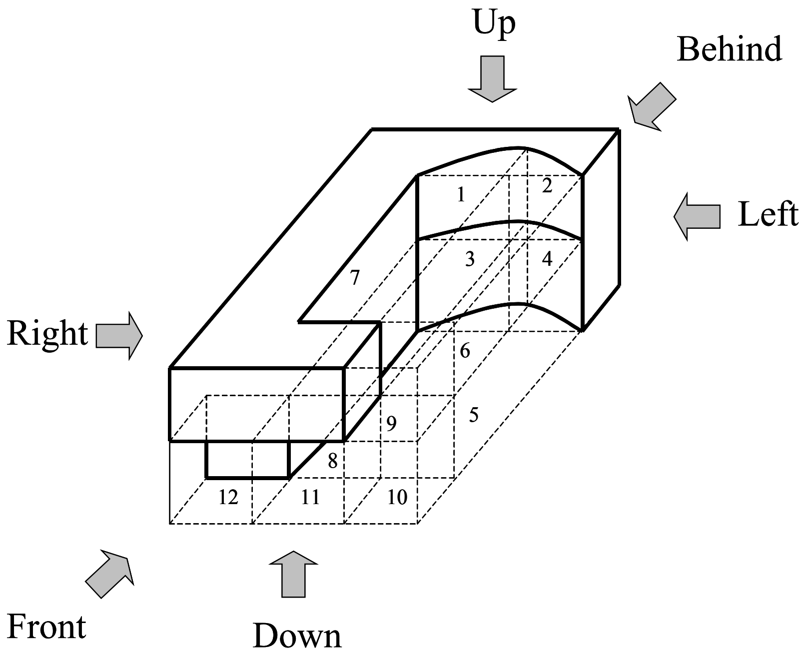

Figure 5. An example of a part

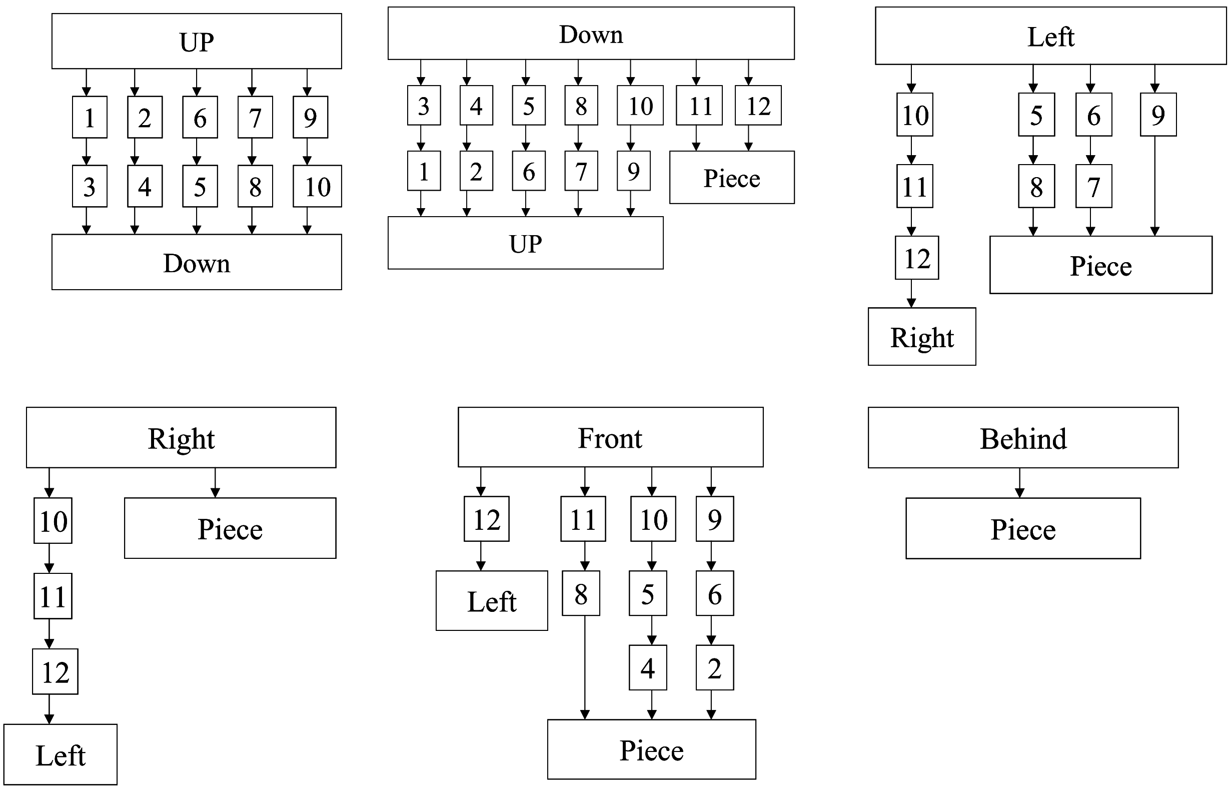

Figure 6. The graph of the part in the figure 4 in the sides UP, Down Left, Right, Front and Behind

Trough the graph in the figure 6, it is possible to define the following setups to machining the rough part:
1 – Machining the features 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 with UP setup and after feature 11,12 with Left setup, Right setup or Down setup. The choice among Left, Right or Down setups can be done analysing the rigidity of the fixture, the roughness and the time to machine in each case.
2 – Machining the feature 5, 6, 7, 8, 9, 10, 11, 12 with Left setup and after feature 1,2,3and 4 with Up setup or Down setup.
3 – Machining the features 10, 11, 12 with Right setup and after 1, 2, 3, 4, 5, 6, 7, 8, 9 with UP setup or Down setup.
4 – Machining features 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 with Down setup.
5 – Machining features 2, 4, 5, 6, 8, 9, 10, 11, 12 with Front setup and 1, 3, 7 with Up or Behind feature.

Then, initially, the best setup can be the Down setup, i.e., the Down face is an Up position. But, it is necessary take the cutting condition and tool path in consideration when define the best setup, because they have influence on the time machining and roughness of the part. The graph on table 1 show, also, that features 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 just can be machined through milling process. The kind of machining process of the feature1 defines how to mill, drill, reamed or thread. So it is necessary to make boundary test, i.e., if the feature 1 has the same points and line of the other feature that can be machined by milling process and form of the feature 1 is different of the circle. It can be machined by milling too.

4. Conclusion

This work has shown a methodology for 2 ½_D machining based on the graph theory. Through this CAPP system methodology is possible to recognize the machining features, to define the best setup, the type of machining that each feature or group of feature will be removed, and how the cutting conditions, the tool path and the generation of the NC program can be defined.

There are 59 types of location the features, moreover, 50 locations just can be machined by milling process. The milling process is the most important to apply the mathematics techniques to get an optimal machining time in the $2^{1/2}$ D machining. Through this methodology, the process planner does not have to spend a lot of time preparing the NC program.

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6. Responsibility notice

The authors, Hugo Marcelo Bezerra de Carvalho and Osíris Canciglieri Junior are the only responsible for the printed material included in this paper.