Development and integration of a 5 axis flank milling feature into a STEP Model

William J E Derigent
University of Lorraine

Ramy Harik
University of South Carolina

Development and integration of a 5 axis flank milling feature into a STEP Model

William DERIGENT, Ramy HARIK, Muriel LOMBARD, Gabriel RIS
CRAN, Research Center for Automatic Control, Nancy, CNRS UMR 7039
Université Henri Poincaré, Nancy I, Faculté des Sciences
Vandoeuvre-lès-Nancy, BP 239 – 54506, France
Phone: +33-3-83684419, Fax: +33-3-83684437, E-mail: {firstname}.{name}@cran.uhp-nancy.fr

Abstract - Feature-based modeling has been considered as the corner stone within the CAD/CAM systems. This is due to the emergent need for integrating design and manufacturing processes. In this paper we present a synthesis of the concepts met within STEP, where we extend to add a flank milling related feature. Then, we present the established algorithms needed for the features qualifications and the machining ability. We end up by applying the proposed concepts, showing a dynamic instantiation of our model through out its machining cycle.

Keywords: features, flank milling, STEP, integration

I. INTRODUCTION

The product life cycle brings into play actors with different trades, each contributing to the definition, the realisation or the integration of a certain product aspect. The PLM step aims at concentrating all the product related information in a global model, in order to divide them between the different actors, by means of external views of particularised data, thus managing the product all along its life cycle.

However, the data handled by these actors results from an intra-trade knowledge, often relating to very specific product aspects. Thus it coexists within the heart of the company various product models related to the trades, with sometimes different granularities which do not share same semantics, and thus, which leads to a communication loss.

Works, as those accomplished within the framework of the C.I.M (Computer Integrated Manufacturing) concept, attempted to adjust this problem by technological solutions aiming at integrating certain models so as to obtain a federate single model allowing different trades data communication. Amongst other things, a federated result consists of an approach aiming at standardising the exchanged data within STEP [BOU, 95a]. The latter aims for a product data representation throughout its life cycle: from design to realisation and recycling. STEP is thus seen as a tool for integration by model of reference. However, there is always a semantic hollowness between the different reference models due to the non-existence of common objects.

Being a partner of the USIQUICK project, our task is to realize the transformer, which converts the design model into a model for the quasi-automatic process planning generation. The transformer qualifies the faces of a CAD model, evaluates the difficulties of machining and carries out calculate workability. USIQUICK considers each CAD model face as a machining feature, labelled "Elementary machining feature". Therefore, one of the main transformer tasks is to verify that all elementary machining features are realisable, within one of the three used methods as defined in USIQUICK(side milling, flank milling, sweep milling). Thereafter, the whole of the calculated data is used by the module of preparation and the module of workability.

The application thus requires making communicate 3 different types of model:
- the design model (CAD),
- the process planning model (PPM),
- the machining model (CAM).

The data model USIQUICK has to be a unique and federated model, in order to optimize exchanges between applications. STEP, tool for integration by model of reference, provides us an ideal standardized modelling framework. However, a certain number of objects currently necessary to USIQUICK are not managed by STEP. The presence of unmanaged STEP objects is mainly due to having USIQUICK dealing with elementary features, not classical ones. Not forgetting that, a data transfer between the transformer and the preparation phase is not completely applicable. It is then necessary to extend STEP, thus allowing the integration of elementary features.

In a first step, we shall present a proposed extension of STEP. This extension will bridge the need to transmit needed information for elementary flank milling features. The objects introduced in this model, are then integrated within the AP214 (Application Control – Part 214) and STEP NC (STEP Numerical Control), leading to a flank milling feature model. The second part exposes the different needed algorithms for qualifying the flank milling features, their attributes, and their machinnability. Ending up, the third part proposes a validation of the diverse proposed concepts on a BETA test work piece showing the UML Object diagram dynamic instantiation of the proposed model, all along its machinability calculus.

II. STEP EXTENSION

A. STEP Architecture

The STEP architecture [ISO, 92a], Standard for Exchange of Product Model Data, is based on a group of components describing, either a method, or a resource, each defined by one or several standard documents. These different components are represented in [BOU, 95a].

Among the different parts of STEP, we are particularly interested in:
→ AP 224 [ISO, 92a]: « Mechanical products definition for process planning using form features », that introduces the notion of form feature.
→ Part 42 [ISO, 92b]: «Geometric and topological representations», that specifies the geometrical structure representation within STEP. We were also keen on checking the STEP NC project, notable the milling data model [ISO 03].

Being committed to standardisation, we combined these different STEP parts, thus generating our proposed model (figure 2).

B. Model structure explication

The elementary features used by USIQUICK are in fact milling features that references to the faces of a CAD model. GAMMA [GAM, 90] sees that « milling features is composed of a geometrical form and specifications with a specified process planning. This latter is quasi-independent of other features processing ».

The elementary USIQUICK feature is labelled “manufacturing_feature ", which is a specification of the “general_feature " entity. In order to respect the previous definition, this object is linked to a geometric form (the object “Shape") while being linked to a process of machining (the object “machining_process "). As specifications, we put the emphasis on a very particular attribute that is the direction of machining (the object " machining_direction ").

Always according to [GAM, 90], « a process planning is a continuous ordered suite of machining operations ». That is due to “Machining_process” being composed of objects “machinining_operation ", representing the machining operations.

Finally, to realize the “Manufacturing_operation", it is necessary to define an instrument able to fulfill the task of machining, so-called the “manufacturing_tool ".

C. Geometrical aspect of the proposed model

As said before, the milling feature is at first a geometrical form. Our object “manufacturing_feature " is therefore linked up with a form, which is in the case of elementary features the face of the CAD model. Most of the existing CAD modellers use the ‘B-Rep’ to represent the piece [ACIS Modeler]. In B-Rep, a work piece is represented by a group of faces, which are linked between each other by means of edges. The model integrates faces and edges, using existing objects in part 42.

These objects owns a geometry: the face is a part of a surface which can be a plan, a cone, a cylinder… and similarly, the edge is a part of a curve which can be a straight line, an arc…The objects "edge_curve" and "face_surface" allow to memorize this type of information.

Moreover, to support algorithms represented in section III, the model uses an enriched version of the object “edge" which carries the attribute of vivicity. The vivicity is a geometric criterion, which evolves according to the angle between the two faces connected to the edge, and their respective geometrical type. USIQUICK defines 4 categories of vivicity (figure 1), similar to the criterions of Kyprianou [KYP, 80]. Therefore, an edge can be:
→ Opened (O): the angle between both faces is superior or equal to 90 °
→ Closed (C): the angle between both faces is inferior to 90°
→ Tangent – Opened (TO): the angle between both faces is equal to 90 °, and only one of both faces is cylindrical convex
→ Tangent – Closed (TC): the angle between both faces is equal to 90 °, and only one of both faces is cylindrical cup-shaped

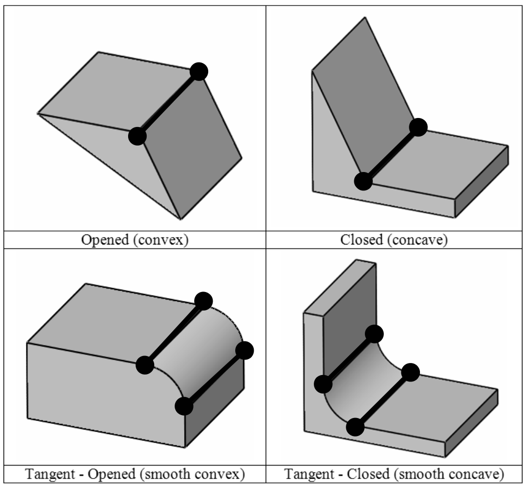

Figure 1. USIQUICK vivicity criteria’s

D. Machining directions modelling

Different attributes are linked to our machining feature which will allow defining entirely its geometry and the awaited characteristics [TOL, 98]. We emphasis on a very particular attribute, that is the direction of machining. The question of the machining direction modelling is not trivial. Let us take the case of a plan for instance. While in end milling we have a unique machining direction (the plan normal), flank milling can be made of an endless number of possible directions.

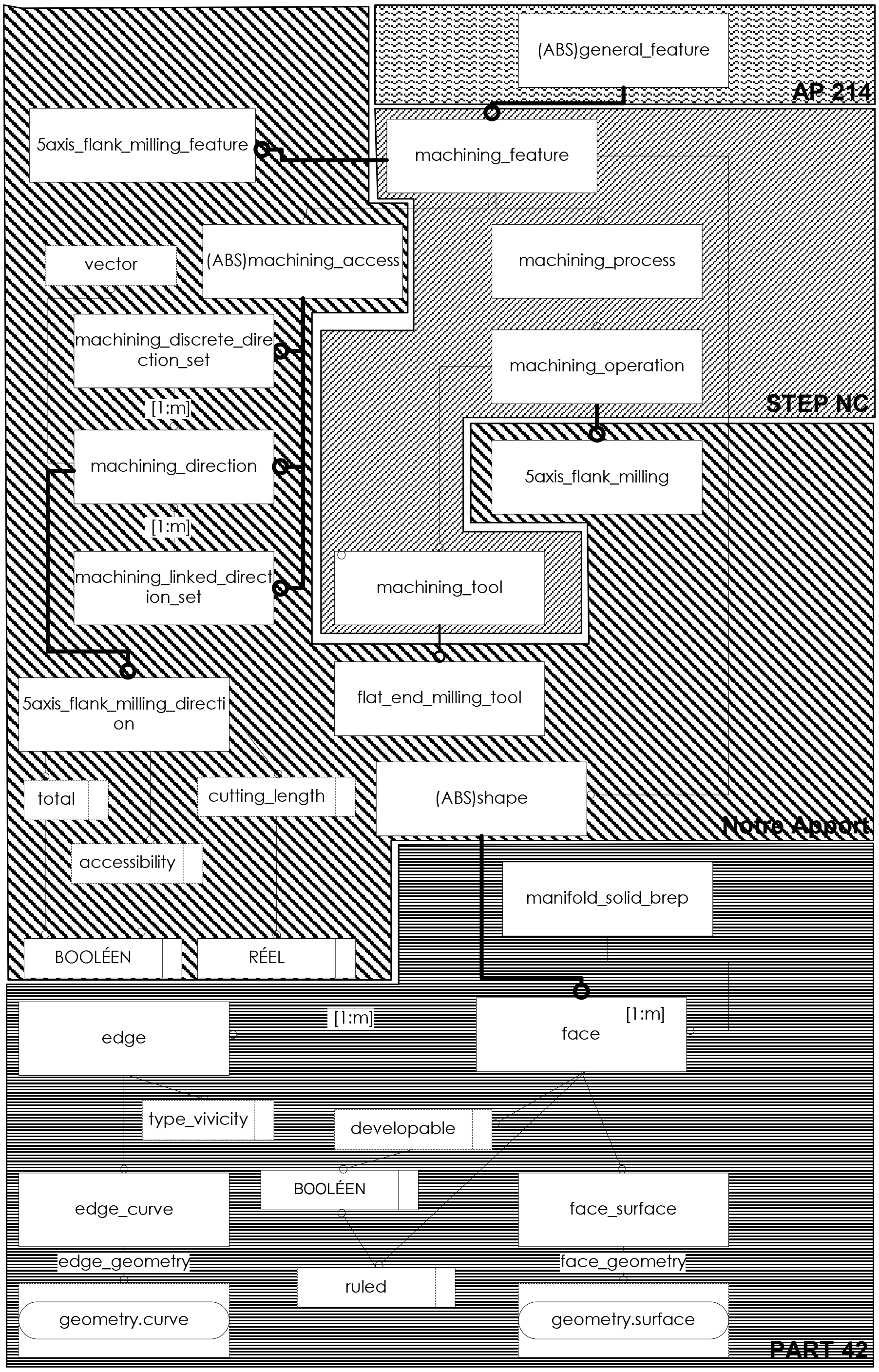

Figure 2. Proposed model

Capponi's [CAP, 04] aeronautical process planning based study puts together these different directions to make groups of directions, named «machining access». Capponi distinguish 3 different types of machining access (figure 3) :

→ Simple machining direction: it is the simplest machining access, i.e. used for holes milling
→ Multiple machining directions (Discreet group): this access represents a group of several machining directions,
→ Come machining directions (uninterrupted group): this access is defined by an uninterrupted succession of directions. In that case, a function of definition of the uninterrupted field must be explained. Every direction of this group is necessary to manufacture the concerned entity. This access of machining is indivisible.

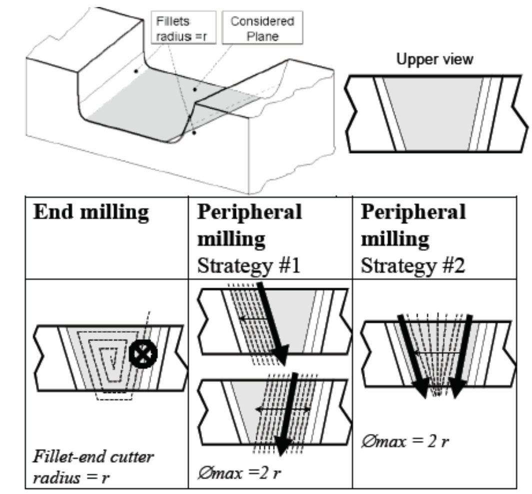

Figure 3. Alternative directions for a planar surface [CAP, 04]

To take into account this taxonomy, we created the abstracted object "Machining_access ", that diverts into:

→ « machining_direction »
→ « machining_discrete_direction_set »
→ « machining_linked_direction_set »

The object 'machining_direction' specializes in a characteristic object of flank milling, the "5axis_flank_milling_direction". It has particular properties: the needed cutting length to accomplish the machining according to this direction (" length "), two boolean attributes (" Accessibility" and "total "), pointing out respectively if the validity of the corresponding machining direction, and if it is complete or partial. A 'partial' direction points out that a party of the surface is can not be manufactured with flank milling, while a 'complete' direction specifies the ability to manufacture all the area, accessible by the specified machining direction. The figure 4 below displays both types of flank milling directions. Complete directions of machining are in black, directions with contact have their accessible part in black, and their inaccessible parts in grey. Details of the machining directions calculus algorithms are exposed in section III.

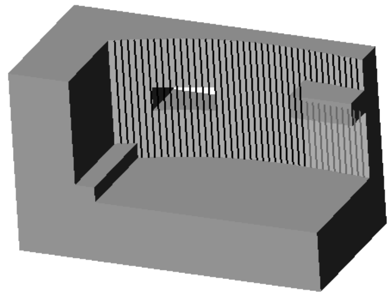

Figure 4. Machining directions contacts with the part

The final model, which can be seen as an enhancement of the model proposed by [HAR, 04], is presented in figure 2. It is written in EXPRESS-G [BOU, 95b], ISO specified language for the description of STEP models.

III. MODEL ALGORITHMS

The following section presents the algorithms used all along the manufacturability calculus. In order to be able to instantiate our model, we thus needed various algorithms. These algorithms permit the detection of possible elementary flank milling features with their respective machining directions.

The algorithms have, as an entrance point, a CAD model, which is composed of parametric surfaces. For each point $P(u,v)$ of a model surface S, the modeler gives us access to the point P coordinates and to the plan normal at the point P.

The logogram figure 5 presents the succession of the algorithms, throughout the machining directions extraction process.

A. Algorithm 1: Detection of a flank milling feature

Ruled surfaces are popular type of surfaces in milling. Let $P_1(u)$ and $P_2(u)$ be two parametric curves. A regulated surface can be generated by the displacement of a line. They are generated starting from a line (or rules) holding on two 3D curves. The equation of the surface $P(u, v)$ is expressed according to $P_1(u)$ and $P_2(u)$ by [LEO, 85]:

$$P(u,v) = (1-v)P_1(u) + vP_2(u) \qquad (1)$$

[BED, 95] shows that flank milling is not possible except on developable ruled surfaces, which are ruled surfaces on which one, moreover, imposes that the surface normal vector is constant along each rule.

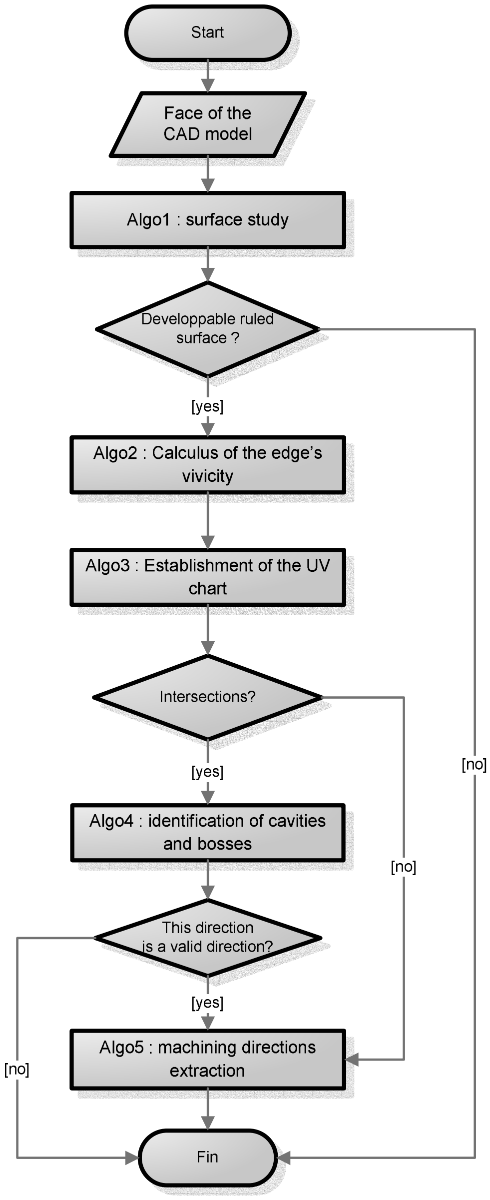

Figure 5. The Algorithm different stages

Algorithm 1 consequently will detect if a face of the CAD model is a possible flank milling feature, by checking that surface is a developable regulated surface, i.e.:

→ isoparametrics all along u or v forms a line, called "rule",

→ All the normals, along the different rules, are collinear.

This is why, one studies isoperimetric surface by placing oneself in the reference mark (*u*, *v*). This task's treatment is relatively simple. By fixing a value of *u*, we calculate the line formed by two various values of *v*. Then we make sure that the various points, having the same *u* value belong to this line. These calculations will be carried out for various *u* values, then identically for various *v* values, in order to know if surface is regulated according to *u* or *v*.

The study of the surface developability intervenes only if the surface is regulated. We calculate the normal on the surface in various points of each rule. If these vectors are collinear, then, the surface has developable.

B. Algorithm 2: Calculus of the edge's vivicity

In this stage, a parameter of vivicity is affected to the edges. We set the value *F* for a closed edge, value TO for an open tangent edge, and the value *O* for an open edge. To determine the vivicity, one calculates m, in various points of the considered edge, according to the following relation [ANW, 00]:

$$m = (\vec{h}_1 \times \vec{h}_2) \cdot \vec{t} \qquad (2)$$

Where: *O* is a point of the considered edge *E*, $\vec{h}_1$ is the normal of the S_1 surface at *O*, $\vec{h}_2$ the normal of the S_2 surface at *O* and $\vec{t}$ the tangent of the edge *E* at *O* (figure 6).

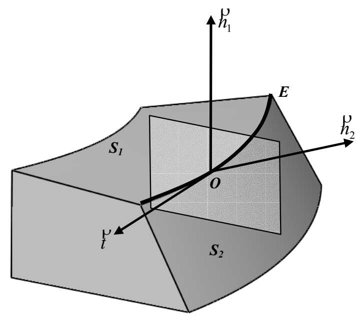

Figure 6. Vivicity calculus

The sign of m will indicate the vivicity of the edge. If m≥0, the edge is open or open tangent, if not, it is closed.

C. Algorithm 3: Establishment of the UV chart

The establishment of the UV [FAR, 92] chart of the borders of the face can be seen like a traditional geometrical projection operation.

The demarche amounts in recovering the various values of the u and v parameters associated with the edges defining the borders of the face and representing them in a Cartesian reference mark UV.

By deferring similarly the surface's rules on the UV chart, two cases can occur, according to the number J of points of intersection between the rule and the UV chart:

→ J=2: our rule preserves its qualification of machining direction and joins the stage 5,

→ J>2: our rule loses its qualification of machining direction, and undergoes the treatment of algorithm 4.

D. Algorithm 4: Identification of cavities and bosses

This stage aims at studying more closely the case of the rules that lost their qualification of machining direction in the previous stage.

The value of J can decrease according to the following proposal: two interior points of contact between the rule and the UV chart contributes of a value of -2 to the final J value, if the intersection of the line formed by these two points with the part body returns the empty set.

By applying this proposal, the rules that lost their qualification as a direction for machining because of a cavity, that doesn't affect the flank milling process, will regain its qualification as a total machining direction.

And thus the rest is limited to the cases of rules that crossover bosses.

These rules are divided into 3 parts:
→ The first accessible part from an end of the machining direction, if it exists,
→ The second accessible part from the other end of the machining direction, if it exists,
→ The 3rd part is formed from what remains from the rule.

Parts 1 and 2 will rejoin the machining directions, without the attribute total for their machining length. We allot to each these parts partial machining directions attribute completed by its cutting length.

E. Algorithm 5: Extraction of the machining directions

As a first result, we gather the total and partial machining directions, in a "machining_linked_direction_set" object.

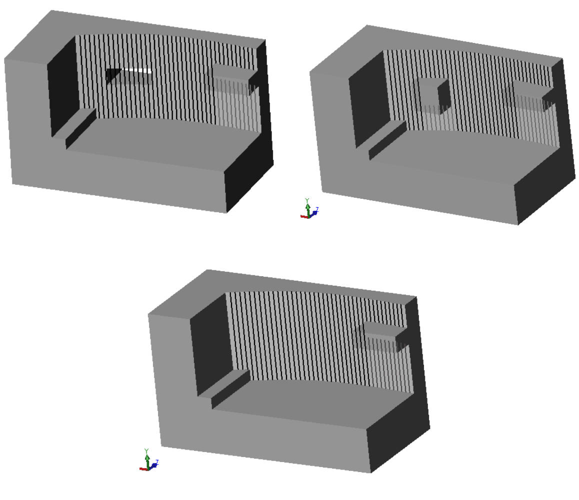

Figure 7. (a) Case of a cavity and a boss ; (b) Case of two bosses; (c) Case of one boss.

IV. MODEL INSTANTIATION

In this section, we propose a validation of our model throughout an instantiation applied on the BETA work piece. The area labelled 1 is the object of our study.

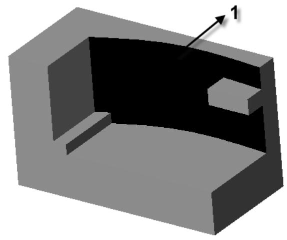

Figure. 8 The work piece BETA and the face 1, object of our study

The model will be displayed in an instantiated UML object diagram. Object diagrams show the structure of a system while it is running. This type of modelling permits to identify which objects participates at a fixed moment. This type of diagrams helps essentially in the exploratory phase, because it has a high level of abstraction.

Our model will be instantiated upon the face selection. At this stage, the face's study is not held. Therefore, the participating objects are purely topological, and thus the different face attributes have their default values.

Figure 2 shows the object diagram post-selection of one face, which is in a general case.

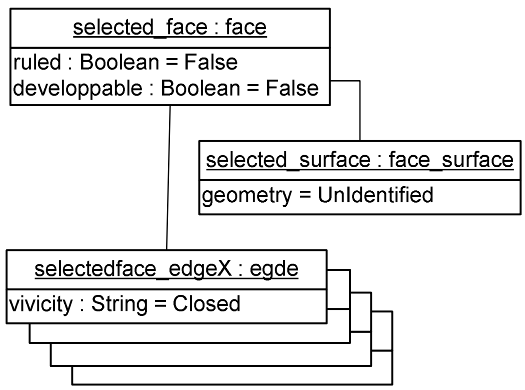

Figure. 9 Post-selection face model

The different algorithms for the face's identification will be applied to fill the different attributes in a second phase. In order to associate a flank milling feature to a particular face, it must be ruled developable. By applying algorithm 1 on our selected face, and algorithm 2 on the face's edges, the attributes of our model takes the value following the algorithms' results. The post-study face object diagram is then:

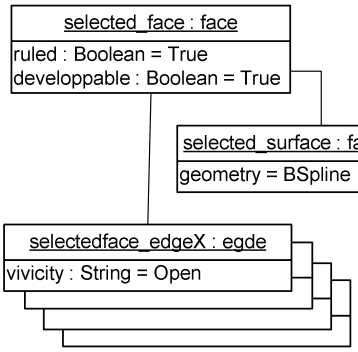

Figure. 10 Post-study face model

A flank milling feature will be associated to our face, hence its qualification as ruled developable. Our process will be composed of 5 axis flank milling operations, carried out by a ball-end milling tool. At this state, our machining_feature_1 object is created, and thus, the milling directions algorithm is launched.

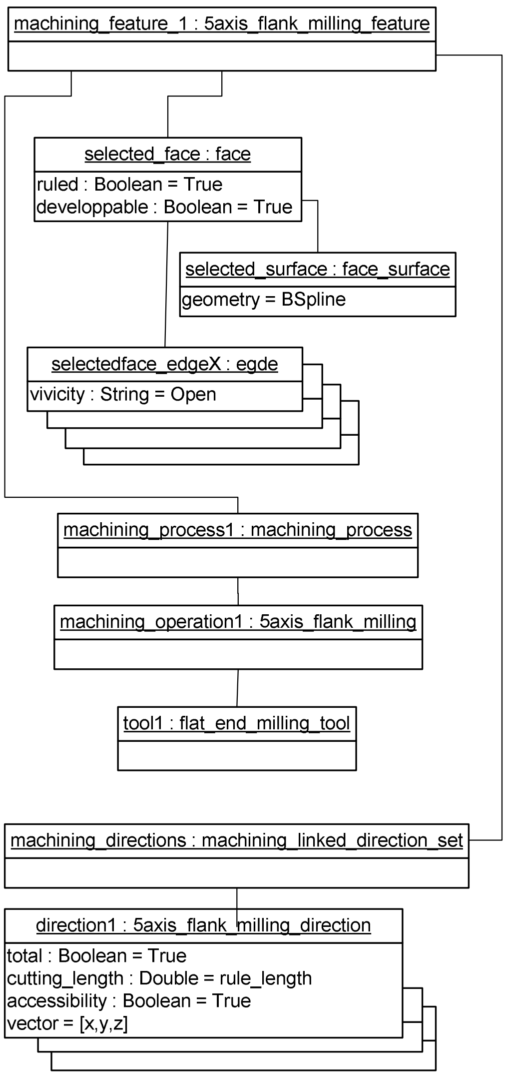

Figure. 11 Post-study machining directions model

The model shows our milling feature that has a geometrical form, which is the selected face. Our feature has a specific milling process which consists of different machining operations. Machining is done according to machining directions established through the mise en route of the various propose algorithms. These directions are partial or total, with the cutting length, accessibility and support vector attributes.

By carrying out the developed code on our face, we reproduce the different machining directions' attributes obtained for step test of value 6 in table 1. These directions are reproduced in the figure 12.

TABLE I
MACHINING DIRECTIONS OUTPUT

Direction	total	accessibility	cutting_length	vector
1	true	true	70.00	{0,0.08,0}
2	true	true	80.00	{0,0.08,0}
3	true	true	80.00	{0,0.08,0}
4	true	true	80.00	{0,0.08,0}
5	false	true	20.51	{0,0.08,0}
6	false	true	20.51	{0,0.08,0}

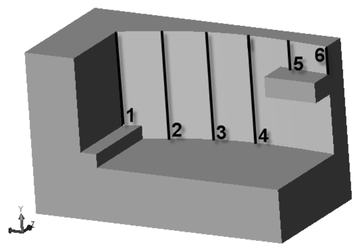

Figure 12. Different machining directions, for a test step value, 6

V. CONCLUSION

Our article presents a data exchange model for the automatic generation of process planning. We consider nevertheless only the case of ruled surfaces machinable in a flank milling mode. This model is supplemented by information coming from data-processing methods having a CAD file input.

The presented model is built partly from STEP objects developed in Part 42, AP 214 and AP 224, in order to guarantee a fast and clean implementation in the norms. However the study led by Capponi within the framework of the USIQUICK project shows the need for a structure of objects, able to take into account the concept of machining access. Nevertheless, this group of objects, oriented towards the process planning generation, was not yet defined in STEP. We thus had to associate newly un-normalized objects with our model, which are the "machining_access" and the "machining_direction".

This structure proposal is only at its beginning, and our objective, on the short term, is to specify it in order to integrate it in the USIQUICK reference model.

REFERENCES

[KOS 99] K. Kosanke, F. Vernadat, and M. Zelm, "CIMOSA: enterprise engineering and integration", in *Computers in Industry*, vol. 40, pp.83-97, 1999.

[BOU, 95a] M. Bouazza, "la norme STEP", Eds. Hermes, Paris, 1995.

[BOU, 95b] M. Bouazza, "le langage EXPRESS", Eds. Hermes, Paris, 1995.

[ISO 94a] ISO 10303, "STEP Product Data Representation and Exchange", *International Organization for Standardization, Subcommittee 4, NIST,* 1994.

[ISO, 01] ISO 10303-214, "Industrial automation systems and integration – Product Data Representation and Exchange, Part 214: Application Protocol: Automotive mechanical design process", *International Organization for Standardization, Geneva,* 2001.

[ISO, 94b] ISO 10303-42, "STEP Product Data Representation and Exchange, Part 42, Integrated Generic Resources: Geometric and Topological Representation", *International Organization for Standardization, Subcommittee 4, NIST,* 1994.

[ISO 03] ISO 14649-10, "Industrial automation systems and integration – physical device control for Computerized Numerical Controllers – Part 10: General Process Data, *International Organization for Standardization,* Geneva, 2003.

[GAM, 90] Groupe GAMA, "La gamme automatique en usinage", Hermès, 1990.

[TOL, 98] M. Tollenaere, "Conception de produits mécaniques, Normes et échanges de données », Hermès, 1998.

[CAP, 04] V. Capponi, F. Villeneuve, and H. Paris, "Handling of alternative processes for machining of aeronautical parts in a CAPP system", IFAC-MiM 2004 Poceedings, Athens, 21-22 Oct. 2004.

[HAR, 04] R. Harik, "CAD/CAM Machining Features", Automated Production Masters Thesis, Université Henri Poincaré, Nancy, France, Jul. 2004.

[LEO, 85] J.C. Léon, "Modélisation et construction de surfaces pour la CFAO", Eds. Hermes, Paris, 1985.

[ANW, 00] N. Anwer, "Méthodologie d'analyse de raisonnement pour la generation automatique des gammes d'usinage en fraisage. Contribution à la caractérisation des entités par analyse des contraintes d'usinabilité ", Ph.D. dissertation, Ecole Normale Supérieure de Cachan, France, Jan. 2000.

[KYP, 80] L. Kyprianou, "Shape classification in computer aided design, Ph. D. dissertation, University of Cambridge, 1980.

[BED 03] S. Bedi, S. Mann, and C. Menzel, "Flank milling with flat end milling cutters", in *Computer-Aided Design*, vol.35, pp.293-300, 2003.