INFELT STEP: An Integrated and Interoperable Platform for Collaborative CAD/CAPP/CAM/CNC Machining Systems based on STEP Standard

Omid Fatahi Valilai and Mahmoud Houshmand

Abstract— **Integrated product development is comprised of CAD, process planning and CNC code generation based on an integrated data structure. To enable various CAD/CAM software solutions to be interoperable, it is necessary to realize reliable and robust information exchange in manufacturing enterprises. To realize interoperability there are two basic approaches: i. To focus on a neutral file format like those provided by the STEP standard to support data exchange between CAD systems as well as CAPP/CAM and CNC machining systems ii. To utilize an active and flexible platform consisting of structures and procedures to enable exchange of data seamlessly. Collaboration management of data exchange is inevitable in a collaborative product development environment. In this paper, the prominent integrated, interoperable and collaborative CAD/CAM information system platforms have been reviewed. To alleviate the problems arising from the shortcomings of the existing platforms, an integrated and interoperable platform for collaborative CAD/CAPP/CAM/CNC systems named INFELT STEP has then been proposed. The different aspects of this platform have been discussed based on an integrated, interoperable and collaborative CAD/CAPP/CAM environment. INFELT STEP has been designed to include multiple layers to support the entire range of application software packages in the CAD/CAPP/CAM product development chain. Using INFELT STEP each application software package can send items of information based on its own data structure to other packages communicating with the platform. The layers within INFELT STEP convert the application software's processed data to the structured data model based on STEP Standard and store the structured data in INFELT STEP's database. Conversely, the INFELT STEP layers also retrieve the structured data based on STEP standard and convert their format to match the CAD/CAM/CAPP application software's data structure in an interoperable environment. The INFELT STEP manages CAD/CAM application software collaboration and also maintains the integration of CAD/CAM/CNC operations based on STEP data structure while supporting the flexibility of application software's interoperability based on their own data structures.**

Index Terms— **CAD/CAM Integration, ISO 10303 (STEP), Manufacturing Interoperability, Manufacturing Collaboration.**

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I. Introduction

Software frameworks and programs that facilitate the distributed product design and manufacturing are becoming more and more important in product development processes [1]-[2]. Different solutions and software have been developed based on these frameworks including different CAD/CAPP/CAM application software tools. Technologies developed for CAD/CAPP/CAM application software tools and CNC post processors are customized within each of their own application domains named as automation islands [3]-[5]. So, the application of these software tools in different enterprises will make trouble where it is necessary to exchange product data among engineers and designers-who are geographically spread and have different goals, knowledge, experiences, tools and resources-to support collaborative product development within an integrated product data structure [6]-[8]. These problems can be classified in three groups:

1) Management of collaboration between different CAx application software tools in product development processes.
2) Enabling the interoperability among different CAx software application tools for product data exchange.
3) Integration of product data through enterprises' product development processes while different CAx application software tools modify the product data.

To solves these problems, researchers proposed different CAx platforms and information systems. Theses platforms and information systems struggled to solve above problems. Qin in 2004 [9] introduced information system with the ability to manage the CAx application software collaboration and integrated data structure but it was not an interoperable platform and lacked for the ability to enable the product data exchange among different CAx application software. XU in 2005 [4], 2009 [3] and Nassehi in 2006 [10] suggested information systems with the ability for product data integration based on STEP standard. However, these systems lacked to manage the CAx application software collaboration and enabling the interoperability for product data exchange between different CAx application software. On the other hand, Peng in 1998 [6] and LO´ Pez-Ortega in 2005 [11] proposed platforms to facilitate the product data exchange between different CAx application software but they lacked for an integrated product data structure. Lee in

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2006 [12] , Canciglieri Junior in 2005 [13], Pisarciuc in 2007 [14] ,Nguyen Van in 2007 [15] and Newman in 2007 [16] proposed platforms that had an integrated product data structure and also enabled product data exchange among different CAx application software tools but they had no procedures and structures in their platforms to manage the CAx application software collaboration.

Considering the mentioned platforms, this article suggests the basic needs for an interoperable and collaborative platform with an integrated product data structure that is enable to solve the mentioned problem. The basic needs for such a platform are:

1) CAD Interoperability :

CAD interoperability is known as a critical factor for using different CAx application software in different enterprises [9], [17]-[20]. There are many situations where it is essential to exchange CAD model data between different CAD systems, or between a CAD system and some other computer-based application system [21], [22]. The platform architecture should be designed in such a way to support exchange of different data structures related to CAD application software working collaboratively through enterprises.

2) CAPP/CAM Interoperability:

Data exchange among CAx systems has been recognized for a long time as a key concept for concurrent engineering which tries to coordinate product development processes involved designers from different departments in the same company, as well as from different enterprises [23], [24]. The interoperability of different CAM application software reduces the production cycle time and costs as well as increasing product quality [25]-[28]. Different CAM application software should be able to work within the platform base on their data structure format. Researchers believe [2], [29] that different CAD software tools must communicate with different CAM software tools to provide the smooth transition from design to manufacturing through enterprises. CAM must communicate with computer numerically controlled (CNC) machine tools to execute the manufacturing activities.

3) Management of CAx collaboration:

Product development processes, comprised of product design, product process planning and manufacturing, is a complicated process which involves groups of designers and manufacturers often with conflicts [30]. It is necessary to share design information within a manufacturing company through the different infrastructures, to enable the company to exchange product information with parts suppliers and collaborating partners in addition to sharing information among internal departments [2], [31]. This need emphasises on managing the product data modification among different CAx application software through enterprises.

On the other hand, globalization in the manufacturing sector is increasing the need for more effective means of collaboration and communication among extended product development teams - including the ability to share product data [22], [26].

4) Supporting distributed enterprises CAx development teams:

Modern manufacturing enterprises are comprised of several CAx development teams spread around the globe, which often contain equipment and software tools from different manufacturers. Immense volume of product information must be transferred between the various facilities and CAx software tools at different locations [32]. It's necessary for a collaborative platform to support distributed CAx development teams.

To complete a design, negotiations among CAx development teams should take place continuously [23]. It gets more important where designers are geographically dispersed; the platform needs to create a naturally collaborative environment in which each authorized participant can communicate with each other without obstacles [23], [33]. Therefore the platforms should have a structure to support distributed product data. The platform should secure the exchange of product data among authorised CAx development teams.

5) CAx product data integration based on STEP

The integration ensures that the CAx systems can store product data effectively across the product development processes [34]. Considerable research performed showed that one of the problems with the current design and process planning software systems is the lack of integration between CAD data output and CAPP data input [35], [36]. On the other hand, the integration of product data helps enterprises to determine the product costs based on CAx processes [37].

To achieve to collaborative CAD/CAM product development so many standards for data exchange have been developed and revised, one of these standards is the STEP (Standard for the Exchange of Product Model Data) which is an international standard that addresses the representation and exchange of product data [38]-[40]. Since the mid-1980s, the international community has been developing the ISO 10303 set of standards, well known as STEP (ISO 10303-1 1994), which has its foundations in many of the earlier standards [4], [41]. The overall objective of STEP is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent from any particular system [42]-[44]. This feature improves the communications within the extended enterprise and helps to support global collaboration among suppliers, business partners and customers [38]. These characteristics make STEP an appropriate choice for product data integration in CAx platforms. The capabilities of this standard easily extend its data structure for new product development areas [8].

STEP is widely used in CAD and product data/lifecycle management (PDM/PLM) systems [43]. This data structure also integrates the CNC machining post processors data structures in manufacturing suits [45]. This paper considers the term of "integration" as integration of product data based on STEP standard.

6) Ability to support new CAx application software

Software houses are involved in development of new CAx software tools. Therefore the platform should be able to easily support new CAx software tools.

Based on authors' pervious research work [46] and above mentioned needs for an integrated and interoperable collaborative CAD/CAM/CNC platforms based on STEP standard, the important CAD/CAM /CNC information system platforms are reviewed in Table 1.

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Table 1. Review of important CAD/CAPP/CAM /CNC information system platforms

Platform	Interoperable platform for CAD	Interoperable platform for CAPP/CAM	Management of CAx and CNC Collaboration	Supporting distributed CAx and CNC machining Enterprises	Capability of CAx and CNC machining integration Based on STEP	Ability to support new CAx application Systems
Multi-Agent System for Computer Aided Process Planning (MASCAPP)[10]	NO	NO	YES	NO	YES	NO
STEP-compliant collaborative manufacturing model[4]	NO	NO	YES	YES	YES	NO
STEP based Engineering Data Management (EDM) system [6]	YES	YES	NO	YES	NO	YES
A STEP-based manufacturing information system [11]	YES	YES	NO	NO	NO	NO
framework for steel bridge information management[12]	YES	YES	NO	NO	YES	NO
Intelligent agent System architecture[55]	NO	NO	NO	YES	NO	NO
Prototype wire EDM system Architecture[54]	NO	NO	NO	NO	NO	NO
CAE system architecture for support multiple viewpoints[51]	YES	YES	NO	NO	YES	NO
Incremental Simulation Modelling for Internet Collaborative Design architecture[9]	NO	NO	YES	YES	YES	NO
Intelligent CAD/CAM system[52]	NO	NO	NO	NO	NO	NO
Three-tier architecture for Digital Manufacturing[14]	YES	NO	NO	NO	YES	NO
VIVACE – EDM architecture[15]	YES	YES	NO	NO	YES	NO
Web Based Collaborative Product Development System using STEP/ XML / X3D[53]	NO	NO	YES	YES	YES	NO
Integrated CAD/CAPP/CAM/CNC[3]	NO	NO	NO	NO	YES	NO
Universal Manufacturing Platform (UMP) [16]	YES	YES	NO	YES	YES	YES
INFELT STEP	YES	YES	YES	YES	YES	YES

II. The Proceeding Research

Considering the weaknesses of current platforms mentioned earlier, this article proposes the INFELT STEP platform. INFELT STEP platform satisfies the needs mentioned above. The mechanisms, procedures, and structures of this platform will be discussed based on factors like interoperability to Support CAD data exchange, CAPP/CAM/CNC machining data exchange among different CAx application software, management of collaboration among CAx application software, Supporting distributed CAD/CAM/CNC Enterprises, Capability of CAD/CAM/CNC integration Based on STEP and Ability to support new CAD/CAM/CNC Systems.

The integrated data structure base on STEP standard and ability to support interoperability for different application software will be discussed in detail. The capability of INFELT STEP to link different CAD/CAM application software and CNC Post Processors to each other based on their own data structures will be discussed.

INFELT STEP consists of several layers. These Layers are combined of different structures and procedures. Collaboration of these layers enables INFELT STEP to overcome the later platforms' lacks. Different aspects of these layers will be discussed in detail.

III. The Proposed Integrated and Flexible Platform for Interoperable CAD/CAPP/CAM/CNC Machining Systems Based on STEP Standard

The structure of the proposed interoperable and collaborative CAD/CAM system named INFELT STEP is designed in such a way to be:

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1) an implementable platform:

It should provide the different aspects of an integrated information system. Therefore, it is designed to enable the different CAD/CAM application software and CNC Post Processors to collaborate in the platform. One way to make sure that a complex process is on schedule is to employ distributed agents that repeatedly and regularly inform the current status of all elements associated with the process [47]. The INFELT STEP is capable of feeding different CAD/CAM application software and CNC Post Processors with latest information. INFELT STEP solves the difficult and complex problems such as none integrated information and problems in collaboration. To achieve a higher collaborative performance the different layers have been designed so that the application software in different CAD/CAM processes can work collaboratively.

2) Interoperable to support different CAD/CAM application software and CNC Post Processors data exchange:

Considering that most of CAD/CAM application software and CNC Post Processors do not ensure STEP standard for data exchange and operation, the INFELT STEP platform should be capable of transferring the required CAD/CAM application software information to them. On the other hand, the INFELT STEP platform should maintain and manage the processed information in an integrated data structure based on STEP standard.

3) Capable to manage collaboration among different CAD/CAM application software and CNC Post Processors:

The INFELT STEP should enable the different CAD/CAM application software to exchange data and information. It should manage the data and information processed by each CAD/CAM software and CNC machine devices. It manages the information exchange between these agents that collaborate with each other.

4) An integrated platform based on STEP standard:

INFELT STEP should satisfy the STEP standard for data integration. The product data and information should be based on STEP standard. The STEP architecture facilitates sharing of common data structures between STEP parts [48].

5) Structured to accept different distributed CAD/CAM application software and CNC Post Processors easily:

INFELT STEP should have a structure and procedures that enable different CAD/CAM application software and CNC Post Processors to join the platform for interoperability. These devices and applications may be distributed. The platform should have procedures to enable them for interoperability.

Based on these factors, INFELT STEP platform consists of different layers. These layers have structures and procedures that enable different CAD/CAM application software and CNC machine devices to collaborate in an interoperable environment. These applications and devices use their own data structure for collaboration. INFELT STEP layers manage the interoperability among them while maintaining data integrity based on STEP standard. These layers enable different CAD/CAM application software and CNC Post Processors to join the platform for collaboration easily. The overall structure of INFELT STEP platform is shown in Fig 1.

INFELT STEP has three kinds of layers; each layer is responsible for specified functionalities. Proceeding, these layers will be discussed.

A. Flexibility Layers

To enable the different CAD/CAM application software and CNC Post Processors to collaborate in an interoperable environment, INFELT STEP platform uses the flexibility layers. These layers are responsible to send and receive the

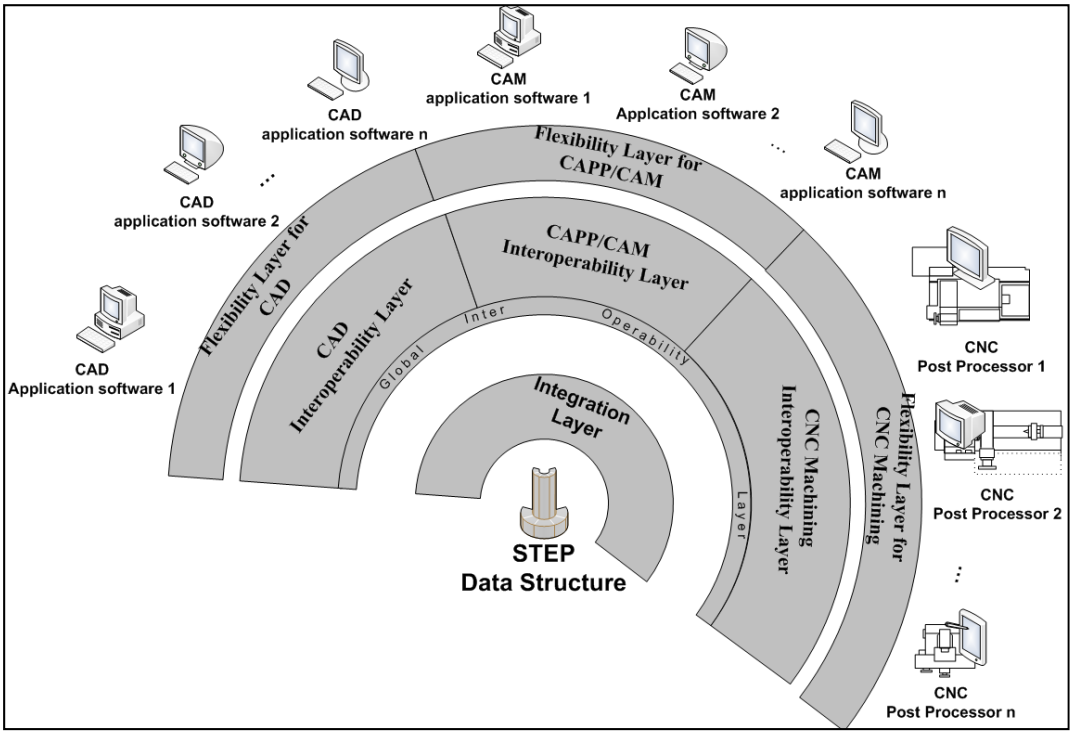

Fig 1. INFELT STEP platform

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data and information to the different CAD/CAM application software and CNC Post Processors based on their own data structure. These layers facilitate to join the new CAD/CAM application software and CNC Post Processors easily. Theses layers have data structures based on CAD/CAM application software and CNC Post Processors data structures. The flexibility layers are consists of interfaces for each CAD/CAM application software and CNC Post Processors data structure. These applications and devices connect theses interfaces to ensure collaboration of CAD/CAM application software. The data and information is exchanged based on CAD/CAM application software data structure within these interfaces. The developed interfaces are parts of the flexibility layers. The main function of the interfaces in the flexibility layers is to check the data validity of exchanged information. These layers communicate with Interoperability layers in XML data format. INFELT STEP has three flexibility layers:

1) Flexibility Layer for CAD to support different CAD application software, Fig 2.
2) Flexibility Layer for CAPP/CAM to support different CAPP/CAM application software, Fig 3.
3) Flexibility Layer for CNC Post Processors to support different CNC machining post processors, Fig 4.

Any applications and devices use their own data structure. These layers are consists of different interfaces that have data structure based on related CAD/CAM application software and CNC machining post processor data structure.

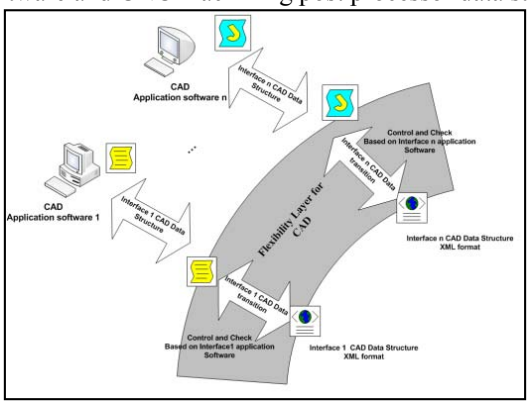

Fig 2. CAD flexibility layer structure and functionality

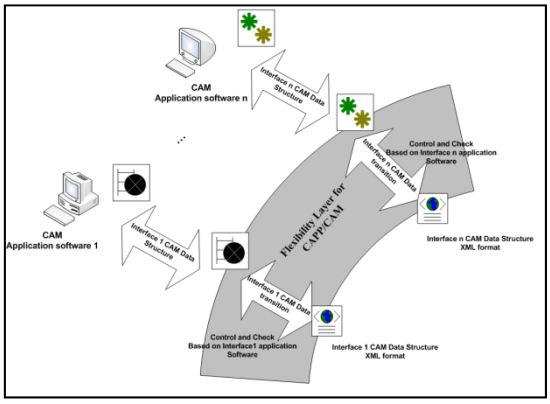

Fig 3. CAPP/CAM flexibility layer structure and functionality

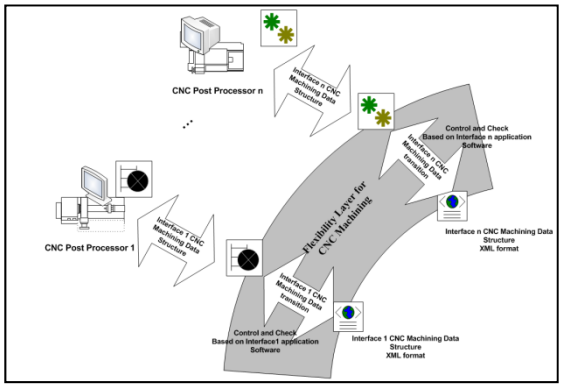

Fig 4. CNC Post Processors flexibility layer structure and functionality

These layers send the CAD/CAM/CNC machining data and information to lower layers named Interoperability layers in XML format. Vice versa, flexibility layers receive the CAD/CAM/CNC machining data and information from interoperability layer in XML format.

These layers enable the INFELT STEP to have flexibility to support different CAD/CAM application software and CNC Post Processors based on their own data structure. The new interfaces can be developed to these layers where they are required.

B. Interoperability Layers

These layers are the brain of INFELT STEP platform. Different CAD/CAM/CNC machining data and information structures in XML format are delivered to these layers. These layers enable different CAD/CAM application software and CNC Post Processors collaboration. INFELT STEP has four interoperability layers:

1) Interoperability Layer for CAD to support different CAD application software, Fig 5.
2) Interoperability Layer for CAPP/CAM to support different CAPP/CAM application software, Fig 6.
3) Interoperability Layer for CNC Post Processors to support different CNC post processor, Fig 7.
4) Global Interoperability Layer, Fig 8.

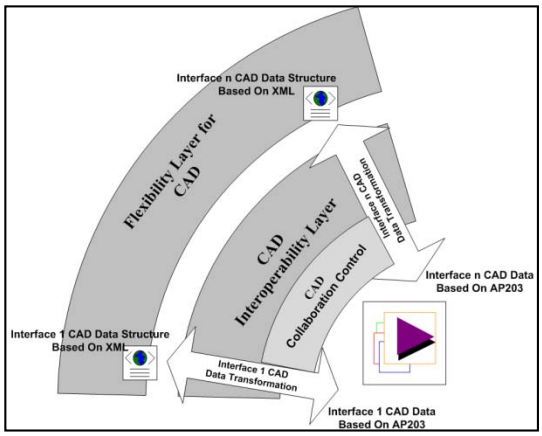

Fig 5. CAD Interoperability layer structure and functionality

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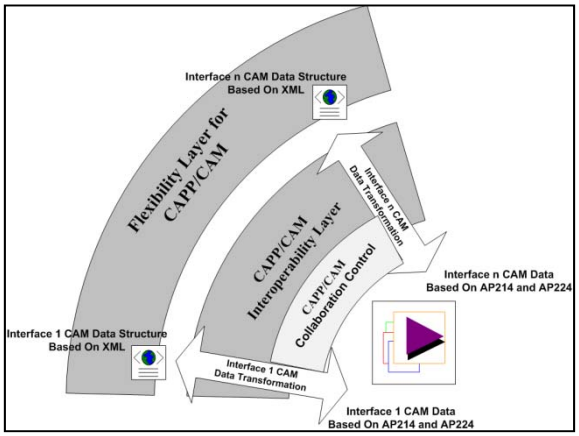

Fig 6. CAPP/CAM Interoperability layer structure and functionality

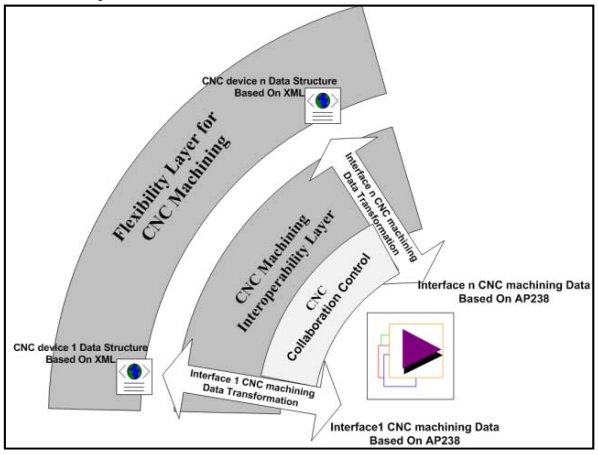

Fig 7. CNC machining Interoperability layer structure and functionality

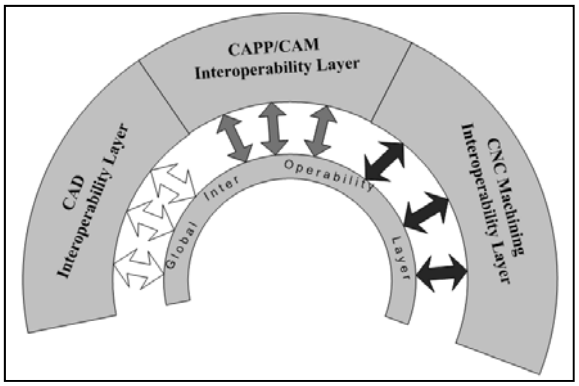

Fig 8. Global Interoperability Layer structure

Interoperability layers enable different CAD/CAM application software and CNC Post Processors to collaborate in the platform. The interfaces in the flexibility layers send the data and information based on their own data structure in XML format to interoperability layers. The interoperability layers process the data and convert them to STEP standard data structure as:

1) The CAD Interoperability layer uses Application protocol 203 data structure
2) The CAPP/CAM Interoperability layer uses Application protocol 214/221/224 data structure
3) The CNC Post Processors Interoperability layer uses Application protocol 238 data structure

In each interoperability layer, there is a procedure called collaboration control. After interoperability layer converts the interfaces' modified data to STEP data structure, collaboration control checks the data. CAD collaboration control ensure that once a CAD application software modified data is received and converted to STEP data structure, it doesn't contradict with other CAD application software. The same functionality exists in CAM interoperability layer by means of CAM collaboration control and CNC interoperability layer by means of CNC collaboration control.

To check the processed data and information validity, the interoperability layers check data and information based on STEP standard. If interoperability layers identify any invalid processed data, they will return these data to related interfaces in flexibility layers. If the converted data validate the constraints, the interoperability layers send this data to Global Interoperability Layer.

The Global Interoperability layer has the responsibility to enable interoperability between CAD/CAM application software and CNC Post Processors. The Interoperability layers act in two stages:

Captures modified product data and information from their related flexibility layer's interfaces. They convert those data to STEP structure based on application protocols defined in those interoperability layers. The interoperability layers perform the control and check operation for validating the modified data among their own layer.

The interoperability layers deliver the data to Global Interoperability layers to check and control the modified data among all interoperability layers. The modified data may be in contrast with other scopes like a CAD modification on design that may endanger CAM modified data for that product.

The global interoperability layer interchanges the product data with lower layer called Integration layer. It receives the stored data from Integration layer and processes it to control and validate the modified data.

The Interoperability layers interchange the data among Flexibility layers and Integration layers. At the flexibility layers, the CAD/CAM application software and CNC Post Processors work with their own data structure. The product data is stored in Integration layer based on STEP standard. The role of Interoperability layers can be defined as a medial structure between flexibility and Integration layer. These layers convert the product data to STEP structure and control the modified data with other information stored in Integration layer to avoid the contrasts.

It should be stated that if all the CAD/CAM application software use STEP data structure, the interoperability layers can perform better.

C. Integration Layer

This layer exchange data with Global interoperability layer. INFELT STEP platform can insure the integration of the product data based on STEP standard by help of this layer. The layer structure is shown in Fig 9.

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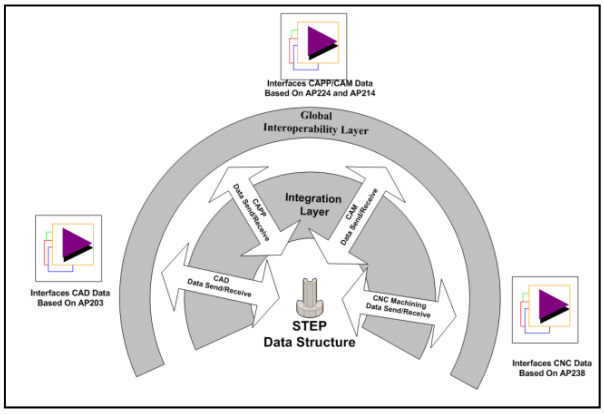

Fig 9. Integration Layer structure and functions

One of the major operations of the INFELT STEP platform is its storage operations. The integration layer is responsible for saving and managing the data. This data is the result of collaborative works. It includes the design of the product, the process plans of the products and the data that lead to the production of this product by means of the CNC machining tools.

The key function in the structure of this layer is the data storage and retrieval based on STEP based data model standard.

STEP standard has data protocols on which the structure of product data-form its design information and data related to its production process data- is organized. The structure that has been used for implementing this standard was based on the integrity of product data [49]. The STEP data model is composed of substructures called Application Protocols (APs). These APs include definitions not only of typical geometry and drafting elements, but also of data types and processes for specific industries such as automotive, aerospace, shipbuilding, electronics, plant construction, and maintenance [41]. Considering the INFELT STEP platform to support CAD/CAPP/CAM processes and CNC machining efforts, the following Application protocols are used in Integration layer:

1) Part 203: configuration controlled design
2) Part 221: functional data and schematic representation for process plans
3) Part 214: Core data for automotive mechanical design processes
4) Part 224:mechanical product definition for process planning
5) Part 235:material information for products
6) Part 238:integrated CNC machining
7) Part 239:product life cycle support

As said in earlier, these APs are widely used in CAD/CAM Collaborative works. The ISO STEP committee (TC184/SC4) has developed application protocol called ISO 10303-25, EXPRESS to OMG XMI binding [50] (also known as Part 25). With the help of this application protocol, the APs' data structures can be transferred to into UML models. Considering that UML (Unified Modelling Language) and are successful for collaborating with STEP standard. This will enable developers to use their familiar UML tools to see the contents of STEP (EXPRESS) schemas and eventually to specify relationships between STEP information models and the other UML models that they use [43]. This makes the INFELT STEP platform an implementable platform.

The usage of AP 239 (product life cycle support) in integration layer is for the development of INFELT STEP to support all product life cycle data. The ability of INFELT STEP to support interoperability while maintaining flexibility for accepting different product data structure and integration based on STEP standard satisfies the needs mentioned above, which many platforms lack.

IV. Conclusion

The comparison of different CAD/CAM application software and CNC Post Processors shown in Table 1. shows that the current platforms cannot accept the new application software's data structure easily. Most of them cannot ensure different CAD/CAM application software to collaborate in an interoperable environment. Some can only work with a specified data structure. Integration of product data, based on STEP standard is not supported by most of them. Today's enterprises involved in product design and Product Process planning demand platforms to enable them to exchange their product data collaboratively. The developed platform in this article named INFELT STEP has a wide capability to support collaborative CAD/CAPP/CAM/CNC machining among different enterprises. INFELT STEP is composed of different layers. These layers enable different application software to work in an integrated environment while using their own Data Structure. The layers interchange the data between application software for collaborative product development while managing and storing data based on STEP Data model. INFELT STEP can easily accept different CAD/CAM application software and CNC Post Processors. The layers make INFELT STEP flexible to support different data structure to collaborate with each other. INFELT STEP simplifies the goal of "short time to market". INFELT STEP platform may be extended to support industrial robots, PLCs, material handling systems in future works.

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