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DEVELOPMENT OF A STEP-BASED COLLABORATIVE PRODUCT DATA EXCHANGE ENVIRONMENT

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ABSTRACT:

In a modern manufacturing enterprise, CAD/CAM/CNC solutions are normally provided by various vendors. This forms a heterogeneous application environment. Despite the many integration approaches developed in the last decades, software integration and product data exchanging are still challenging issues that need to be addressed. In this paper, the authors proposed a collaborative product data exchanging mechanism based on a Distributed Interoperable Manufacturing Platform (DIMP). In this platform, STEP (ISO 10303) and STEP-NC (ISO 14649) data formats are utilized to support the data flow. A novel data exchanging mechanism is developed to provide the right amount and level of product data subset to the users.

KEYWORDS

STEP, STEP-NC, interoperable, data exchange, product data sharing

1. INTRODUCTION

During the past few decades, manufacturing business has been developed remarkably with the help of CAx software and CNC tools. The product design starts from CAD (Computer Aided-Design) application and CAPP (Computer Aided-Process Planning) software helps the users to work on the detailed process planning. After the manufacturing information is finalized by the CAE (Computer-Aided Engineering) system, the output will be sent to CNC (Computer Numerical Control) system which will drive the machine tools to manufacture the product finally.

Although such computer-aided technologies can bring benefits to the manufacturing industry magnificently, integration and interoperability issues are still unsolved. Due to heterogeneous enterprise environments in which business partners find themselves, multiple data formats, interfaces and databases are defined and used, thus forming a highly heterogeneous data environment. According to the calculation done by Parasolid's business development manager (Anonymous, 2000), approximately 20% of the product models imported from different software kernels still contain errors that have to be manually fixed, not to mention the data loss during conversions among different software applications. Based on the survey among the German manufacturing industry (Konstruktion, 2006.), it is reported that more than 75% of the large design problems are directly related to the causes of different CAD versions or systems, different file formats and conversions.

Therefore, it is necessary to bridge the gap between different applications and establish a high-performance data flow in such an environment. In the rest of this paper, recent research work achieving system interoperability and data portability has been reviewed. A data exchanging mechanism based on DIMP is presented toward the end.

2. STATE-OF-ART INTEROPERABLE RESEARCH

In recent years, research has been carried out all around the world to achieve an interoperable and collaborative environment with heterogeneous software applications. In the following part of this section, recent research works are reviewed and discussed.

2.1. STANDARDIZED FILE FORMATS

In the current industrial and economic context, heterogeneousness has become a noticeable issue for manufacturing enterprises. System integration and interoperability is addressed as one of the key needs that have to be achieved (Panetto and Molina, 2008). A widely recognized information model is in need, especially for a collaborative and distributed environment.

To work on multiple versions and views of a shared model, Sadeghi et al. proposed a collaborative architecture to allow experts to share and exchange design information (Sadeghi et al., 2010). In this architecture, product design is exchanged through a standardized constraint-based model to maintain complex relationships in multi-disciplinary collaborative design. Thanks to this data model, conflicts happening during synchronization process can be described and resolved via the notification mechanism.

Besides the design applications, research has also been taken to integrate the whole CAD/CAM/CNC chain. For facilitating a web-based design-manufacturing environment, Álvares and Ferreira proposed a web-based system using a data structure similar to ISO14649 data model (Álvares et al., 2008). In their system, files in neutral formats are passed along a serial software chain composed by WebCADFeatures, WebCAPP and WebTuring applications. To integrate more applications seamlessly and efficiently, Brecher et al. proposed an Open Computer-Based Manufacturing system (OpenCBM) (Brecher et al., 2009). In this system, standardized file formats are chosen to reduce the cost of data transferring and exchange.

In a heterogeneous environment, data exchanging is a challenging issue when proprietary software tools are integrated within the same architecture. Oh and Yee presented a method for semantically mapping different business documents to a conforming document format, given inevitable existence of multiple product representations (Oh and Yee, 2008). In this research XML format is adopted to support web-based applications and an SOA (Service-Oriented Architecture) model through web.

2.2. STEP/STEP-NC TO BRIDGE THE GAP

Since standardized format is a potential solution to realizing interoperability, research using international standard format is taken as well. STEP (the Standard for the Exchange of Product data (ISO, 1994)) is established to describe the entire product data throughout the life cycle of a product. STEP contains different Application Protocols (APs) which provide data models for targeted applications, activities or environments. Compared with previous standards, these data models offer a set of effective tools for CA-interoperability solutions (Gielingh, 2008).

Recently, a system named INFELT STEP was proposed to maintain the integration of CAD/CAM/CNC operations based on STEP data models (Valilai and Houshmand, 2010). In this three-layered system, different sections are defined in each layer to interface different CAD, CAPP/CAM and CNC software packages. INFELT STEP has a distinct capability of enabling collaboration of different enterprise-wide CAD/CAPP/CAM/CNC systems in the design and production of a product using multiple APs of the STEP standard.

In the past few years many companies have studied and introduced PDM, focusing on cost-cutting and shortening the product development cycle. To provide a solution via a common method of sharing standard product and design information, a STEP-compliant PDM system is developed to fulfil the demand for logically integrated product data which is stored physically in a distributed environment (Yang et al., 2009). In this system, STEP-based PDM schema is defined in XML format to support the web service connecting PDM systems of several partners through an open network accessible via the internet. As another utilization of XML, Makris et al. propose an approach providing efficient data exchanging in which the web is utilized as a communication layer (Chryssolouris et al., 2004). Combining STEP concept with XML, this work supports the integration of decentralized business partners and enables the information flow within the value added chain (Makris et al., 2008).

Moreover, the data model for computerized numerical controllers, which is also known as STEP-NC (ISO, 2003), was established as an international standard in 2003. As a data model to connect CAD/CAM systems with CNC machines, STEP-NC completes the integrated loop of CAD/CAM/CNC. It has been proven that STEP-NC provides contribution to both system interoperability and data traceability (Asiabanpour et al., 2009). Hence, it becomes possible to implement interoperability in a STEP/STEP-NC complaint environment (Newman et al., 2008).

Nassehi et al. proposed a framework to combat the incompatibility problem among CAx systems (Nassehi et al., 2008). In this framework, STEP-NC data model is utilized as the basis for representing manufacturing knowledge augmented with XML schema while a comprehensive data warehouse is utilized to store CNC information. The platform is further explained in (Newman and Nassehi, 2007). The system consists of manufacturing data warehouse, manufacturing knowledgebase, intercommunication bus, and diverse CAx interfaces as main structures. Mobile agent technology is used to support the intercommunication bus and CAx interfaces.

Recently, Mokhtar and Houshmand (Mokhtar and Houshmand, 2010) studied a similar manufacturing platform combining with the axiomatic design theory to realise interoperability among the CAx chain. Two basic approaches are considered, utilizing interfaces and utilizing neutral format based on STEP. The methodology of axiomatic design is proposed to generate a systematic roadmap of an optimum combination of data exchange via direct (using the STEP neutral format) or indirect (using bidirectional interfaces) solution in the CAx environment.

Besides the approaches mentioned above, there are methods developed to strengthen the interoperability along STEP/STEP-NC based CAD/CAM/CNC chain. For instance, Vichare et al. developed data models to describe all the elements of a CNC machine tool (Vichare et al., 2009). In this approach called UMRM (Unified Manufacturing Resource Model), machine specific data is defined in the form of an STEP-compliant schema. This data model acts as a complementary part to the STEP-NC standard to represent various machine tools in a standardized form, which provide a universal representation of the manufacturing information at the tail of CAD/CAM/CNC chain.

3. PRODUCT DATA EXCHANGING MECHANISM VIA DIMP

Although using STEP/STEP-NC is a possible solution to achieving system interoperability, some drawbacks can be observed at the same time. Since the key concept of STEP is to provide an integrated information resource, it may bring up synchronization and confidentiality issues. In the modern industry, manufacturing business is normally conducted cooperatively. When the same type of product is manufactured or provided by different suppliers or sub-contractors simultaneously, it is necessary for these suppliers/ sub-contractors to communicate with each other, and to achieve synchronization and traceability. Moreover, when a product is manufactured by different suppliers one after another, a serial data flow forms. Passing an integrated product data package along the supply chain may breach the confidentiality requirement of the suppliers, especially the one on the upper data stream. To combat these synchronization and confidentiality issues, a data exchange mechanism is designed based on a Distributed Interoperable Manufacturing Platform (DIMP) to minimize data exchange and data transfer.

3.1. SYSTEM ARCHITECTURE OF DIMP

DIMP is proposed to achieve an interoperable environment integrating multiple CAD/CAM/CNC software packages (Wang et al., 2010). In DIMP, a Service-Oriented Architecture is utilized to fulfil the generic demands from the users directly (Figure 1). Initially DIMP collect the users' request and generate a service request list in a pre-defined document format. Based on this list, the platform allocates related software packages and product document, and then organizes them as a serial of software service before it is passed to the user. From the user's point of view, the process can be concluded as "request, find, bind and provide", which is detailed discussed in (Wang and Xu, 2011).

As shown in Figure 1, the platform consists of three main modules which are Supervisory Module, Database Module and Application Warehouse Module. Supervisory Module (SM) plays as the global control centre of the platform, which is detailed discussed in. After the user's request being collected, SM analyzes the request list and generates an optimized service list to achieve this request. In the Application Warehouse Module, software tools are repackaged based on the functionality as Application Modules (AMs), which are developed to be self-contained and executed autonomously. Based on the service list, selected AMs will be meshed as a "Virtual Service Combination" and delivered to the user to fulfil his/her own need.

In the Database Module, all the information of the AMs are defined and stored, such as basic functionality description, input/output type, authorization level and etc. Such information will be mapped to the user's request list and analyzed by the Supervisory Module before appropriate AMs are selected and delivered. Besides the AM information, DIMP's database contains Project/Product documents as well. Along with the native data format of AM's, the product data are also saved in the STEP and STEP-NC neutral data format for archiving purposes. As mentioned above, despite the advantage of STEP/STEP-NC data format, intelligent property protection issues still exit, thus a collaborative product data exchange mechanism is designed and developed.

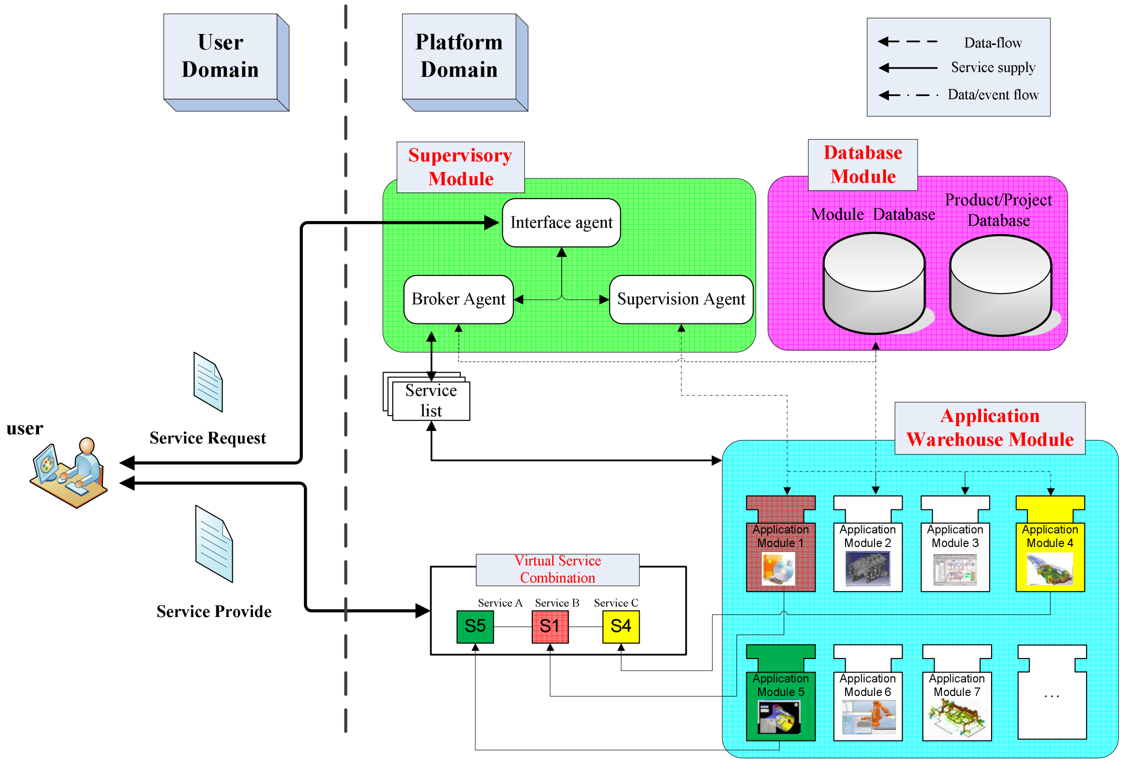

Figure 1. Service-oriented DIMP architecture (Wang and Xu, 2011)

3.2. *COLLABORATIVE PRODUCT DATA EXCHANGING MECHANISM*

As mentioned above, when a number of suppliers, contractors and sub-contractors are working on one project cooperatively, it is even more important to overcome the synchronization and confidentiality issues. Based on DIMP, the concept of Data Packet (DP) is conceived. A DP is defined as a set of self-contained mobile cluster of data. The key concept of DP is to 'provide the right amount of data to the right people in a right manner'. Once the Service List allocates the data subset in need, the Data-Localization Mechanism extracts and generates a stand-alone file before it is packaged in the Virtual Service Combination. After the DP is processed by the user, the modified information needs to be updated. In this mechanism, DP is able to be "reassembled" back to the data source, which is defined as the Data-Integration Mechanism. In general, the goal is to develop an algorithm to identify the logical connections amongst different data subsets across different levels. According to these connections, a stand-alone file containing DP is generated and delivered to the user. In practice, since STEP/STEP-NC describes product information from an object-oriented perspective, it is possible to identify and extract data in a specific scope. This provides the user an interoperable environment to work on the appropriate subset of data. Then the synchronization issue mentioned above is relieved and confidentiality issue overcome.

3.2.1. Data-Localization Mechanism

The concept of DP is realized by the pre-/post-processors encapsulated along with the AMs. After the service list is generated by SM, the pre-processor will search in the database and locate the top level information assign by the work task. After the DP is located, all the related information is extracted and transformed into a self-contained file for the target application.

To realize the DP concept, it is required to extract and process a DP from a STEP physical file (ISO, 2002). However, since the instance of entities are defined in a text-based structure, it is necessary to re-describe the product information in the STEP files. Because STEP/STEP-NC describes the information in a task-oriented way using 'entities' and 'reference relationships', such logics can be described in a tree-structure, thus a meta-data model is defined to re-represent the product information from a Part 21 file. In this data model, the instance of entities stored in a STEP file can be denoted as 'Nodes' and the relationships between nodes denoted as 'Edges'. For one tree node, all the information defined in the original data source will be kept.

The process of DP's extraction process can be summarized as Figure 2. When the top level entity of a DP is assigned, this entity will be defined as the first 'Father Node'. All the information defined in the entity is transformed and kept as attributes of the Father Node. When the attribute is pointing to another node (Child Node), a temporary Edge will be built and attached to the Father Node. After Father Node's analysis is done, the mechanism will re-check the Service List. If the DP has got enough information according to the Service List, the system will withdraw unused temporary Edges and generate an executable STEP file based on the DP extracted. If the last Father Node has not reached the end of DP, which means the user requires more information around the Node, the system will allocate the Child Node attached on the Edge as the next Father Node and run the analyse process again until all the information in need is collected. By defining father-child logics, this mechanism enables user to access the right amount of data fulfilling his/her demand across various data levels. For instance, DP generator is able to provide the general information to the user such as the name and owner of a project, while the technical details, dimensions, and parameter information of a specific task can be packaged in DP as well.

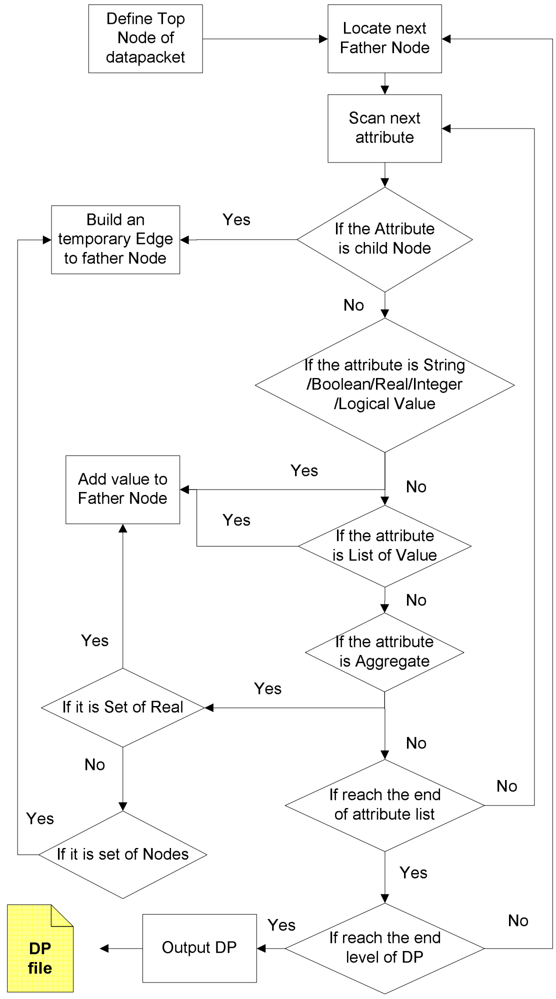

Figure 2. DP Analyze process

3.2.2. Data-Integration Mechanism

After the user finishes his/her job with the DP file, DIMP detects the output results and the post-processer is initialized before data packets are re-assembled to the data source since the STEP/STEP-NC stores the product data in an object-oriented way, which helps maintain the integrity of the data and reconnect the broken links between DP and original data source. In some complex cases, if multiple changes are applied to the same data set by different users, the Data Integration Mechanism will synchronize the changes and made a backup version for each of them in the Product/Project Database.

Thus the history of the product data is made traceable. To maintain consistent data semantics and syntax, a validation mechanism is in place.

As part of the post-processor, the validation mechanism detects the unreasonable parameters, such as too large/small dimensions for a manufacturing feature and ill-defined manufacturing information (e.g. minus diameter of a driller). Furthermore, harmonization between DP and data source will be validated as well. For instance, if the depth of a pocket is changed in the DP while the toolpath depth remains unchanged in the data source, the validation system will detect the conflict and send a warning message to the user. At completion of the validation process, the post-processor shuts down and a service-end message is delivered to the Supervisory Module before a new service is launched. Thanks to the object-oriented nature of STEP/STEP-NC, it is possible to develop the validation mechanism based on the concept of DP.

3.2.3. Case study

To implement the DP concept and evaluate the algorithm, a Graphical User Interface (GUI) is developed for the data exchanging environment. The test product information is stored in a STEP-NC file of ISO14649-11 example 2 (ISO, 2004). As illustrated in Figure 3, the first section of the part program is the header section marked by the keyword "HEADER" (Figure 3). In this section, some general information and comments concerning the project are given, e.g. filename, author, date and organization. The second and main section of the program file is the data section marked by the keyword "DATA". This section contains all the information about manufacturing tasks and geometries.

To develop the system, JAVA language has been chosen because of its interoperability amongst different platforms. The system is developed using Java Development Kit (JDK) in Java Runtime Environment (JRE). First of all, the STEP-NC physical file is read in by the system and interpreted in to the meta-data model, which is defined in a tree-structure. In this way, the text-based STEP-NC information is transformed into programmable classes which are capable of being analysed and processed. After receiving the control message from the Supervisory Module, the system searches in the structure tree and start the DP process.

Assume that a user requires viewing basic information about a MACHINING_WORKINGSTEP and detailed information of its feature called PLANAR_FACE. According to the service list based on the customer's request, the system first of all locates the top level of the DP and scans its entity classes. All the information of this entity is delivered to the new DP tree structure and the connections between this entity and others are tagged and recorded in the system.

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('ISO 14649-11 EXAMPLE 2',
            'COMPLEX PRORGRAM WITH VARIOUS
MANUFACTURING FEATURES'),'1');
FILE_NAME('EXAMPLE2.STP',
        …
        …);
FILE_SCHEMA(('MACHINING_SCHEMA','MILLING_SCHEM
A'));
ENDSEC;

DATA;
#1= PROJECT('EXECUTE_EXAMPLE2',#2,(#7),$,$,$);
#2= WORKPLAN('MAIN WORKPLAN',(#4,#5,#6),$,#14,$);
...
...
#7= WORKPIECE('PART 2',#13,0.01,$,$,$,(#9,#10,#11,#12));
...
#78=BORING($,$,'BORING_HOLE2',20.,$,#266,#270,#230,$,
15.,15.,$,$,$,.T.,1.,$);
...
#101=COMPOUND_FEATURE('COMPOUND_FEATURE_H
OLE2',#7,(),#371,(#108,#109,#110));
#108=ROUND_HOLE('HOLE2_FLAT_BOTTOM',#7,(#78),#36
9,#545,#546,$,#214);
…
ENDSEC;
END-ISO-10303-21;
```

Figure 3. STEP-NC data structure

After the first level of data is collected, the process of extracting next level of product information starts. The PLANAR_FACE feature "PLANAR FACE1" is set as the new Father Node and transmitted to the DP automatically. Then the system will continue the loop of data-collecting. When all the required information is extracted, the reference relationships between the DP and the rest of the file are saved in the Database Module for the future updating. Meanwhile DP data model is written back in the Part21 physical file format and saved to the system. As illustrated in Figure 5, the output file contains the exact amount of information requested by the user, and all the logic relationship between entity instances are kept intact.

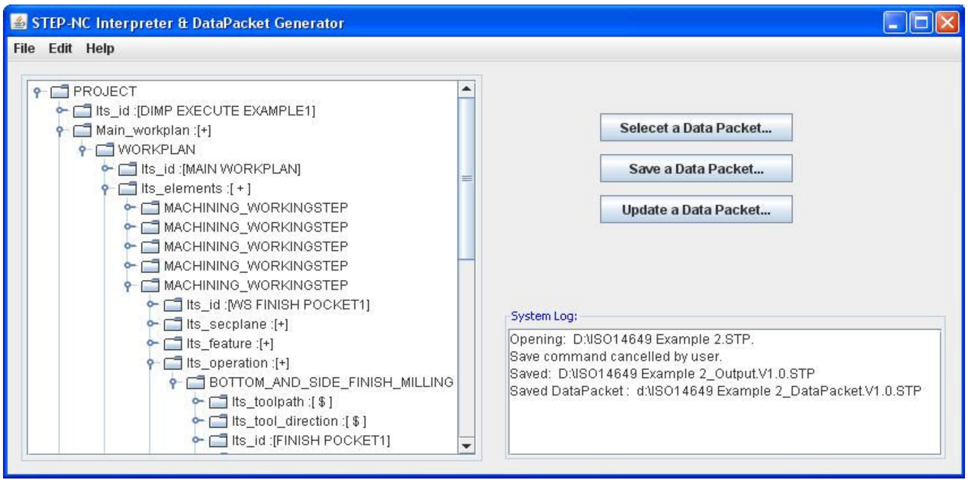

Figure 4. STEP-NC Interpreter/DP Generator

```
ISO-10303-21;

HEADER;
FILE_DESCRIPTION((''),'2;1');
FILE_NAME('DataPacketOutput.stp','2011-5-20T15:36:51+13:00',(''),(''),'ST-
Developer for Java 1.0','','');
FILE_SCHEMA(('COMBINED_SCHEMA'));
ENDSEC;

DATA;

#10=MACHINING_WORKINGSTEP('WS FINISH PLANAR
FACE1',#11,#13,#12,$);

#11=ELEMENTARY_SURFACE('SECURITY PLANE',$);
#12=PLANE_FINISH_MILLING($,$,'FINISH PLANAR
FACE1',10.0,$,$,$,$,$,$,$,$,2.5,$);
#13=PLANAR_FACE('PLANAR FACE1',#14,(#12),#15,#16,#17,#18,$,());

#14=WORKPIECE('SIMPLE WORKPIECE',$,0.01,$,$,$,($,$,$,$));
#15=AXIS2_PLACEMENT_3D('PLANAR FACE1',$,$,$);
#16=ELEMENTARY_SURFACE('PLANAR FACE1-DEPTH PLANE',$);
#17=LINEAR_PATH($,$,$);
#18=LINEAR_PROFILE($,$);
...


ENDSEC;

END-ISO-10303-21;
```

its_secplane
its_operation
its_feature
its_workpiece
feature_placement
depth
course _of_travle
removal_boundary

Figure 5. Output Data Packet file

4. CONCLUSIONS

Nowadays, manufacturing organizations are facing interoperation difficulties because of the heterogeneous data environment they are in and software vendors they are dealing with. Meanwhile product lifecycle management is challenged by the conflict Synchronization and Confidentiality issues. This paper introduces a novel Data-Packet concept to represent the product semantics via STEP/STEP-NC data model. The Data Localization/Integration mechanisms prove that it is practicable to process a data subset containing reasonable amount of information. These methods enable the users to work on product components across different levels of abstraction using different representations. Furthermore, users are able to synchronize the parallel modifications after the data subsets are processed in a distributed environment.

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