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Product data reuse in product development: a practitioner's perspective

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Abstract. Although much PLM implementations and research have focused Q1Qon data storage and management, real value of data is achieved through its reuse, as data is considered to be an asset that acquires its value only by its consumption [1].The general data reuse process is described and two variants identified: 1) data reuse that results from stakeholders' personal initiative; and 2) organization-driven data reuse. The data reuse process can lead to two positive outcomes: either the data is reused as-is or it is evolved/adapted to a new context. The data reuse process is analyzed and decomposed into a series of activities. Challenges associated with these activities are identified. Some of these challenges are analyzed so as to identify their constraints and their enablers – one of which is data spreading among multiple information systems (PLM, ERP, MPM, file systems, etc.). This paper therefore helps identify the steps toward improving data reuse.

Keywords: Data Reuse, PLM, Product Development, Data Value, Product Data

1. Introduction.

Reuse is a natural reflex embedded in our thinking process from when we first started owning tasks as children. Reuse can be considered both as a resourceful behavior and as a sign of intelligence, hence, instructors frequently advise their students not to re-invent the wheel.

If we consider the product development process, we observe that data reuse is a natural reflex for most designers. However, even though PLM vendors stress the data reuse argument to promote their solutions, information structure itself often limits efficient information reuse.

Prior research works focused on sub-activities of the data reuse process, such as: design data explosion [2], design knowledge formalization [3], similar design data retrieval [4] and design data modeling [5]. Lund et al. [2] propose the storage of design variations as metadata in order to leverage speed and versatility of the database.

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A generic schema for parametric objects has been created to efficiently store designs in two parts—a master model and the variation data. This approach was deployed on "Teamcenter engineering". To confirm this work we remarked through several tool benchmarks that some current PLM tools don't allow the storage of assembly constraints. From another perspective, other PLM tools editors are working to explode design data to allow it's storage in the database and improve its accessibility. This required major changes to their CAD tools data model.

Dante Pugliese et al. [3] proposed an approach based on a specific coding of parts and assemblies. The code represents the main information on specific component and why the component is created in a particular manner. For example, a shaft should be coded using numbers for the dimensions, but also alphanumerical characters, which provide information on the morphology, assembly procedures, adaptability for a specific use, and soon. The coding approach proposed by this paper is similar to what's known in industry by "Smart Numbering". It was used in for many years in the past when companies were paper based and it was difficult to store relations between documents and objects. The issue related to this approach is that it's impossible to standardize all types of features and relations. From a data reuse perspective, we can't dissociate those information's from the intrinsic properties of the object.

Jin et al. [4] proposed a solution to improve design data retrieval by adding engineering semantic information into an existing parts library using an engineering semantic web (ESW). This approach is one that some PLM editors started to market as part of their PLM portfolio. One of the common tools is "Exalead" product of Dassault Systemes.

Lacroix [5] proposed a different approach where the geometry and the constraints expressed in STEP are the core of the data representation, to model and query data within a mechanical engineering reuse system whereas its regular usage is for data exchange.

These research works focus on specific aspects of the vast data reuse objective. However, there is a need to contemplate the end-to-end data reuse process so as to help engineering firms achieve the expected ROI. This paper proposes a practitioner's perspective, built from industrial observations of PLM tool implementations made while consulting with different aerospace companies. We aim at formalizing the data reuse process and activities, as well as at identifying its key challenges. This will be a starting point toward a global thinking to improve the data reuse process, combining current approaches and tools. Before exposing the practical view of product data reuse within a PLM context, a description of the basic data reuse process and its challenges are presented. A context definition and overview of the basic concepts are described.

a. What is Data reuse?

According to the software engineering discipline, design reuse is the process of building new software applications and tools by reusing previously developed designs. New features and functionalities can be added by incorporating minor changes. Design reuse involves many activities utilizing existing technologies to cater to new design needs. The ultimate goal of design reuse is to help developers create better products, maximizing value with minimal resources, cost and effort [6]

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In information technology, design reuse is the inclusion of previously designed components (blocks of logic or data) in software and hardware [7]

In product development, design reuse is the process of designing new products by reusing data and information from existing products. We consider that design reuse in product development can be categorized into one of two types: Partial Reuse and Complete Reuse. In the first category, only a portion of the information is reused from existing products, while for the second category all the information is reused.

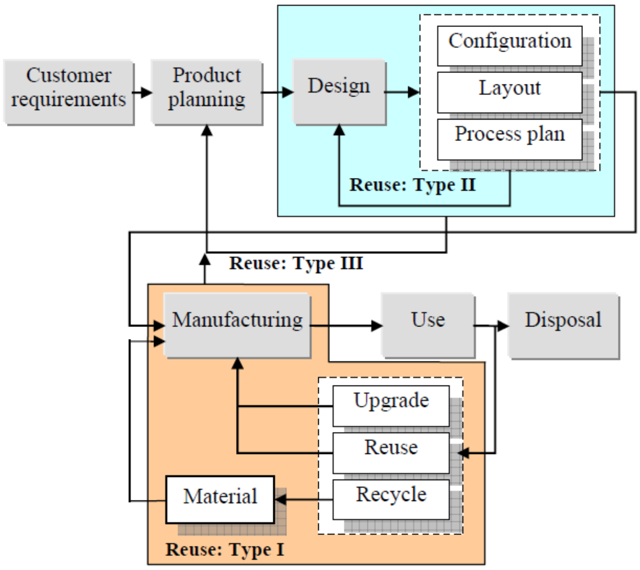

Figure 1. Type of design reuse in the product life-cycle, [8]

Based on the objects to be reused, three types of design reuse can be defined (Figure 1):

- End-of-life product reuse: the reuse and recycling of obsolete products so that they return to the product lifecycle (Type I);
- Reuse of existing manufacturing resources: the reuse and sharing of production processes (Type II); and
- Reuse of product information and design knowledge: a prerequisite for the two previous types of reuse because design ultimately determines the extent to which products and manufacturing resources can be reused (Type III).

The current paper focuses on the third type, specifically product information.

b. Why is Data reuse important?

Before exploring design reuse in a PLM context, its necessity is described below [8].

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Necessity

In today's market, no enterprise can afford the time and resources to design an entire product without reusing previous product design data. The reuse of existing knowledge is critical for design rapidity and continuity and has a direct impact on the time to market.

A simple example is template creation in Microsoft Word. Sometimes we spend a few hours to create a new document template, but once it is created, it becomes very useful and simplifies new document creation.

The design process can be decomposed into two main phases: the planning/thinking phase and the execution phase. The first phase is especially appreciated by most designers because it is a creative process in which they define what they want to create with greater freedom. The execution phase is where the output of the first phase is converted into a formal deliverable understandable by everyone. One of the key values addressed by the design reuse process is that it is should be integrated with the requirements management process [9]. This assumption can significantly increase the benefits that companies might receive from an efficient design reuse process.

c. What is reused: Data, Information or Knowledge?

Data, information and knowledge were clearly and hierarchically defined through the DIK model [10] and other research works such as reference [11] .The general term which is frequently used when talking about reuse in a product development context is "Data". The

d. PLM and data reuse.

Before the reuse process can be presented in detail, we clarify what, among data, information and knowledge is reused in a PLM context.

Product data and information are kept and managed by current PLM tools, but that is not the case for "Knowledge". Based on practical experience with PLM tools, we have observed that most do not capture "knowledge". A concrete example is "intelligent 3D models", known as "Knowledgeware". When a designer changes a set of parameters, the 3D model and some related features are automatically updated based on predefined technological rules. The PLM tool keeps the 3D model result of the automation, but the technological rules are not exposed. Technological rules are embedded in the 3D model's document and can be edited only by the CAD tool. To overcome this gap, most current PLM tools have the capability to manage links and relationships between and among different information sources. Some examples of these are document-to-document links, parent and child links, part and document links, etc…

This paper does not focus on classifying what is managed by PLM tools. In the following sections we use the term data to represents "data", "information" and "knowledge", which is how it is most commonly used in PLM.

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2. Data Reuse Process

The data reuse process model has been described in a number of research works [12], [13], [14]. One model, illustrated in Figure 2, consists of three processes and six knowledge resources [8]. The three processes are: Design by reuse, domain exploration and design for reuse. The six knowledge resources are: Design requirement, domain knowledge, reuse library, domain model, evolved design model and completed design model [15].

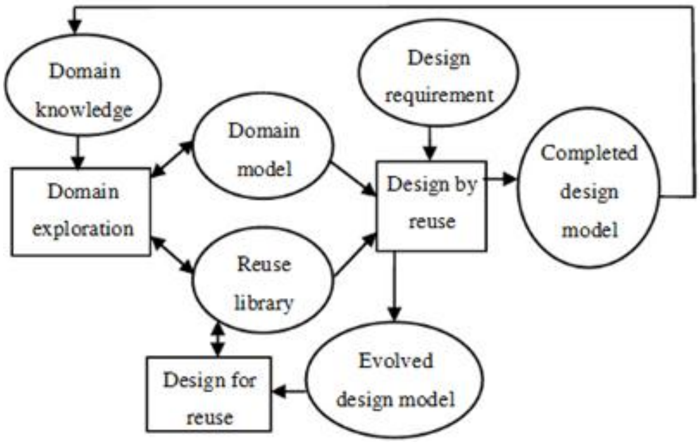

Figure 2. Design reuse model [15]

According to reference [6] two inter-related process methodologies are involved in the systematic design reuse process model:

1. Gathering Information: The process of collecting information, processing and modeling to assemble related data; and
2. Information Reuse: The effective use of data.

The design reuse process has four major components: 1) Retrieve, 2) Reuse, 3) Repair and 4) Recover.

Details presented as well the approach by which the design reuse model was described in Figure 2 are not sufficient to identify process challenges.

We were fortunate to have come across different data reuse processes, thanks to having had the opportunity to work on different PLM project initiatives and implementations at different aerospace businesses. The next section presents our practitioner perspectives on how the data reuse process is decomposed. IDEF0 methodology was used to describe the reuse process activities.

a. Unplanned (ad hoc) Reuse

Unplanned (or ad hoc) reuse is user-driven. According to our observation and analysis of industrial use-cases, unplanned reuse counts three main variants: use the

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data as is, evolve it and keep the link, or evolve it without the link. Furthermore, we propose to divide unplanned reuse process into the following steps (Figure 3):

1. **Define criteria**: Based on new requirements/specifications and on experience, the user defines the criteria required in order to search for similar data. For example, a process planner chooses to search for an existing process plan of a new part based on material, tolerances and geometry.
2. **Search**: Based on the defined criteria, the user searches for similar data within the knowledge domain (existing data). The output of this activity is a list of potential data to be reused. In the above example, the process planner obtains a list of potentially useful process plans, some of them respecting all of the new part tolerances.
3. **Select and decide**: From the potential data to be reused, the user selects the appropriate data and estimates if it will be reused as-is or if it needs to be evolved. Company policies about reuse have a direct impact on this activity. For example, data reuse is sometimes prohibited between commercial and military products.

4. a. **Reuse as-is**: Obviously, in this case the data has been decided to be used as-is. The data is incorporated in the new context without modification. This data is then classified as "common data".

4. b. **Evolve with link**: This route is preferred if a significant amount of the selected data is common and will not be modified. The data is duplicated and the link to the original data is maintained. The data is then incorporated in the new context.

4. c. **Evolve without link**: If the data needs to be radically modified, it is duplicated and the link with the original data is broken. The modifications to the data are then carried out. In the above example, the process plan of the new part would be created from the selected process plan.

5. **Complete development**: The data is completely evolved (adapted) according to the new context requirements.
6. **Measure** (when there is data evolution): The data reuse benefits are measured in terms of time, cost and quality.
7. **Maintain**: Data used as-is or evolved with its link to the original data is classified in a common library. This action represents the process of managing changes made to the reused data as well as the links between original and evolved data. When a change is proposed to a block of common data, an impact analysis is done and approval is required from all the impacted data consumers.

b. Planned Reuse

This type of reuse is business-driven. This type of reuse is part of a product program's requirements and it is frequently initiated within the same product family, most often as a cost reduction strategy. Usually, the components of the product to be reused are specified. We propose to divide the planned reuse into the following steps (Figure 4):

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1. **Get the purpose**: This first step performed at the project or business level, is where the new requirements and the target data to be reused are identified, as well as the reuse objectives. So as to achieve cost reduction, the project owner defines the criteria required to analyze the reuse feasibility. For example, the project directive requires that engines A from such existing aircraft program be reused.
2. **Feasibility study**: Based on existing data as well as on the defined criteria, this step implies that the assigned individual analyzes the reuse feasibility before acceptance. A simulation of reusing the target data is performed and the potential impacts of reusing the target data are captured. Other criteria are also analyzed, such as data availability and data reuse policies. In the above example, the designer conducts a performance analysis on engines A and find that they can't be reused as is.
3. **Confirm reuse**: This activity consists of approving the reuse feasibility to the initiator and defining which data is to be reused as-is versus which needs to be evolved. The reuse percentage can be estimated. For some aerospace products, the intent could be to reuse 100% of one of the assemblies, but after analyzing the feasibility only 80% may be confirmed for the product program team.

4\. a. **Reuse as-is**: (same as section 2.a).
4\. b. **Evolve with link**: (same as section 2.a).
4\. c. **Evolve without link**: (same as section 2.a).
5\. **Complete development**: (same as section 2.a).
6\. **Measure** (in the case of evolution): (same as section 2.a).
7\. **Maintain**: (same as section 2.a).

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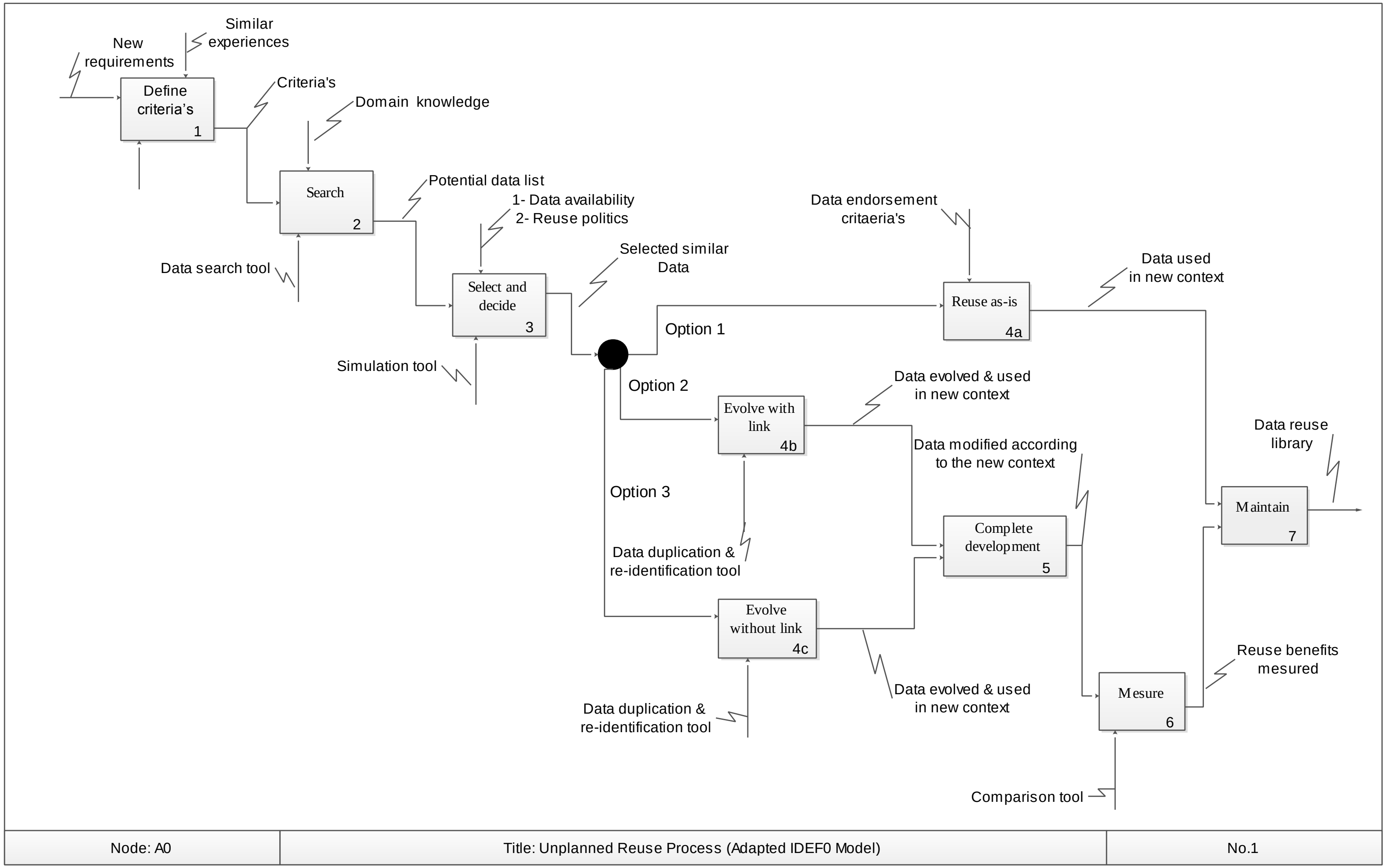

Figure 3. Unplanned reuse process

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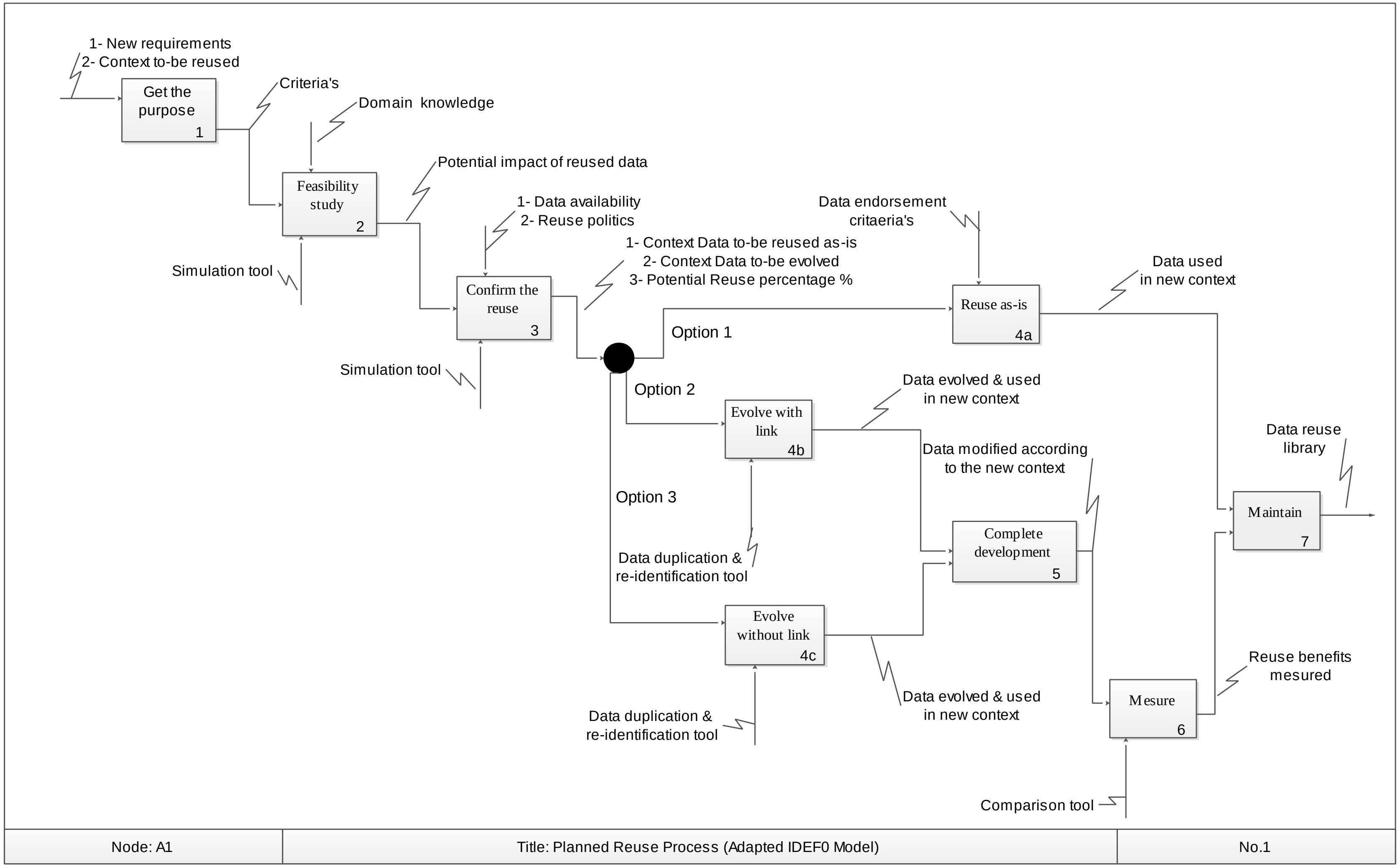

Figure 4. Planned reuse process

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3. Data Reuse Use-Cases and Challenges in a PLM Context

a. Data Reuse Use-Cases

Based on observations of industrial PLM project implementations, we have developed a list of some common data reuse use-cases:

1. Released assembly is reused as-is within the same product structure (context).
2. Released assembly is reused as-is in a different product structure.
3. Released assembly is evolved and reused in a different product structure while maintaining the link with the original one.
4. Released assembly is reused in a differently-configured product structure and evolved, while maintaining the link with the original one.
5. Released process plan is reused in a different product and evolved without maintaining the link to the original process plan.
6. Non-standard existing approval process (workflow) is reused on a part in a different context.
7. Product requirements are reused in a different context.

Due to pages length limitation, only examples of the 2nd and 3rd use-cases are described in the current paper.

Use-Case II: Released Assembly is reused as-is in a different product structure.
The purpose here is to reuse a released assembly “Assembly 1” in a different product, “Product 2” (Figure 5). In PLM this operation is commonly called “instantiation”. It implies reusing “Assembly 1” from “Product 1” without changing its definition. Although the concept of instance has existed for many years, some companies still do not make use of it, and it is not part of the data model of some IT systems. For those situations, the data is attached to the product context for which it was created and it is owned and released under that product context. In such cases, there is a real challenge to reuse “Assembly 1”, because if it was released under “Product 1’s” context it must then be re-released under “Product 2”. One of the strategies to overcome this process/tool limitation is to do a fictive release by adding the following note: “Assembly 1” noted as released under “Product 2”.

Use-Case III: Released Assembly is evolved and reused in a different product structure while maintaining the link with the original one.
The purpose of this use-case is to duplicate “Assembly 1” into “Assembly 1E” as well as its child’s “Part 1” and “Part 2” and their related 3D & 2D documents (Figure 6). “Assembly 1E” is then instantiated under “Product 2”. According to industrial observations with PLM tools, this capability is only partially fulfilled. Some of these tools allow Bill-Of-Material (BOM) duplication by re-identifying all the structure, while others accomplish this by re-identifying only the top level Assembly. The missing capability is related to both 3D and 2D document duplication while evolving their links. This activity is frequently done separately by the user, and it can become very complex, especially when document-to-document links exist. For example, the 3D document of “Part 1” has a link with the 3D document of “Part 2”. This link has to be updated after “Assembly 1” evolution to obtain a link between the 3D document of “Part 1E” and “Part 2E”.

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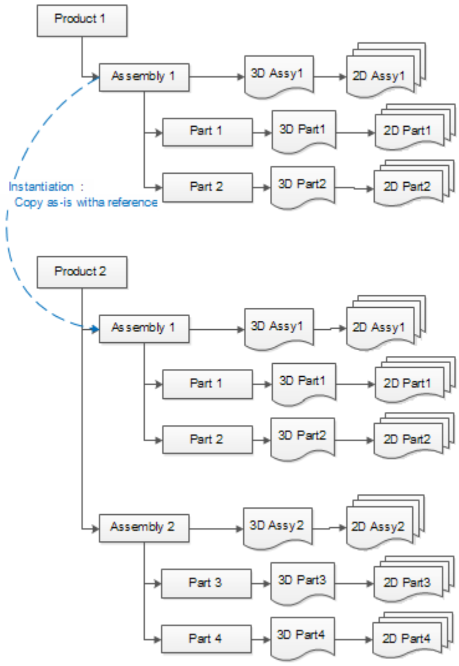

Figure 5. Released Assembly is reused as-is in a different product structure

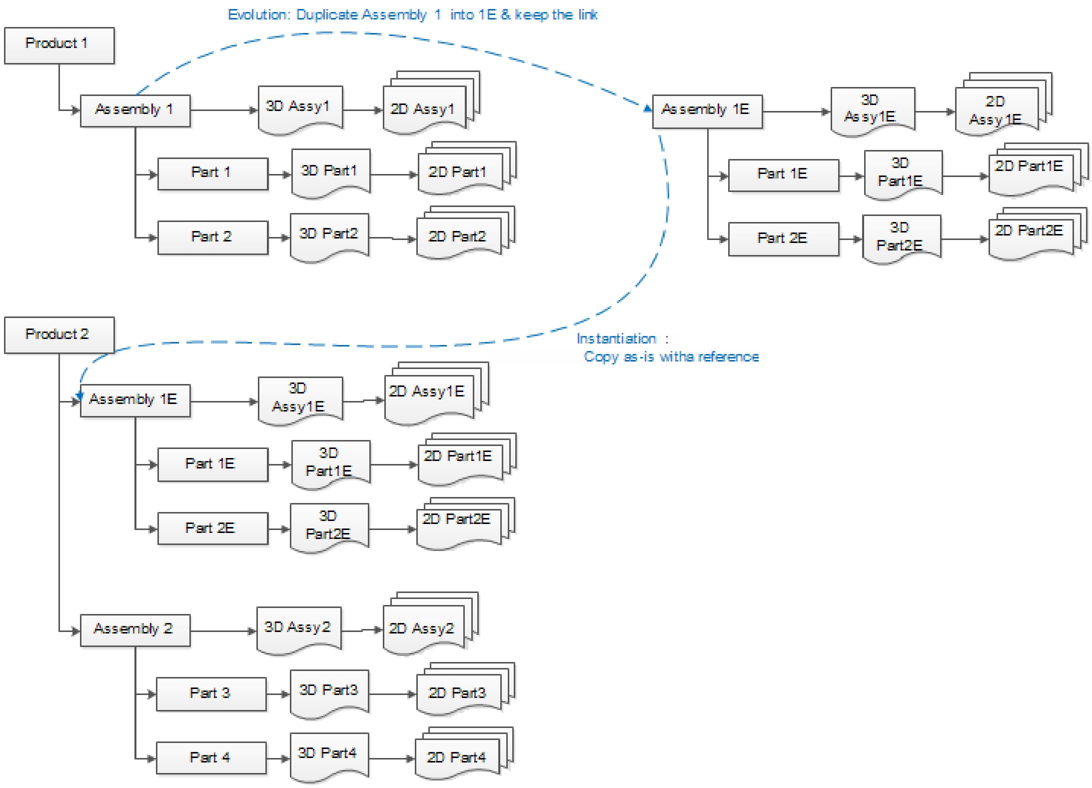

Figure 6. Released Assembly is evolved and reused in a different product structure while maintaining the link with the original one

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b. Data Reuse Challenges in a PLM Context?

The following items document some of the key reasons why data reuse in a PLM context is difficult.

In traditional product development, each project has its own cost; but data reuse benefits are global for all projects. In some cases more time could be spent to create and to structure data in a reusable way for a first project in order to simplify the reuse for subsequent projects. The challenge that arises relates to the cost and benefit of structuring something, so as to promote reuse, without being sure that reuse will be achieved.

Data reuse is not a systematic approach in many companies' product development process; they may have no framework for data reuse and it is not a part of the company culture. In some cases data reuse plays a role in new product development initiatives, but there is not yet a formal approach to achieve it.

The PLM solutions now available are characterized by efficient data sharing processes supporting collaboration within extended enterprises. They still lack the essential capabilities that would facilitate the reuse of design process knowledge such as identifying similar workflows [16].

Current PLM systems are based on creating links between objects such as parts and documents, process plans, test reports, and so on. One of their main purposes is to capture all intermediate links between a customer's specifications and an inspection of the characteristics of the manufactured part. With an object-link-based approach it becomes difficult to organize partial data reuse: reusing objects partially, requires their isolation, re-identification and disconnect from the previous domain by keeping a link with the original one. Within this activity, previous object-links should be evolved. For example, reusing partially an existing process plan is a complex task. It should be first duplicated under a new name, links between process plans operations should be evolved, and connection with previous engineering part have to be cut.

Product Data reuse is promoted as part of the key benefits of PLM tool through different software modules such as Product Portfolio Management, BOM Management, Enterprise Knowledge Management,…Having the opportunity of practicing these modules we considered essential to differentiate between the following concepts: reusing data between product configurations versus different products. The first type is supported by functionalities offering the creation of "Product Configurations" or "Product Variants". The second type is more complex and difficult to implement because the concept of configuration could be used only within the same product family and not between different product families.

The different data models and locations of PLM systems and other data management tools such as ERP (Enterprise Resources Planning) and MES (Manufacturing Execution System) make data reuse a very complex task. For example, when evolving data within the PLM system, the same activity has to happen in the equivalent system that 'owns' the related data, and associations between the two need to be rebuilt.

Processes and tools to maintain data tagged as "reused" or "common" are lacking in most PLM tools. Some capabilities are offered, such as retrieving where the data is used or adding attributes like "Common Data". One factor reinforced by this limitation is "data format evolution". CAD data formats evolved significantly over the last 10 years; this has led to there being different formats at the same time for the same part. One well-known example is CATIA V4 model versus the CATIA V5 model versus the V5 MBD model; each of these CAD data models defines the same part.

A major factor participating in slowing-down product data reuse is product development budgets: Most of the aerospace companies are allocating budgets for product development by specific program or program family that will automatically inherit the ownership of all the created product data. A new program requiring the reuse of data from an existing product will be considered as a slave and could not change the data

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without the approval of the program owning it. To overcome this situation, an enterprise programs governance model should be implemented. It will extend the ownership of the budgets and data from the program to the enterprise level.

4. Conclusion

The current paper gave a practical view of the data reuse process within a PLM context. To highlight the lack of formalism related to product data reuse in a PLM context we considered essential to describe two main situations: “unplanned reuse” and “planned reuse”. This will help build specific methodologies and tools per data reuse activity and challenges. Common PLM reuse process use-cases were presented and key challenges related to the data reuse process as well as their enablers were highlighted. The current paper introduced the classification and documentation of the reuse process problem in a PLM context to allow future analysis of possible solutions. Other practical views related to the reuse process were not discussed such as the “ROI”: in any reuse process initiative, a cost-benefits analysis is required in order to justify the related investment.

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