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EXPLORATION OF COLLABORATIVE DESIGN SPACES: ENGINEERING INTERACTIONS AND WORKFLOWS IN PRODUCT DEVELOPMENT

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EXPLORATION OF COLLABORATIVE DESIGN SPACES: ENGINEERING INTERACTIONS AND WORKFLOWS IN PRODUCT DEVELOPMENT

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ABSTRACT

Product Lifecycle Management (PLM) initiatives can improve an enterprise's efficiency by increasing collaborative design opportunities within its business structure. PLM solutions provide digital mediums to collaborate on all aspects of a company's workflow, including engineering, testing, manufacturing, marketing, business, and field support services. This paper examines the major PLM tools and software used to establish a collaborative engineering design space; computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), and product data management (PDM). The interactions between these PLM tools and a design team's organizational structure are analyzed to determine some of the most effective PLM integration strategies to improve collaboration for all business functions. Engineering enterprises may split their work functions into technical and non-technical categories and match them with PLM solutions to create a collaborative design space that integrates all departments. A case study presents a university design team whose objective was collaborative creation of a digital twin for a scale tracked vehicle. The Siemens Teamcenter software tool was integrated within the team's design procedures to improve the process. The results of integrating advanced PDM software into their workflow, including troubleshooting issues and problems, were explored in this paper. PDM and workflow interactions throughout the case study produced many unique outcomes that require additional PLM engineering solutions. Overall, advanced PDM software increased collaboration and efficiency of their design process.

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CHAPTER ONE

INTRODUCTION

Over the 21st century, product lifecycle management (PLM) initiatives have swept the engineering industry, with more companies transitioning to digital collaborative design methods over existing engineering design strategies. With enterprises realizing the wealth of possibilities for PLM systems and how they will change their organizational structure and capabilities, engineering design processes have changed dramatically, from a traditionally closed environment to incorporating multiple departments into a collaborative design space. The shift in mindset towards a collaborative design process produces many issues, such as engineering productive workflows to include all aspects of a business. Integrating PLM initiatives into an existing engineering design process can also cause problems due to poor assimilation into the current business structure. Some of the issues associated with integrating PLM into current product development processes are analyzed in this paper, with a few of the most critical obstacles studied further in an educational case study. The resulting analysis features research on PLM tools and how they assimilate into engineering design processes to form a collaborative design space.

Product Lifecycle Management is a virtual thread for an enterprise’s workflow, bringing together all business functions to increase the efficiency of a company’s operations. A business may implement a PLM system for many reasons with multiple objectives and goals. At its core, PLM is a product management system that incorporates a business’ entire product portfolio into a central operating system. One main objective of implementing PLM into a business’ workflow is to improve product performance by developing efficient relationships between its functions, such as human resources, marketing, engineering, manufacturing, and field service. A product's lifecycle, ranging from its design to testing and manufacturing, is displayed in Figure 1.1.

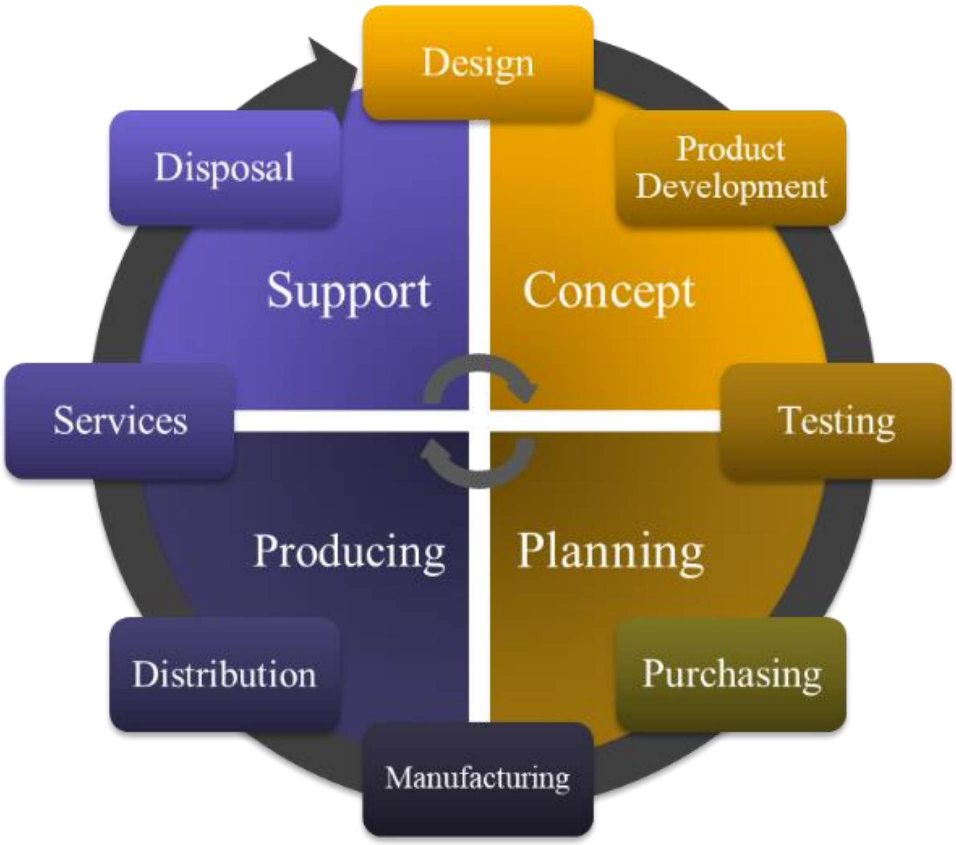

FIGURE 1.1: Common tasks comprising the lifecycle of a product

The product's lifecycle contains numerous supplements from multiple different business functions. The goal of PLM is to manage these stages of a product's lifecycle, decrease product cost, increase product revenue, and maximize the value of a business's product portfolio for the customer. PLM solutions provide a range of management and engineering tools that are utilized by all business departments to increase the efficiency of product management and reach their long-term goals [1].

PLM initiatives have applications in many different industries. An essential aspect of using PLM software in the aviation industry is the optimization benefits for servicing and repairing aircraft to ensure airline and passenger safety [2]. In the energy sector, Failla *et al.* [3] researched how oil and gas businesses use PLM solutions to manage manufacturing bills of materials for turbomachinery. Product management tools such as the bill of materials are a vital aspect of PDM software that is discussed further in this paper. A key outcome of utilizing PLM software for product development is the creation of a digital twin. In the production of electric vehicles, digital twins of lithium-ion battery packs are used to simulate extreme conditions and "improve the safety and service life of the battery packs" [4]. Pollard *et al.* [5] describe how the electrical and electronic (E&E) sector was subjected to research on how PLM initiatives fit into the circular economy paradigm. Many common themes involved in PLM, such as resource management, product-life extension, reuse, and waste management, are also involved in developing circularity indicators for "measuring and monitoring the circularity of E&E products" [5]. In addition to PLM's application to physical products, virtual engineering research by Morshedzadeh *et al.* [6] uses PLM systems to create a new information model to house virtual models of historical artifacts from an automotive company. With an extensive network of applications for PLM systems, researchers are focusing on how to implement PLM solutions in engineering enterprises.

Implementing PLM solutions into an existing business infrastructure can come with its challenges. For example, Anandavel *et al.* [7] discuss how migrating data and information from existing storage networks to cloud PLM solutions is "a challenging task which demands overall change management in the organization." Incorporating change management into an enterprise is an important issue that will be examined in the case study later in this work. Another problem with implementing PLM systems is providing proper data access to all contributors to an enterprise's collaborative design space [8]. Data access management requires a mapped network of all employees and certain privileges granted to each in all PLM software. Conlon [9] shares how the traceability of changes within a workflow allows a business to track fundamental alterations and the present status of a product. PLM solutions use traceability systems to manage a product's versions, so all departments of an enterprise can utilize current product data and track previous versions to use in upcoming product development [9]. An additional critical issue with implementing PLM systems into a business' infrastructure is integrating each of the PLM software to form a cohesive network. Information technology experts are required to tackle the complete setup of these systems while integrating them within the existing data framework. Several of these challenges will be examined and discussed in the case study section of this work.

An essential aspect of implementing PLM systems into a business' engineering design process is understanding how each department within the organization can interact to achieve their financial, performance, and customer goals. An enterprise's organizational structure is what changes its PLM initiatives. For example, certain businesses may need more PLM solutions than others, ranging from computer-aided design and engineering software to product data management software. The organization's structure also dictates how each PLM tool integrates with others within each department. Figure 1.2 visually represents the main aspects of an enterprise's organizational structure. Within the organization model, some departments cover every part of a company's needs, including engineering, manufacturing, and marketing. Similarly, to Figure 1.1, these departments encompass aspects of the engineering design process and product lifecycles such as design, testing, manufacturing, and services.

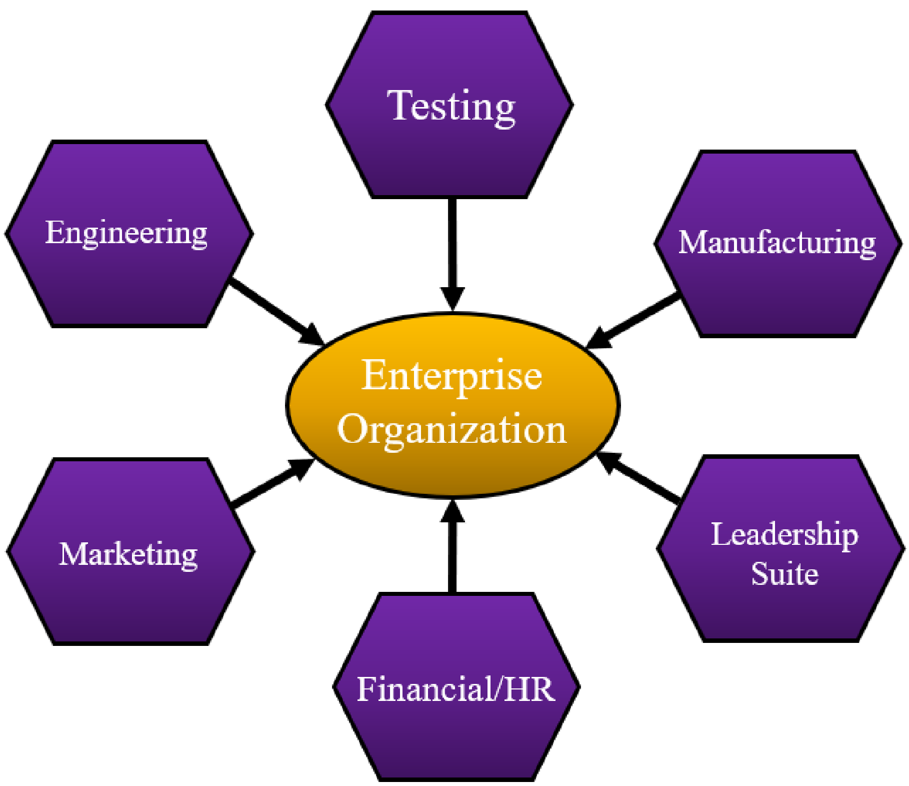

FIGURE 1.2: Traditional departmental roles within an enterprise before PLM implementation

Before the early 21st century PLM initiatives, the business structure looked very similar to Figure 1.2. Each department contributed individually to the overall success of the enterprise, with limited collaboration between them. Each aspect of the business, from product development to manufacturing, to distribution and services, was tackled by individual departments. With limited collaboration between departments, business functions often transpired slower and less efficiently than after PLM implementation. PLM initiatives changed how businesses were structured by integrating all departments into a common thread to collaborate on each business function. Many improvements to companies' business functions were made from PLM initiatives, including increased communication and collaboration on every aspect of the product development process. PLM initiatives combine some of the responsibilities in each department to create a collaborative design space that improves the efficiency of the engineering design process and decreases overall product cost. As Stark [1] described, PLM initiatives involve "the activities of managing a company's products … in cross-functional business processes across the product lifecycle." The idea of transforming a business from an individualistic, functional unit to a "cross-functional business" has made them successful across all business units.

As PLM initiatives were frequently implemented across the engineering and product industry, the organizational structure changed dramatically from enterprise to enterprise. Companies implemented different PLM solutions based on their needs. As a result of these changes, collaboration amongst departments within businesses increased. Some of the most significant alterations of an enterprise's organizational structure are shown in Figure 1.3.

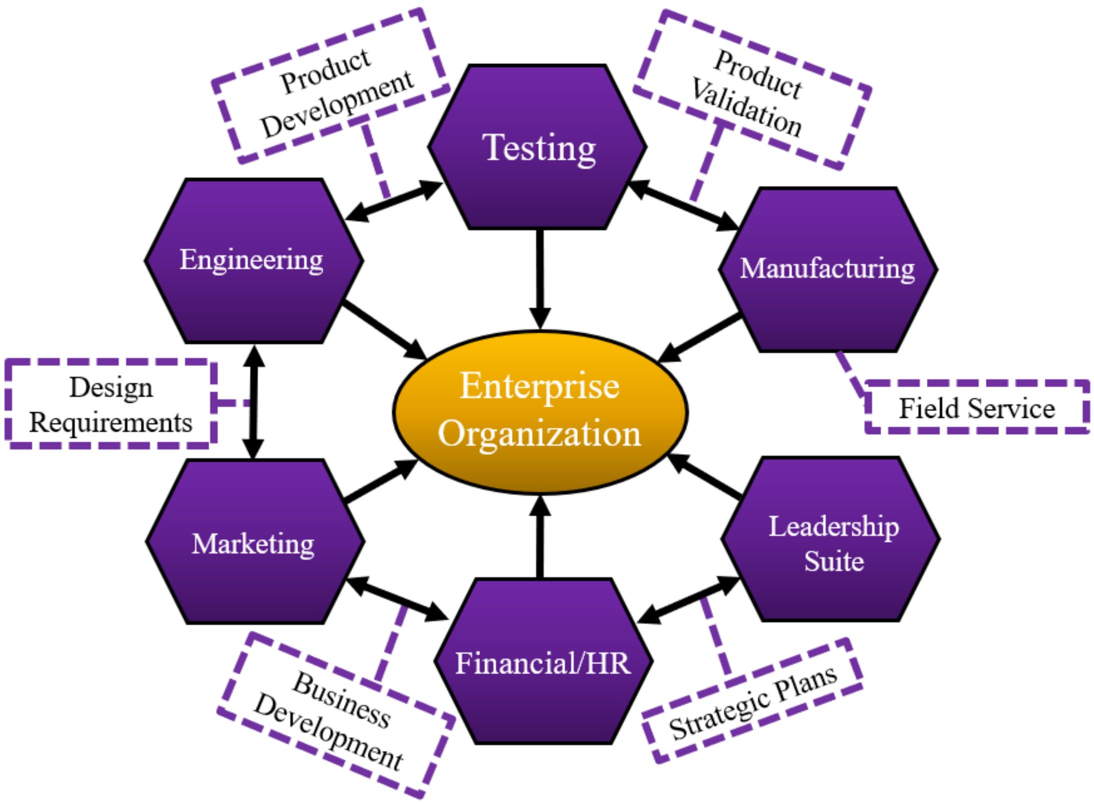

FIGURE 1.3: Post-PLM implementation within an enterprise based on the digital background to enhance department interactions

The main differences between Figure 1.2 and Figure 1.3 are the bi-directional arrows between each business unit and the purple dashed boxes attached to each of the arrows. The purple dashed boxes represent standard business processes that occur between departments. These business processes range from product development and validation to business development and strategic planning. PLM solutions increase the efficiency of these business processes by improving collaboration of all aspects of the enterprise. For example, product data management software allows engineering, testing, manufacturing, and marketing departments to collaborate on design requirements for any product. Also, computer-aided design software improves product development and validation collaboration by engineering, testing, and manufacturing departments. The other key difference between Figure 1.2 and Figure 1.3 is the bi-directional arrows between each business unit, representing the collaborative design strategies between all departments within an enterprise. PLM initiatives drive collaboration by linking all departments into a virtual thread through the different PLM tools discussed in the next section of this paper.

CHAPTER TWO

PLM TOOLS

A business may utilize many PLM resources to achieve its long-term goals. PLM resources include methods, facilities, data management, applications, and people. The resources most consistent with use in engineering design are product data management (PDM) and PLM applications. Figure 2.1 displays the digital backbone of many PLM applications used in industry.

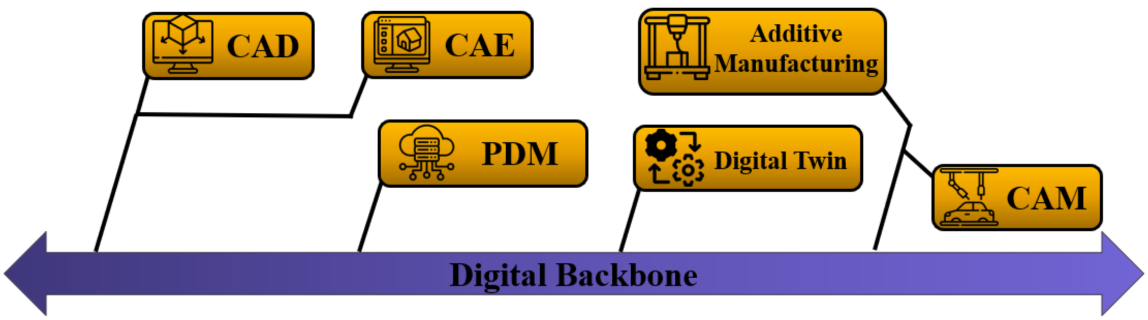

FIGURE 2.1: PLM digital backbone with select virtual engineering functions displayed, including AM, CAD, CAE, CAM, and PDM

The digital backbone comprises typical design applications such as computer-aided design (CAD) and computer-aided engineering (CAE) software. In addition, computer-aided manufacturing (CAM) and additive manufacturing are critical resources that improve a company's manufacturing processes' accuracy and efficiency. The combination of these applications and the addition of some others make up the bulk of a digital twin, a virtual tool composed of a database of computer models to be used in addition to a physical model to estimate the behavior of a product. To store all the product files from the other PLM resources, a product data management (PDM) application is necessary. PDM systems are among the most critical elements in a business' PLM resources. PDM systems provide the correct information for all business functions whenever required. In stark contrast to the engineering design process of the 20th century, PDM systems integrate departments into the design process that have had limited involvement before.

2.1 Computer-Aided Design (CAD)

Computer-Aided Design (CAD) software is critical to the success of PLM systems and solutions, as it forms the basis for product development. CAD is a software tool used in engineering for digital design, drafting, and prototyping. The primary purpose of CAD software is to assist designers in the engineering design process by allowing them to create accurate 3D models, designs, and drawings. CAD software also supports increased collaboration amongst engineering teams on graphics and procedures, which improves the efficiency of the engineering design process in the industry. The software enables engineers to explore contrasting designs and make changes to meet the requirements of the product and customer. Nzetchou et al. [10] explore semantic enrichment methods of CAD models in PLM systems and their degrees of industrial implementation. CAD enrichment gives engineering collaborators an additional layer of metadata to improve their designs and the efficiency of the engineering design process.

In addition to the design process, CAD software plays a prominent role in manufacturing, including prototyping and iterative manufacturing. Rapid prototyping is essential for a business because it boosts efficiency and minimizes waste. CAD models aid engineers in rapid prototyping by providing a digital, readable file of any part or assembly that can be prototyped through additive manufacturing or machine fabrication. Also, CAD software has allowed a new, adaptive form of iterative manufacturing by creating a shared, central repository for product data that can be utilized by engineering, manufacturing, marketing, and many other departments to boost the efficiency of the engineering design process. Paul et al. [11] employed CAD models to develop a "predictive tool based on machine learning" that can improve the yield efficiency of their simulation models and, in turn, advance the additive manufacturing methods they use for rapid prototyping. CAD software is critical in every engineering design process stage and a crucial tool to the PLM infrastructure.

2.2 Computer-Aided Engineering (CAE)

Computer-Aided Engineering (CAE) software is another crucial design tool used to simulate and analyze the behavior of products and designs under different environments. There is a range of additional CAE software, including finite element analysis (FEA), fatigue and structural analysis, computational fluid dynamics (CFD), electromagnetic simulation, and multibody dynamics (MBD). Each software package focuses on a specific environment under which a design would be subjected. One of the primary purposes of CAE software is to reduce prototyping costs, as it allows engineers to test their strategies under contrasting loading conditions before building expensive prototypes. Also, CAE software can improve product design performance through optimization tools, as defined by Murthy et al. [12] in their chain load optimization of fuel pump lobe phasing for a BS6 diesel engine.

One of the main applications of CAE software in PLM systems is the creation of a digital twin. A digital twin is a digital representation of a physical product whose primary purpose is to improve the efficiency of the engineering design process by creating a digital model that can be controlled and optimized through real-time simulations. The primary purpose of creating a digital twin is to reduce the cost of the concept and detailed design stage in the design process, as explained by Kolbachev et al. [13]. In addition to the cost-saving benefits of creating a digital twin, another main advantage includes creating a high-accuracy model of an object or system that is too complex or dangerous to test in a physical situation. These intricate designs could require expensive, controlled environments to test them in, which would further increase the cost of the prototyping and testing stages of the design process. Overall, CAE software is essential to PLM software and collaborative design tools.

2.3 Computer-Aided Manufacturing (CAM)

Computer-Aided Manufacturing (CAM) software plays a vital role in the automation of manufacturing processes. CAM software works with CAD software to convert a 3D model into a set of instructions that a machine can use to manufacture a product. CAM software has many benefits, ranging from increased manufacturing efficiency to improved quality control. CAM software increases the accuracy and consistency of manufacturing processes, all while decreasing the cost of manual integration of CAD drawings with machines. Another benefit of using CAM software is that it can optimize manufacturing processes. As Nikolov et al. [14] describe, CAM systems are critical in generating optimal technological strategies for machining mold elements using CNC machines. The optimization strategies utilized by CAM software can increase efficiency and reduce the overall cost of engineering design processes.

In addition to integrating CAM and other digital tools in the engineering design process, CAM software can integrate with additive manufacturing (AM) to further enhance the manufacturing process and increase production efficiency. Additive manufacturing is a process that involves designing and creating a product by layering material incrementally on a base structure. Additive manufacturing has many advantages, including increased efficiency and quality of rapid prototypes in industrial and research settings. CAM software can integrate with additive manufacturing to optimize the manufacturing process. Feldhausen et al. [15] explore how "various CAM strategies could be deployed for AM to improve process efficiency or enable localized control over part performance." With the introduction of CAM software into the industry, digital tools have successfully integrated into the engineering design process, creating a collaborative environment that improves overall product quality.

2.4 Product Data Management (PDM)

Product Data Management (PDM) is a system used to store and manage product lifecycle data. PDM software is critical in developing an efficient Product Lifecycle Management system. It maintains data regarding many aspects of a product's development, such as CAD models, CAE simulations, bill of materials information, CAM models, and pricing and manufacturing data. The primary purpose of PDM software is to increase collaboration amongst all departments of an enterprise by allowing them access to data from other departments that they would not usually have access to. In addition, PDM software helps reduce costs and improve the quality of product designs as it optimizes the engineering design process by integrating software mentioned in the previous subsections, including CAD, CAE, and CAM software. Lucky et al. [16] discuss how the construction industry integrates Product Data Templates (PDT) and Product Data Sheets (PDS) into their PDM environment to create a shared information model that improves collaboration among stakeholders and designers. Implementing integrated applications allows PDM systems to manage product data effectively.

Another essential aspect of PDM systems is the creation and tracking of workflows. Workflows are tasks that replicate business processes to reach a specific objective or goal. Workflows automate standard functions such as assigning tasks, change management, design reviews, and prototype fabrication processes. In a traditional PDM system, workflows can be managed and changed internally, with templates guiding each process from start to finish. Workflows drive the engineering design process by increasing the efficiency of standard design processes and simplifying complicated processes to flowcharts that all departments of an enterprise can utilize. Bruun et al. [17] explore the functional workflow capabilities of PDM and PLM systems in modular product design. Overall, PDM systems and workflows improve the efficiency of engineering design processes and collaboration between multi-disciplinary teams.

CHAPTER THREE

COLLABORATIVE OPPORTUNITIES

Over the 21st century, PLM initiatives have integrated into existing business infrastructures to create digital collaborative design spaces. Digital collaborative design spaces differentiate from existing product development strategies by including all departments for product input related to design, manufacturing, and development. A digital collaborative design space can consist of many different things, including business functions, product development inputs, and PLM software. Figure 3.1 is a visual representation of all the various features of a collaborative design space, including those listed above. The shapes are color coded to match the categories discussed earlier. For example, each of the light orange circles and ovals represents inputs into the development of a product, including field data, CAD models, CAE analysis, customer feedback, requirements, bill of materials, and sales and marketing. In addition, the green diamonds separate the product inputs into separate business functions, testing, design, research, and business. Lastly, the purple boxes on the outside, denoted by arrows to dashed ovals, represent the PLM tools and software that would be used to improve collaboration within the business functions and product inputs. The PLM tools listed in each box are specific examples of software used for each application. Several other examples of software that could have been placed into each box, but the ones listed are some of the most prominent examples for each application. There are many collaborative opportunities in each facet of a business' operations. In the next two sections, collaborative opportunities are split into technical and non-technical categories and discussed further.

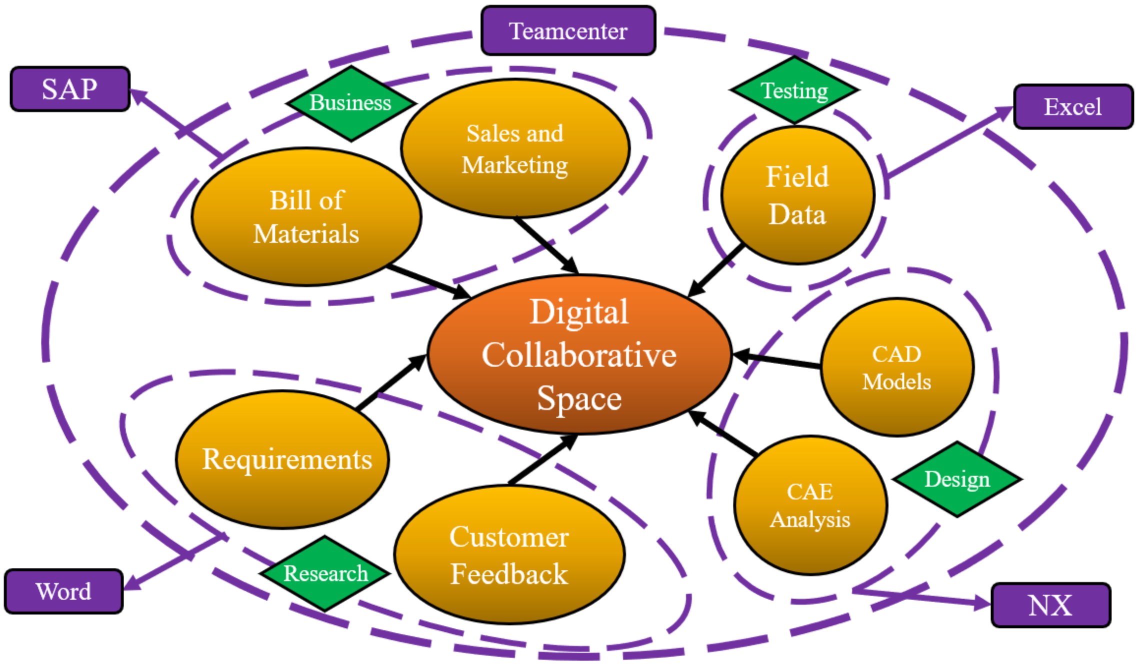

FIGURE 3.1: Collaborative digital design space with identification of software tools commonly applied

3.1 Technical (Engineering and Manufacturing)

There are many opportunities for collaboration in all technical aspects of a digital collaborative design space. In Figure 3.1, the technical inputs to the digital collaborative design space include "CAD Models," "CAE Analysis," "Field Data," and technical "Requirements," all falling under the "Testing," "Design," and "Research" business functions. CAD software has undergone many changes since its invention in the late 1950s, including additions of electrical and mechanical elements and integration features with CAE software. Collaborative CAD software has become a significant focus of industry development over the past couple of decades, with PLM initiatives leading the way. Deng et al. [18] explain how multi-user CAD (MUCAD) software allows "virtual, real-time collaboration, with the potential to expand the learning outcomes and teaching methods of

CAD." MUCAD systems allow for collaboration within engineering departments and other technical business units, such as manufacturing and testing [18]. An entire business can benefit from collaborative design using CAD software. Integrating CAD and CAE software can provide many new opportunities in a digital collaborative design space.

CAE analysis is a critical piece of the engineering design process and contributes to a product's success or failure. CAE primarily aims to reduce the design cycle time by running simulations of environments and loadings that a model or product may undergo in their normal operating conditions. Gathering CAE analysis from CAD models requires an integrated simulation package compatible with the CAD model file type. Many different CAE packages correspond to other loading conditions or applications, as described earlier, including finite element analysis (FEA), computational fluid dynamics (CFD), thermal analysis, and multibody dynamics. A collaborative opportunity in the CAE software space researched by Cramer et al. [19] is constructing a "Collaborative Architecture" for each CAE tool to integrate through a compatible CAD application. The purpose of this type of system is to "allow designers specializing in different CAE tools to access, view, or capture the functionality offered by other CAE applications in real-time without returning to the source CAD system" [19]. This system would contribute significantly to a digital collaborative design space by decreasing the design cycle time and increasing the efficiency of the engineering design process. In Figure 3.1, the example application encircling both the "CAD Models" and "CAE Analysis" circles in the "Design" business function is Siemens NX. NX is a CAD software offered by Siemens that includes many crucial design functions, including modeling, optimization, and finite element analysis simulation. NX also integrates with other Siemens PLM solutions, including their PDM software Teamcenter, which will be discussed in the Case Study section of this paper.

Another critical technical input to a collaborative design space is field data and technical requirements. One of the primary purposes of gathering field data is to begin benchmarking research for use in the preliminary concept generation and design stage of the engineering design process. Storage of this data is a common problem for PLM solutions, with multiple solutions available. In Figure 3.1, the application listed as an example for storing field data is Microsoft Excel. Excel is a spreadsheet tool that can compute dataset's basic and advanced mathematical functions. Excel files can be easily shared across a business database through PDM software. Collaborative opportunities are available through PDM software, as they are commonly instantaneously updated for users to access all field data across an enterprise through a central repository. Another example of a collaborative opportunity in field data management is using a cloud digital twin. Research on cloud digital twins for metal additive manufacturing by Liu et al. [20] shows that collaborative data management solutions demonstrate "efficient data communications" and allow for "process optimization" throughout their business structure. Field data is also a key input to creating technical requirements for any product in the initial design stages. Technical requirements are generated through customer input and benchmarking research and can be stored in Microsoft Word documents. Similarly, these Word files can be added to PDM software to be easily accessible for all users in a business. Collaborative opportunities for creating technical requirements lie in the collective functions of PDM software. Stakeholders in the product design from every department in a business can access and edit the technical requirements documents from the company's PDM software. All of these collaborative opportunities relating to the technical inputs of the engineering design process are incorporated into PLM initiatives of the 21st century.

3.2 Non-Technical (Business Functions)

In a digital collaborative design space, the non-technical inputs include "Sales and Marketing," "Bill of Materials," and "Customer Feedback," each a part of the "Business" and "Research" business functions. The first non-technical input discussed in further detail is "Customer Feedback." Customer feedback is a crucial facet of the engineering design process, as the customer can provide critical input to the construction of a product through design reviews. Prabhakaran et al. [21] discuss how collaborative opportunities exist in the communication of customer feedback through the creation of "an interactive and immersive virtual environment for design communication." Research on creating a virtual reality environment for furniture, fixture, and equipment (FFE) design communication for stakeholders reveals that "the presented framework can highly improve the efficiency, design coordination, and productivity" of the FFE design process [21]. Additionally, this prototypical VR system increases collaboration amongst all stakeholders for any design problem by allowing them to give feedback on particular design choices or methods instantaneously. Overall, collaborative initiatives in the communication of customer feedback can improve the efficiency of the engineering design process.

Next, the "Bill of Materials" and "Sales and Marketing" non-technical inputs to the digital collaborative design space in Figure 3.1 allow businesses to configure their purchasing and marketing strategies for their product portfolio. A bill of materials (BOM) is a structured list of the components of a product, including materials, parts, and assemblies. A bill of materials is an essential source of information for the sales and marketing departments, as they can provide links to documentation and drawings of the most important aspects of products. One collaborative opportunity in using a bill of materials is the creation of a collaborative bill of materials (C-BOM) [22]. Shamsuzzoha et al. [22] relate how research on a collaborative bill of materials among manufacturing firms allows "companies [to] collaborate with each other from the early conceptual phase of the product, where necessary design and engineering are undertaken." Collaboration amongst businesses on product development would require a network of information and expertise through a standard bill of materials. For manufacturing firms, this collaborative tool would need to "facilitate frequent exchange of information" that "contributes to the collaborative product design" [22]. An example of a PLM tool that incorporates a bill of materials into a cloud-based setting is SAP ERP (enterprise resource planning). SAP is a software system that "helps run core processes in a single system for departments such as finance, manufacturing HR, supply chain, services, procurement, and others" [23]. The benefits of using a cloud-based system such as SAP ERP include the increased collaboration of all departments on specific aspects of the product department. Collaborative opportunities on non-technical inputs to the digital collaborative design space are vital to PLM initiatives, as they improve collaboration in all aspects of the engineering design process, including the non-technical parts, such as customer feedback, bill of materials, sales, and marketing.

CHAPTER FOUR

CASE STUDY

A case study was conducted with the PLM Processes Creative Inquiry (CI) team at Clemson University to implement ideas from the digital collaborative design space into an educational setting. The goal of the CI team is to develop a digital twin of a scaled, tracked robotic platform. In pursuit of this goal, industrial PLM concepts and tools will be utilized to improve collaboration amongst team members and the efficiency of the design process. The tracked vehicle the CI team attempts to recreate as a digital twin is a T'REX Robot Tank Chassis, shown in Figure 4.1. For PLM resources, the CI team already uses Siemens NX as their CAD software and Microsoft Excel as their PDM solution. To improve their design process's collaboration and efficiency, we will implement Siemens Teamcenter as an additional PDM tool. For the CI team, Teamcenter will be integrated into their existing design process as a database for NX CAD files and a facilitator for product development through the use of workflows. The following two sections will discuss the benefits of using advanced PDM software, including features such as CAD and PDM integration, engineering workflows, and collaborative design tools. Additionally, an overview of the difficulties encountered when integrating the software will be discussed, and some steps will be taken to troubleshoot these problems.

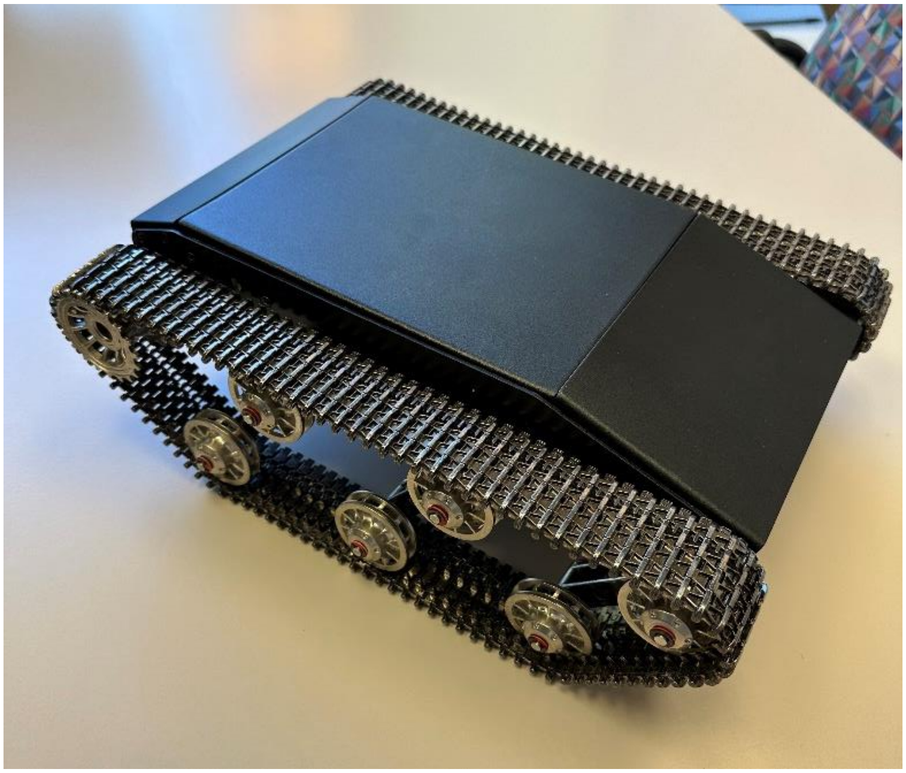

FIGURE 4.1: A scaled tracked vehicle serves as the basis for collaborative study with Creative Inquiry students

4.1 PDM Application

In Figure 3.1, the purple, dashed outer circle surrounding the entire digital collaborative design space is labeled "Teamcenter," a Siemens PDM software that incorporates all aspects of the digital collaborative design space into its functionalities. PDM software is one of the essential parts of the digital collaborative design space, as it facilitates all of the different PLM processes discussed earlier in this paper. Teamcenter can integrate CAD, CAE, and CAM software into its central database to create a repository for all product-related data. For the CI team, Teamcenter will be a foundation for building the tracked vehicle's digital twin. To introduce Teamcenter to the team, an introductory presentation was created and presented, showcasing some of the software's essential features, including item creation, workflows, change management, and bill of materials. The presentation communicates information on the benefits of using an integrated PDM system like Teamcenter. The presentation also incorporated several demos on the basic functionality of Teamcenter, including items, workflows, change management, and bill of materials. An example presentation slide for an item creation demo is shown in Figure 4.2.

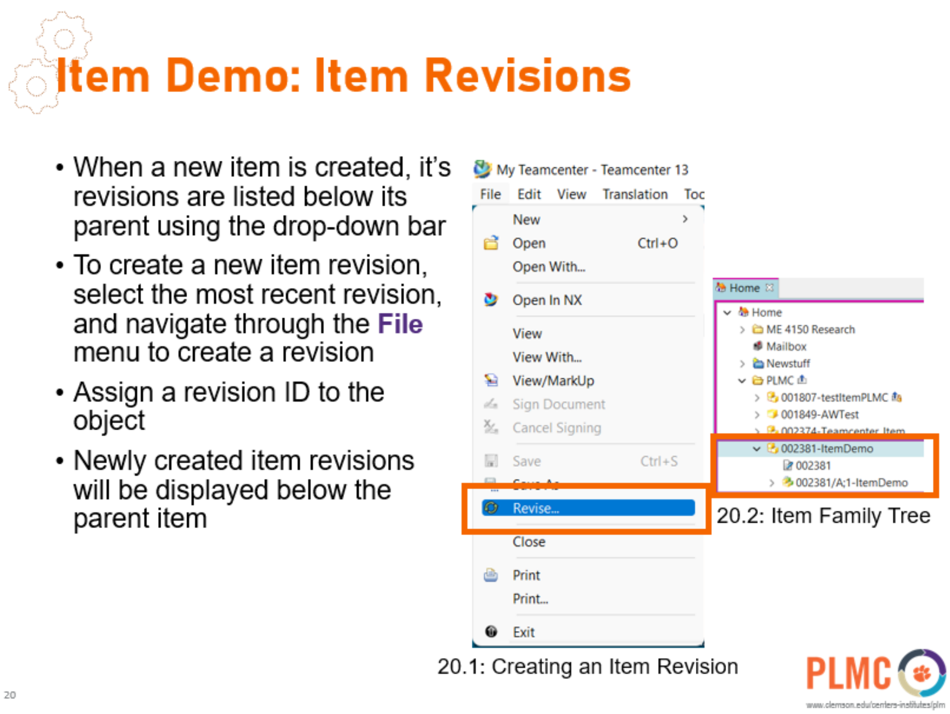

FIGURE 4.2: Teamcenter software instruction - item demonstration

After the Teamcenter presentation was given to the CI team, Teamcenter 13 was installed and set up on the desktop computers in the Product Lifecycle Management Center's (PLMC) computer lab on Clemson University's main campus. Each member of the CI team was assigned a Teamcenter account that they could log into remotely using Teamcenter's active workspace or through a PLMC lab computer in the rich client. The team would utilize the most crucial feature of Teamcenter throughout their design process is the NX/Teamcenter integration. The team used this integration to improve the efficiency of their engineering design process. It allowed them to navigate quickly through the list of parts, assemblies, and drawings for the tracked vehicle while easily downloading and uploading new versions of these files automatically. Teamcenter can open an NX part file from its central database through the Active Workspace and Rich Client. One problem the CI team encountered when trying to utilize the NX/Teamcenter integration was the difficulty in transferring existing part files from their Excel PDM file to Teamcenter's server. Figure 4.3 displays the solution to this problem, a screenshot of the dialog box that uploads NX part files into Teamcenter. This feature allows users to upload parts or assemblies from their local server or file database into Teamcenter's servers. The feature can be found in NX's "File" menu bar, titled "Import Assembly into Teamcenter." Teamcenter allows users to customize their import options within the dialog box, including the file name and revision, item type, and destination folder. Once the options for each uploaded part are configured, Teamcenter can validate the information in its database and perform a dry run of the upload. After confirming the uploaded parts, the files can be uploaded to Teamcenter's server. Figure 4.3 adds three of the CI team's original part files to the upload list. In the left-hand column, drop-down lists for the naming conventions of the items are available. Newly uploaded items can be named using their original file name or a different name based on the user's preference. Additionally, the items can be listed in Teamcenter with an identification and revision number. After the naming conventions are chosen, the user can specify the type of files that they are uploading. For the CI team's application, the “Item” type was chosen, as it allows them to attach different types of data files to each specific item. Next, the user can change the destination folder that each item will be uploaded to. In Teamcenter, folders can be created for individual users to sort their items and documents based on different projects or products. Overall, Teamcenter’s import feature has allowed the CI team a seamless transition to Teamcenter from their previous system.

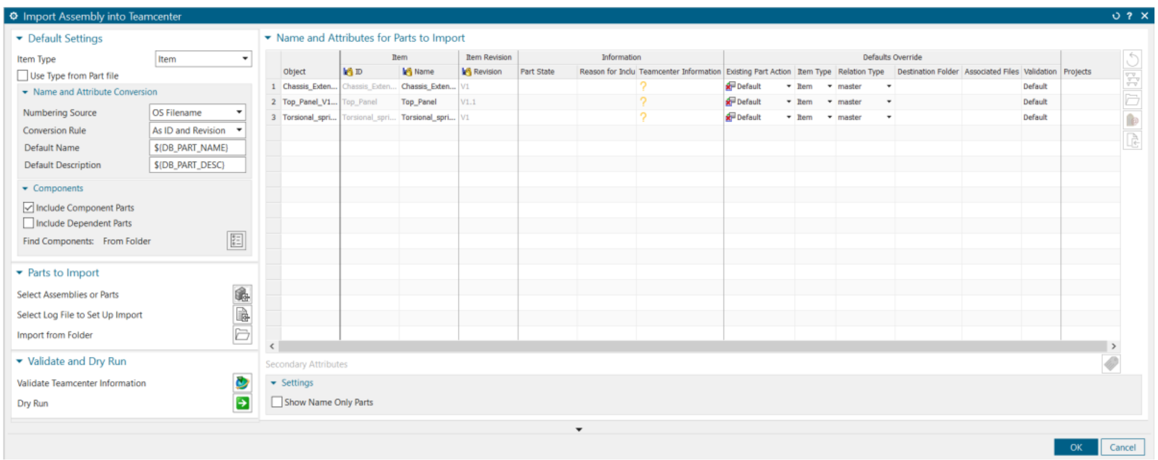

FIGURE 4.3: Import assembly into Teamcenter dialog box

The other significant features of Teamcenter that the CI team are utilizing in their design process are workflows. A workflow is a step-by-step release process that models many basic business functions. Workflows can route an item for design review and approval, manage the change management process, and track manufacturing and design processes. A block diagram of an example Change Review (CR) workflow in Teamcenter is shown in Figure 4.4. The Change Review workflow has many unique features, including assigning specialists and a review board to specific tasks. Workflows always begin with a user assigning participants to each task and providing descriptions of the needed work. For this workflow, a plan for the change must be proposed by a specialist and checked by an engineer.

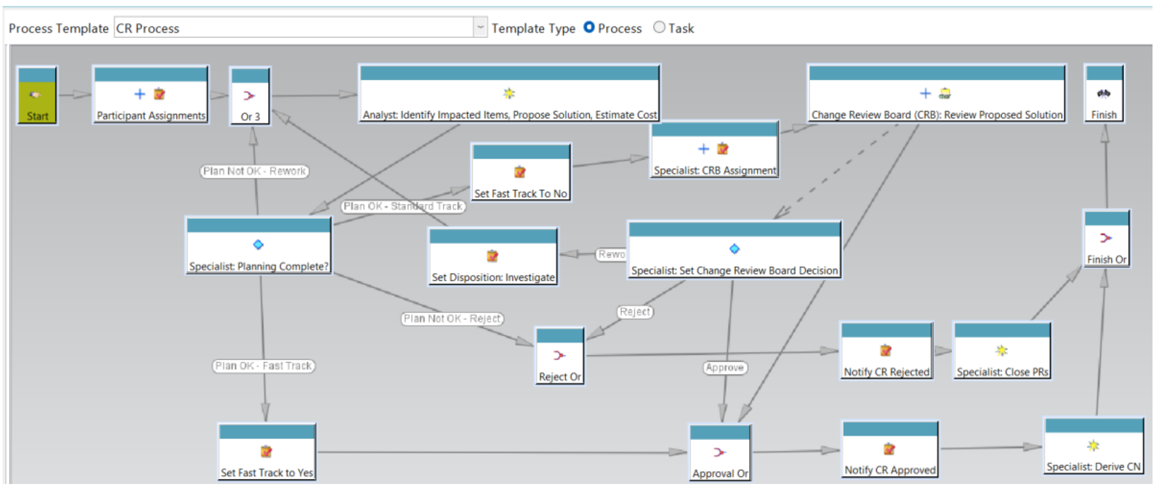

FIGURE 4.4: Change review workflow

If the proposed plan is approved, the workflow can be fast-tracked, or standard-tracked. If fast-tracked, the workflow then moves to the approval process, where the Change Review Board (CRB) reviews the proposed solution and either approves or rejects the proposed plan. This Change Review workflow would be ideal for large engineering companies with many stakeholders invested in the design process. However, for this case study, the workflow is too complex and intricate for many basic design processes the CI team will complete. Instead of this complicated review process, the CI team will employ a basic workflow that includes assigning a task to either a group or individual user,

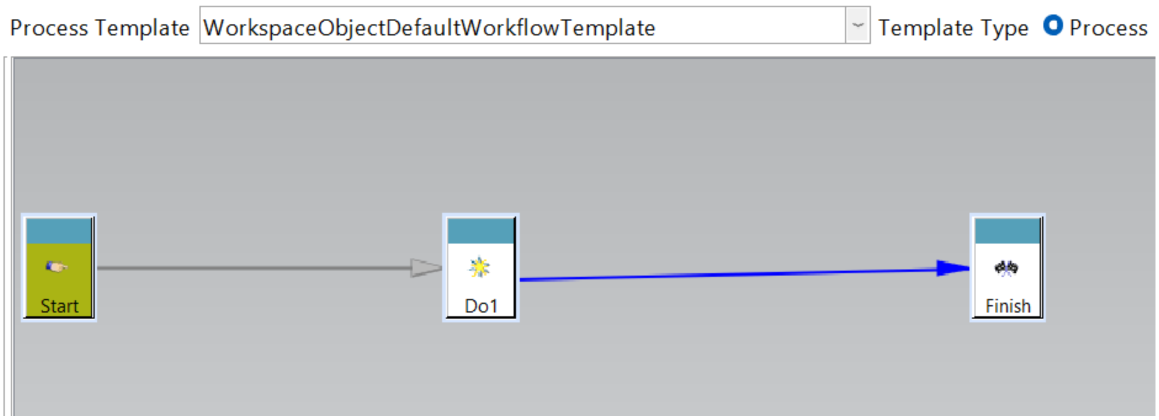

FIGURE 4.5: Workspace default workflow within Teamcenter

completing that task by the assigned user(s), and finalizing the workflow. A block diagram of this described workflow is displayed in Figure 4.5. The workflow consists of a single step, a "Do" task. Within the task, a description of the assignment is included, as well as options to edit or complete the task. Once a workflow is completed, each box in the block diagram is highlighted green, and the workflow is removed from a user's worklist. For the CI team, this simple workflow is ideal for the basic design processes they will complete. For example, a team member can assign a workflow to a part file that requires another member to create a 2D drawing of the part. In general, workflows allow team members to communicate and collaborate on different design aspects with a built-in digital process to guide them.

4.2 Troubleshooting and Results

Throughout the Teamcenter implementation process, the CI team encountered many problems integrating the software into their existing design process. One major problem was connecting Teamcenter with NX using the Teamcenter/NX integration. After Teamcenter was installed on the PLMC lab computers, the link between the two software needed to be established, and the integration could not be utilized. After thorough troubleshooting, a Siemens software technician was contacted to help correct the issues. After weeks of communicating and collaborating with the technician, it was determined that an error in Teamcenter's preferences caused the disconnected link between NX and Teamcenter, which was quickly fixed after the solution was identified. Another issue the team faced was with the Workflow Designer perspective permissions in Teamcenter. The Workflow Designer perspective is a feature of Teamcenter that allows users to design their workflow processes, specifically for different business functions. An essential aspect of the CI team's digital twin development is creating scaled CAD models of other parts of the tracked vehicle. The team could benefit tremendously from a customized workflow replicating the design review process they already use for their CAD models. However, Teamcenter does not allow non-database administrators (non-DBA) to use the Workflow Designer perspective to design workflows. A screenshot of the error message received after attempting to use the perspective is shown in Figure 4.6.

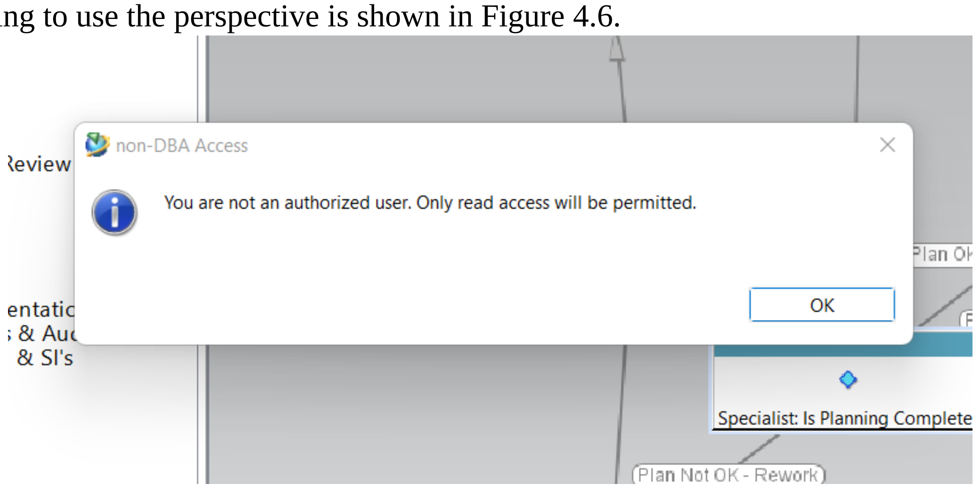

FIGURE 4.6: Workflow designer error

Unfortunately, this error could not be fixed, and due to server limitations, authorizations for certain users could not be granted to use this feature. However, the templates in Teamcenter cover most of the possible workflow processes the CI team will use. Therefore, the team will move forward with the workflow templates instead of the original designs.

Although the CI team has learned Teamcenter quickly and is utilizing it weekly to improve the efficiency of the engineering design process, it is still very early in the implementation of the PDM tool, and concrete results still need to be gathered. From conversations with members of the CI team, positive impressions of Teamcenter are a common theme. Teamcenter has allowed them to improve the speed and performance of their design process by utilizing the Teamcenter/NX integration. Also, the engineering workflows increased collaboration amongst team members on all design aspects of the digital twin. Overall, using advanced PDM software like Teamcenter provides many benefits to a company or design team. The specific benefits of implementing Teamcenter in the CI team will be researched further in future projects.

CHAPTER FOUR

CONCLUSION

PLM initiatives have positively contributed to the digital collaborative design space by increasing collaboration amongst all departments in the engineering design process. PLM tools such as CAD, CAE, CAM, and PDM software have provided a medium for collaboration on different aspects of the process, from design and simulation to manufacturing and data management. One of the essential PLM resources is advanced, digital PDM software that can integrate with other PLM tools to create a digital collaborative design space. Implementation of Siemens Teamcenter in a design group case study resulted in increased collaboration and efficiency of their design process.

APPENDICES

Appendix A

PLM Processes Creative Inquiry Tank

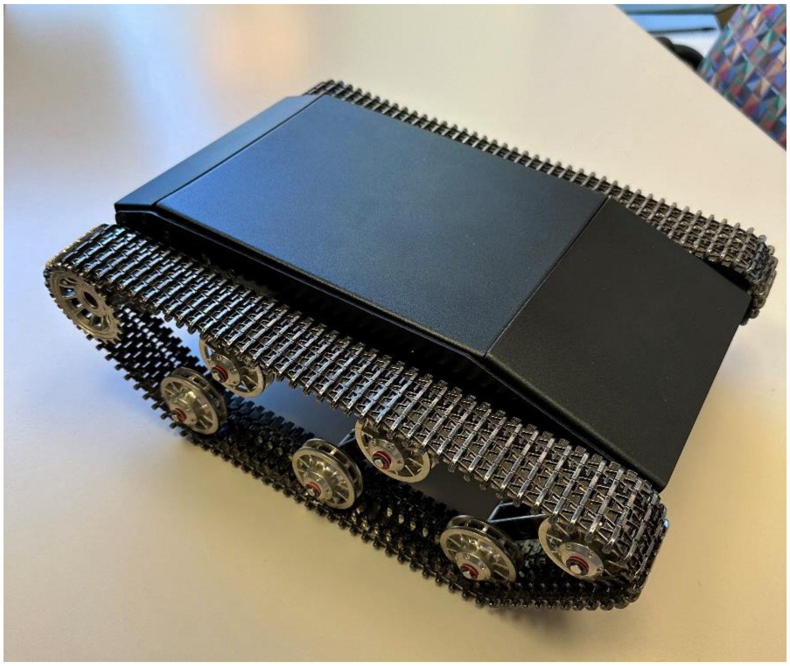

Figure A.1: Tank – Bottom View

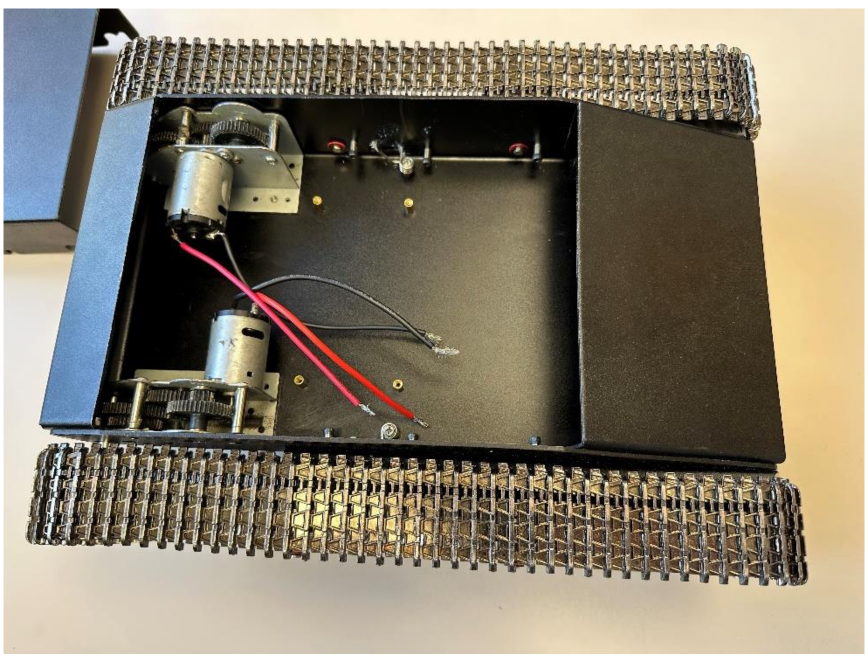

Figure A.2: Tank – Top View

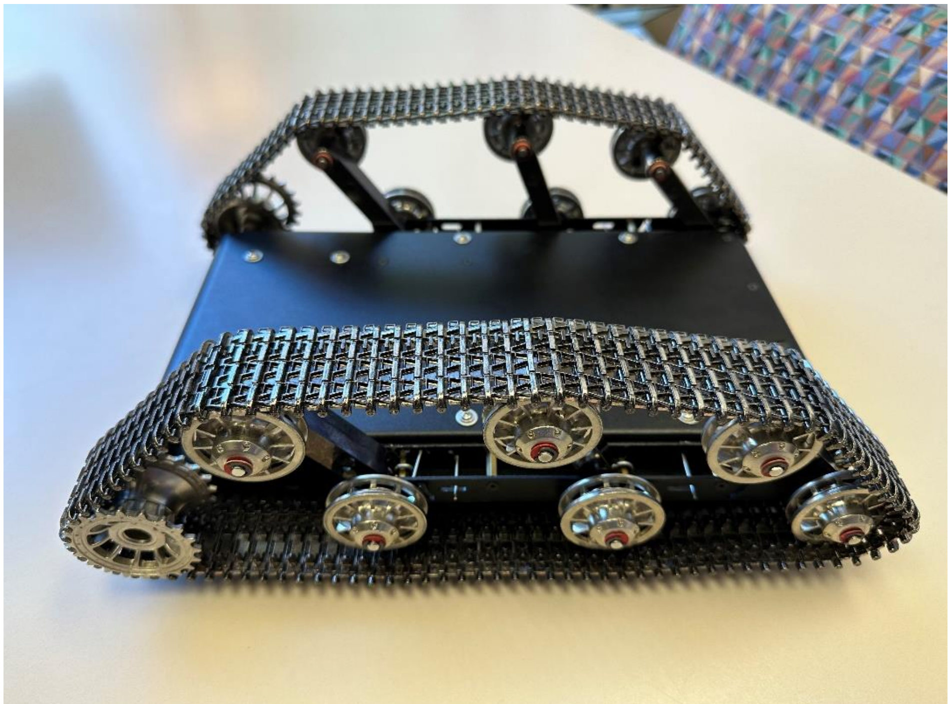

Figure A.3: Tank – Bottom View

Appendix B

Teamcenter Workshop Presentation Slides

1

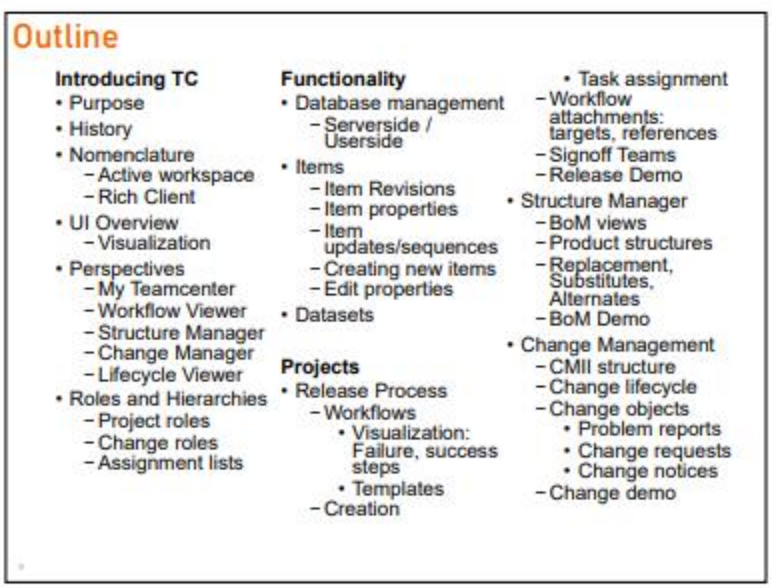

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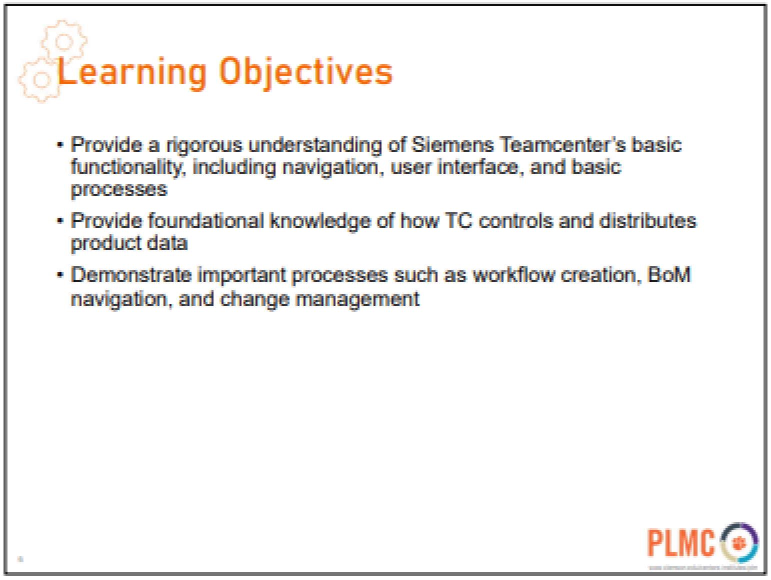
Figure B.1: Teamcenter Slides (1)



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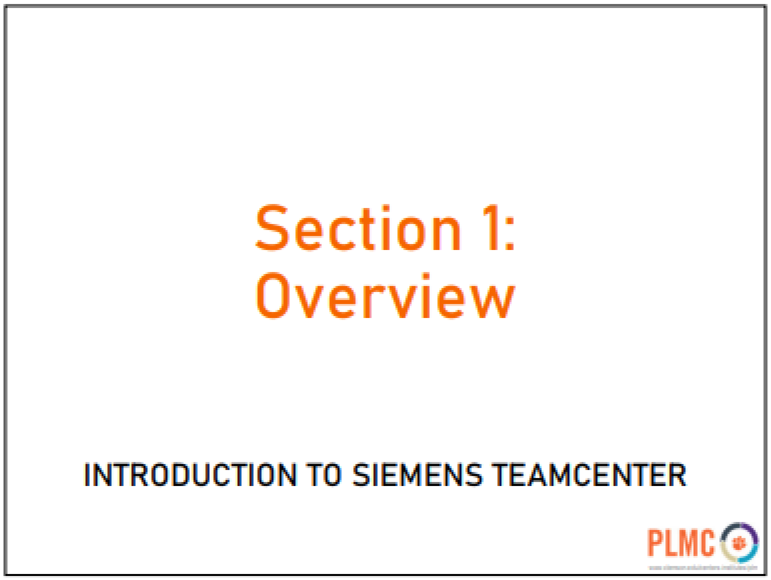

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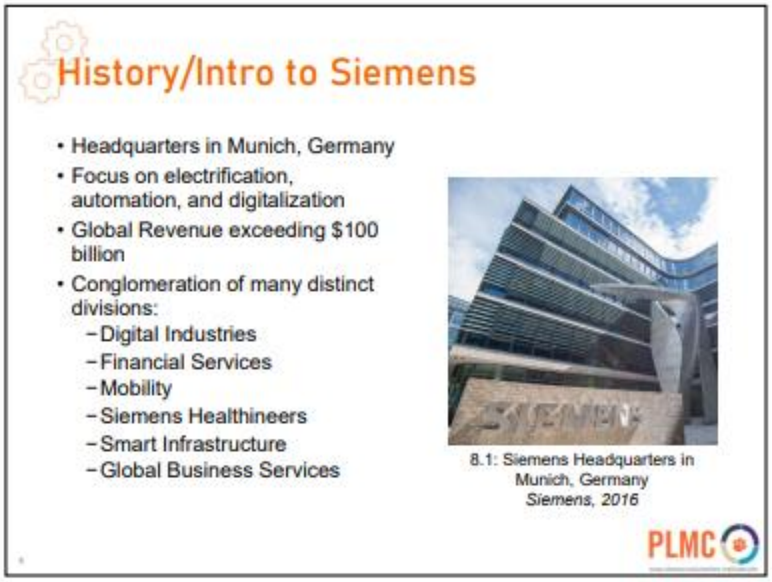

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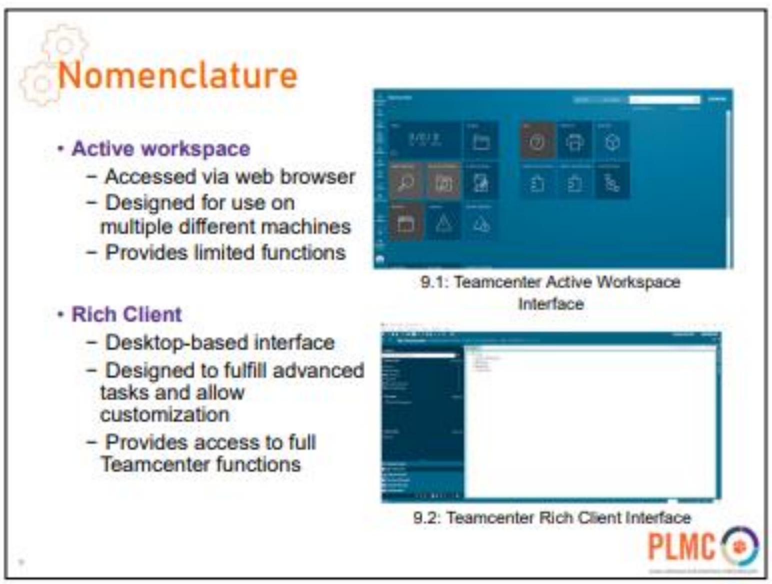

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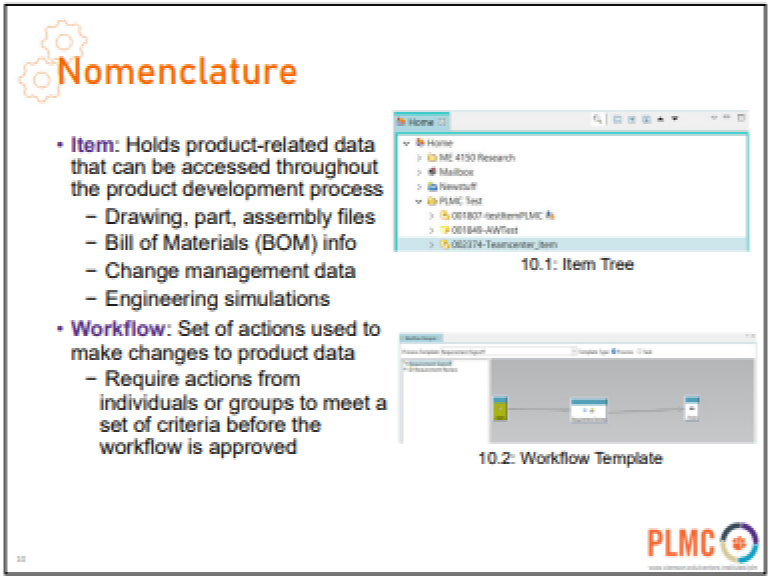

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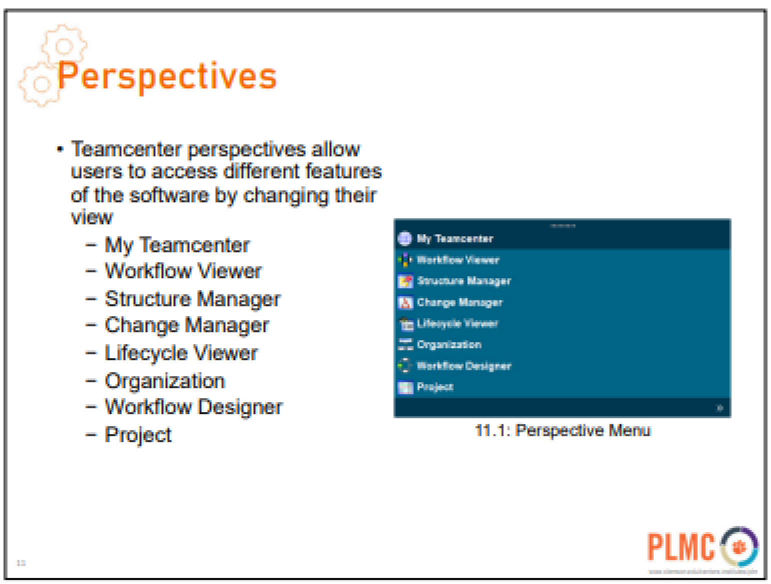

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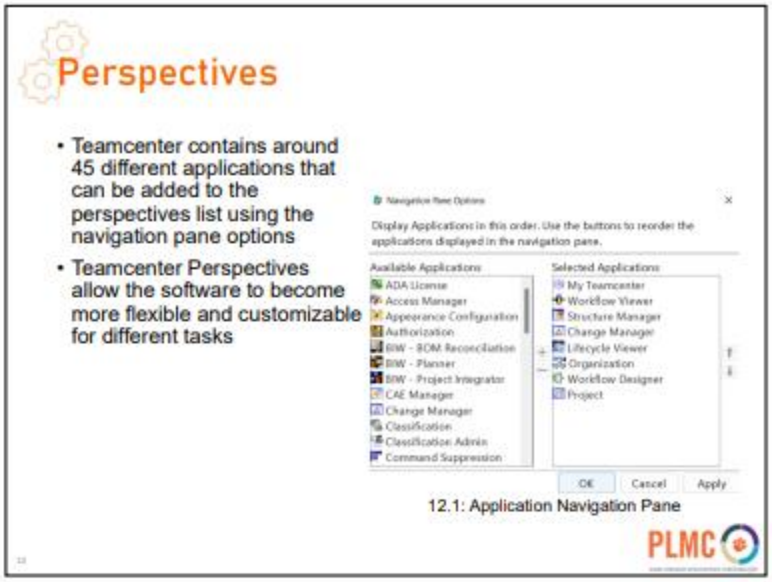

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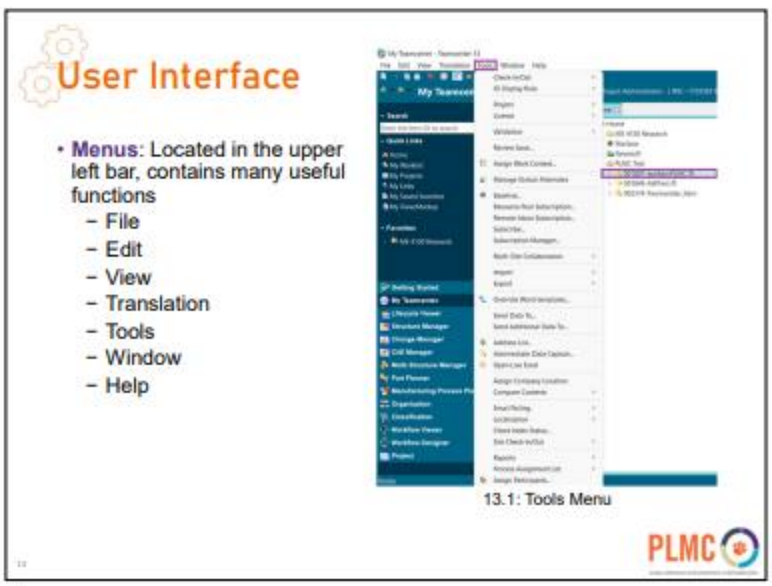

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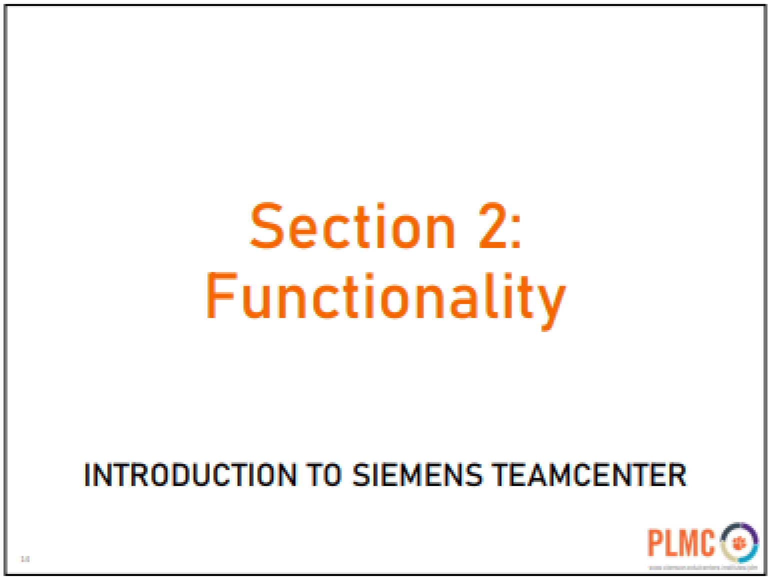

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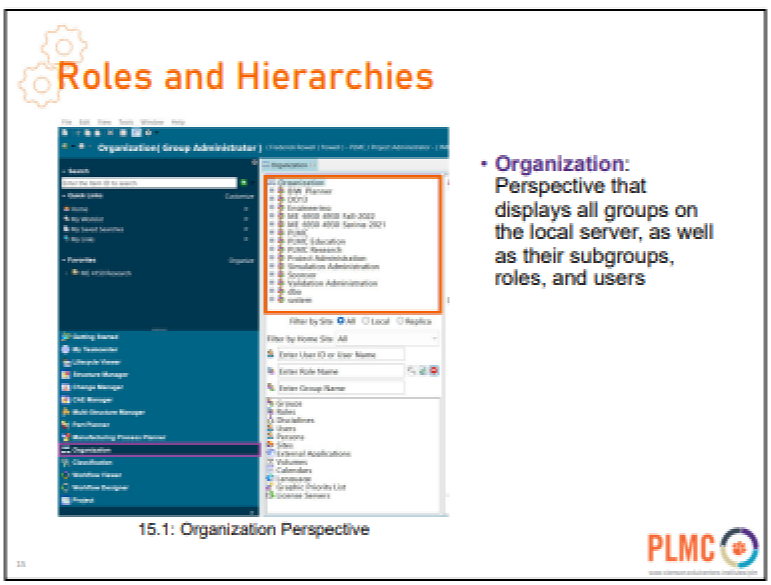

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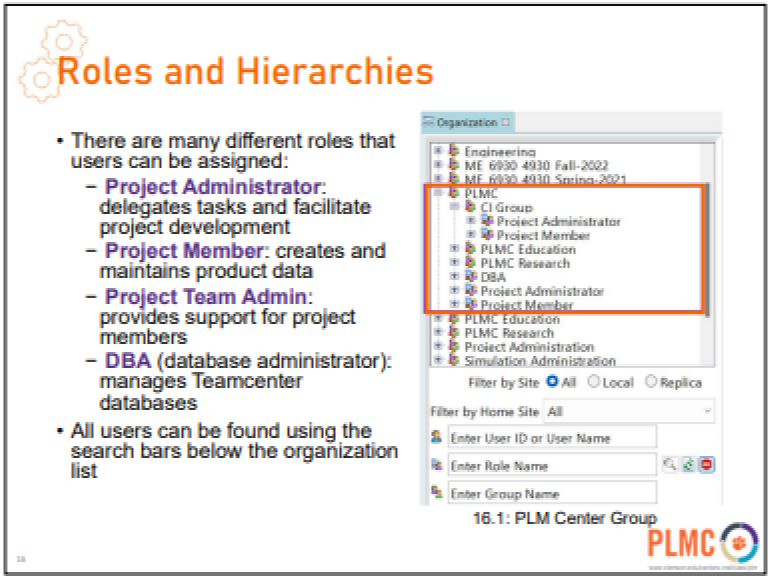

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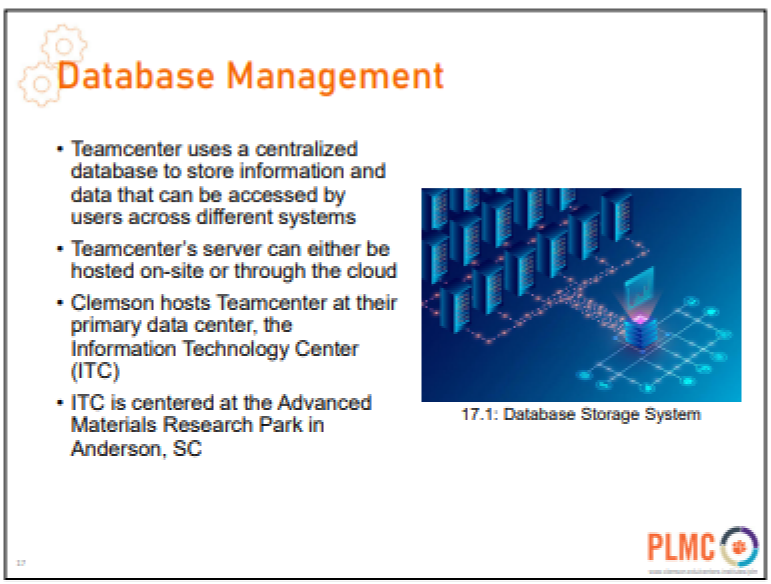

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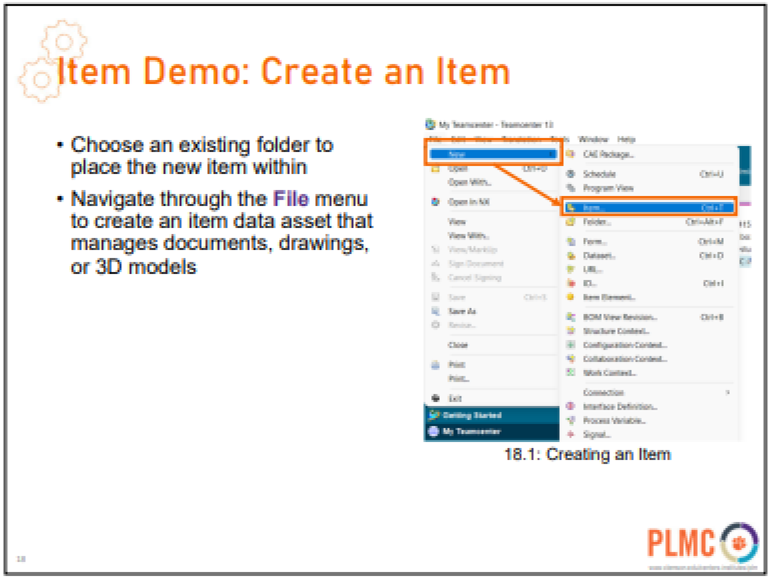

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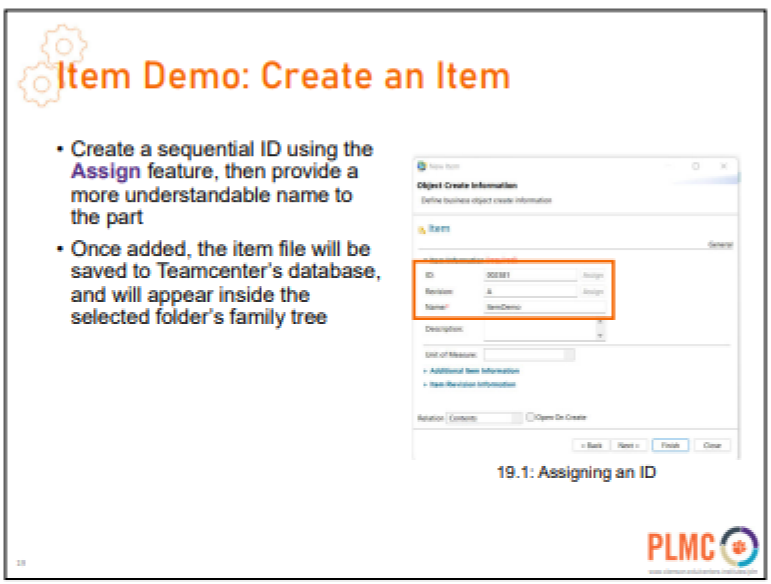

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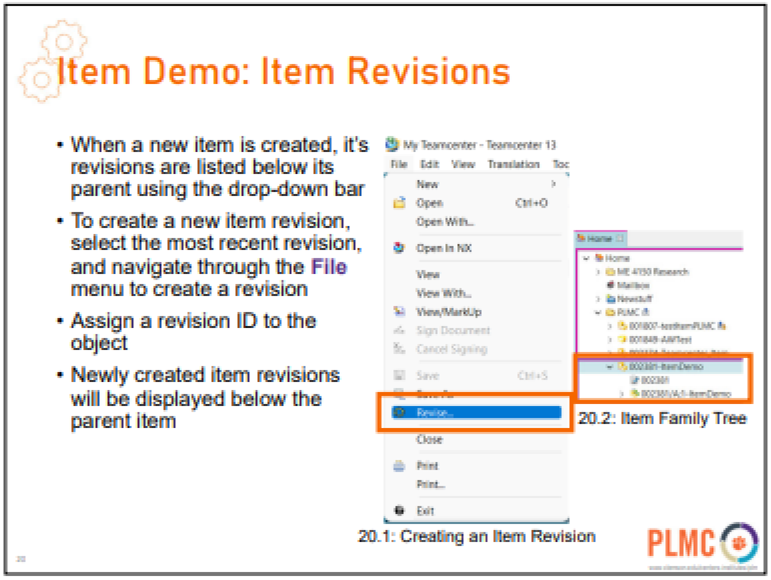

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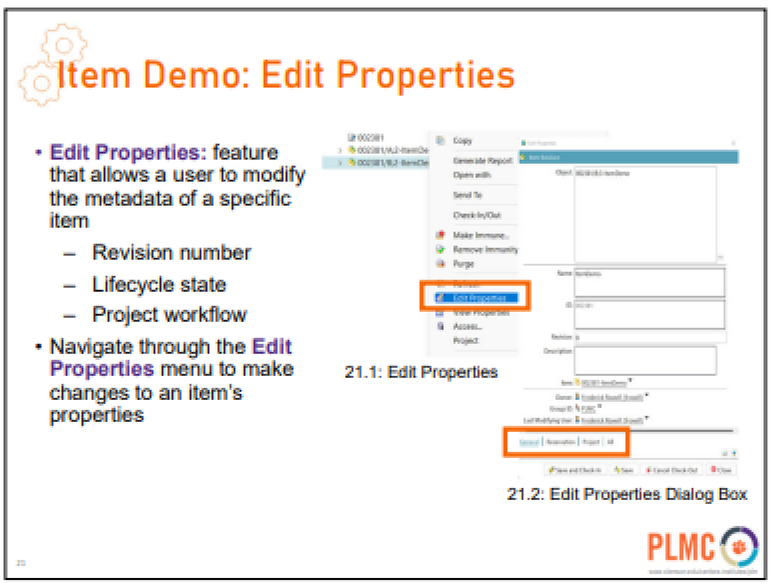

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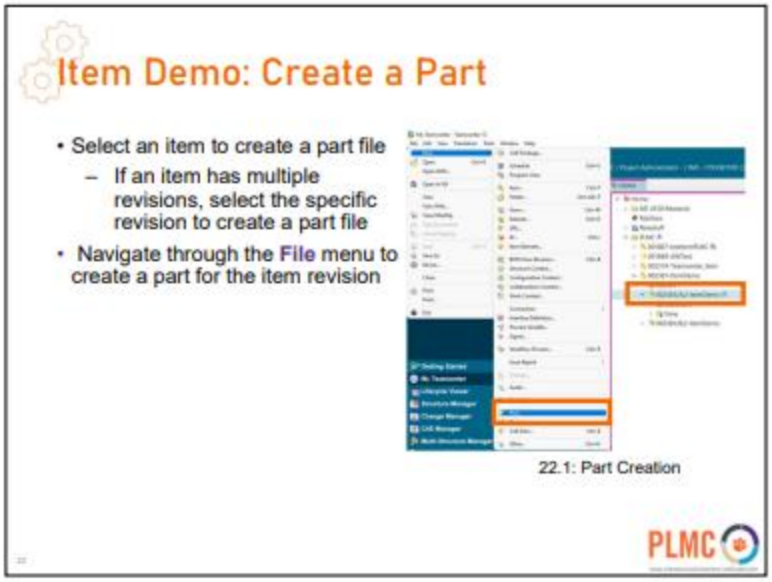

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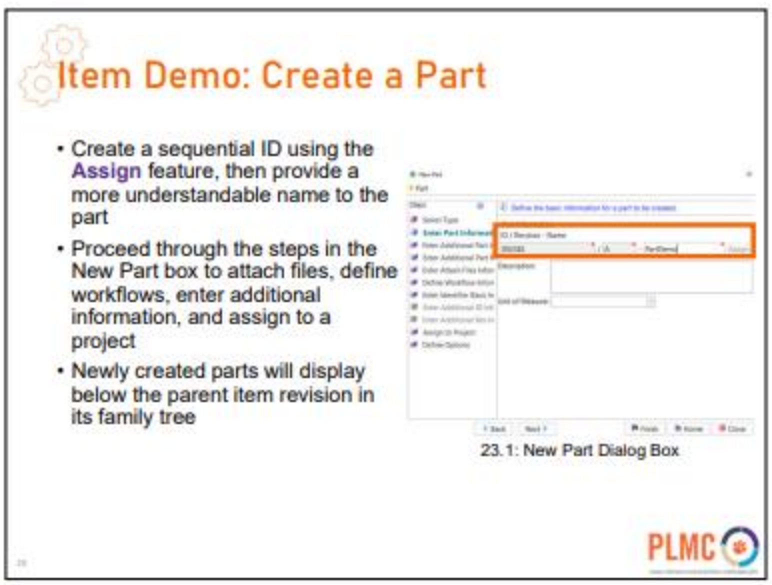

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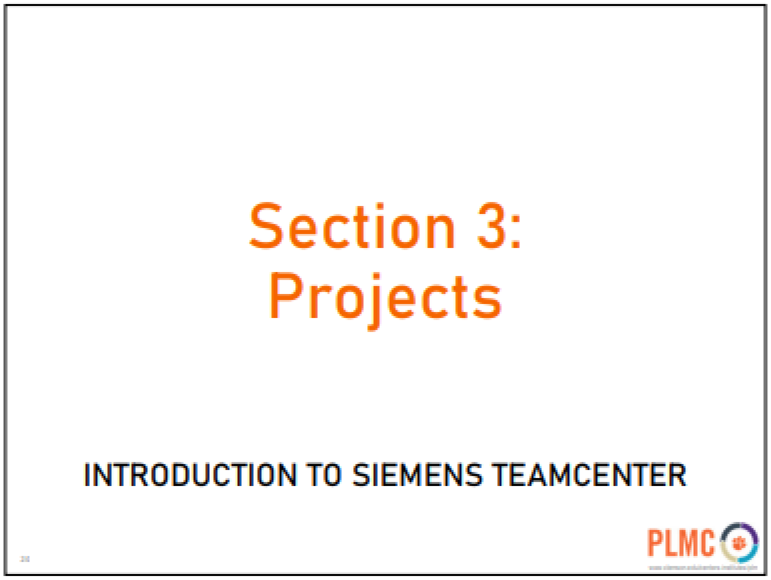

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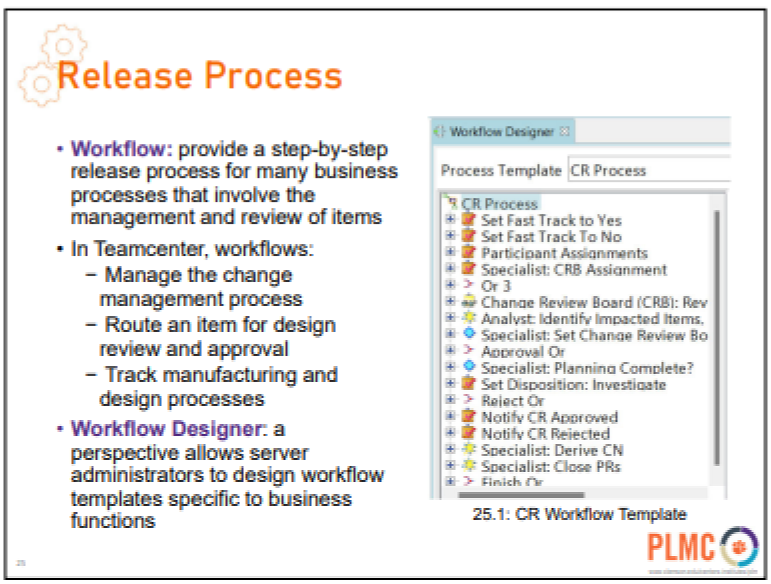

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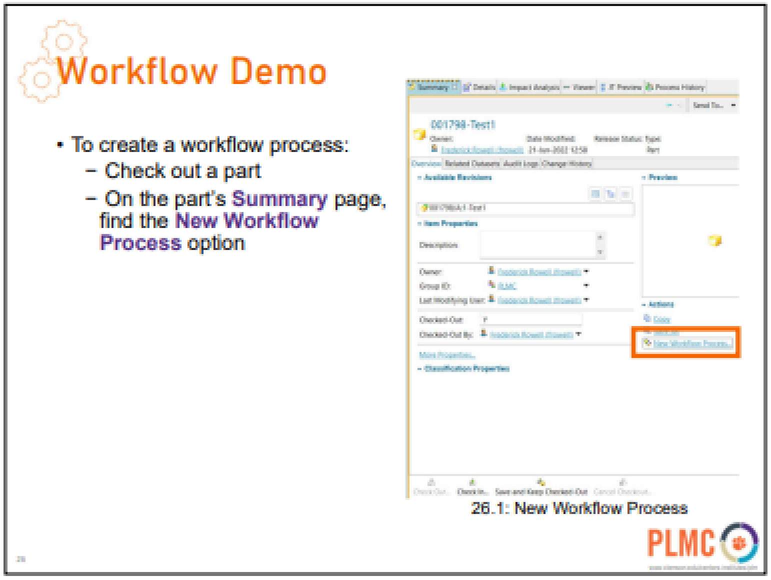

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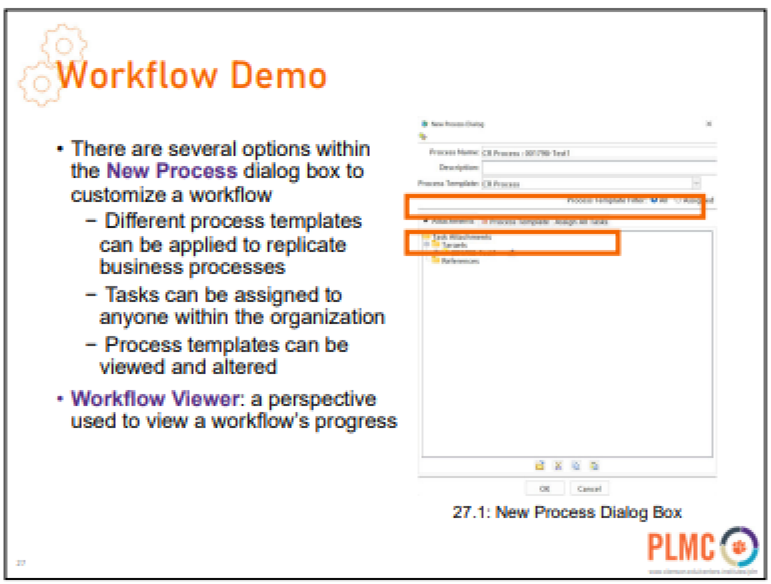

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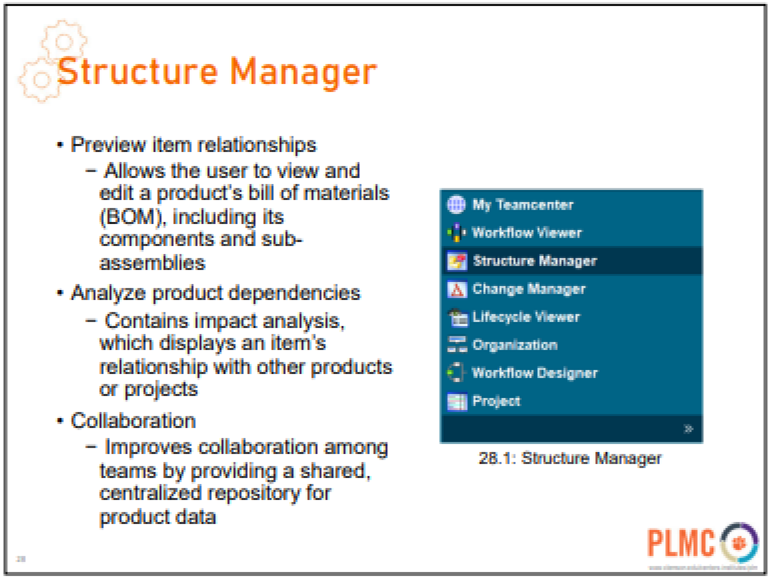

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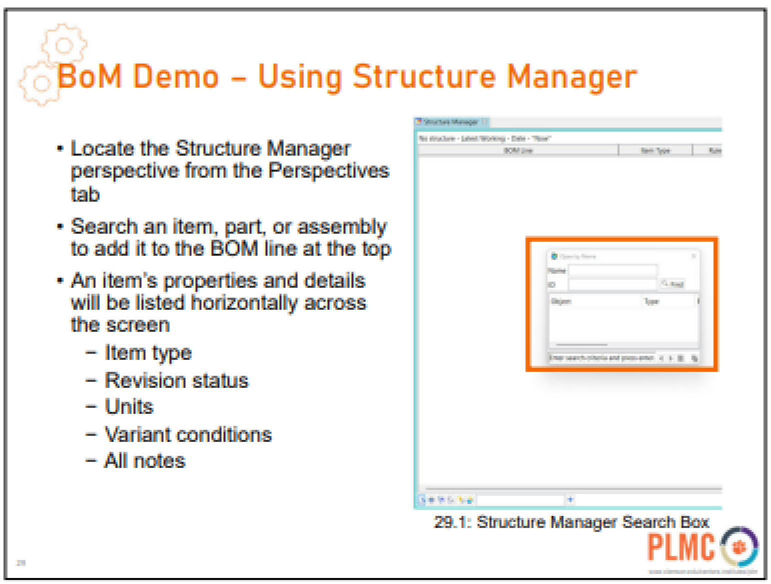

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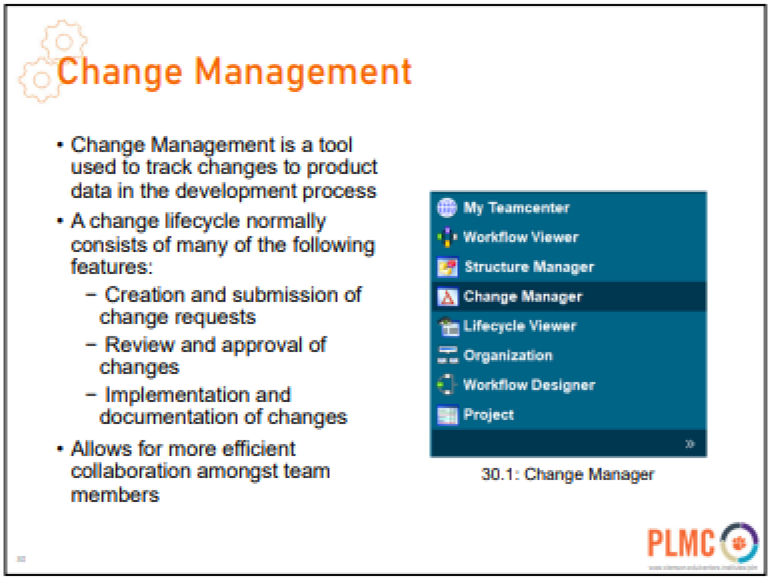

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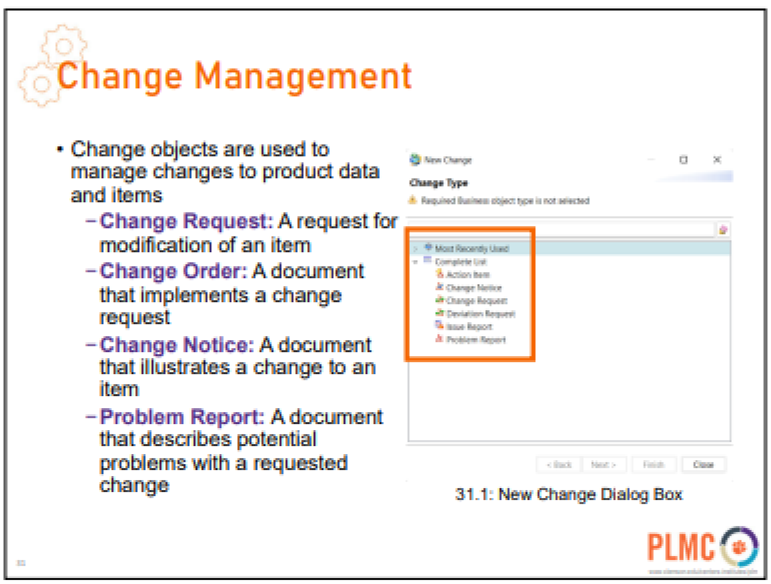

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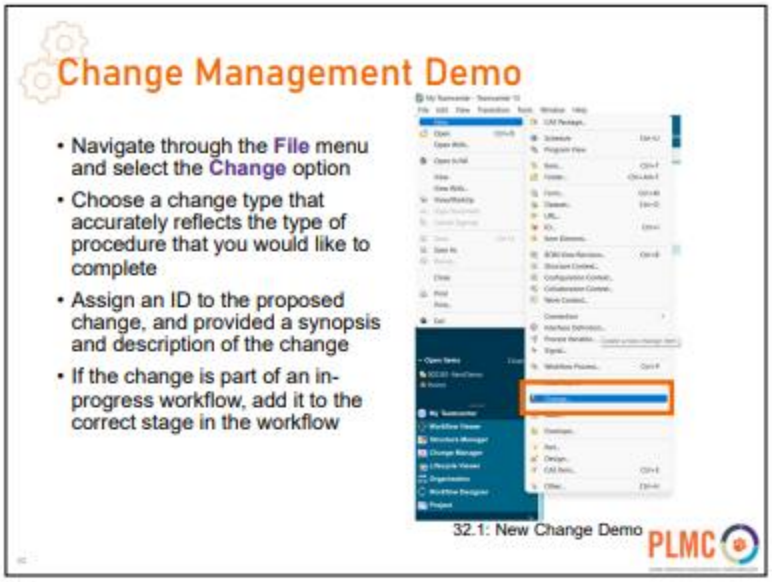

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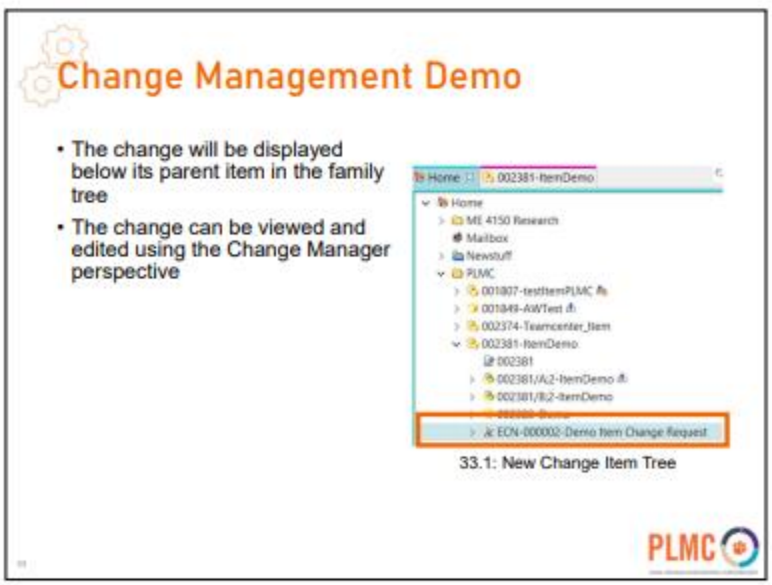

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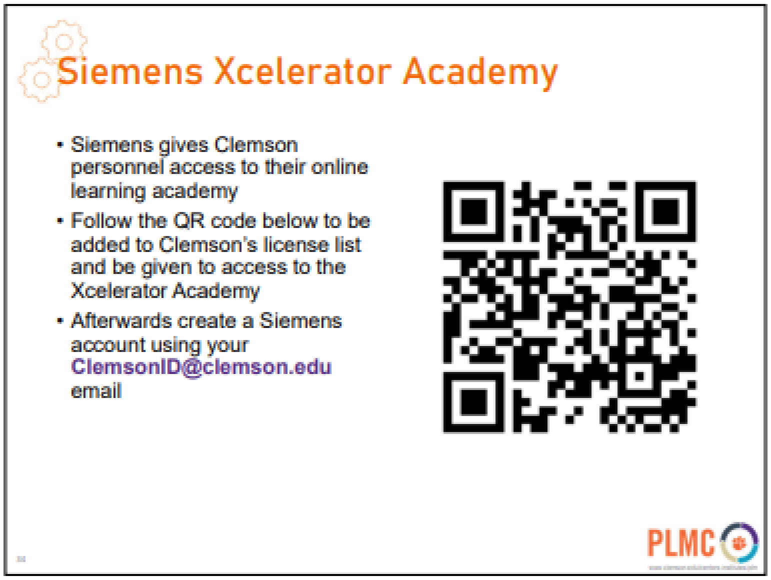

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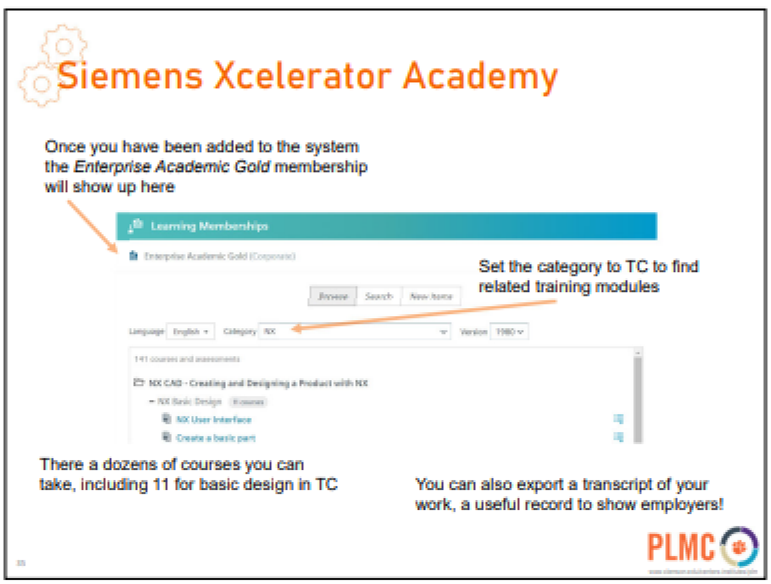

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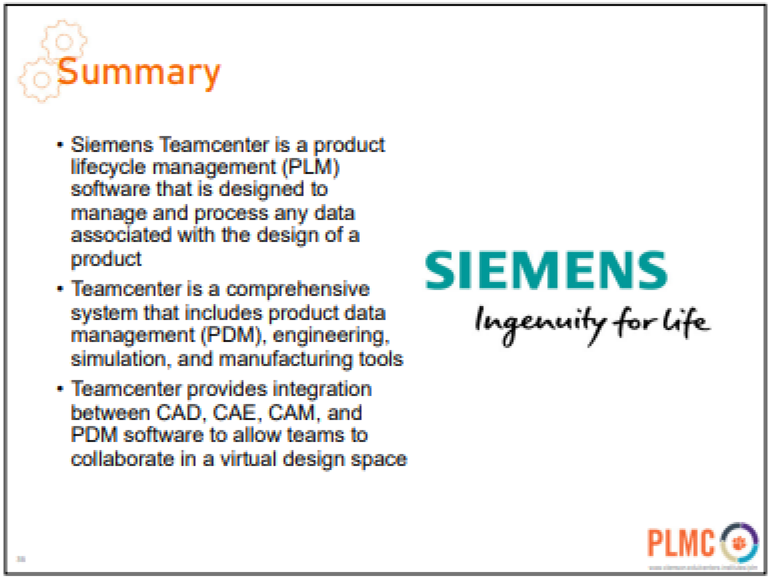

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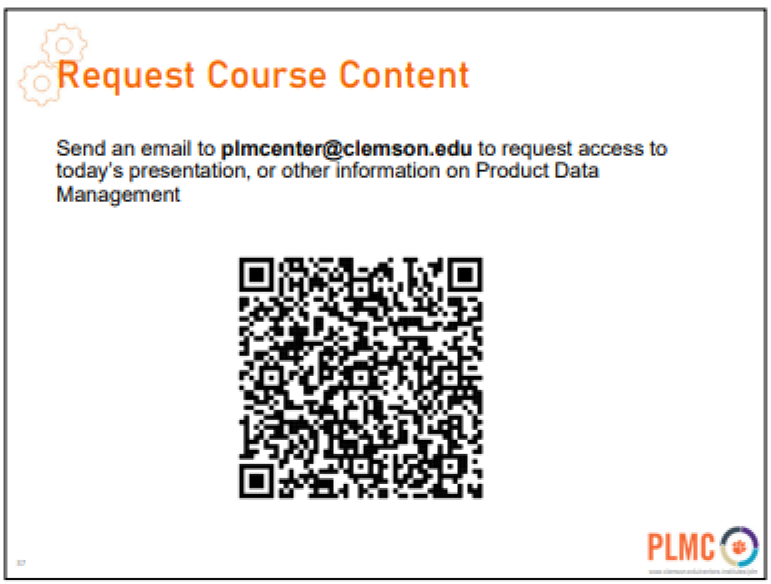

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Figure B.17: Teamcenter Slides (17)

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Figure B.18: Teamcenter Slides (18)

Appendix C

Departmental Honors Presentation Slides

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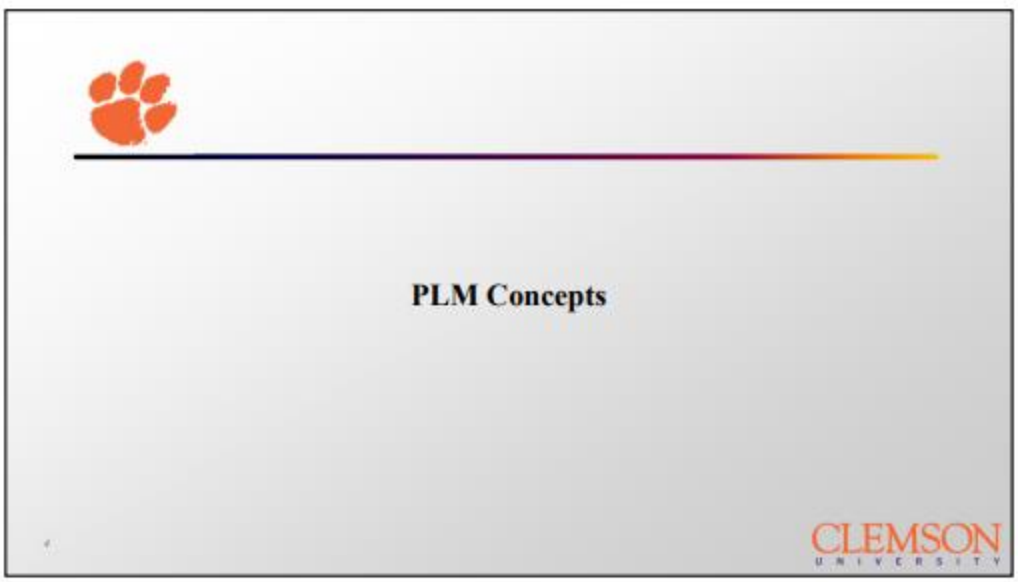

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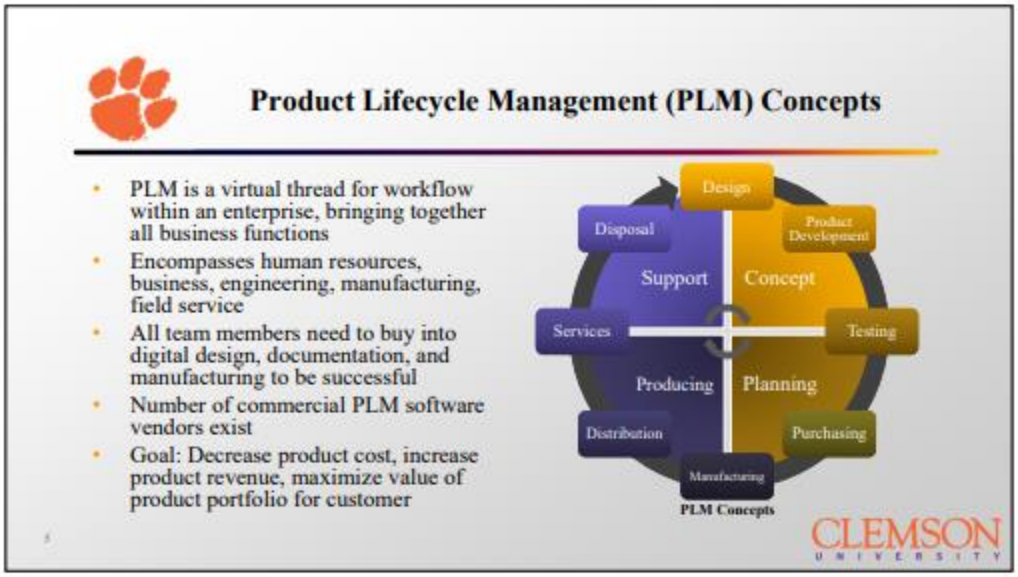

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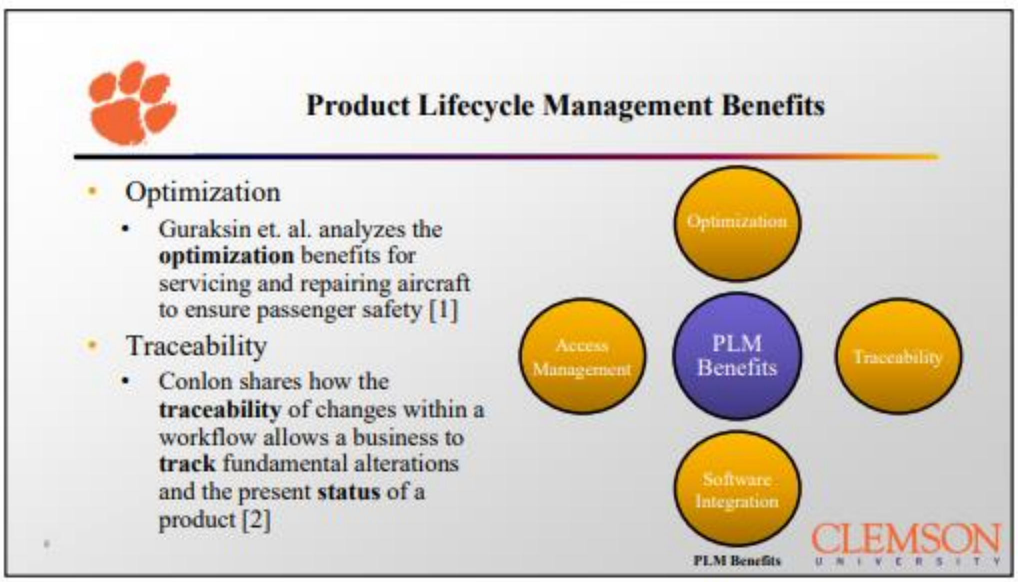

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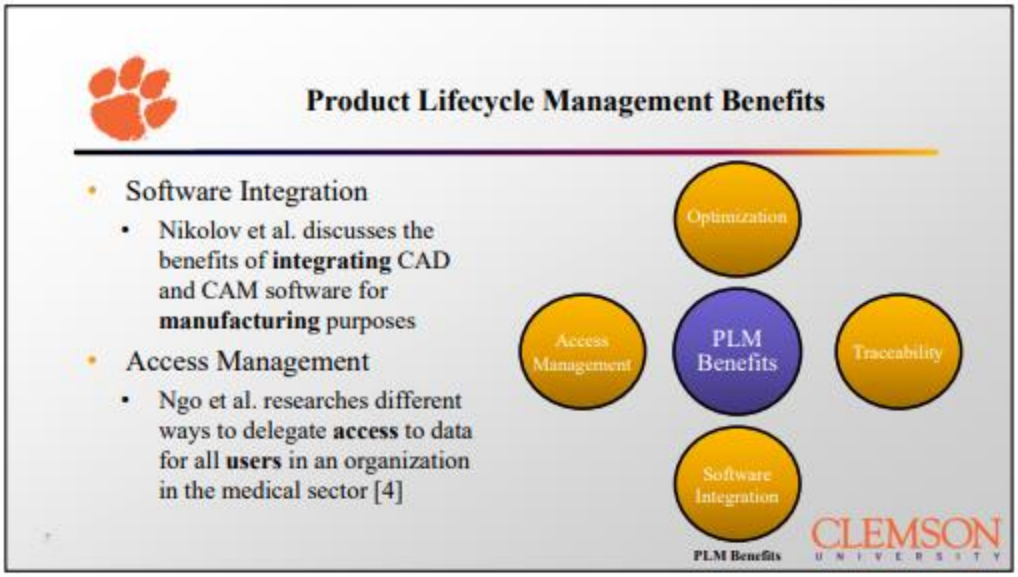

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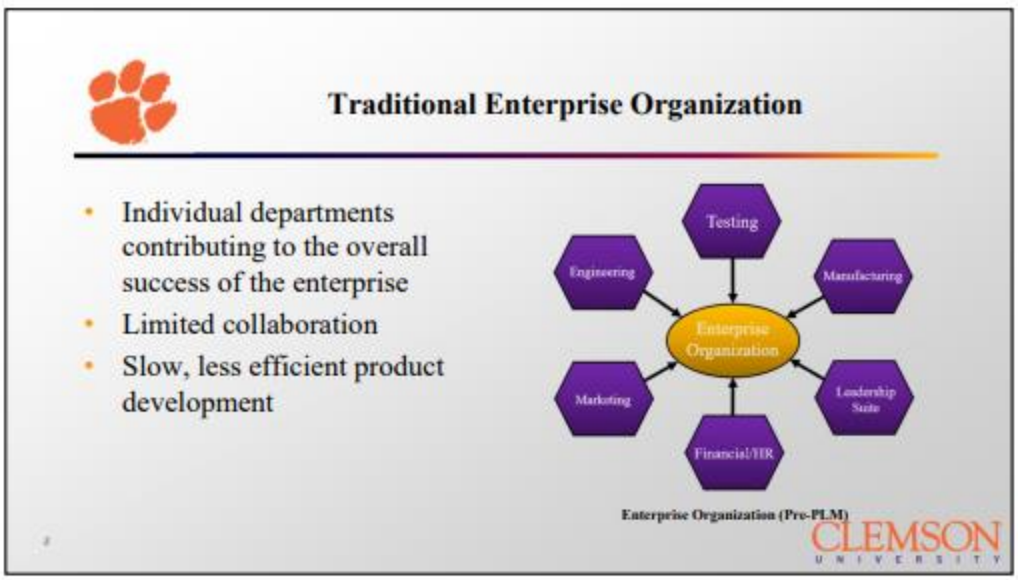

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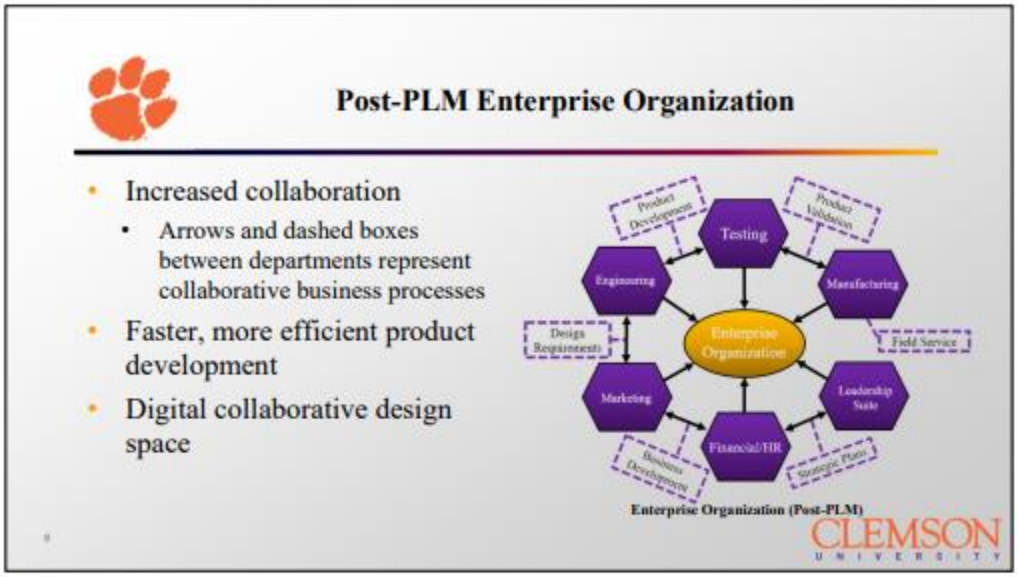

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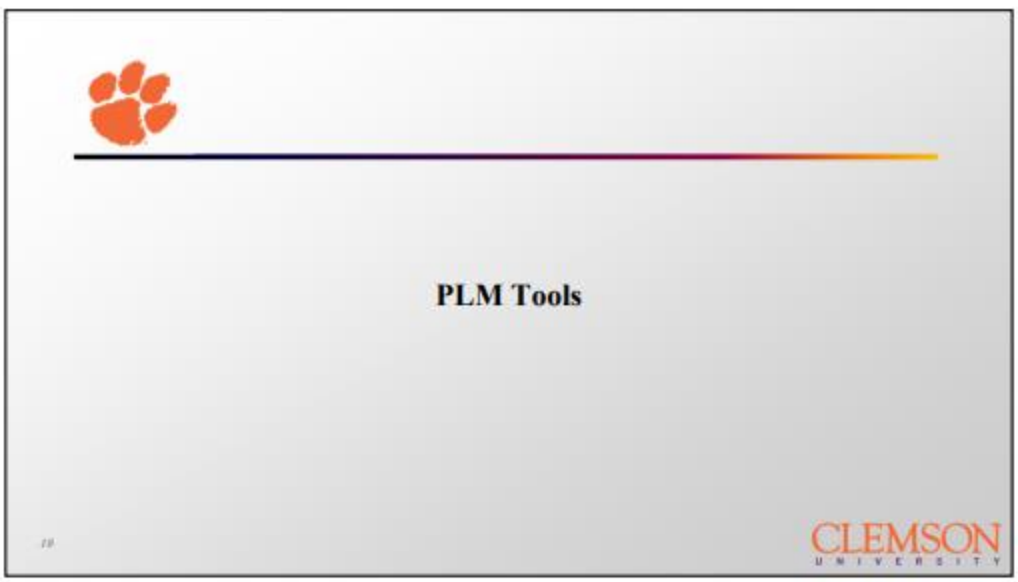

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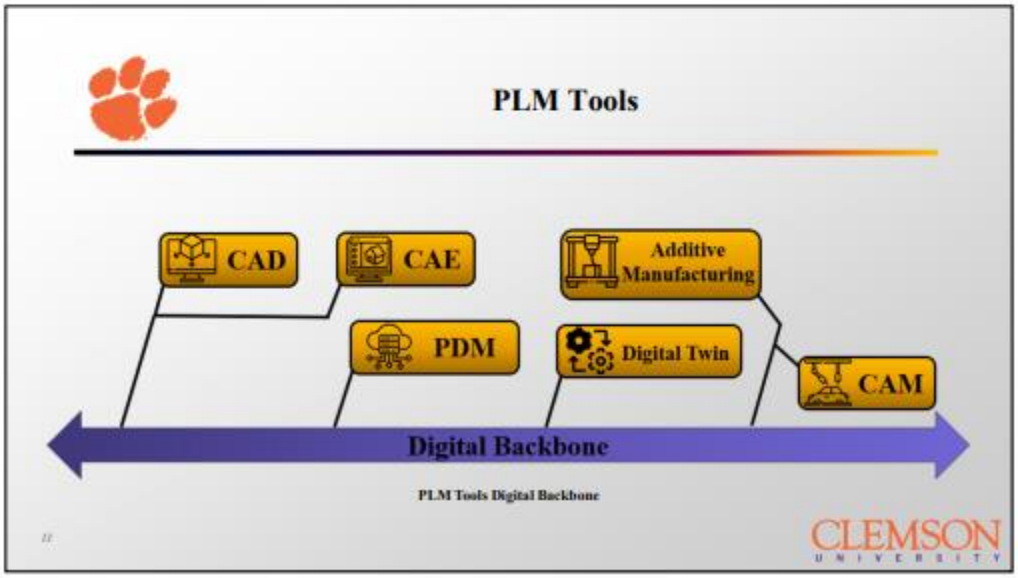

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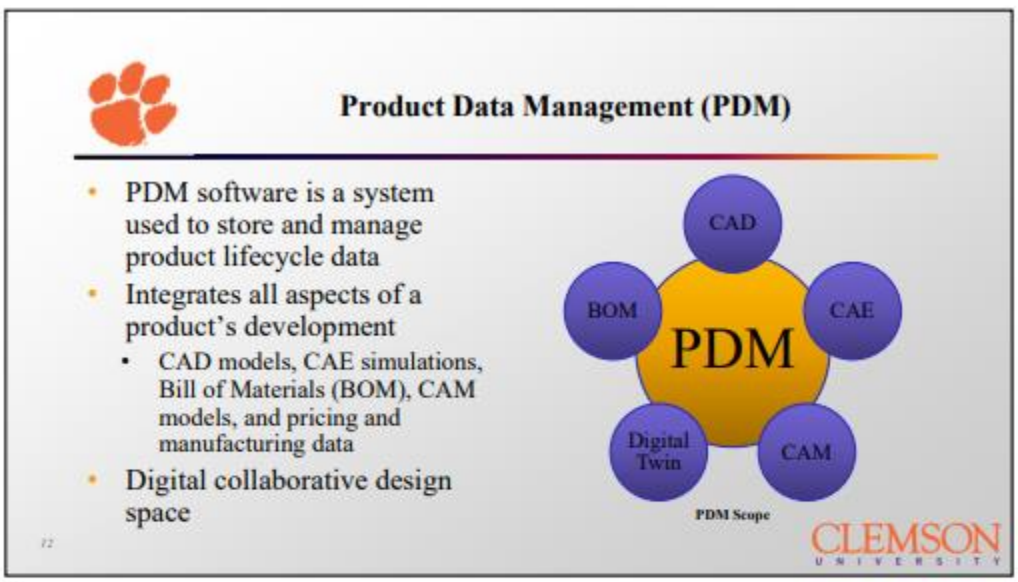

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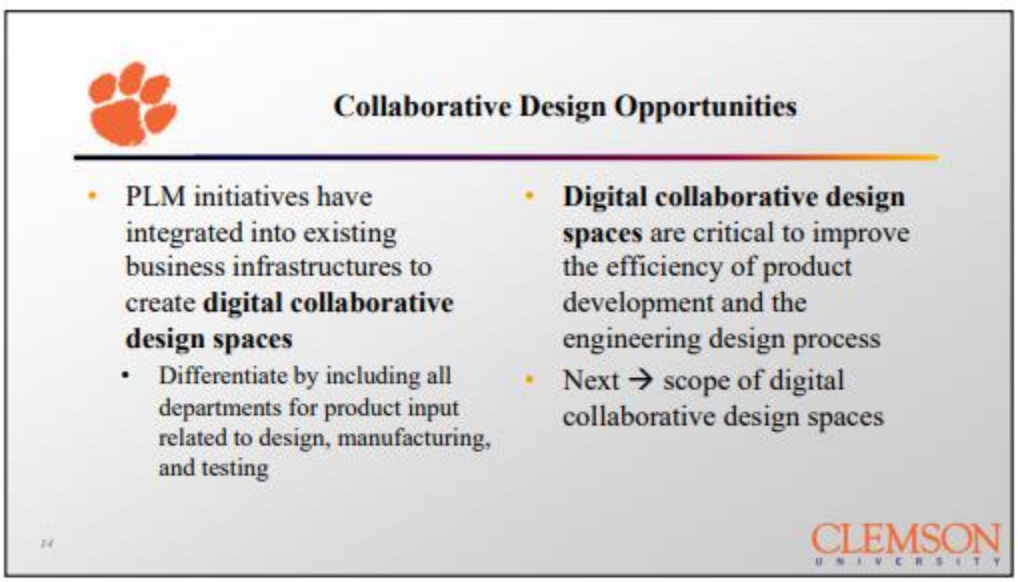

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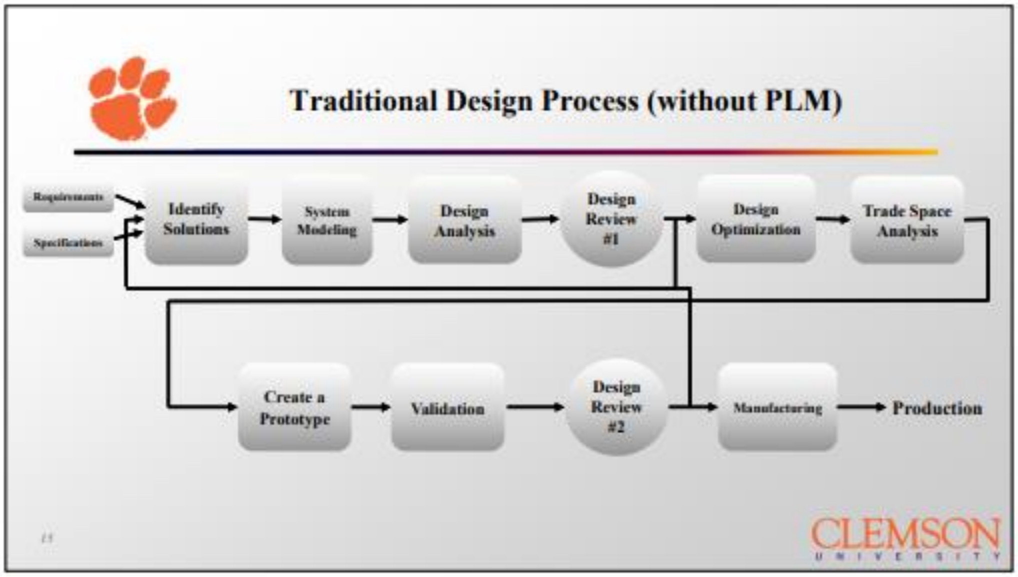

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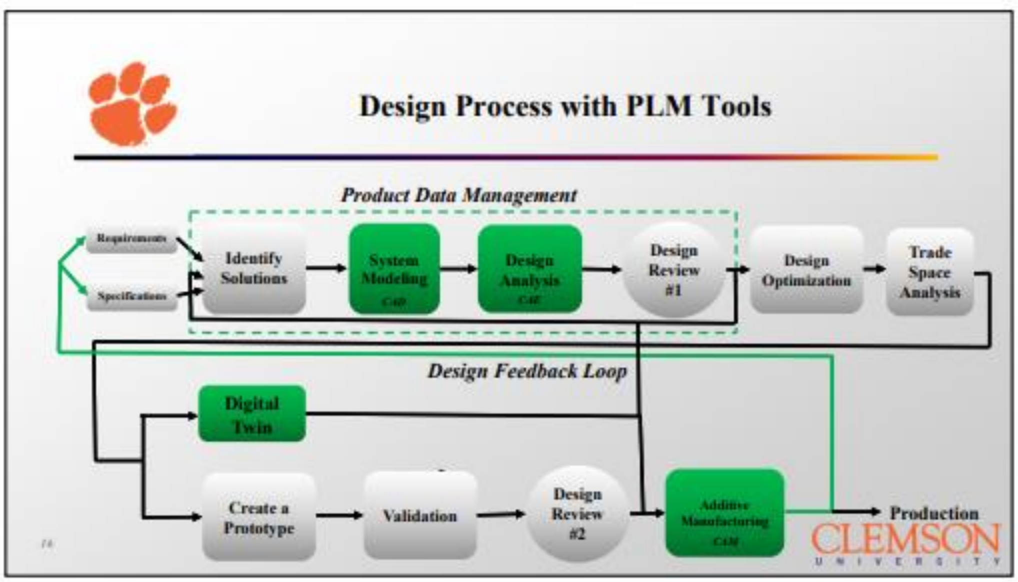

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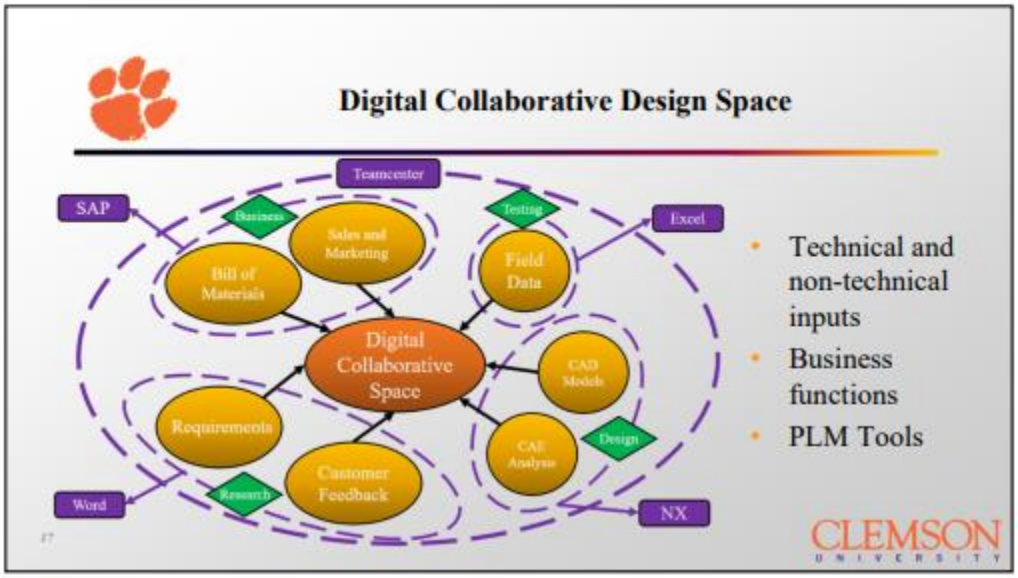

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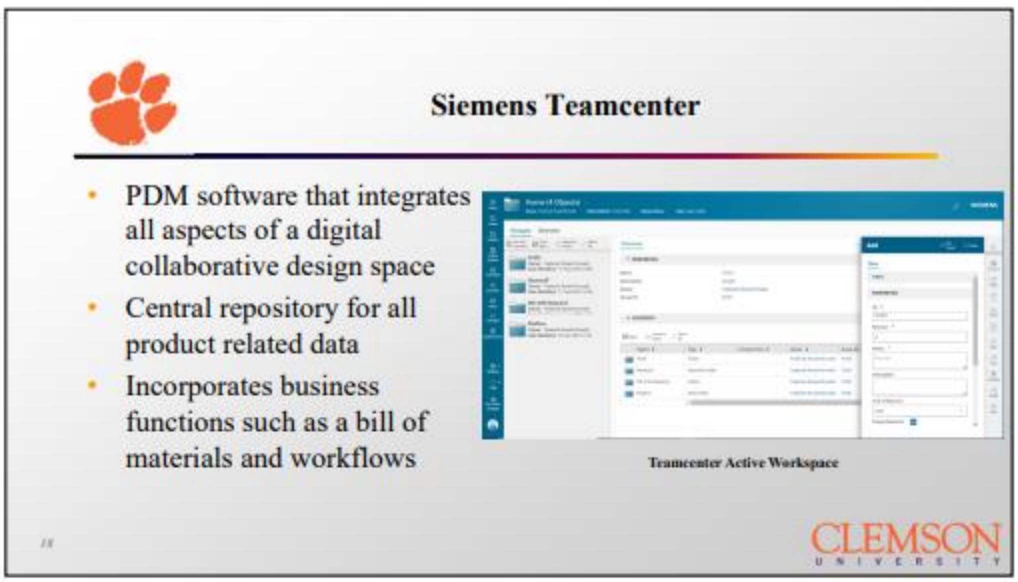

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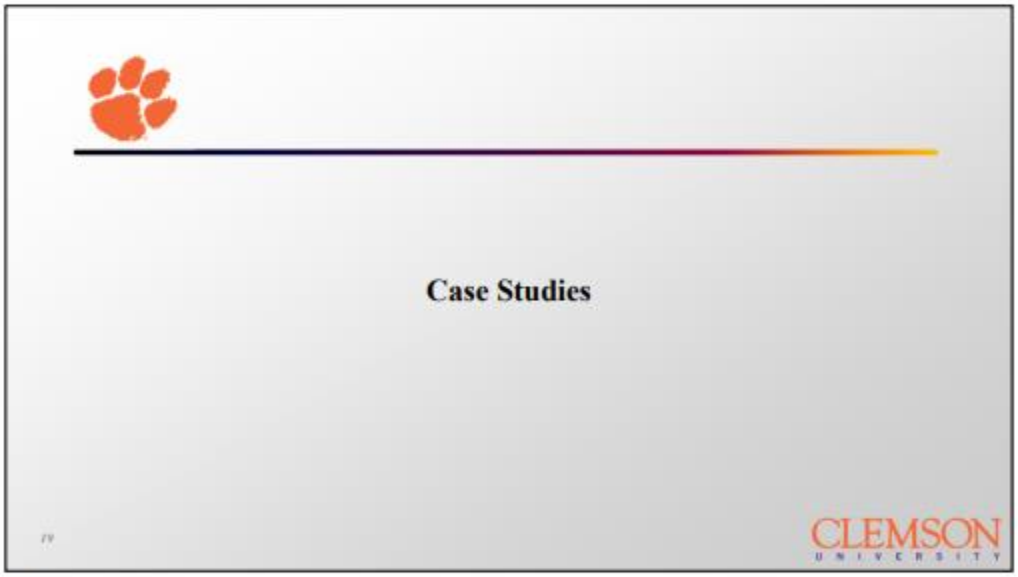

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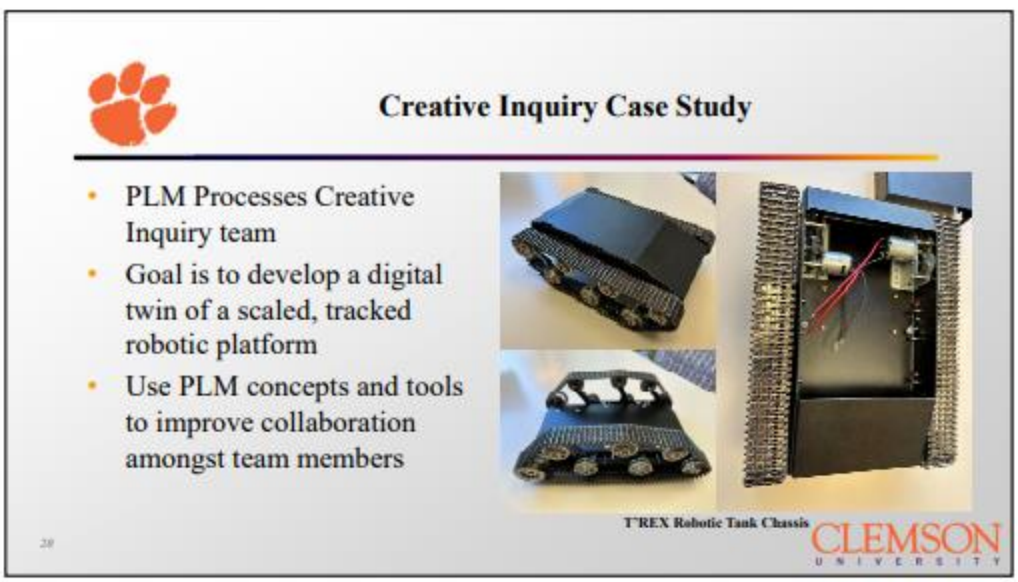

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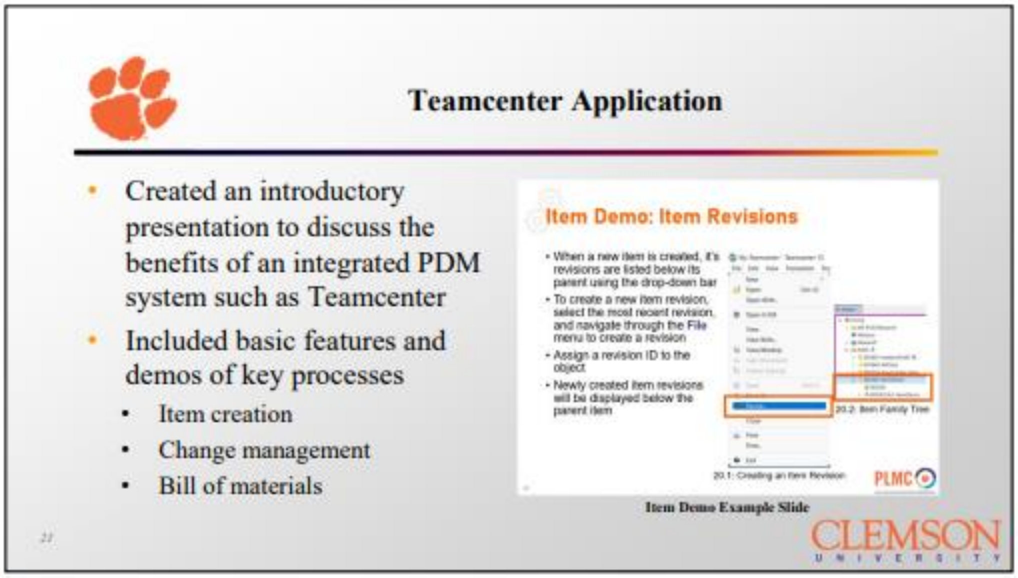
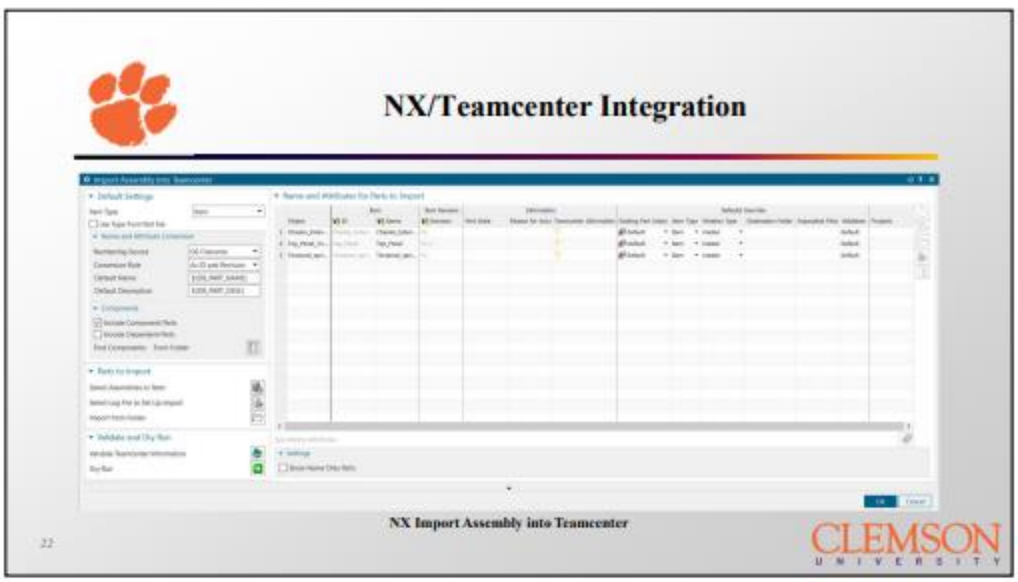
Figure C.10: Final Presentation (10)

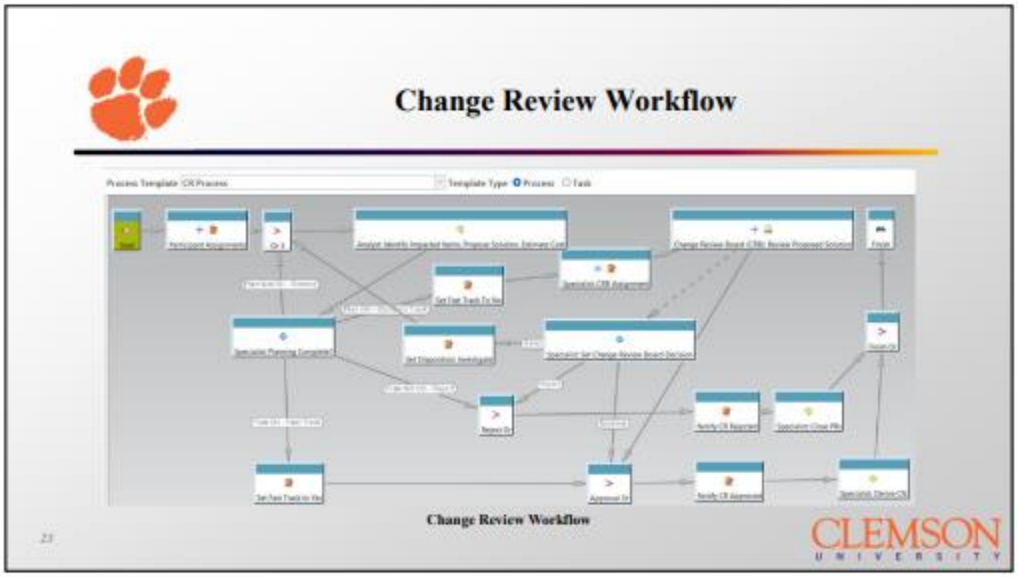


21



22

Figure C.11: Final Presentation (11)



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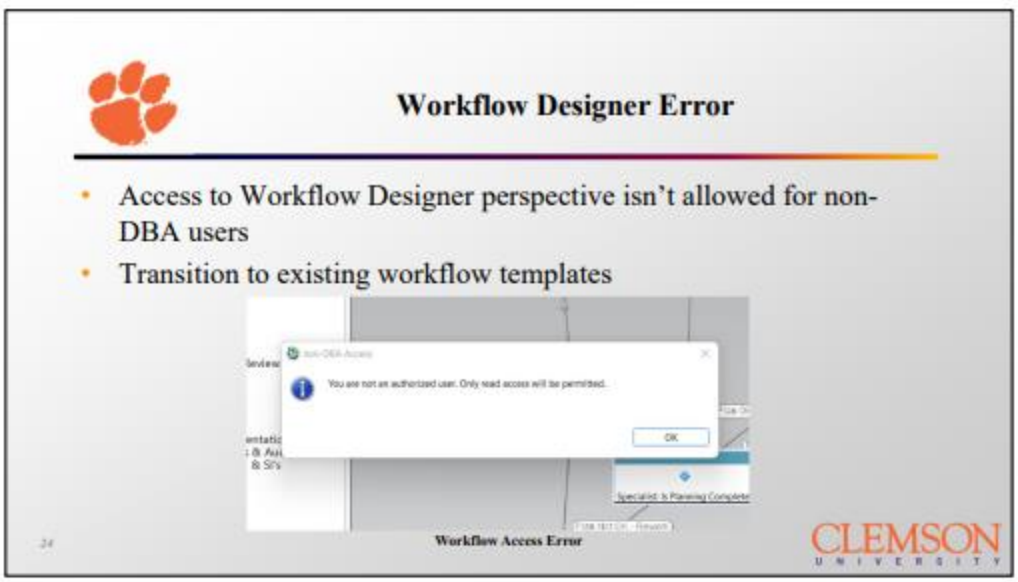
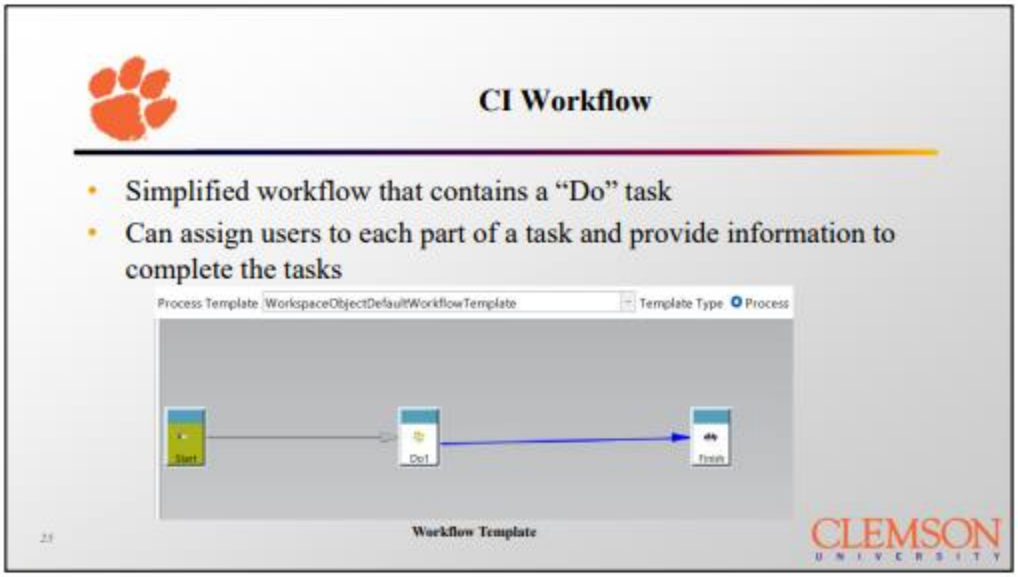
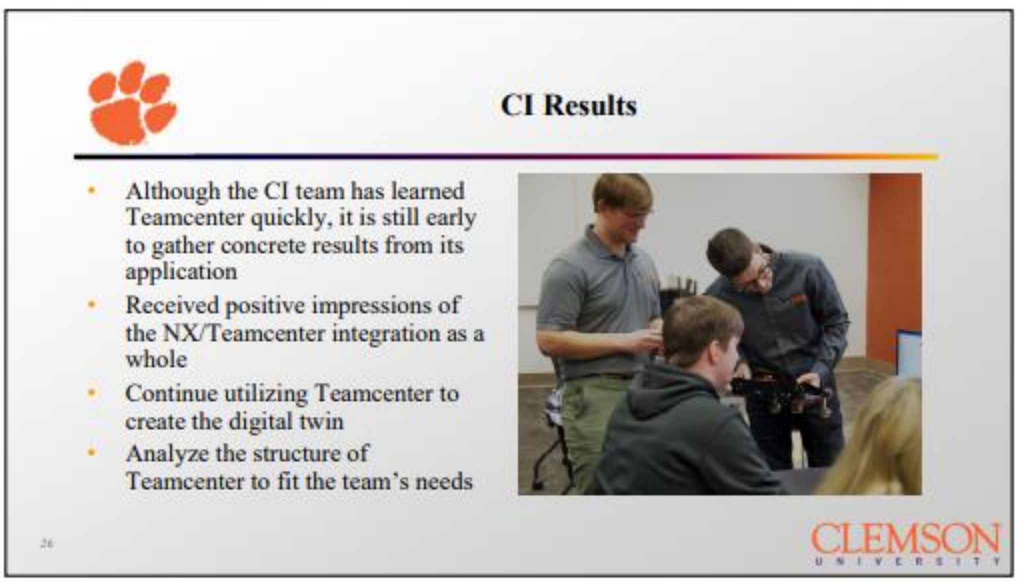


24

Figure C.12: Final Presentation (12)

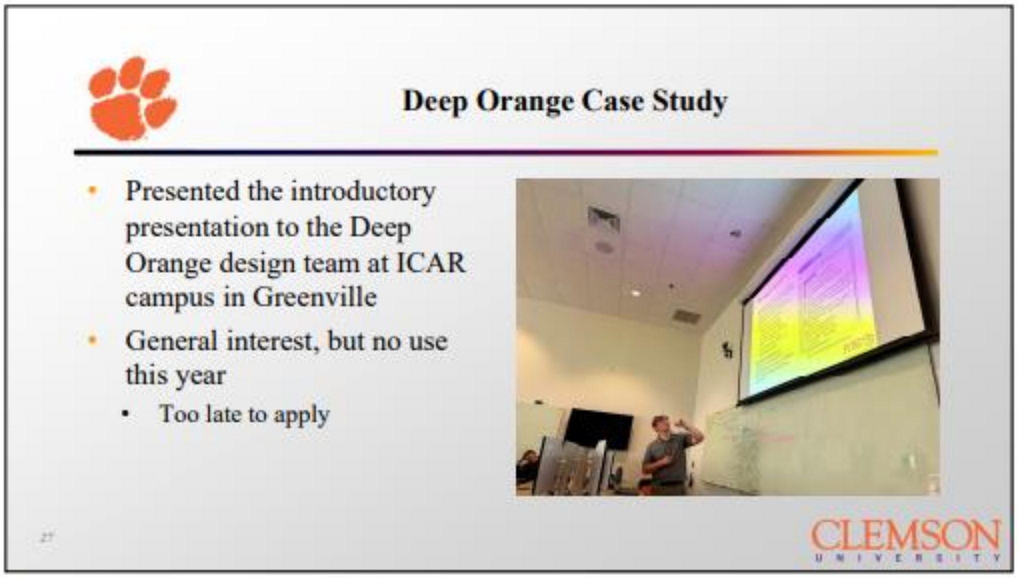


25



26

Figure C.13: Final Presentation (13)



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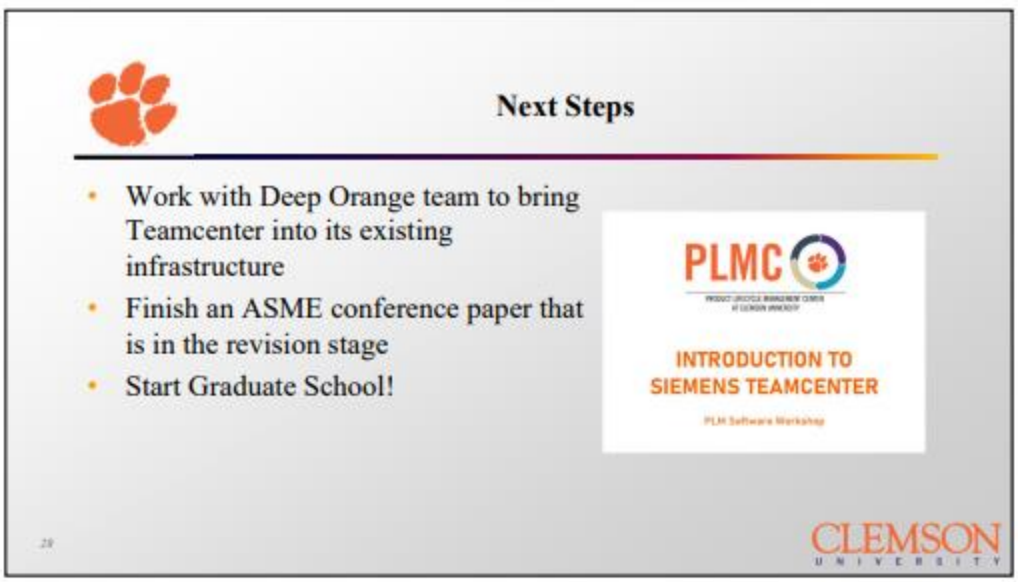

28

Figure C.14: Final Presentation (14)

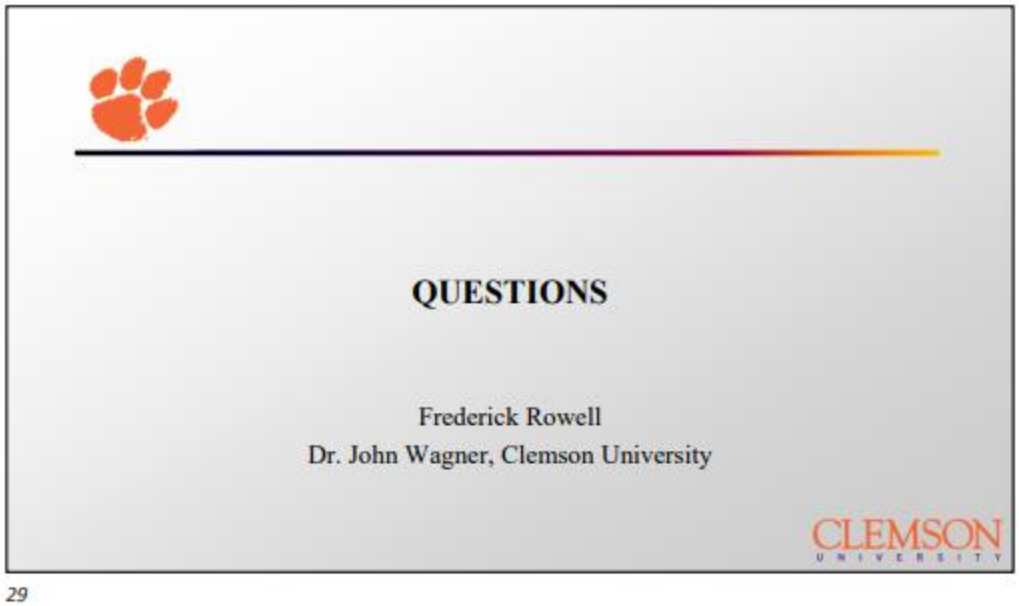

Figure C.15: Final Presentation (15)

Appendix C

Teamcenter Presentation

Figure D.1: Teamcenter Presentation

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