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## Innovative Digital Manufacturing Curriculum for Industry 4.0

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### Abstract

Manufacturing companies across all major industries are facing serious challenges trying to competitively design and manage modern products, which are becoming increasingly complex multi-domain systems or “systems of systems”. Model-based systems driven product development (or SDPD, for *Systems Driven Product Development*) has been proposed as a solution based on driving the product lifecycle from the systems requirements and tracing back performance to stakeholders’ needs through a RFLP (Requirement, Functional, Logical, Physical) traceability process. The SDPD framework integrates system behavioral modeling with downstream product design and manufacturing process practices to support the verification/validation of the systems behavior as products progress through all phases of the lifecycle, as well as the optimization of trade-offs decisions by maintaining the cross-product digital twin and thread for global decision optimization in an efficient and effective way. We have developed an innovative digital manufacturing curriculum (designed around the SDPD paradigm) that is based on the digitalization of the SE (Systems Engineering) process through the integration of modelling and simulation continuum, in the form of Model-based Systems Engineering (MBSE), with Product lifecycle management (PLM). At the core of this curriculum is a shift of focus from theory to implementation and practice, through an applied synthesis of engineering fundamentals and systems engineering, that is driven by a state-of-the-art digital innovation platform for product (or system) development consisting of integrated software (digital) tools spanning the complete lifecycle. The curriculum consists of three key components, namely, modelling and simulation continuum, traceability, and digital thread. The curriculum provides a foundation for implementing the digital twin and supports the training of the next generation of engineers for Industry 4.0. The digital manufacturing (or SDPD) framework is applied in the design and optimization of an electric skateboard. The implementation demonstrates: 1) The benefits of digitalization/model-based engineering when developing complex multi-domain products or systems; 2) The ability of students to effectively complete a real-life modern product development within the time line of one semester; 3) The provision of MBSE curriculum for Engineering Education 4.0, characterized by key, integrated skills for the digital enterprise and Industry 4.0.

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*Keywords:* Digital manufacturing; Digital thread; Industry 4.0; SDPD

### 1. Introduction

The complexity of today’s products stems from the fact that they involve a multitude of sub-systems, multiple engineering domains, and several variants and system architectures. It is also the result of the fact that these products consist of sub-systems that interact and need to be integrated. Typical examples are smart interconnected devices or systems such as smart phones, smart watches, complete drug delivery solutions, autonomous vehicles, etc. The increasing complexity of

modern products has been greatly influenced by a dramatic increase in the number of disciplines involved within a product. Moreover, technological convergences in various applications of engineering domains are happening at an unprecedented rate and magnitude. Such complexity of products coupled with global competitiveness among companies demands streamlined product development approaches to be implemented that can utilize the complete potential of cutting-edge technologies in design and manufacturing. The so-called Industry 4.0 or the Fourth Industrial Revolution necessitates a

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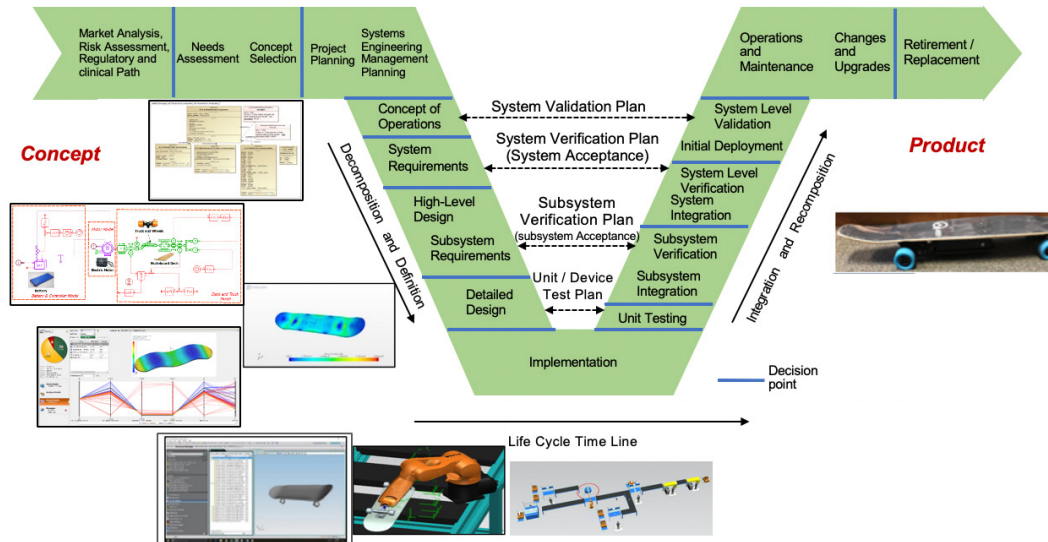


Fig. 1. Digitalization of SE process

change of perspective in developing products that are actually cyber-physical systems and demand a fundamental shift in the way we design and manufacture products, augmenting traditional engineering approaches with significant technologies that will enable Industry 4.0.

Digital manufacturing in its broader sense (i.e. digital product development or lifecycle) has been proposed to address the challenges faced when developing modern products. This is at the heart of Industry 4.0 which is enabled by extensive digitalization as well as the fusion of technologies to build cyber physical systems and the smart factory/product. In a way, it marries advanced manufacturing techniques with the Internet of Things (IoT) to create a digital manufacturing enterprise that is not only interconnected, but also communicates, analyzes, and uses information to drive further intelligent actions back in the physical world. One of the key enablers of digital manufacturing is the concept of product lifecycle management (PLM), a business strategy that supports the development of products including the information needed to support them throughout their lifecycle [1]. PLM can be implemented using a software tool as a backbone for data management by including supporting tools from several disciplines that are integrated with it throughout the system's lifecycle. These tools span various domains and are usually referred to as end-to-end lifecycle data management tools.

Although PLM deals with the nitty-gritties of lifecycle management, it can be considered method-agnostic and hence systems engineering discipline is used to define the design and development activities. Systems Engineering (SE) process has been proposed and actually adopted by a number of organizations and companies to handle the complexity of developing complex modern products or systems [2 - 5]. It was very quickly realized that a switch from document-based implementation of SE to Model-based Systems Engineering (MBSE) is necessary to support the digital transformation and industry 4.0, including enabling the digital enterprise. According to International Council of Systems Engineering

(INCOSE), MBSE can be defined as the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [7]. There are several tools and techniques that support SE/MBSE but are not part of the whole PLM process even though the concept of lifecycle collaboration is shared among both and the convergence of these two technologies is an industry trending topic.

The ability to design modern products (which are typically multi-domain systems) using an integrated digital platform (PLM + MBSE) that spans the lifecycle is at the heart of the digitalization revolution which drives the digital enterprise and Industry 4.0. A typical design course in a Mechanical Engineering program applies the basic design process to develop a product with a focus on the mechanical aspect; typically, without using, an integrated digital platform for the design, that spans and supports the lifecycle of the product. This work addresses for the current limitations, and provides an education that is more aligned with industry 4.0: 1) The need for a digital manufacturing framework and simulator for the digital enterprise that can be used to demonstrate best practice in developing modern products; 2) The need to educate the next generation of engineers for industry 4.0.

The above achieved by developing a unique curriculum that demonstrates the digitalization of the Systems Engineering process through the integration of modeling and simulation continuum (in the form of MBSE) with Product lifecycle management (PLM), which is referred to as Model-based System Driven Product Development (SDPD), Figure 1. SDPD is a form of Model-based Engineering (MBE) that is extended to include digital manufacturing. It can also be defined as the integration of the digital twin with the digital thread [8]. This course expands the scope from product design to Systems lifecycle. In addition, it applies the SE process (vs. Design process), and employs an integrated digital platform that spans the lifecycle of multi-domain products (or systems),

characterized by an integrated modeling and simulation continuum, traceability to the stakeholders needs and requirements, and PLM capabilities for enabling the digital thread.

The proposed curriculum is implemented in the form of a SE Capstone course in a three-level engineering education (as shown in Figure 2) that prepare students for Industry 4.0, namely Engineering Education 4.0. In the first level, students learn the fundamentals including the enabling technologies of Industry 4.0 (AI, Predictive analytics, IoT, System modeling and simulation, Cybersecurity, VR, etc.). The second level consists of the specialized courses in the area of Systems Engineering, which is the process that has been adopted by major organizations and companies. The third level is the synthesis of all the knowledge in levels 1 and 2, and its implementation in real-life product (typically a multi-domain system), as part of SE capstone course. The implementation at level three uses an integrated digital platform and uses the SE methodology covered as part of specialized courses taken as part of level 2. In the innovative course digital manufacturing, the SDPD framework is introduced as an open and modular solution to cross-domain collaborative product development, manufacturing and in-service support which fully integrates modeling and simulation to predict product and process performance across a wide range of disciplines and domains, including mechanical, electrical, software and controls.

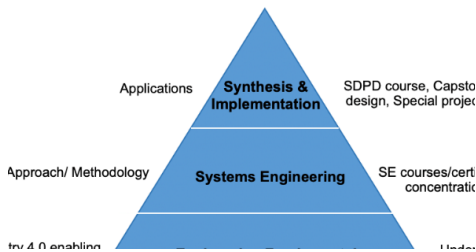


Fig. 2. SDPD curriculum as part of engineering education

The SE Capstone course is a special version of the typical Capstone (design) course. There are mainly three differences in term of process (methodology), product (application) and digitalization between this SE capstone (or SDPD) course and other typical capstone courses, as described in Table 1.

Table 1. Differences between SE Capstone and typical Capstone courses

	SE Capstone course (SDPD)	Typical Capstone courses
Process (methodology)	SE process	Design process
Product (application)	Multi-domain system	Mechanical product
Digitalization	Integrated digital platform (to enable both digital twin and digital thread) that spans the lifecycle	Limited digital capabilities

In this course, the underlying fundamentals and theories of system modelling is covered. On the other hand, the SE methodology is presented as the backbone process for SDPD. Also, other topics pertaining to the design, manufacturing, and optimization of a multi-domain systems are covered/reviewed to the extent that is needed to realize the effective and intelligent use of the tools and their implementation in the case studies and final project. The projects are defined and implemented by teams. The application is required to consist of a multi-domain system. Teams are expected to conduct the complete product development process using SDPD framework and methodology.

## 2. Framework

The SDPD course consists of three key components: 1) Modeling and simulation continuum; 2) Traceability; 3) Digital thread. Students will learn how to use different engineering models of different fidelity levels at different point in the system development process in order to make the development process more efficient and practical. Full integration or co-simulation of different models are also implemented. The digital thread is implemented using PLM as the backbone to support the integration of the different models used throughout the development cycle. For example, the engineering bill of materials (EBOM) that is automatically extracted from the CAD model is used to generate the manufacturing bill of materials (MBOM) and bill of process. Figure 3 shows a process flow used in the SDPD course. The PLM platform is also used to create a workflow and manage all system, product, and process data. The process flow starts with the creation of high level “0-D” system model using MBSE. Then, a 1-D system simulation is developed. 3-D computer-aided-design (CAD) models of the product are created and simulated using several computer-aided-engineering (CAE) techniques to optimize the design of different components. The manufacturing process is then created and simulated using computer-aided-manufacturing (CAM) tools. This framework integrates a “digital twin” (0D to 3D integrated modeling continuum) with the digital thread enabled by PLM backbone.



Fig. 3. SDPD process flow used for the case study implementation

## 2.1. Model-based Systems Engineering

The first step in SDPD process flow is to create a system model. According to the INCOSE definition, a system is an integrated set of elements, subsystems, or assemblies that accomplish a defined objective. The elements of the system interact with each other and the environment. These elements include products (hardware, software, and firmware), processes, people, information, techniques, facilities, services, and other support elements. Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems [7]. System engineering focuses on designing and managing complex systems over their life cycles including activities such as specification, design and analysis, integration, verification and validation of the product to be developed.

Systems Engineering has become prevalent in various industries like automotive, defense, aerospace, etc. Until recently, systems engineering was carried as an engineering practice, with the help of documents to manage and pass information across system lifecycle phases. Although the document-based approach in systems engineering could be successfully realized with proven benefits, it had some fundamental limitations. Moreover, increasingly complex systems demand a more formalized approach to carry out SE activities. Model-based approach is becoming the industry standard in systems engineering. Taking its roots from software engineering, the formalization of SE is called Model-Based Systems Engineering (MBSE).

The output of systems engineering activities is a coherent model of the system where emphasis is placed on evolving and refining the model using model-based methods and tools. The system model is an integrative representation of the system structure and behavior, sometimes referred to as system architecture. In order to develop a complete system model, it is necessary to have a modeling environment that supports modeling using graphical/textual language, a well-defined modeling methodology and an intuitive tool interface. The system model constitutes a variety of information that is reflective of the stakeholder requirements in the form of various architectural viewpoints using a number of modeling artifacts.

The main purpose of MBSE is to identify the system's functional and non-functional requirements based on the needs of the various stakeholders such that a model can provide an architectural representation of the system that is compliant of these requirements. For systems engineering model to be complete, it must represent the system's functional and logical architecture, along with a physical architecture, all at various levels of abstraction. The system functional requirements help identify the various system-level functions which are further decomposed and allocated to various logical subsystems and components of the system. A physical architecture is the technical solution of the logical architecture. These architectures together constitute the structural and behavioral representation of the system which is further subject to evaluation. At the moment, there are various commercial and open source system modeling solutions available for systems engineers to effectively design their respective systems. Their

choice of the solution is highly influenced by factors such as the application domain, industry, fidelity of the model required for SE activities, etc.

SysML (Systems Modeling Language) is a general-purpose modeling language to support the systems engineering activities by allowing the use of descriptive models [8]. SysML is based on the object-oriented concepts in software engineering, hence supporting high reusability of the artifacts while modeling. A system can be modeled using SysML with the help of a modeling tool that supports SysML's object-oriented modeling. In this unique curriculum, we use a system model developed in SysML as a reference to develop a multi-physics simulation architecture.

## 2.2. 1D System Simulation

Once we have a system architecture model in place that defines the structure and behavior of the system, it should be validated against its functional requirements. In other words, the system's logical architecture shall be validated to assess the system performance based on inputs such as the system component parameters. Model-based system simulation is a means to analyze the behavior of the system with help of continuous/discrete dynamic simulation models.

The diagrams in SysML precisely capture the system requirements and allow to describe the structure and behavior of the system. However, analyzing the behavior of the systems to assess requirements is not provided by SysML. Various SysML tools provide simulation capabilities which are still limited. Hence, predictive analysis of system models must be done by simulation using domain-specific simulation tools. In an MBSE workflow, a simulation architecture can be defined based on the logical architecture developed in the modeling tool. A model-based simulation architecture consists of the various system components and subsystems linked to each other through ports and interfaces. These components are designed using mathematical equations of the system components. The links or interfaces between these components facilitate the exchange of information, energy, objects through the respective ports of the components. A mathematical solver is used to solve these equations based upon the attributes defined for system components as inputs and the results can be interpreted in the form of graphs and values for different system variables. Some of the most widely used system simulation software include Simcenter Amesim, GT Power, Mathworks Simulink and DS Dymola. For our simulation purposes, we chose Simcenter Amesim because of its easy-to-use concepts and vast number pre-built component libraries.

## 2.3. CAD Simulation

After stakeholder needs and requirements are known, detailed engineering of 2D drawings or 3D models can be created. Computer-aided design (CAD) is typically used to aid the designer in the creation and optimization of the models. Recently, several CAD software can be integrated with MBSE tools and provide traceability analysis of the CAD geometry and stakeholder requirements. This integration allows

designers to increase their productivity and also improve the quality of the design.

#### 2.4. CAE Simulation

The next step in SDPD process is to perform engineering analysis of the 3D CAD geometry (product simulation and optimization). Computer-aided engineering (CAE) tools are used in different types of engineering analysis including finite element analysis, computational fluid dynamics, and multibody dynamics. Commonly, engineers need to use several software tools to simulate a component or product assembly. As products and materials become increasingly complex, product development (design cycles) time will dramatically increase. As such, CAE software tools with integrated solvers providing powerful solutions for different type of analysis (i.e. linear and nonlinear structural analysis, dynamic, acoustics, and thermal analysis) are needed to help make informed decisions. Product can be analyzed and simulated to predict system performance during the early design stages.

CAE modeling and simulation software provides an excellent way for engineers to cost-effectively evaluate how their products will perform under expected operating conditions. However, performance of complex products depends on a large number of design variables. To find the best design that satisfies certain criteria and multiple constraints, engineers need to run the simulation multiple times and would take several weeks to accomplish manually. Design optimization software takes modeling and simulation to the next level by allowing engineers to determine appropriate design variables that yield product designs with exceptional performance and dramatically reduces design time.

#### 2.5. CAM Simulation

Once the design is optimized, the next step is planning its manufacturing. This includes designing the manufacturing process, simulating the process for validation and optimization, designing the production line, and simulating the assembly and optimizing the production. The core of the manufacturing workflow is the CAD model and EBOM (engineering bill of material). The latter is used to automatically generate the MBOM (manufacturing bill of material) from which the bill of process or BOP is generated. On the other hand, CAM is also used to simulate the manufacturing of individual components. The most commonly used process is machining, where tool path is automatically generated once the operation is defined in terms of its sequences and their parameters. Current digital tools support all of these functionalities. The extent to which all these steps are integrated and/or automated varies from digital platform to another. Some of the most advanced ones support the digital thread to connect CAD to CAM in a seamless way. For example, Siemens digital platform provides tools to enable the digital thread and support the integration for design (or CAD) and manufacturing (or CAM).

### 3. Case Study Implementation

This SDPD course was designed to give an exposure to the overall product lifecycle from capturing requirements to

estimating the parameters which would help an industry to assess the productivity and profits from the product. To demonstrate the use of SDPD process flow, a case study of an electric skateboard is presented in this paper. Electric skateboard is a multi-domain system involving mechanical, mechatronics, and electrical systems.

As a backbone of digital thread for SDPD implementation of electric skateboard, Teamcenter suite of PLM software was used for storing different type of files (including Amesim output, NX 3D model of the skateboard deck and Star-CCM+ analysis file). This will bring many benefits including having one source of data, defining different levels of authorizations for people involved in the process based on their roles and reflecting changes in any of operations on a single database.

Project workflow describing individual tasks and the task sequence required to complete SDPD course process flow was created in Teamcenter. Each task defined a set of actions, rules, and resources used to accomplish that task. Each student was assigned a role in a team. The software allows students to keep track of their team progress and any revision of the shared files. Each team of students required to do a research on electric skateboard currently available on the market, interviewed electric skateboard users, and proposed a new improved design.

#### 3.1. System Design

After researching and interviewing stakeholders, students had to translate stakeholder's needs into requirements (as shown in Figure 4) and used MBSE tool to develop system model. In this example, the system model of an electric skateboard was developed using Cameo Systems Modeler. The system architecture precisely captures the system requirements and allows to describe the structure and behavior of the system. This static representation of the system model acts as the single source of truth for the information of the to-be developed product. Different types of SysML diagrams including block definition diagram (BDD), internal block diagram (IBD), parametric diagram, activity diagram, use case diagram, and state machine diagram were created.

Figure 5 and 6, respectively, show example of block definition diagram and activity diagram created in Cameo Systems Modeler for electric skateboard case study. The block definition diagram describes the architecture of the electric skateboard system and represents the system hierarchy in terms of systems and subsystems. Activity diagram describes control, input, and output flows among actions/operations.

△ Name	Text
1 SN01	The system shall transport the user <u>at least</u> 10 miles at an average speed of 10 miles per hour in a single charge
1.1 SN01-1	The system shall transport user with a speed <u>greater than</u> 10 meter per second
1.2 SN01-2	The system shall transport user for <u>at least</u> 10 miles in a single charge
2 SN02	The user <u>shall be</u> able to control the speed and stop within safe distance
2.1 SN02-1	The user <u>shall be</u> able to control the speed
2.2 SN02-2	The user <u>shall be</u> able to stop within safe distance
4 SN03	The skateboard shall stop within safe distance
5 SN04	The skateboard <u>shall have</u> speed setting for Novice, Regular and expert levels
6 SN05	The skateboard shall use commercially available off the shelf materials (COTS)
7 SN06	The skateboard shall use readily available energy source with sufficient energy to meet daily needs
8 SN07	The system <u>shall have</u> a portable controller to energize the skating engine, control speed and monitor operation status

Fig. 4. List of stakeholder requirements

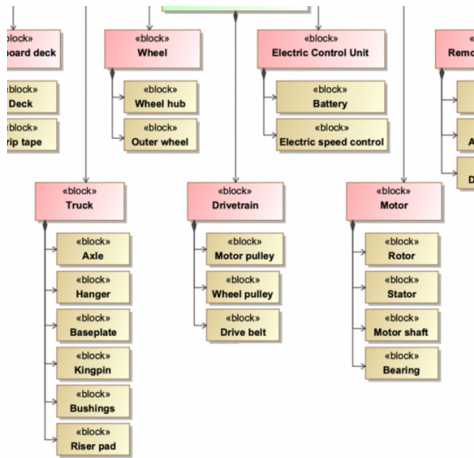


Fig. 5. Block definition diagram (BDD) of electric skateboard

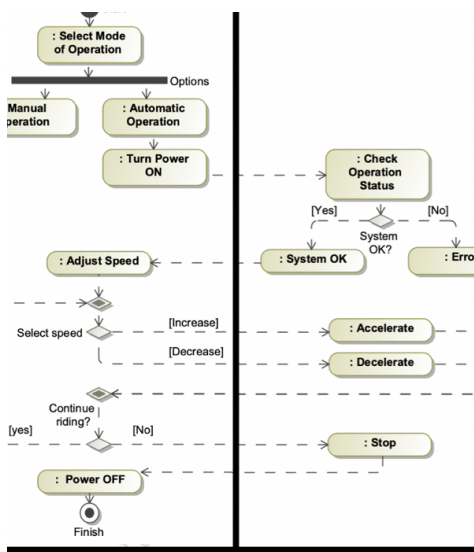


Fig. 6. Activity diagram describing electric skateboard operation

3.2. 1D System Simulation and Optimization

Electric skateboard is a multi-domain system consisting of both mechanical and electrical components. System-level simulation can be done using a dynamic model developed from a multi-physics system architecture in a 1D simulation tool. In this case study, Simcenter Amesim is used for the modeling and analysis of the multi-domain electric skateboard system. The system (shown in Figure 7) is modeled using a number of components that are provided in the component libraries. The modeling is done by the four modes of operation in Amesim. These are: 1) Sketch mode; 2) Submodel mode; 3) Parameter mode; 4) Simulation mode. The system components are created

and linked in the “sketch mode”. Distinct mathematical expressions for the components are assigned in the “submodel mode”. The features and parameter of the components are entered in the “parameter mode”. The simulation run is initiated, and the results are analyzed in the “simulation mode”.

Amesim was used to perform system simulation of the Electric Skateboard to validate performance requirements. Based on different diagrams created in Cameo, including block definition diagram (used for structural representation of the system), requirements diagram (used for defining the requirements of the Skateboard, parametric diagram or par (defining different equations related to the electric skateboard), etc., the 1D model of the electric skateboard was created and the simulation was run in batch mode to show different outputs caused by different user’s weight and varying wheel radius of the skateboard wheels. Figure 8 shows variation of displacements of the skateboard for different wheel radius and user’s weight.

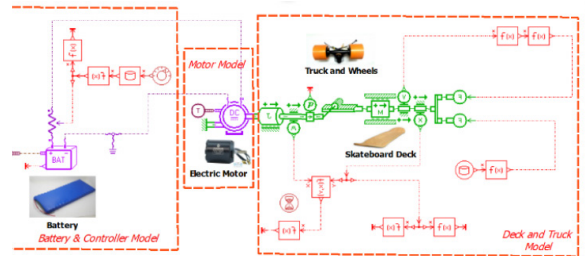


Fig. 7. 1-D Multi-domain system model

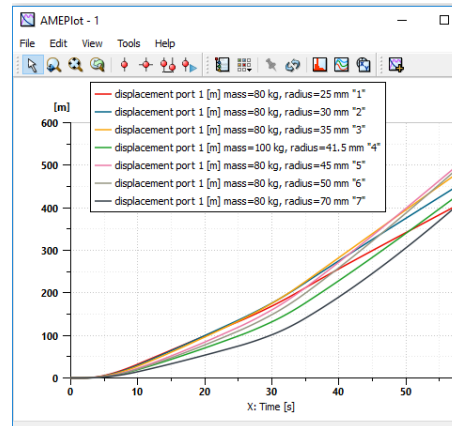


Fig. 8. Amesim output showing displacement of the electric skateboard over time for different wheel radius and user’s weight

3.3. 3D Design

3D geometry model of electric skateboard was created using NX software. Figure 9 shows 3-D model of skateboard deck component. The initial geometry of each electric skateboard component was obtained from stakeholder requirements and 1-D system model optimization. In addition, students can perform design requirements validation within NX software.

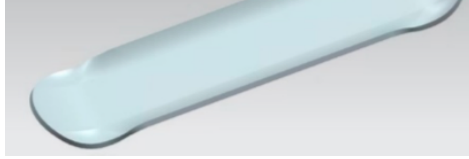


Fig. 9. 3-D model of skateboard deck

### 3.4. Product Simulation

After 3D CAD geometry model of electric skateboard was created, different types of engineering analysis can be performed. In this paper, structural analysis of the skateboard deck using Finite element analysis is presented. The analysis was carried out in STAR-CCM+ software. According to the stakeholder requirement that the skateboard shall be withstand the maximum user's weight of 200 lb, the normal force applied on the top surface of the skateboard was selected to be 900 newton (N). The boundary condition used in the model was the 8 holes connected to the skateboard truck and wheels at the bottom side of the skateboard deck. Figure 10 shows the plot of Von-Mises stress of the skateboard deck.

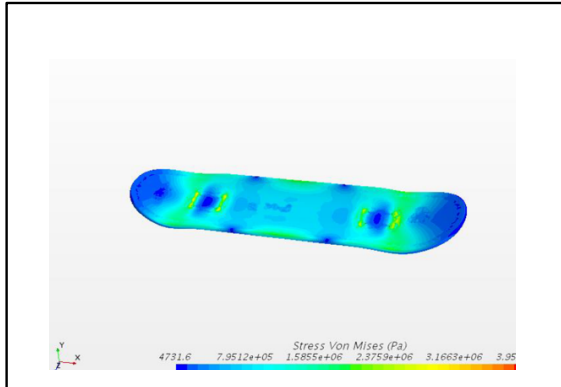


Fig. 10. Von-Mises stress of skateboard deck

### 3.5. Product Optimization

The next step in SDPD process flow is to perform design optimization of the product. The optimization process was done using HEEDS MDO (Multi-disciplinary Design Optimization) software. HEEDS MDO allows students to automate the search for better and more robust designs according to multiple criteria, while simultaneously satisfying multiple constraints and using a large number of design variables. For the skateboard case study, the design optimization objective was to minimize the volume of the skateboard deck with subjected to displacement and von-Mises stress constraints. The design variables considered in this case study were the thickness and the length of the skateboard deck. The number of optimization run was set 100. Figure 11 shows the screenshot of output

summary after completed 100 runs. Only 38 designs were feasible, 54 designs were infeasible, and 8 designs were error.

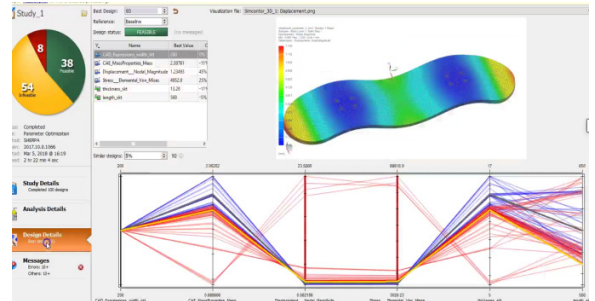


Fig. 11. Design optimization of skateboard deck

### 3.6. Manufacturing Process Design

The manufacturing process design can be done concurrently with the product design to ensure that manufacturing constraints are reconciled during product design process. In this step, students need to create engineering bill of materials (BOM), manufacturing BOM, and manufacturing bill of process (BOP). Teamcenter Manufacturing Process Planner (MPP) module was used in the case study of electric skateboard. MPP enables user to manage manufacturing data, process, resource, and plant information in an integrated product and production lifecycle environment.

### 3.7. Manufacturing Process Simulation

After engineering BOM, manufacturing BOM and BOP were created, students are required to develop manufacturing plan and simulate manufacturing processes. Tecnomatix process simulate was used in this step. Figure 12 shows the assembly of skateboard deck and wheels using a robot. Tecnomatix software allowed students to design, simulate, offline program the operations of robot to optimize product efficiency.

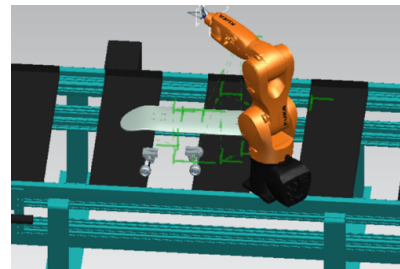


Fig. 12. Assembly process simulation

In addition to process simulation, students required to create plant design to simulate the overall manufacturing processes and calculate production throughput. Tecnomatix Plant Simulation software was used in this step. Plant Simulation can bring different benefits to the manufacturing processes including: material flow optimization, resource utilization and logistics for all levels of plant planning from global production facilities, through local plants, to specific lines. An assembly

line of electric skateboard was simulated in both 2-D and 3-D simulation as shown in Figures 13 and 14, respectively. Tecnomatix plant simulation uses discrete event simulation (DES) techniques which required product arrival time and processing time for each work station. After running the Tecnomatix plant simulation, students were able to verify the feasibility of an assembly process and get an estimate of the throughput and resource utilization for the electric skateboard manufacturing process. What-if scenario were also performed by varying the number of available resources to optimize the process throughput.

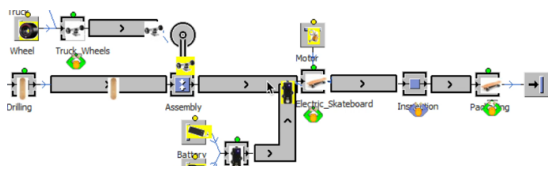


Fig. 13. 2-D simulation of electric skateboard manufacturing process



Fig. 14. 3-D simulation of electric skateboard manufacturing process

#### 4. Conclusion

Model-based systems driven product development (or SDPD) has been proposed as the framework for developing an innovative digital manufacturing curriculum that supports the training of the next generation of engineers for Industry 4.0. The curriculum provides a foundation for implementing the digital twin and its integration with the digital thread. Students learn and practice a new methodology, SDPD, which basically consists of driving product development digitally using integrated models and a digital thread across the cycle. The product here is a multi-domain system. The process is driven by systems requirements and traceability is established for verification. This knowledge is core to what companies nowadays are looking for as its most relevant to the development modern products, which are becoming increasingly complex.

The SDPD framework integrates high level system modeling to capture stakeholder needs and requirements with system's simulation. The latter allows for efficient and cost-effective sizing of the system components from different domains (electric, mechanical, controls, etc.) and is interfaced with 3D component design and optimization. This represents the modeling and simulation continuum. Design is integrated with manufacturing through a digital thread, including process design, process simulation and plant simulation. PLM and Systems model enable the traceability throughout the lifecycle

of development. The proposed digital manufacturing curriculum was introduced as part of SE capstone and was also implemented in capstone design. This work has demonstrated/produced the following:

1. Exemplary MBSE curriculum for Engineering Education 4.0
2. The development of key, integrated skills for the digital enterprise
3. The ability to demonstrate the benefits of digitalization/model-based engineering to industry, including: Greater innovation in product development, increased efficiency, faster time-to-market, increased adaptability/agility/customization, knowledge re-use, and better ability to comply with standards
4. The ability to synthesis knowledge and skills acquired over the course of college engineering education and to apply them effectively to complete a real-life modern product development within the time line of one semester

The next step consists of extending the curriculum to cover the digital twins for product, production, and performance. Also, verification/simulation techniques such as MIL, HIL, and SIL, will be introduced for a more complete implementation of the SE V-diagram. Currently, a prototype of the electric skateboard is being tested and validated against the results from both the Amesim 1D simulation and Nastran 3D CAE. In parallel, we are developing the digital twin of the electric skateboard by embedding different sensors for a more comprehensive assessment and real time data collection during actual operation.

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