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System Lifecycle Handler — Spinning a Digital Thread for Manufacturing

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Abstract. Transforming the manufacturing economy from paper-based information flows to a seamless digital thread across geographically distributed supply chains has the potential to reduce cycle time by 75% and save manufacturers $30 billion annually. The "Digital Thread for Smart Manufacturing" project at NIST[1] is developing methods and protocols for completing a digital thread running through design, manufacturing, and product support processes. In this paper, we present a proof-of-concept *System Lifecycle Handler* (SLH) software environment being developed for the digital thread initiative. The SLH provides services to build, manage, query, and visualize the digital thread by connecting heterogeneous artifacts ranging from requirements and system architecture to PLM/CAD/CAM and simulation models to machines and sensor data streams. The SLH software environment leverages the Syndeia platform, and exposes its capabilities via a web dashboard and standard REST/HTTP API.

Motivation: Model-Based, Smart Manufacturing

A recent economic study released by the National Institute of Standards and Technology (NIST) estimates that a cyber-physical infrastructure enabled by linked-data and systems-thinking would save United States (U.S.) manufacturing $100 Billion annually (Anderson, 2016). Manufacturing accounts for one-third of the U.S. economy. The total manufacturing value chain is estimated to be $5.5 Trillion (MAPI Foundation, 2017). The value chain starts at the mining and processing of raw materials, moves through the production systems, and ends with wholesaling, transportation, retail distribution, and servicing activities. $3.60 of value is added to the economy for every one dollar of manufacturing value (Meckstroth, 2017). In addition, Meckstroth estimates that 3.4 full-time equivalent (FTE) non-manufacturing sector jobs are created for every one FTE manufacturing job. All of this points to final manufacturing demand accounting for 34% of U.S. Gross Domestic Product (GDP), with 59% of manufacturing demand attributed to exports (Giffi et al., 2017).

Between 1998 and 2015, manufacturing productivity grew three times faster than the service economy (MAPI Foundation, 2015). While manufacturing exhibited growth and success, significant opportunity remains. One study found that simply transitioning from paper-based processes to (digital) model-based processes, for design through production, would achieve an approximately 75% reduction in cycle-time (Hedberg Jr et al., 2016). Further, enhanced sensing and monitoring,

[1] https://www.nist.gov/programs-projects/digital-thread-smart-manufacturing

seamless transmission of digital information, and advances in analyzing data and trends would save manufacturers $30 Billion annually (Anderson, 2016).

But industry is also approaching the fundamental limits of what its tools and processes can manage. Data, system, and viewpoint interoperability remains a challenge for industry (Trainer et al., 2016, Ruemler et al., 2016, Feng et al., 2017, Hedberg Jr et al., 2017b, Regli et al., 2016). Industry needs connected systems and linked-data federated across enterprises. Point-to-Point interoperability (e.g., file-based data translation) is not enough. Industry must stop thinking about data interoperability through mapping exercises and instead focus on domain and interface interoperability.

However, domain interoperability (e.g., design to manufacturing) requires a normalized method for accessing and contextualizing data at different points of the product lifecycle. Often the focus of interoperability has been confined to the formats in which the data is stored and not the semantics. Focusing on the information for the “thing” being represented in the data would help industry keep more focus on solving problems for the thing than focusing on communication and data exchange. Further, actors in industry must also consider the interfaces, outputs and inputs, on the boundaries of their domains. Standard interfaces between domains must be developed and understood to support efficient flow of required information through the product lifecycle. This effective communication of information brings with it an almost $8 Billion return-on-investment annual opportunity (Anderson, 2016).

We recognize that context varies based on the phase of the lifecycle (e.g., design, manufacturing, quality). In addition, context varies based on the level of interaction with data (e.g., systems, operations, enterprises) (Regli et al., 2016). Thus, geometry and manufacturing specification is not enough to define products – behavioral and contextual definitions are required too. Furthermore, all three aspects must be generated, documented, and communicated using an agile and dynamic method.

The digital thread concept shows promise for supporting industry’s needs. This paper outlines the digital thread concept, describes a methodology for linking and tracing data throughout the product lifecycle using the digital thread, and presents a prototype implementation of the methodology to enable the digital thread.

Digital Thread for Manufacturing

The digital thread is an integrated information flow that connects all the phases of the product lifecycle using accepted authoritative data sources, e.g. requirements, system architecture, technical data package (US Department of Defense), three-dimension (3D) computer-aided design (CAD) models (Kraft, 2016, Hedberg Jr et al., 2016, Wardhani and Xu, 2016), and project tasks. The product lifecycle is a complex heterogeneous system (or system-of-systems depending on how one draws the system boundaries). The aim of digital thread is to develop an integration framework that brings all phases and systems of a product lifecycle together to enable efficient and effective measurements of the lifecycle in support of data-driven methods. Specific interests relate to knowledge building, decision support, requirements management, and control. A major goal for enabling the digital thread is linking universally heterogeneous information systems and data sets across the various domains (e.g., design, manufacturing, quality) of the product lifecycle dynamic ways without requiring one-to-one data mapping.

Hedberg Jr et al. (2017a) proposes a Lifecycle Information Framework and Technology (LIFT) idea to support effective implementation of the digital thread. The framework is comprised of three levels: (1) product lifecycle data, (2) data certification and traceability, and (3) data-driven applications. In general, the LIFT ideas strives to link data across the information silos, while building trust through traceability, for driving applications with data. Hedberg Jr et al. (2017a) also introduces an example schematic (Figure 1) of technology for linking and integrating systems. The proposed technology would utilize agent-based adapters connected to the typical client support systems (e.g., product data management, enterprise resource planning, manufacturing execution, quality management) used in industry. The adapters would support micro-services (e.g., query, data retrieval, control) that would manage the curation, discoverability, retrieval, and observation of data from across the federated product lifecycle. The adapters connect the various client support systems through a master handle system that acts as a data "traffic cop" to aggregate all related data to a particular thing and present unified results back to user in the client support system with which he/she is most comfortable working (Hedberg Jr et al., 2017a).

Our work builds on the framework and technology presented by Hedberg Jr et al. (2017a). We consider the master handle system to be a type of "in-out bus" for data to flow and link. This manufacturing in-out bus (Figure 2) would enable linking people, machines, federated data, things, and systems together – thus, supporting a digital-thread infrastructure that brings full lifecycle cyber-physical connections to reality. Links and relationships between artifacts would be generated and tracked in near-real-time using the agent-based adapters. Generating a graph of all data and links across the product lifecycle for a product is assumed to be a large unstructured data set. However, by tracing the links and relationships while users interact with the data, structure could be inferred through observation and lifecycle-wide information models could be generated dynamically. The digital thread is inspired by the ideas of Digital Twin (Glaessgen and Stargel, 2012) and Semantic Web[2] in the context of manufacturing.

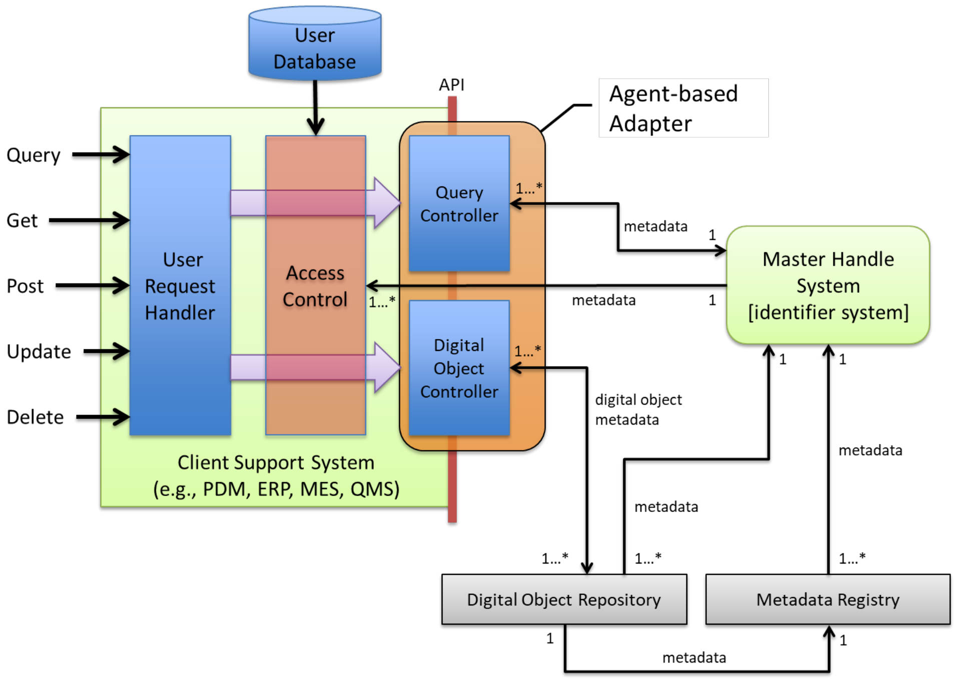


Figure 1. Example technology schematic for partially enabling the digital thread with linked data through the use of agent-based adapters, applications programming interfaces, and a master data handling system [from (Hedberg Jr et al., 2017a)].

[2] https://www.w3.org/standards/semanticweb/

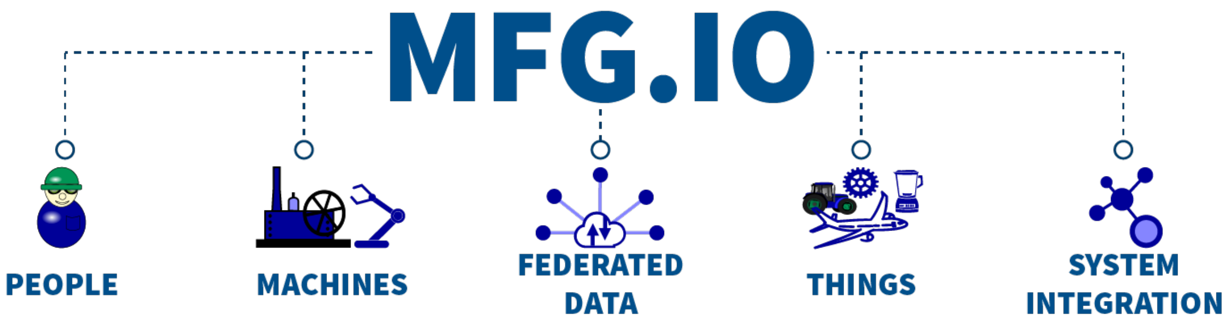


Figure 2. Supported artifacts of a manufacturing in-out bus-like handle system.

System Lifecycle Handler for Digital Thread

The *System Lifecycle Handler* (SLH) software platform realizes the LIFT framework and provides services and APIs to build, manage, update, visualize, and query the digital thread. In this section, we present the functional requirements for the System Lifecycle Handler system, followed by a description of its conceptual architecture. The System Lifecycle Handler builds on the Syndeia software platform developed by Intercax. We also present an overview of the Syndeia platform, specifically focusing on the key services used by the System Lifecycle Handler.

Requirements

In this section, we present the functional requirements for the System Lifecycle Handler (SLH) system.

Identifying artifacts and relationships in the digital thread – The SLH system should be able to identify various types of artifacts and their inter-relationships in the digital thread. This includes both virtual artifacts such as models, model elements, data, documents, and software, as well as physical artifacts such as organizations, machines, tools, factories, operators (human and robotic), sensor devices, raw materials, and physical parts/assemblies. The SLH system should also be able to navigate relationships between the artifacts, such as the relationships between the design model of a part, the software used for authoring that model, the machine instructions used for manufacturing the part, the physical part produced by the machine, and the quality inspection report on that part. Without the relationships, we would end up with silos of artifacts and not a continuous digital thread.

Unique global identifier system (GID) for the digital thread – The SLH system should provide a unique, global identifier system (GID) for addressing and searching all artifacts and their inter-relationships in the digital thread. This is a challenging task because the information about the artifacts participating in the digital thread originates from multiple repositories, databases, and software environments—requirements managed in requirement management systems (e.g., Jama or DOORS), system architecture models in SysML modeling tools (e.g. MagicDraw, Rhapsody), part structure BOM and CAD models managed in a PLM system (e.g., Teamcenter, Windchill), and manufacturing machine instructions and data as MTConnect streams. Each type of repository/database provides its own identification system that is local to artifacts and relationships managed in it. However, when we build a digital thread by federating artifacts from multiple repositories, we need a global identifier system that can be used to address any artifact or inter-relationship throughout the product lifecycle.

Multiple-step resolver system for global identifiers – The digital thread has to work in a world of computer firewalls, network security, and multi-layer authentication. The global identifier for an artifact in the digital thread may not be a single URI, as in a generic Linked Data[3] approach, but an ordered set of addresses (URIs or other identifier types) that have to be resolved recursively to navigate through multiple layers of namespaces, firewalls, and authentication servers. The digital thread includes data that is originating from multiple sources, e.g. flat files (spreadsheets and documents), computer models, real-time data streams, and hardware. The identifier system for the data may range from cells in a spreadsheet to unique string-based identifiers for a part in a computer model, to URIs provided by a REST/HTTP service.

Consider the example shown in Figure 3 where the design model of a part managed in a PLM system needs to be assigned to a specific machine in the factory that will make this part. For simplicity, we will assume that the same organization is designing and manufacturing the part. In a globally distributed supply chain, the challenge presented here will be compounded. The abbreviation *A(x,base)* is used to represent the address of an artifact *x* in the context of the *base* artifact. The address can be a URI or some form of an identifier that can be resolved. At the highest level, an organization artifact (*Org*) may have a gateway server available on the internet (world wide web) for all incoming requests, denoted as *A(Org, www)* in the figure. Next, the gateway servers for the various divisions in the organization are generally not reachable directly from the open internet due to firewalls, but reachable from the organization's gateway server. *A(DesignDiv,Org)* and *A(ManufDiv,Org)* are the addresses of the design division and manufacturing division of the organization in context of the organization. Similarly, *A(PLM,DesignDiv)* is the address of the PLM server reachable from the design division, and *A(P,PLM)* is the address of the part P in the context of the PLM server. Hence, the global identifier and address for part P is an ordered set of addresses: {*A(Org,www), A(DesignDiv,Org), A(PLM,DesignDiv),A(P,PLM)*}. To reach part P, the SLH should provide a resolver system that recursively traverses the chain of addresses, authenticating the request at each base artifact to reach the next artifact. A similar resolution process has to be followed to reach machine M. Once the part P and machine M can be reached uniquely in this manner, we can establish a relationship that part P is made by machine M. A collection of these relationships spins the digital thread.

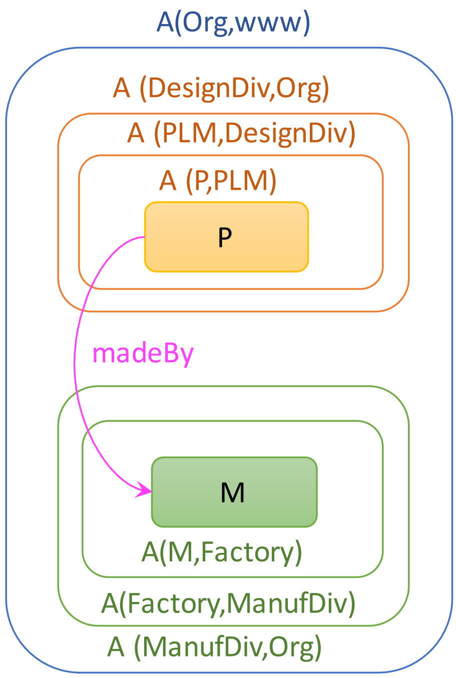


Figure 3. Multi-level addresses for locating artifacts across enterprise layers

Common handler system for global identifiers – The SLH should provide a common handler system in which we can input the global id of an artifact and lookup its meta-data, e.g. the name, type, address, and any other attributes of the artifact that are published openly. If additional details for the artifact are requested, the handler system can invoke the resolver system (as described above) to fetch the complete artifact. This handler system is similar to the Distributed Object Identifier (DOI) handler system available at http://dx.doi.org/ where one can provide the DOI number for any document to lookup its meta-data and obtain the URI to the original source of the document on the internet. One would still need to be authenticated to fetch/download the document. For the SLH system, we will be using *mfg.io* as the domain name for handle server.

[3] See the "References" section.

Search and query artifacts and their versions in the digital thread – The SLH system should provide a common platform to search, query, and generate/register new artifacts. This includes, for example, connecting to a requirements management system and querying requirements, their relationships, and attributes; or connecting to a PLM system and iterating over the multi-level BOM for a hardware assembly and querying mass properties (e.g. bounding box) for parts; or connecting to a machine and analyzing real-time data streams as a part is being made.

Building a digital thread by establishing connections between artifact – The SLH system shall provide capabilities to generate/register artifacts in the digital thread and to link them using connections. This includes, for example, generating design models from requirements (design synthesis), or generating simulation models and manufacturing process plans from design models, or registering new machines and machine configurations on a factory floor. Further, the SLH system should enable automated generation of connections between artifacts when one is generated from the other e.g. connections between design and analysis models are automatically generated when analysis models are generated from design models. Manual creation of connections between artifacts can be laborious.

Figure 4 shows a representative example of a digital thread where requirements in a requirements management system are connected to mechanical design model elements in a CAD system. The latter is then connected to CAM models, which are then connected to quality inspection tests. We can see both intra-model connections (solid arrows) between artifacts originating in the same repository or system, and inter-model connections (dashed red lines) between artifacts in different repositories.

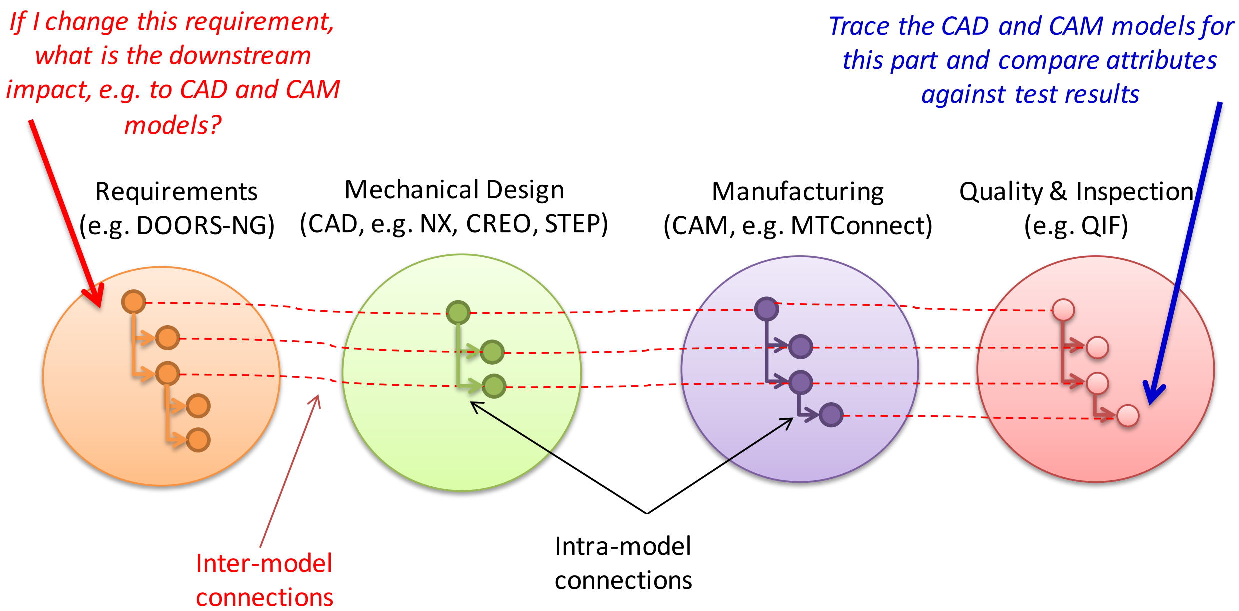


Figure 4. A representative example of a digital thread for manufacturing

Traceability, impact analysis, and continuous validation and integration of the digital thread – The greatest impact of the digital thread is in the continuous analyses that can be performed on it. At the first level, we have basic traceability when one can traverse the digital thread using the intra- and inter-model connections, starting with any artifact. However, as shown in Figure 4, a greater capability is to use graph pattern matching and graph traversals to assess the upstream and downstream impact of changes in any artifact [Bajaj, Backhaus, et al., 2017]. For example, computing the downstream impact of changes in a requirement, or querying upstream requirements and analyses done on a part when it fails during operation.

Digital thread as the information flow highway –The inter-model connections in the digital thread can provide highways for seamless flow of information in multiple directions. For example, if design parameters of a part in a CAD model are connected to machine instructions for manufacturing that part, then changes in the design parameters can be synchronized to machine instructions, or conversely tolerances achievable by machines can be communicated to designers working with part geometry. The flow of information across the inter-model connections may not just be primitive data but complex model structures, such as synchronizing simulation models (e.g. Simulink model) connected to system architecture models (e.g. SysML internal block structure).

Visualization and graph queries on the digital thread – The SLH system should also provide capabilities to visualize the digital thread and perform graph queries to answer questions.

Exposing the digital thread as an API – The SLH system should expose the digital thread as a service with a RESTful API so that higher-level analysis and verification applications can be built and deployed for design, manufacturing, and operation teams.

SLH Software Architecture

Figure 5 illustrates a high-level conceptual architecture of the System Lifecycle Handler (SLH) that satisfies the functional requirements presented above and implements the LIFT framework.

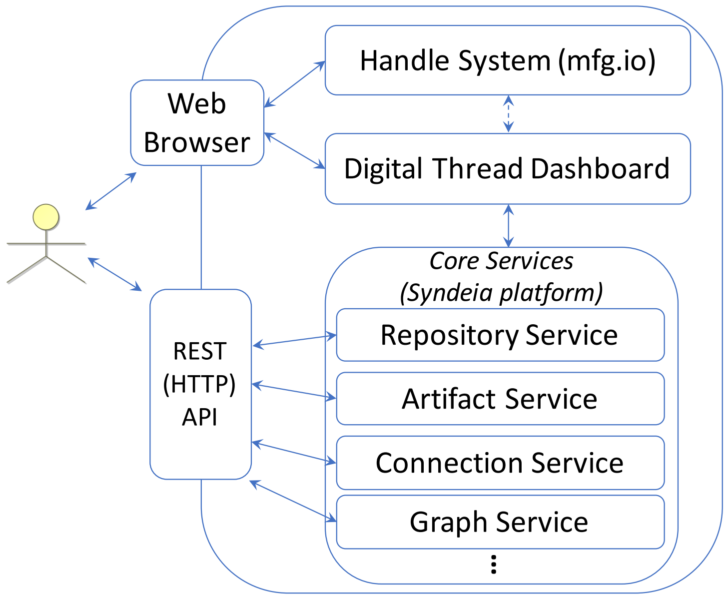


Figure 5. High-level conceptual architecture of the System Lifecycle Handler

In its current state, the SLH system includes three major components:

Handle System – We have deployed a Handle.Net server at https://hdl.mfg.io/. Using the global ID for any artifact in the digital thread, the Handle System can provide metadata about that artifact, such as (a) name of the artifact, (b) type of the artifact and the schema, (c) author of the artifact, (d) location of the artifact, and (e) other attributes. Figure 6 illustrates the metadata for the design of a heat sink for avionics printed circuit board, as provided by the Handle System accessed via a web browser. Each artifact in the digital thread graph has a URL which the resolver can use to fetch the actual artifact after necessary authentication.

Digital Thread Dashboard – This is a web dashboard that provides the ability to browse, query, and visualize the digital thread or any of its sub-graphs. This dashboard is currently being built using the Syndeia platform and will provide views similar those presented in Figure 7 for accessing and browsing various repositories and databases, Figure 8 for generating artifacts and creating connections between artifacts in a digital thread, Figure 9 for verifying the consistency of connected artifacts, Figure 10 and Figure 11 for visualizing the digital thread graph and sub-graphs, and Figure 12 for executing graph queries on the digital thread. The Digital Thread Dashboard invokes the core services of the System Lifecycle Handler system provided by the Syndeia platform.

Handle Values for: 20.500.11993/d2mi.cad.827-9999-904.stp

Index	Type	Timestamp	Data
1	**URL**	2017-08-31 03:29:03Z	https://smstestbed.nist.gov/tdp/d2mi/CAD/827-9999-904.stp
2	**TYPE**	2017-08-31 03:29:03Z	cyber.data.model.design
3	**SCHEMA**	2017-08-31 03:29:03Z	http://schema.org/ProductModel
4	**DATE_CREATE**	2017-08-31 03:29:03Z	2017-07-06
5	**ATTRIBUTE**	2017-08-31 03:52:13Z	(see below)


```
{
  "@context": "http://schema.org",
  "@graph": [
    {
      "@id": "#model",
      "@type": "ProductModel",
      "additionalType": "http://www.productontology.org/id/heat_sink",
      "description": "A heat sink for an aerospace avionics printed circuit board",
      "gtin13": "6921407390089",
      "name": "Aluminum Heatsink"
    },
    {
      "@type": "DigitalDocument",
      "fileFormat": "application/step",
      "about": "Design model for a heat sink for an aerospace avionics printed circuit bc
      "author": "https://hdl.mfg.io/20.500.11993/nist.tdh1",
      "additionalType": "http://www.productontology.org/id/heat_sink",
      "hasDigitalDocumentPermission": [
        {
          "@type": "DigitalDocumentPermissionType",
          "permissionType": "http://schema.org/WritePermission",
          "grantee": {
            "@type": "Person",
            "name": "Thomas Hedberg",
            "identifier": "https://hdl.mfg.io/20.500.11993/nist.tdh1"
          }
        },
        {
          "@type": "DigitalDocumentPermissionType",
          "permissionType": "http://schema.org/ReadPermission",
          "grantee": {
            "@type": "Audience",
            "audienceType": "public"
          }
        }
      ]
    }
  ]
}
```


Figure 6. Metadata for any artifact in a digital thread available via the handle server (hdl.mfg.io)

Syndeia Platform Services – The System Lifecycle Handler leverages the core services and the API of the Syndeia platform. Syndeia® is a software environment for integrated model-based engineering. It provides core services for weaving a Total System Model graph of a product/system by combining models and data originating in a variety of software repositories and tools, such as SysML tools, PLM and ALM environments, databases, requirements and project management systems, databases, and simulation tools. Syndeia leverages open standards such as STEP, REST/HTTP, and OSLC.

The four main services of Syndeia that are being leveraged for the System Lifecycle Handler are presented below. These services are available via a graphical user interface and a standard REST/HTTP API.

(a) *Repository Service* provides the capability to connect to enterprise data repositories, such as PLM systems, ALM systems, requirements management systems, databases, and simulation tools/environments. Users can search, browse, and query artifacts in various repositories using a common platform.

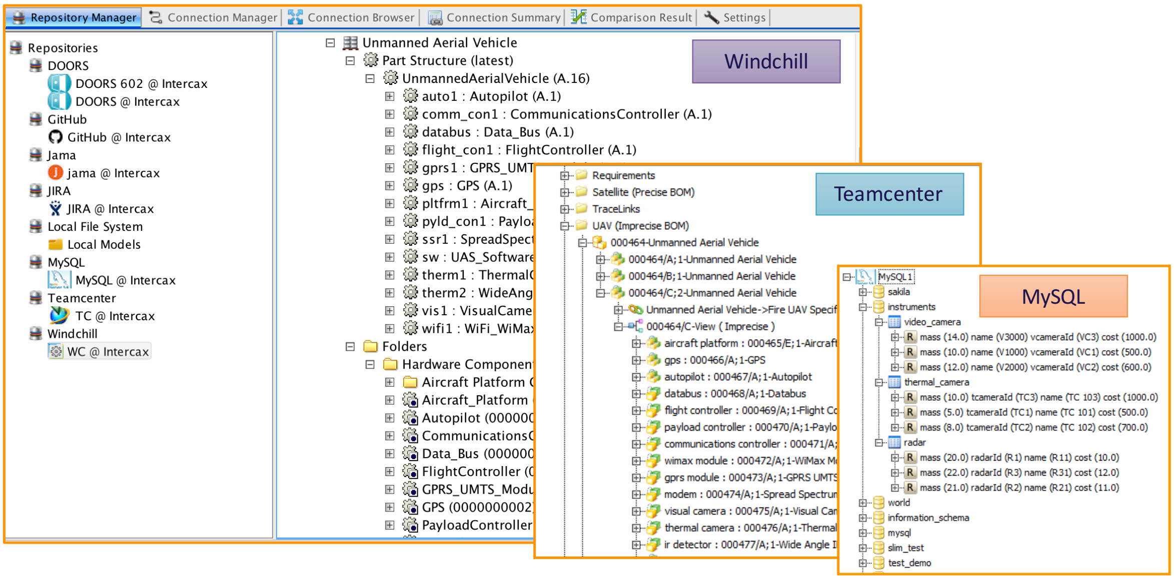


Figure 7: Repository view in the Syndeia Dashboard

(b) *Artifact Service* provides the capability to search and query the attributes, structure, and interfaces of all artifacts in the digital thread, from CAD models to machine tools, as shown for PLM systems (Windchill, Teamcenter) and a MySQL database in Figure 7.

(c) *Connection Service* provides the capability to create inter-model relationships between artifacts in various repositories or perform model transformations to generate artifacts and connections, as shown in Figure 8. This service also provides the ability to compare and synchronize connected artifacts, as shown in Figure 9 below.

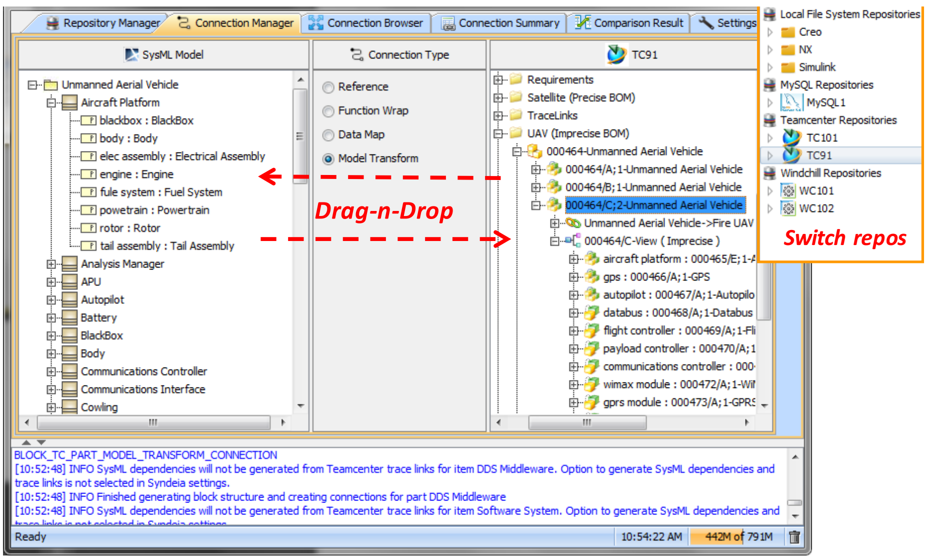
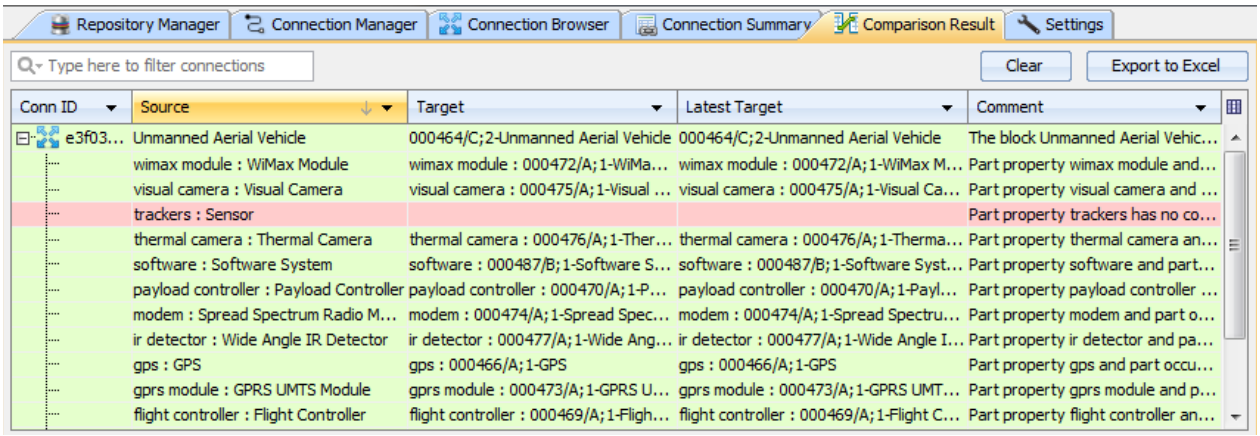


Figure 8: Drag and drop interface to generate models and create inter-model connections



Conn ID	Source	Target	Latest Target	Comment
e3f03…	Unmanned Aerial Vehicle	000464/C;2-Unmanned Aerial Vehicle	000464/C;2-Unmanned Aerial Vehicle	The block Unmanned Aerial Vehic…
	wimax module : WiMax Module	wimax module : 000472/A;1-WiMa…	wimax module : 000472/A;1-WiMax M…	Part property wimax module and…
	visual camera : Visual Camera	visual camera : 000475/A;1-Visual …	visual camera : 000475/A;1-Visual Ca…	Part property visual camera and …
	trackers : Sensor			Part property trackers has no co…
	thermal camera : Thermal Camera	thermal camera : 000476/A;1-Ther…	thermal camera : 000476/A;1-Therma…	Part property thermal camera an…
	software : Software System	software : 000487/B;1-Software S…	software : 000487/B;1-Software Syst…	Part property software and part…
	payload controller : Payload Controller	payload controller : 000470/A;1-P…	payload controller : 000470/A;1-Payl…	Part property payload controller …
	modem : Spread Spectrum Radio M…	modem : 000474/A;1-Spread Spec…	modem : 000474/A;1-Spread Spectru…	Part property modem and part o…
	ir detector : Wide Angle IR Detector	ir detector : 000477/A;1-Wide Ang…	ir detector : 000477/A;1-Wide Angle I…	Part property ir detector and pa…
	gps : GPS	gps : 000466/A;1-GPS	gps : 000466/A;1-GPS	Part property gps and part occu…
	gprs module : GPRS UMTS Module	gprs module : 000473/A;1-GPRS U…	gprs module : 000473/A;1-GPRS UMT…	Part property gprs module and p…
	flight controller : Flight Controller	flight controller : 000469/A;1-Fligh…	flight controller : 000469/A;1-Flight C…	Part property flight controller an…

Figure 9: Compare interface for comparing the connected artifacts and producing a report

(d) *Graph Service* provides the capability to visualize, query, and traverse the digital thread, as shown in Figure 10, Figure 11, and Figure 12. This service leverages production-strength graph databases (e.g. Neo4j) to manage the digital thread graph and query/traverse it using graph pattern matching languages (e.g. Neo4j Cypher). The services also provides various forms of graph visualization. For example, Figure 10 shows all the inter-model connections between the models participating in a digital thread at a given time.

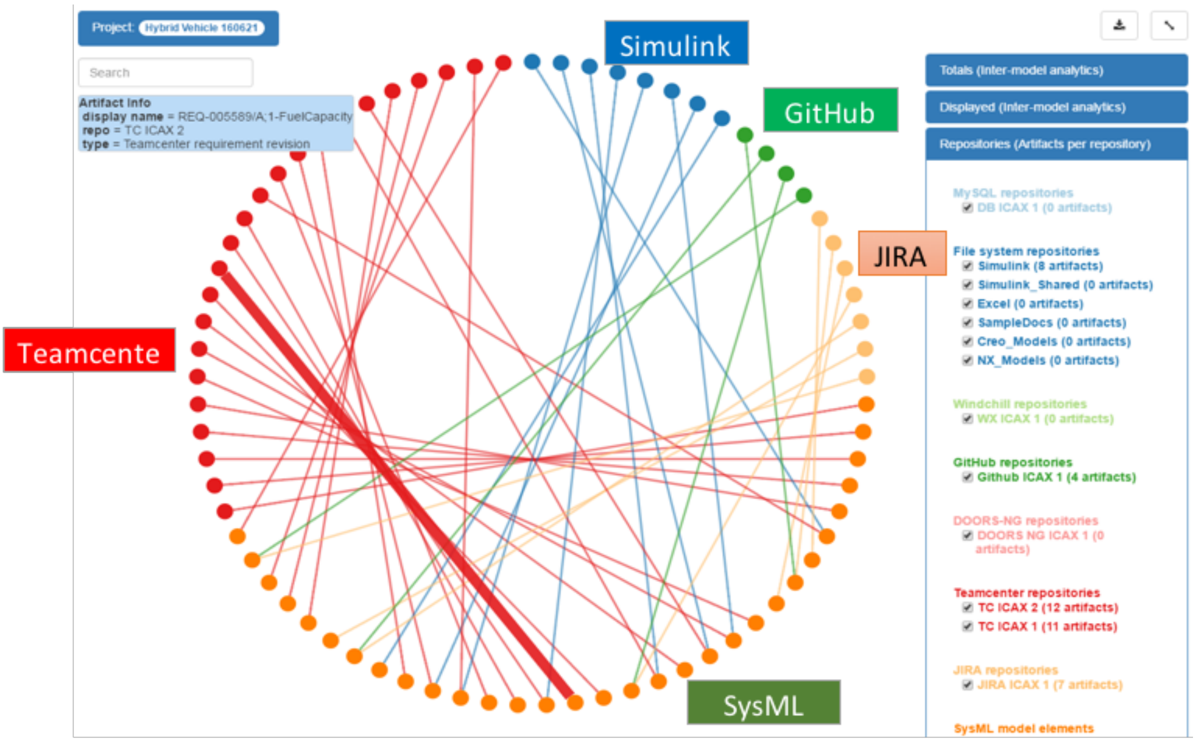


Figure 10: Visualization of inter-model connections in the digital thread at a given point in time

Figure 11 illustrates the result of progressively querying the inter- and intra-model relationships in the digital thread starting with the SysML block for a Hybrid Powertrain of an automotive vehicle (LHS node). Expanding the intra- and inter-model relationships shows connections to issues in JIRA, simulation models in Simulink, parts in Teamcenter, and control system software in GitHub, all of which are related to the Hybrid Powertrain at various degrees-of-separation.

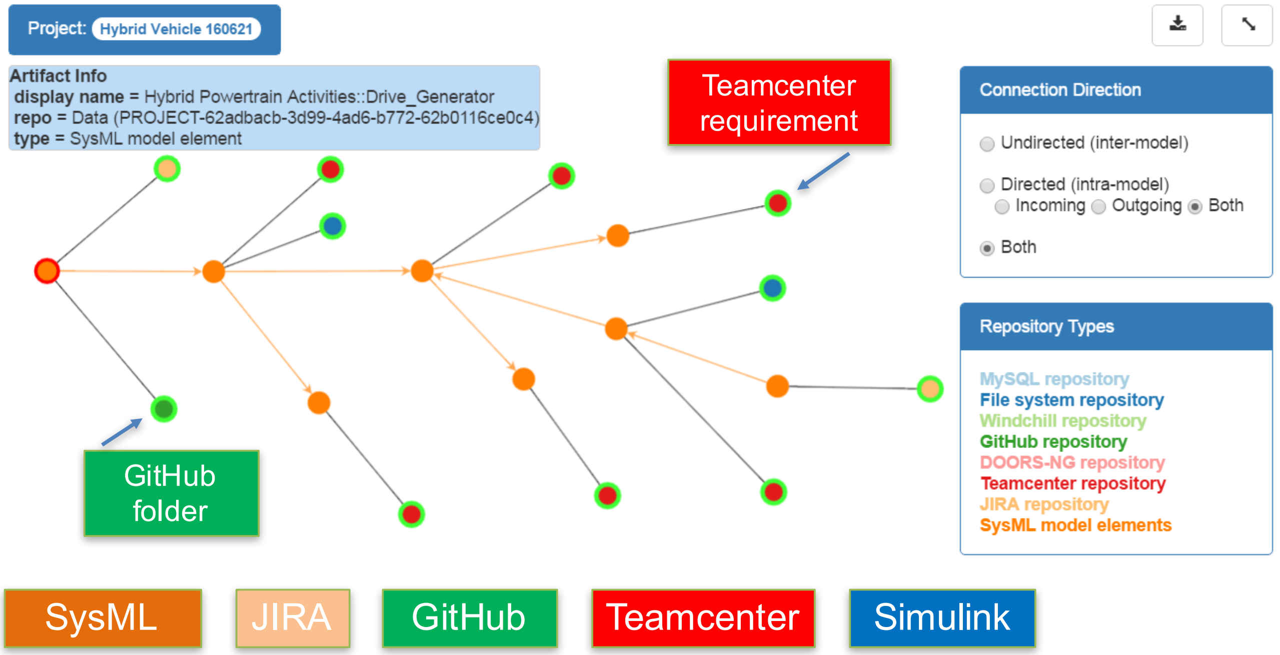


Figure 11: Traversing the digital thread graph starting with an artifact

Figure 12 illustrates graph queries performed on the digital thread. The LHS of the figure shows the result of a pattern matching query where we are providing two artifacts (nodes) and checking if a path exists between those artifacts using intra- and inter-model connections. The two artifacts are: (1) Electrical System part managed in Windchill PLM system (red node), and (2) UAV system represented as a SysML block (yellow node). The response of the query is the complete path using intra- and inter-model relationships. The RHS of the figure is the response of a similar graph pattern matching query to assess if changing a requirement in DOORS-NG (grey node) will impact the hardware design of the UAV platform assembly managed in Windchill (red node).

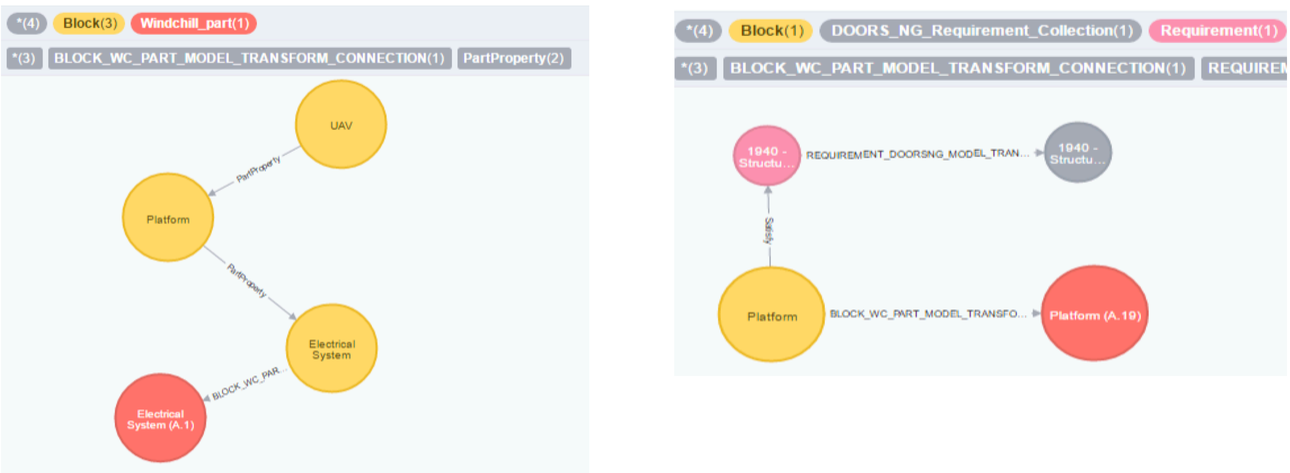


Figure 12: Graph queries on the digital thread graph

All Syndeia services presented above are exposed using standard REST/ HTTP API. Figure 13 shows an example of a REST GET request to get all repositories participating in the digital thread. The result of the GET request is shown on the RHS of the figure.

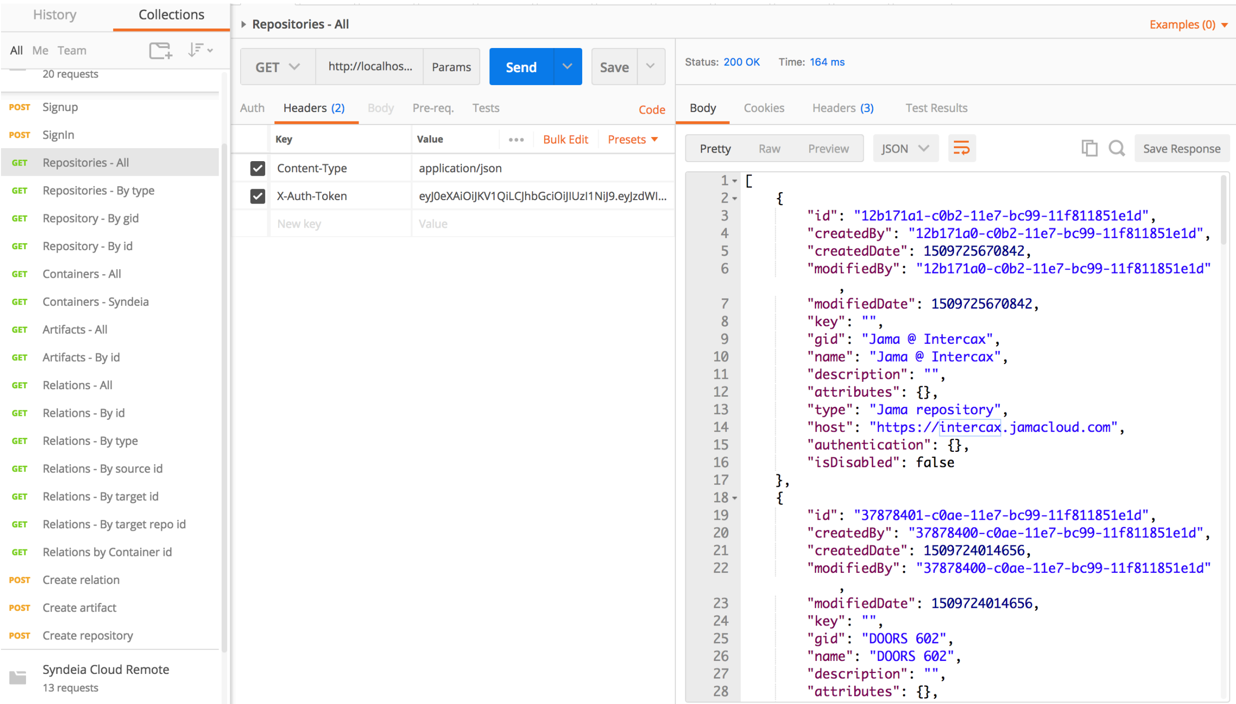


Figure 13: Syndeia services in the System Lifecycle Handler are exposed using a REST/HTTP API (Example GET request shown in Postman REST client)

Summary

In this paper, we have presented the motivation and foundations for a digital thread for manufacturing. The work presented in this paper is being performed under a grant project of the NIST Digital Thread initiative. The paper presents the *System Lifecycle Handler* software environment for spinning, managing, visualizing, and querying a digital thread for products/systems. We have presented the key functional requirements and the high-level conceptual architecture of the System Lifecycle Handler. Further, we have also presented the current state of the development of the System Lifecycle Handler, including the handle server as a common metadata registry for all artifacts in the digital thread; a web dashboard; and core services to connect to data repositories in the digital thread, query and search artifacts, create and synchronize connections between the artifacts, and query and visualize the digital thread. These core services build upon the Syndeia platform, and are exposed via REST/HTTP API endpoints.

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Biography

Manas Bajaj, PhD is the Co-Founder and Chief Systems Officer at Intercax. He has led multiple government and corporate sponsored R&D projects over last 10 years, including SBIR Phase 1 & 2 awards. He has led the development of several commercial software applications, including the *Syndeia* platform referenced in this paper. Dr. Bajaj is also leading the development of the *System Lifecycle Handler* software framework at Intercax, in collaboration with NIST. Dr. Bajaj earned his PhD (2008) and MS (2003) in Mechanical Engineering from Georgia Tech, and BTech (2001) from Indian Institute of Technology (IIT), Kharagpur, India. He has been actively involved in the development of the OMG SysML standard and the ISO STEP standards, and is a Content Developer for the OCSMP certification program. Dr. Bajaj is the author of numerous technical papers and articles. He is a co-developer of a widely popular SysML and MBSE training program with over 4500 participants since 2008. He enjoys playing tennis and cricket for leisure.

Thomas Hedberg, Jr. is a member of the Systems Engineering group in the Systems Integration Division (SID) of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). Mr. Hedberg is the Project Manager of the Digital Thread for Smart Manufacturing project in the Smart Manufacturing Operations Planning and Control program and the Co-Leader of the Smart Manufacturing Systems Test Bed. Mr. Hedberg is also a Voting Member of the American Society of Mechanical Engineers (ASME) Y14.37, Y14.41, and Y14.41.1 subcommittees from the ASME Y14 suite of standards. Mr. Hedberg has a strong interest in the areas of model-based enterprise, smart manufacturing, product-lifecycle management (PLM), data/information flow in the lifecycle, product-data quality, product-data visualization, and long-term data archival and retrieval (LOTAR).

Mr. Hedberg is a registered Professional Engineer (PE) in the State of Arizona and the State of Maryland. He is a lifetime senior member of the American Institute of Aeronautics and Astronautics (AIAA) and an active member in the American Society of Mechanical Engineers (ASME), American Association for the Advancement of Science (AAAS), International Council on Systems Engineering (INCOSE), SME, and the National Society of Professional Engineers (NSPE). When not conducting research, Mr. Hedberg enjoys playing ice hockey, general aviation, and cycling.