34th Annual INCOSE international symposium
hybrid event
Dublin, Ireland
July 2 - 6, 2024

SoS - Global Solutions to Global Problems Using UAF

Kristina Carroll
Studio SE, Ltd.
Larkspur, CO USA
kristina.carroll@studiose.design

Allison Lyle
Studio SE, Ltd.
Larkspur, CO USA
allison.lyle@studiose.design

Rae Lewark
Studio SE, Ltd.
Larkspur, CO USA
rae.lewark@studiose.design

Casey Medina
Studio SE, Ltd.
Larkspur, CO USA
casey.medina@studiose.design

Aurelijus Morkevičius
Dassault Systèmes and Department of Information Systems
Kaunas University of Technology
Kaunas, Lithuania
aurelijus.morkevicius@3ds.com

Abstract. This paper applies Unified Architecture Framework (UAF) to a case study which defines the global copper market as an enterprise comprising a diverse set of stakeholders and independently operating businesses and industries, with the goal to understand how they might evaluate, execute, or modify their behaviors in response to the diminishing global copper supply. Specifically, we sought to determine if the framework viewpoints, modeling language, and workflow guidance provided in the UAF specification could support the analysis. In a true System of Systems (SoS), the solution (or any improvement) relies on the cooperation of a multitude of independent and unrelated businesses and industries. Several viewpoints of UAF were evaluated to model the SoS, which reveal how certain entities may be motivated to implement solutions, and how those decisions may impact others within the SoS. We also provide observations from the analysis which may serve to improve the utility of UAF in other applications.

Keywords. System of Systems (SoS), Unified Architecture Framework (UAF), Model-Based Systems Engineering (MBSE), Circular Economy, Global Environmental Sustainment, Socio-economic Sustainment.

Introduction

The Background and Origin of UAF

The UAF is a standard to develop architectural descriptions for commercial industries, federal governments, and military organizations. In September 2013, a Request for Proposal for a Unified profile for DoDAF and MODAF (UPDM 3.0) (later renamed to Unified Architecture Framework) was created. In 2017, UAF 1.0 became an official Object Management Group (OMG) standard. In 2022, it became an ISO/IEC 19540 standard. Though a defense industry standard, the scope of UAF was designed beyond defense architectures. One of the mandatory requirements for UAF was "Architecture Modeling Support for Defense, Industry, and Government Organizations." As a response to this requirement, UAF version 1.0 was designed to be industry domain agnostic (OMG, 2013). It is applicable in the management and development of enterprise level systems of systems, to Internet of Things (IoT) architectures (Morkevičius, Bisikirskiene, & Bleakley, 2017), and to Mission Engineering (Martin & Alvarez, 2023).

The paradigm shift from a document-centric systems engineering approach to model-based systems engineering (MBSE) revealed gaps in the MBSE approach, one of which was that no standardized methodology was available for SoS or for enterprise systems engineering (ESE). Modeling languages such as Unified Modeling Language (UML) and Systems Modeling Language (OMG, 2019) are neither frameworks nor methodologies and must be combined with another methodology to become deployable. The lack of a standard methodology results in differently structured models with incompatible views. This inhibits the exchange of data between models and the ability to communicate with other teams, increases overhead in tool customization, and highlights the need for specific training. The models also become difficult to integrate and reuse (Morkevičius, Bisikirskiene, & Bleakley, 2017). This is where standard frameworks like UAF and their guidance documentation intend to bridge the gap by providing an organized structure, domain meta-model, modeling language (UAFML), and modeling workflow.

UAFML is an extension of UML. It has also a dependency from a SysML profile. UAF elements, such as Capability, Operational Performer, are inherited from a SysML Block. They inherit all the features of a SysML Block and all analysis techniques applicable to the SysML Block, e.g. SysML parametrics (Morkevicius, Bisikirskiene, & Jankevicius, 2020). This allows users to build precise, executable architectures, perform automated trade off analysis, run what-if scenarios, verify requirements, and add traceability to the systems and software models (Hause, Bleakley, & Morkevicius, 2016). This is big advantage over architecture frameworks like TOGAF and decisive factor to choose UAF for this research.

Applications of UAF

While UAF is prominent in the defense industry, there is increasing adoption of the framework outside of the defense application. Corporations are the secondary adopters of UAF, but government and non-government organizations needing to deploy system-of-systems in both the civil and scientific sectors have the opportunity to integrate UAF into their processes. The National Environmental Satellite, Data, and Information Service (NESDIS) ground enterprise and NASA's Joint Polar Satellite Systems (JPSS) ground project are both successful system-of-systems architecture examples which reveal the MBSE approach reduces rework, increases accuracy, and enables robust and informed decision-making (Barnes, 2018). Other case studies show UAF models influence continued system engineering efforts for construction and excavation equipment electrification (Sjöberg, Kihlström, & Hause, 2017) as well as the software architecture for application development (Sjöberg, Kihlström, & Hause, 2017).

Other publicly available case studies are the Submarine Warfare Federated Tactical Systems (SWFTS) project by Lockheed Martin (Rogers & Mitchell, 2021), Airbus Helicopters (Wirtz, 2023), UAF for IoT architectures (Morkevičius, Bisikirskiene, & Bleakley, 2017), and Smart Cities (Hause & Hummell, 2016). Through the analysis of the global copper market and the need to find solutions for depleting reserves, we propose UAF as a potential tool to model global issues and their solutions, specifically in the transition from linear to circular economic systems.

Case Study: Global Copper Supply

With globalization of markets, there is increased resource and service demand, which drives the need for a global approach for our system design and integration (Meadows, Randers, & Meadows, 2005; Whiteman, Walker, & Parego, 2012). Policy makers, regulators, think-tanks and trade associations can benefit from applying systems thinking tools to complex global challenges. Can the approaches and tools used by the systems engineering community aid in this effort?

As the global economy continues to grow and demand for resources increases, we must develop infrastructure and material flows that sustain human civilization within the operating limits of the planetary resources (Meadows, Meadows, Andrews, & Behrens, 1972). When the limits of a resource are not planned, we set our economic systems for eventual failure (Gamage & Hyde, 2015). To lay the foundation for a resilient and prosperous future, we must rethink our economic systems, as well as the way we design our products and manage their material flows. By designing systems with circular material flows, we increase our global economic resilience (Romero-Hernandez & Romero, 2018; Bocken, Boons, Baldassare, 2019; Münch, Benz, & Hartmann 2022).

Copper, a vital component of any product or system operating by electrical power, is an excellent candidate for a circular use cycle, as it can be reused, repurposed, and recycled nearly indefinitely (ICA, 2022). The coverage of planetary copper supply is an economic concern as copper demand is projected to increase with the growth of both digital and sustainability sectors (e.g., energy grid, transportation). As the global reserve dwindles, the refinement process is more labor and energy-intensive resulting in higher cost to produce equivalent copper products. These new costs are diverted to the buyers causing copper-dependent industries to feel the strain of shrinking access to high-quality raw copper (Kapur & Graedel, 2006; Northey, Mohr, Mudd, Weng, & Guirco, 2014).

The predominant waste management infrastructures in certain industries, such as healthcare, combine all materials, leaving single-use copper lost to landfills and incinerators (Reijinders 2003). This is a mismanagement of usable material, as 95% of copper-containing products have the potential to be reused, recycled, or repurposed, however only around 40% of global copper is recaptured before entering the landfill (Wang et al, 2021; ICA 2022). In the United States, approximately 67% of copper is lost to waste streams (Wang et al, 2021). With the projected copper reserves showing viability for only 20 more years, it is time to look to other solutions (Northey, Mohr, Mudd, Weng, & Guirco, 2014).

UAF as a Framework to Model the Copper Market Enterprise

Per the Enterprise Architecture Guide for UAF (OMG, 2022), UAF architecture models "provide a means to develop an understanding of the complex relationships that exist between organizations, operations, systems and services and enable the analysis of these things to ensure that they meet the expectations of the user community." Further, UAF provides a means to represent an enterprise architecture that enables model stakeholders to focus on specific areas of interest while retaining sight of the big picture. (OMG, 2022). UAF is a prime candidate to explore the analysis of the transformation of copper material flows at a global scale that comprises multiple organizations, operations, and services.

UAF, unlike many other frameworks, provides formalized, strategic methodology and viewpoints that enable the development and deployment of capabilities requiring the orchestration of multiple organizations. Other frameworks lack the precision that UAF incorporates and use terminology that is defense centric. UAF uses terminology that is familiar across the systems architecting community, as it implements language that is consistent with ISO/IEC/IEEE 42010. When analyzing global problems, such as the global copper supply, it is essential to use terminology that is as universally accepted as possible to avoid unnecessary confusion when introducing systems thinking and engineering to industries that may not be familiar with those concepts.

In a traditional systems development process, engineers begin by addressing a problem with a proposed solution. In the following case study, the proposed method is to create a circular copper economy by introducing capabilities such as copper reuse, repurpose, or recycle to solve the global issue of a dwindling copper reserve. It is essential to understand if organizations that comprise the copper market enterprise are motivated to actively pursue an internal transformation of copper waste management to address the global issue. By using UAF, the value proposition of this idea can be addressed. Particularly, the driving factors prompting organizations to work together to overcome the global issue as well as the individual opportunities that do and do not address the root cause.

The intended outcome of analyzing the copper market enterprise using UAF is to effectively identify and analyze the drivers and opportunities that encourage (or discourage) the conglomerate of organizations, operations, and services that operate within the global copper market to actively participate in a global transition to circular utilization of copper. The eventual goal is to develop a strategic deployment plan that decomposes the capabilities required of individual organizations to enable this transition. Profit margin is essential for nearly all organizations; thus, analyses need to be performed to understand the willingness of organizations to fund capability implementations that combat the challenges experienced due to a dwindling copper supply. A cost and benefit analysis must be performed, and it should take into consideration the long term cost of doing nothing (or simply raising their own cost of products) to address the global issue. The question remains - Is active participation in the transition to a circular economy the most compelling opportunity?

Application of UAF to Copper Market

Stakeholder Identification

The Operational Activity Diagram on the right in Figure 1 illustrates the material flow for copper utilization in the case of a medical device, wherein the copper is specifically used in cables designed to connect electrosurgical devices to their power unit. The healthcare sector treats these cables as biohazardous waste and discards the cables for subsequent incineration, producing heavy metals, toxic chemicals, and air pollutants into the atmosphere. This results in a linear materials flow. The industry or business sector responsible for each step in the material handling is identified and defined as belonging to a given Enterprise tier, shown on the left in Figure 1.

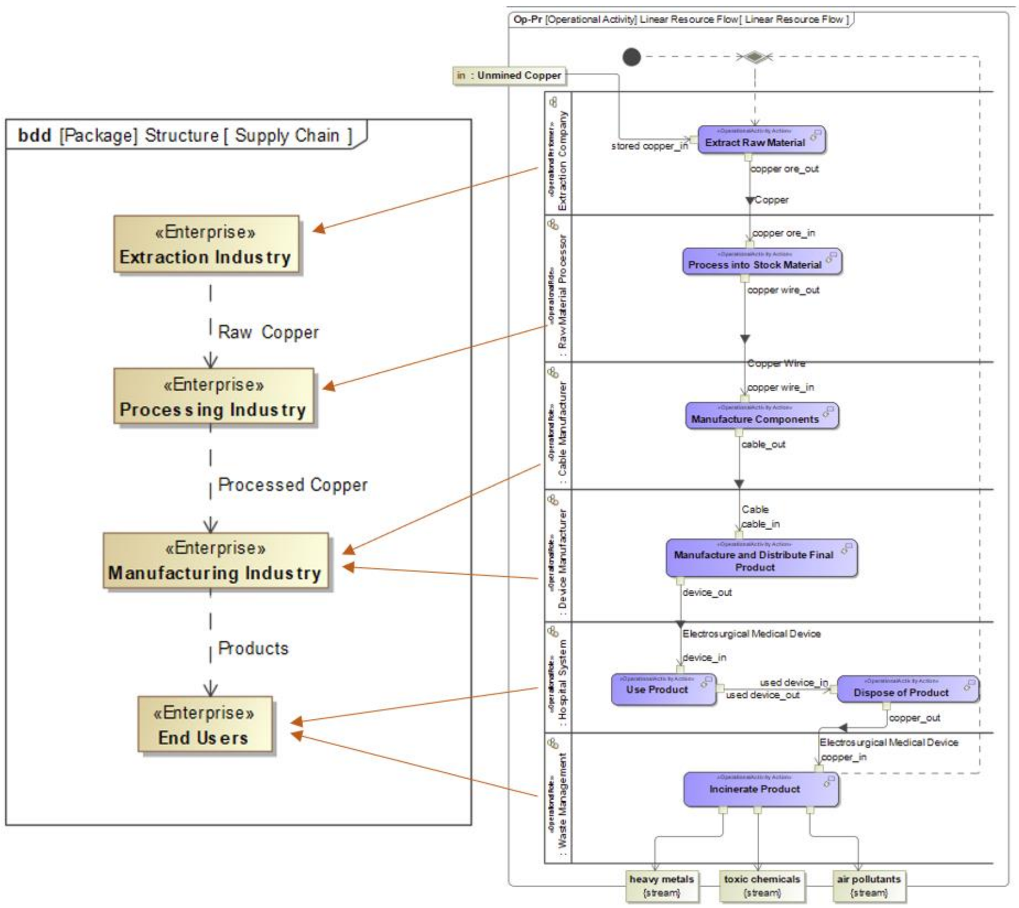

Figure 1. On the right, an Operational Activity Diagram showing the transformation of raw copper into a finished medical device. Operational Performers in the copper processing were mapped Enterprise "tiers" within the supply chain on the left.

Each process step in the linear material flow of copper is represented as an Operational Activity Action and Operational Performers (in this case, various organizations) play a role in the life cycle. The operational performers play an active role but are also considered stakeholders in the enterprise. Per the Enterprise Architecture (EA) Guide for UAF, a stakeholder is defined as a "role, position, individual, or organization or classes thereof, having an interest, right, share, or claim, in an entity or its architecture" and an Operational Performer is defined as "a logical entity that is capable to perform operational activities which produce, consume, and process resources" (OMG, 2022). These organizations have vested interest in the plan to move towards a circular economy and perform an active role in that transformation.

The primary stakeholders can be categorized into four main tiers, represented in Figure 1:

- Tier 1: Those who are directly impacted by the extraction of raw copper copper (ie an extraction or mining organizations)

The other tiers are stakeholders who are indirectly impacted by the extraction process of raw copper.

- Tier 2: Those who receive raw copper and process it into a usable form (ie. raw material processors)
- Tier 3: Those who receive processed copper and manufacture products (ie cable and electrosurgical device manufacturers)

- Tier 4: Those who are end users of the products (ie. hospital systems and waste management organizations)

When we consider the global copper market and linear supply chains, Tier 3 consists of a conglomerate of stakeholders, including, but not limited to those in the transportation, construction, telecommunications, electronics, industrial equipment, healthcare, consumer goods, and defense and military industries. Many of these industries have no direct relation to one another other than the fact that they rely on the same supply chain and use the same material to manufacture products. It is important to recognize changes at the top of the supply chain (Tier 1) have a compounding impact on the lower tiers.

Although Operational Performers are part of the Operational Architecture, when considering solutions to global issues as a SoS, the operational performers are stakeholders, and it is essential to identify and analyze the unique drivers of these stakeholders to understand the strategic motivation. This is required to begin moving towards a circular economy and to enable the transformation to operational performers.

Strategic Drivers

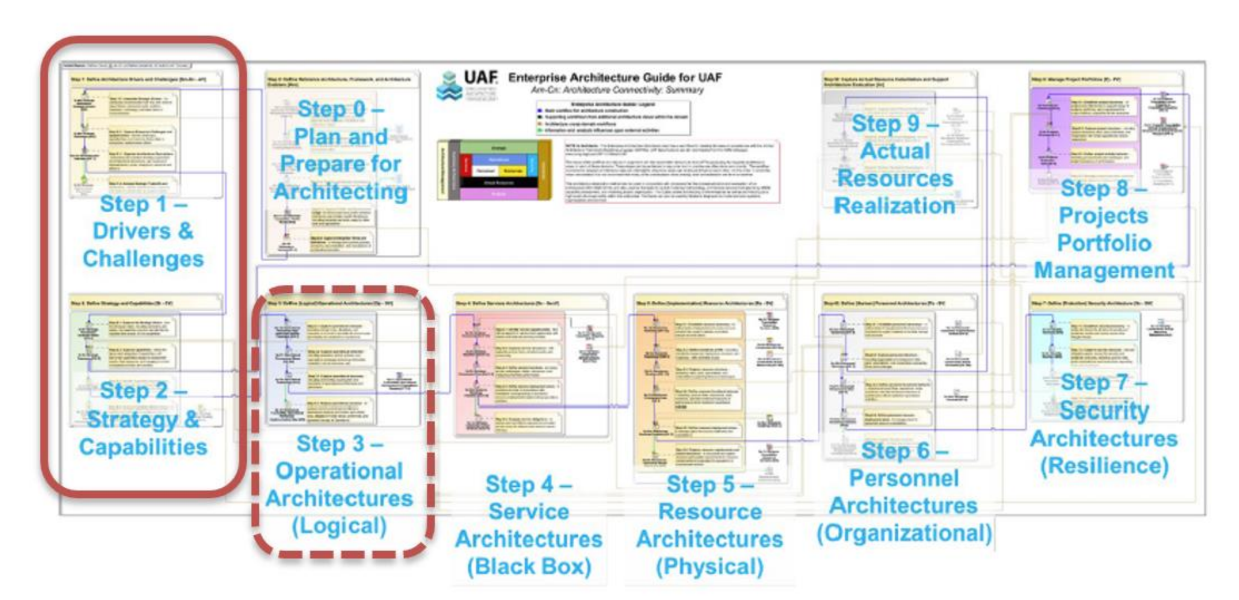

Figure 2. Recommended Workflow steps for EA Guide for UAF. This work focused on Steps 1-3.

Following the identification of stakeholders, we consulted the Workflow prescribed in the EA Guide, shown in Figure 2. Per Step 1.1 of the Workflow (Assemble Strategic Drivers), strategic drivers were identified for the global copper use enterprise. Three categories of strategic drivers were identified:

1. Overarching Drivers (copper supply, demand)
2. Tier specific Drivers (cost increases, availability, regulation)
3. Indirect Drivers (environment, public perception)

Overarching drivers are those which influence the whole of the copper enterprise. Depletion of the copper supply and increase in copper demand are overarching drivers for the enterprise. This commands attention from the extraction industry, as well as the copper processing and recycling industry, as they have the power to directly partake in activities to affect global outcomes. Potential and impending drivers were identified as well, such as regulations for recycled content, environmental protections, and oversight for labor conditions. While not in effect at the time of writing (or of significant motivation), the potential for regulation of copper extraction may be a significant motivator for an industry to make changes to deter future oversight.

Tier specific drivers are any additional drivers that may impact individual stakeholders who may not have visibility to the root cause (ie diminishing copper supply and increased overall demand.) While the overarching drivers impact all businesses and industries, the tier specific drivers may have a compounding effect for lower tiers. For most lower tier producers and users, the increase in material cost was the primary driver for their operation.

Indirect drivers were identified based on social or ethical motivations, such as public perception and environmental disruption, which, in the current operating context, would be considered isolated and secondary to all other drivers. For example, the extraction of copper requires the excavation of rock and releases toxic chemicals into the surrounding environment. This does not directly impact all stakeholders of the copper supply market but is influential as the United Nations released the 2030 Agenda for Sustainable Development in 2015.

Enterprise Challenges and Opportunities

Given the overarching drivers of decreased copper availability and increased copper demand, the extraction industry is presented with challenges related to physical access and quality of copper veins, which increase extraction costs.

The second and third tiers (processors and manufacturers) may be presented with challenges in the form of cost increases passed down by the extraction industry and decreased incoming material supply which affects lead times and manufacturing throughput. Processors and manufacturers may have additional challenges such as competition and poor public perception for being unable to keep up with product demand. Depending on the specific enterprise and challenge, a multitude of opportunities are possible to address these challenges. To maintain profitability, the most common opportunities that present themselves, and that we see across industries, are to increase the product cost to consumers. An alternative is to decrease internal resources (i.e. shut down of manufacturing plants, compensation cuts, job elimination, etc.), which, by definition, may be an opportunity to cut operating costs but presents additional internal challenges.

However, with a finite copper reserve, acting solely on the opportunity to increase product cost to maintain profitability is short-lived. We must therefore identify and promote opportunities that are viable and sustainable for future generations. This translates into new business opportunities for lower tier users and manufacturers. Throughout our analysis, we identified opportunities for the medical device company to redesign their electrical cable to be modular for re-use, which could be recirculated within a hospital for multiple uses (and subsequent cost savings). Additionally, raw copper processors and cable manufacturers can incorporate recycling into their businesses. These businesses can leverage the existing copper harvesting and recycling networks to capture discarded electrical cables (from any industry) for return to the global copper stockpile.

Following the workflow from the EA Guide, we mapped Drivers to Challenges, Challenges to Opportunities, and Opportunities to Capabilities, using the designated relationships. We utilized the Dependency Matrix offered by UML for this exercise, which allowed us to step through each intersecting cell for a given row/column pair and discuss the context of the relationship. This illuminated the need to be able to define a given Driver, Challenge, Opportunity, or Capability based on its context within a given system tier, as some were redundant or required different definitions based on the system from which it originated.

It is necessary to understand the full spectrum of challenges and opportunities across the multi-tiered enterprise and map them to the stakeholders in each tier. In the current Unified Architecture Framework, it is difficult to link challenges and opportunities to specific operational performers and to show the cascading chain of cause-and-effect relationships between all entities within the enterprise. It is necessary to show these connections to then show how the effects of capability implementation at one entity influences the challenges and opportunities of other entities.

Once opportunities are linked to the operational performers (as the operational performers are enterprises), the full scope of capabilities for the enterprises can be defined and grouped into phases with assigned resources. The financial cost of resource implementation can be rolled up using various analysis tools to understand the total cost and timeline of converting to a circular economy for a given enterprise. The cost and time may then be analyzed against the cost of copper inflation to understand the point at which it makes sense for the enterprises to be fully functioning in a circular economy. Risk to organizational success can then be linked to capability implementation as well as the capability implementation and timelines of other enterprises.

Discussion

While applying UAF for modeling circular transition of copper production cycles, we observed the applicability of UAF as a tool for modeling transformation of a single enterprise. However, there is a lack of studies and formal guidance on how UAF can be applied for the SoS case. From this case study, we provide observations and alternatives for consideration.

Utility of UAF

- UAF encourages engineers to think beyond their individual roles. This results in a transition from a systems design-based approach to a systems thinking approach.
- By starting from the strategic viewpoint, we are compelled to recognize all opportunities capable of addressing challenges, not just the most favorable choices for individual organizations.
- The framework enables us to link the capabilities, and then actual resources, that would enable potential opportunities to be realized.
- Although not yet performed for the case study introduced in this paper, the vocabulary and syntax of the framework allow for a cost/benefit and risk analysis of the resources required for given capabilities, enabling comparative analyses between opportunities.

Opportunities for UAF

Modeling Independent Systems within the Enterprise. UAF defines Enterprise as a purposeful or industrious undertaking (especially one that requires effort or boldness) (OMG, 2022). When we analyzed the Global Copper Market, we included multiple enterprises, who have their own drivers, challenges, and opportunities. For those operating in the same material markets, the effects of one enterprise can lead to drivers of another lower tier enterprise. While the guidance does acknowledge that there may be drivers that arise for lower tier systems, it does not elaborate further. Currently there is no simple way to express this and no simple way to associate drivers, challenges, and opportunities to different enterprises. Additionally, a lower tier system, having agency in its own business decisions, may produce effects which have a bottom-up impact. We modeled two approaches:

a. Model Enterprises as structural enterprise phases. In this approach we lack an easy way to show communication between enterprise phases. There is also no way to define their behavior. The only advantage is that we can connect Opportunities to enterprise phases directly.

b. Model Enterprises as Operational Performers. In this approach we gain the ability to easily connect Operational Performers and define their behaviors. However, we were not able to directly connect performers to motivational elements from the strategic domain. This relationship can only be derived via a transitive route.

Both approaches are limiting, and more development is needed to ensure success during deployment. We chose the latter by using dependencies to fill the gaps and connect necessary elements.

Commercial Adoption of UAF. UAF extends the SysML language with rich vocabulary and syntax. Some of the terms are derived from standards, such as ISO 42010 Systems and software engineering – Architecture description. Most of the terminology is carried over from DODAF, MODAF, UPDM, and NATO NAF. DODAF, MODAF, UPDM, and NATO NAF are specific to the military and although UAF demilitarized these frameworks to be consistent with Enterprise Architecture, many industries, in which MBSE is being adopted, are unfamiliar with the concept and terminology associated with Enterprise Architecture. Although UAF has been adopted by a few industries, the complexity and intuitiveness of terminology and relationships may become a bottleneck for widespread commercial adoption. Although the language is consistent with ISO/IEC/IEEE 42010, this standard is not well known across all industries that are involved in global problems. Organizations must make significant investments in their infrastructure and people if they desire to transition to UAF. Alternatively, these organizations could develop alternative frameworks by extending UAF or SysML using domain specific terminology and simplified methods. That, in and of itself, may be problematic for modeling global problems as global problems span across multiple domains.

Outcomes for the Copper Enterprise

While this work was primarily focused on vetting UAF in a new domain, there are some observations that can be drawn for the benefit of the stakeholders in the copper enterprise. Policy advisors and regulators may look at the relationships between the strategic elements (Drivers, Challenges, Opportunities) relative to existing Capabilities, Resources and Operational Performers. We utilized Dependency Matrices and Relation Maps to view the connective thread among and between enterprises. This view may enable one to determine how we can incentivize or eliminate barriers to implementing preferred Opportunities, based on the desired effects. By evaluating the Challenges and observing those which are shared by several enterprises, policy makers or industry might investigate options for offsetting those challenges by providing financial or infrastructure support to affected Operational Performers. By viewing who has a tie to a given Opportunity, there may be a potential to incentivize action and encourage cooperation (or competition, for the benefit of the end user). Examples of Relation Maps are shown in Figures 3 and 4.

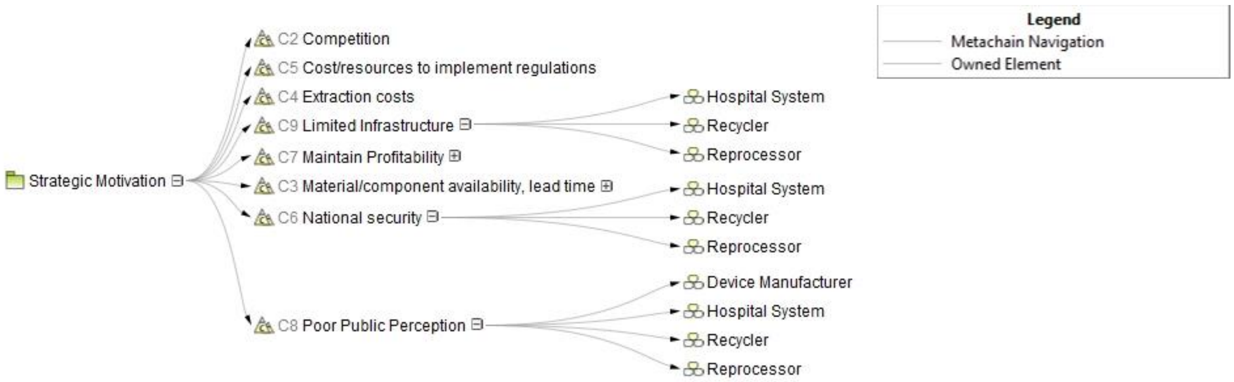

Figure 3. Sample Relation Map showing tiers of stakeholders (modeled as Operational Performers) linked to Challenges.

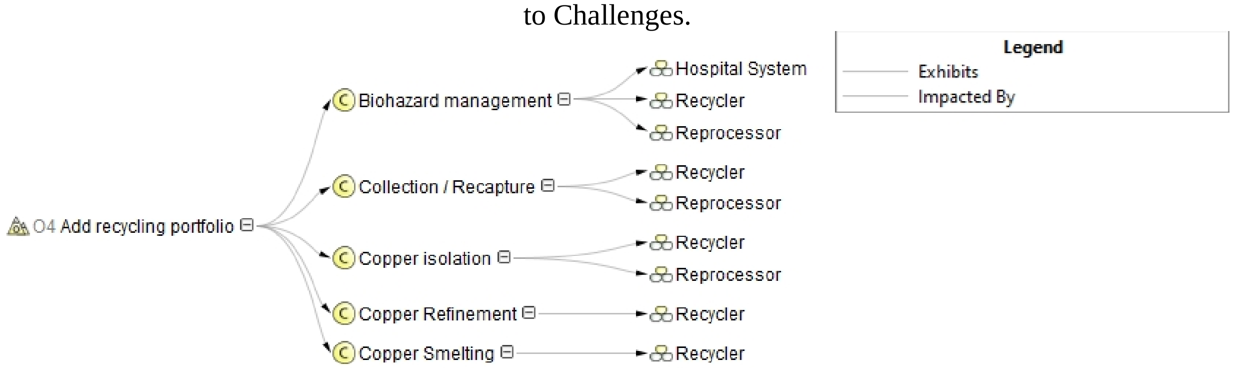

Figure 4. Sample Relation Map showing Capabilities needed to advance copper recycling opportunities.

Conclusion

The framework viewpoints, modeling language, and workflow guidance provided by UAF offered a useful lens to observe the motivations of the global copper enterprise. By defining terms for the strategic elements and offering relationships to connect Drivers, Challenges and Opportunities, one can visualize the thread of cascading causes and effects for a single enterprise with a defined goal. When applied to a complex system of systems, comprised of multiple, independent enterprises, each with unique and non-converging goals and drivers, there is a need to attribute strategic elements for each enterprise. Further, if we wish to promote the use of UAF in new (or non-traditional) domains, there may be a barrier to entry in adopting the language without extensive coaching or consultation from UAF experts. Although the nuance of the strategic motivation of the copper enterprise could not be fully captured, UAF and its corresponding guidance proved to be a useful tool in the quest to map global solutions for global challenges.

References

Bankauskaite, J., Strolia, Z., Morkevicius, A. (2023) Towards an approach to co-execute systems models at the enterprise level. INCOSE.

Barnes, P. (2018). Utilizing MBSE to Modularly Architect the NESDIS Ground Enterprise. *14th Annual Symposium on New Generation Operational Environmental Satellite Systems.* http://jetsi.com/wp- content/uploads/2018/01/AMS2018Poster_Final.pdf

Bocken, N., Boons, F., Baldassare, B., (2019). Sustainable Business Model Experimentation By Understanding Ecologies of Business Models. *Journal of Cleaner Production*, 208, 1498-1512. doi.org/10.1016/j.jclepro.2018.10.159.

Gamage, A., Hyde, R., (2012). A Model Based on Biomimicry to Enhance Ecologically

Sustainable Design. *Architectural Science Review*, 55(3) 224-235. DOI:10.1080/00038628.2012.709406.

Hause, M., Bleakley, G. and Morkevicius, A. (2017), Technology Update on the Unified Architecture Framework (UAF). *Insight*, 20: 71-78. https://doi.org/10.1002/inst.12153

Hause, M. and Hummell, J., (2016). Making Smart Cities Smarter – MBSE Driven IoT. *INCOSE International Symposium*, 26: 1675-1690. https://doi.org/10.1002/j.2334-5837.2016.00253.x

Kapur, A., Graedel, T.E., (2006). Copper Mines Above and Below the Ground. *Environmental Science & Technology*, 40(10): 3135-3141.https://doi.org/10.1021/es0626887.

International Copper Association, (2022). International Copper Association Recycling Brief. 10/20/17-ICA-BR-GL-HE-03-EN.

Martin, J.N. and Alvarez, K.E. (2023). Using the Unified Architecture Framework in Support of Mission Engineering Activities. *INCOSE International Symposium*, 33: 1156-1172. https://doi.org/10.1002/iis2.13075.

Meadows, D. H., Meadows, D. L., Randers, J., Behrens, W.W., (1972). The Limits to Growth. *Universe Books New York*. ISBN 0-87663-165-0.

Meadows, D.H., Randers, J., Meadows, D.L., (2005). Limits to Growth: The 30 Year Update. *Earthscan London.* ISBN-10: 1-84407-144-8.

Morkevičius, A., Bisikirskiene, L., Bleakley, G. (2017). Using a systems of systems modeling approach for developing industrial Internet of Things applications. *12th Systems of Systems Engineering Conference (SoSE)*, (pp. 1-6). Waikoloa, HI.

Morkevicius, A., Bankauskaite, J., and Jankevicius, J., Towards Standards-based Execution of System of Systems Models. *2020 IEEE 15th International Conference of System of Systems Engineering (SoSE)*, Budapest, Hungary, 2020, pp. 157-162, doi: 10.1109/SoSE50414.2020.9130510.

Münch, C., Benz, L.A., Hartmann, E., (2022). Exploring The Circular Economy Paradigm: A Natural Resource-Based View on Supplier Selection Criteria. *Journal of Purchasing and Supply Management*, 28(4), doi.org/10.1016/j.pursup.2022.100793.

Northey, S., Mohr, S., Mudd, G.M., Weng, Z., D., Guirco, (2014). Modeling Future Copper Ore Grade Decline Based On A Detailed Assessment Of Copper Resources And Mining. *Resources, Conservation, and Recycling*, 83, 190-201. doi.org/10.1016/j.resconrec.2013.10.005.

Object Management Group, (2019) OMG Systems Modeling Language (OMG SysML TM), Version 1.6. https://www.omg.org/spec/SysML/1.6/.

Object Management Group, (2022). 'Unified Architecture Framework (UAF) 1.2'. https://www.omg.org/spec/UAF.

Reijnders, L., (2003). Recovery Of Dissipating Copper And The Future Of Copper Supply. *Resources, Conservation, and Recycling*, 38(1), 59-66. doi.org/10.1016 /S0921-3449(02)00148-9.

Rogers, E.B., Mitchell, S.W. (2021). MBSE delivers significant return on investment in evolutionary development of complex SoS. *Systems Engineering*; 24: 385–408.https://doi.org/10.1002/sys.21592.

Romero-Hernandez, O., Romero, S., (2018). Maximizing The Value Of Waste: From Waste Management To The Circular Economy. *Thunderbird Special Issue: Companies In The Circular Economy*, 60(5), 757-764. doi.org/10.1002/tie.21968.

Sjöberg, P., Kihlström, L., Hause, M. (2017). An Industrial Example of Using Enterprise Architecture to Speed Up Systems Development. *INCOSE International Symposium*, 27: 401-417.

Wang, T., Berrill, P., Zimmerman, J.B., Hertwich, E.G., (2021). Copper Recycling Flow Model for the United States Economy: Impact of Scrap Quality on Potential Energy Benefit. Environmental Science & Technology, 55(8), 5485-5495. Doi.org/10.1021/acs.est.0c08227

Wirtz, J. (2023). Applying UAF and the Airbus MBSE Framework Within Future Combat Air System Development (Airbus), Jörg Wirtz, *UAF Summit, Reston.* https://youtu.be/W8cwyW9ty5Y?si=1KvaoWDohkmynYIkaccessed November 2023.

Whiteman, G., Walker, B., Perego, P. (2012). Planetary Boundaries: Ecological Foundations for Corporate Sustainability. *Journal of Management Studies.* doi:10.11117/j.1467-6486.2012.01073.x.

Biography

Kristina Carroll. Kristina Carroll is a Principal Trainer and the Director of Product Development for Studio SE. She teaches advanced topics in MBSE and has an affinity for analyzing complex, cross-disciplinary problems using the Cameo System Modeler's Simulation Toolkit. Kristina has extensive experience in the medical device and cell therapy fields and has demonstrated success in using systems thinking and statistical methods for product and process development, optimization, and characterization. Kristina earned a M.E. in Biomedical Engineering from the Rutgers University and a B.S. in Chemical and Biological Engineering from the University of Colorado at Boulder.

Allison Lyle. Allison Lyle is a Principal Trainer and consultant for Studio SE, teaching practical methods for applying systems thinking and deploying MBSE tools to analyze and model complex systems. Allison is also a practicing engineering consultant, specializing in new product development in the sustainability and medical device domains. Her experience and expertise span from preliminary market research and problem definition to technology feasibility assessments, product development, and commercialization. Allison is an OCSMP, holds a M.S and B.S. in Mechanical Engineering from the University of Colorado, and a B.A. in Communications from the University of Iowa.

Rae Lewark. Rae Lewark is an ecologist with Studio SE, focused on the integration of human and ecological systems through sustainable design. Having performed research in both the arachnid biodiversity of Ecuador and the anthropomorphic influence of ecologies in film and literature, Rae operates in the intersection between environment and human behavior. A freedive athlete and trainer, she believes strongly the reintegration of humans and the environment begins with reconnecting to nature. Her experience includes regenerative system building, circular economy design, and biomimicry-based sustainability. Rae graduated from the University of Colorado at Boulder with a degree in Environmental Studies specializing in Ecology.

Casey Medina. Casey Medina leads Studio SE as the President and CEO. Under his leadership, Studio SE provides a range of exemplary professional development courses including Model-Based Systems Engineering. He has practiced systems and quality engineering across industries including medical device, aerospace, defense, and transportation industries. His expertise extends across disciplines including system development, requirements engineering, model-based systems engineering (MBSE), human factors, quality engineering, risk management, and medical device design control. Professionally, he is focused on developing the art of systems engineering in a manner that fosters adoption and acceptance by organizations resistant to change. He applies systems engineering practices and principles to enable rapid system development and is working to enhance the use of MBSE as an enabler for usability and human factors analyses. He has deployed MBSE to analyze social systems and homelessness. Casey and his team at Studio SE are pioneering the use of MBSE to evaluate natural systems and deploy MBSE to manage and solve sustainability issues.

Aurelijus Morkevičius. Aurelijus Morkevičius has 20 years of experience in systems and software engineering. Currently, he is a director of industry business consultants for systems engineering in Dassault Systems, CATIA brand. His areas of expertise are model-based systems and software engineering, as well as enterprise architectures (UAF, DoDAF, NAF). Aurelijus works with companies such as Aerospace Corporation, Airbus, BAE Systems, Boeing, and MITRE. Aurelijus is INCOSE CSEP and OMG Certified UML, Systems Modeling and BPM professional. He is also the co-chairman and the leading architect for the current OMG UAF standard. Aurelijus is the originator and the main author of MagicGrid framework. He is the Dassault Systems representative in the INCOSE and NATO Architecture Capability Team. Aurelijus received his PhD in Information Systems Engineering from Kaunas University of Technology in 2013. Aurelijus is a professor of practice in the same university, book author, author of multiple articles, and a speaker in multiple conferences.