Securing Your Eggs in Multiple Baskets – Assuring a Resilient and Secure Supply Chain

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Abstract

The global supply chain is a complex system of system relying on other complex systems of systems (SoS) to achieve their goals. To take a typical example, Enterprise A is supplied essential parts on a regular basis to manufacture its products. To place the order requires global financial systems, integrated email systems, the internet, multiple telecommunications systems, supply software provided by large companies. To deliver the parts may require air and maritime transportation systems, the rail network, interstate highway systems, road haulage companies, and state and local transportation systems. When these complex systems fail, the impact can be global, and the results catastrophic. Recent examples were the shortage of Personal Protective Equipment (PPI) during the COVID pandemic, computer chip shortages delaying the assembly and sales of cars, and most recently the baby formula shortage. These were due to disruptions in the supply chain caused by an overreliance on single sourced suppliers who failed to deliver, transportation disruptions, outsourcing of critical parts, supplies, and medicines to distant countries, and an overreliance on "Just In Time" for inventory management. This is the case of placing too many eggs in too few baskets, and often just one basket. In addition, counterfeit or substandard parts and products can enter the supply chain. This has included critical mechanical parts on aircraft, chips containing spyware, and substandard or out of date medicines substituted for the real thing resulting in serious illness and death. This complex SoS needs to be examined, studied and understood in the same way as a mission critical system: threats, vulnerabilities, and risks need to be identified and mitigated and assurance cases defined to ensure a solid and reliable supply chain. This paper will look at the supply chain of an example factory system to determine how some of these problems can be predicted, prevented, mitigated, and solved using the UAF, RAAML and assurance case techniques.

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Agenda

- The Global Supply Chain
- Supply Chain Issues
- Modeling Systems of Systems and Enterprises
- Security Controls and Mitigations
- Example Supply Chain Model
- Conclusions
- Questions?

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History of the Global Supply Chain

- **Keith Oliver, coined the terms "Supply Chain" and "Supply Chain Management“ in 1982.**
- **“Supply chain management (SCM) is the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption”. (Oliver, 1982).**
- **In reality, supply chains have always existed.**
- **Early humans gathered in tribes and family units and started to cooperate and specialize their skills.**
  - Usually one-on-one transactions, with people who knew and trusted one another.
  - Over time the supply chain expanded
  - The Roman Empire to the land-based Silk Road between the Far East and Europe.
  - Exchanges occurred between multiple suppliers and transporters, often incurring taxes by the governments, and danger from bandits en route to the final destination.
  - The sea route around the Cape of Good Hope developed to circumvent the bandits, middlemen and taxes,
  - Christopher Columbus’ voyage was an attempt save time and avoid the dangers of the Cape of Good Hope.
  - Trade with the New World further expanded international trade.

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The Modern Supply Chain

- **Henry Ford's mass production and assembly lines laid the foundations for supply chain management.**
  - Producing consistent products on a large scale with increased efficiency changed and expanded trade and supply chains irreversibly.
- **Container shipping was developed throughout the 20th century.**
  - International standards for size and weight were established in 1968-1970
  - Increased quantity of goods, increased the speed of freight movement and decreased cost.
  - Standardized and specialized ships, railcars and trucks were developed to these standards.
  - More effective warehousing processes, transport terminal efficiency, the improvement of the transport process including loading and unloading goods, warehouse processing, initiated a new era of globalized trade. (Levinson, 2006)
- **The Japanese innovated Supply Chain Management in the 1980's and early 1990's with "Just In Time" and "Kan Ban"**
- **This increasing risks by tightening time constraints but allowed Japanese businesses to run leaner and save money and space for part storage.**
- **Western businesses introduced these processes helping manufacturing, suppliers, and the industrial workforce.**
- **Computerization and Simulation of Supply Chain Management followed.**

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The Dynamic Supply Chain

- The driving principle behind the supply chain and all commerce is capitalism, the desire for profit and to provide value for customers.
- Adam Smith wrote of the invisible hand as a metaphor for the unseen forces that move the free market economy.
- Through individual self-interest and freedom of production and consumption, the best interests of society are fulfilled.
- Throughout the evolution of the supply chain, the enabling principles were transportation, supply, communication, and trust.
- The global supply chain is having problems in all these areas.

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Current Supply Chain Issues

- **Transportation**
  - Trucker shortage due to vaccine mandates
  - Long Beach Port Problems
- **Supply**
  - COVID 19 Lock downs and work stoppages
  - COVID PPE shortages
  - Chip Shortage
  - Single sources products: Chips, medicine, PPE, etc.
- **Communication**
  - Breakdowns within and across organizations
- **Trust/ Certification**
  - Lack of proper supplier qualification
  - Counterfeit or substandard parts
  - Substandard or out of date medicines
  - Fake critical mechanical parts on aircraft
  - Bait and switch con trick of bad PPE
  - Chips containing spyware
  - Certification of prevenance of products, organic, no child/slave labor, sustainably sourced, USA sourced, Fair Trade, etc.

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So, what do we do now?

- **Transportation**
  - Limit the distance between buyers and providers
  - Ensure backup routes are available
- **Supply**
  - Minimize single sourced parts
  - Increase local warehousing
- **Communication**
  - Ensure visibility throughout the links of the supply chain
  - Increase production metrics to properly gage demand
- **Trust/ Certification**
  - Establish assurance cases for all parts of the supply chain
  - Apply risk management at all levels
- **Accept that the global supply chain is a complex system of systems which cannot be controlled but can be managed if understood.**

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Supply Chain Risk Management (SCRM)

- **SCRM is a systematic process for managing supply chain risk by identifying susceptibilities, vulnerabilities, and threats throughout the supply chain and developing mitigation strategies to combat those threats whether presented by the supplier, the supplied product and its subcomponents, or the supply chain. SCRM will be applied to all information systems and weapons systems that are designated as, or comprised of, any of the following:**
  - a. National Security Systems, Automated Tactical Systems, and automated weapon systems as defined by Army regulation 25–2.
  - b. Mission Assurance Category I systems, as defined by Department of Defense Instruction 5200.44.
  - c. Systems registered as mission critical in Army portfolio management system or the Department of Defense's information technology repository.
  - d. Other systems that the Army Acquisition Executive or CIO/G–6 determines are critical to the direct fulfillment of military or intelligence missions.

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MODELING SYSTEMS OF SYSTEMS AND ENTERPRISES

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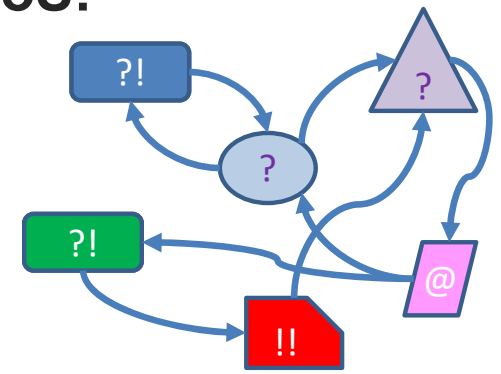
Systems of Systems

- **Definition: A system of systems (SoS) is "a collection of systems, each capable of independent operation, that interoperate together to achieve additional desired capabilities.“ (Mitre)**
- **Maier (1998) postulated five key characteristics of SoS:**
  - operational independence of component systems
  - managerial independence of component systems
  - geographical distribution
  - emergent behavior, and
  - evolutionary development processes



- **Other aspects**
  - Have multiple levels of stakeholders with mixed and possibly competing interests
  - Have multiple, and possibly contradictory, objectives and purpose
  - Have multiple, different, operational priorities with no clear escalation routes
  - Have multiple lifecycles with elements being implemented asynchronously
  - Have multiple owners making independent resourcing decisions

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The Supply Chain as an SoS

- **Operational independence**
  - The supply chain is operated by entities. They are a collection of independent operators, government institutions, and international conglomerates. They operate independently to support their individual customers. Support of the overall is of secondary importance.
- **Managerial independence**
  - Each of the supply chain entities must comply with a variety of different standards, rules, laws and regulations. There are various government institutions that oversee different companies. However, they maintain their operational independence separate from that of the supply chain.
- **Evolutionary development**
  - New systems, technologies or ConOps may be introduced by any of the companies as required to evolve and adapt to the changing environment, latest technology needs or stakeholder requirements. This will affect both the individual system as well as the SoS.
- **Geographical distribution**
  - The supply chain is geographically distributed by its very definition.
- **Lifecycle independence**
  - Even within the individual companies there will be multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion to meet their customer needs.

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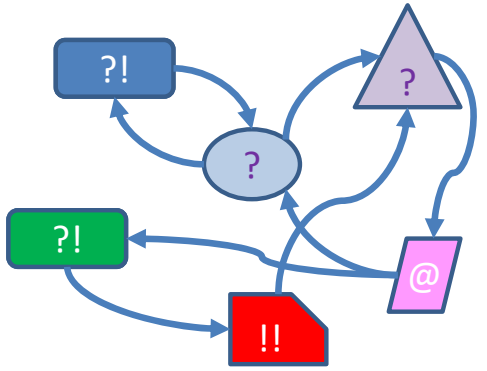
Types of SoS

- **Directed**
  - SoS is created and managed to fulfill specific purposes.
  - Constituent systems are subordinate
  - Airports, Air Traffic Management, etc.
- **Acknowledged**
  - Recognized objectives, a designated manager, and resources.
  - Systems retain their independence.
  - Changes are based on cooperative agreements
  - Defense systems, governments, etc.
- **Collaborative**
  - Component systems interact voluntarily to fulfill central purposes.
  - Public utilities, Cell phone network, Cable TV, global supply chain etc.
- **Virtual (Basically, the internet)**
  - No central management authority or centrally agreed upon purpose.
  - Invisible mechanisms maintain it.
- **(Maier, 1998; Dahmann and Baldwin, 2008, ISO 21839, 2019):**



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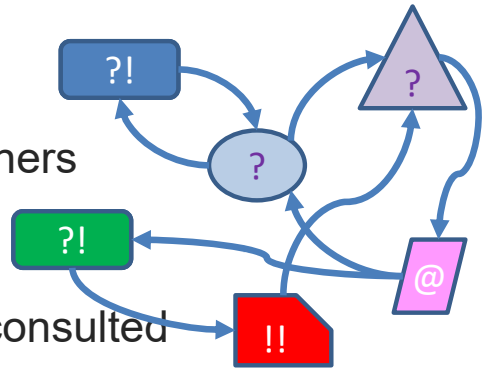
Importance of the SoS to the Supply Chain

- **Multiple levels of stakeholders**
  - Changes cannot simply be mandated but must be negotiated.
  - Changes will take time to negotiate and implement
- **Multiple, and contradictory, objectives and purpose**
  - There is no “Common Good”. Benefits for one can adversely affect others
  - Proposed changes can cause infighting delaying implementation
- **Multiple, different, operational priorities**
  - Owners, stakeholders, shareholders, customers, regulators must be consulted
  - Competition is fierce between and across different entities.
- **Multiple System lifecycles**
  - Production cycles may not match demand
  - ROI to replace newly installed systems is difficult
- **Multiple owners making independent resourcing decisions**
  - Competition has cut operating margins limiting discretionary funds
  - In a distributed, global, supply chain, enforcement can be impossible



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Unified Architecture Framework (UAF)

- The UAF is used for defining system architectures and system of systems architectures
- It is focused on the scope, needs, strategy, expectations, stakeholders, and long-term plans
- It is built on SysML, so has built-in traceability to system development in SysML.

Great for large organizations to figure out what they are doing and why.

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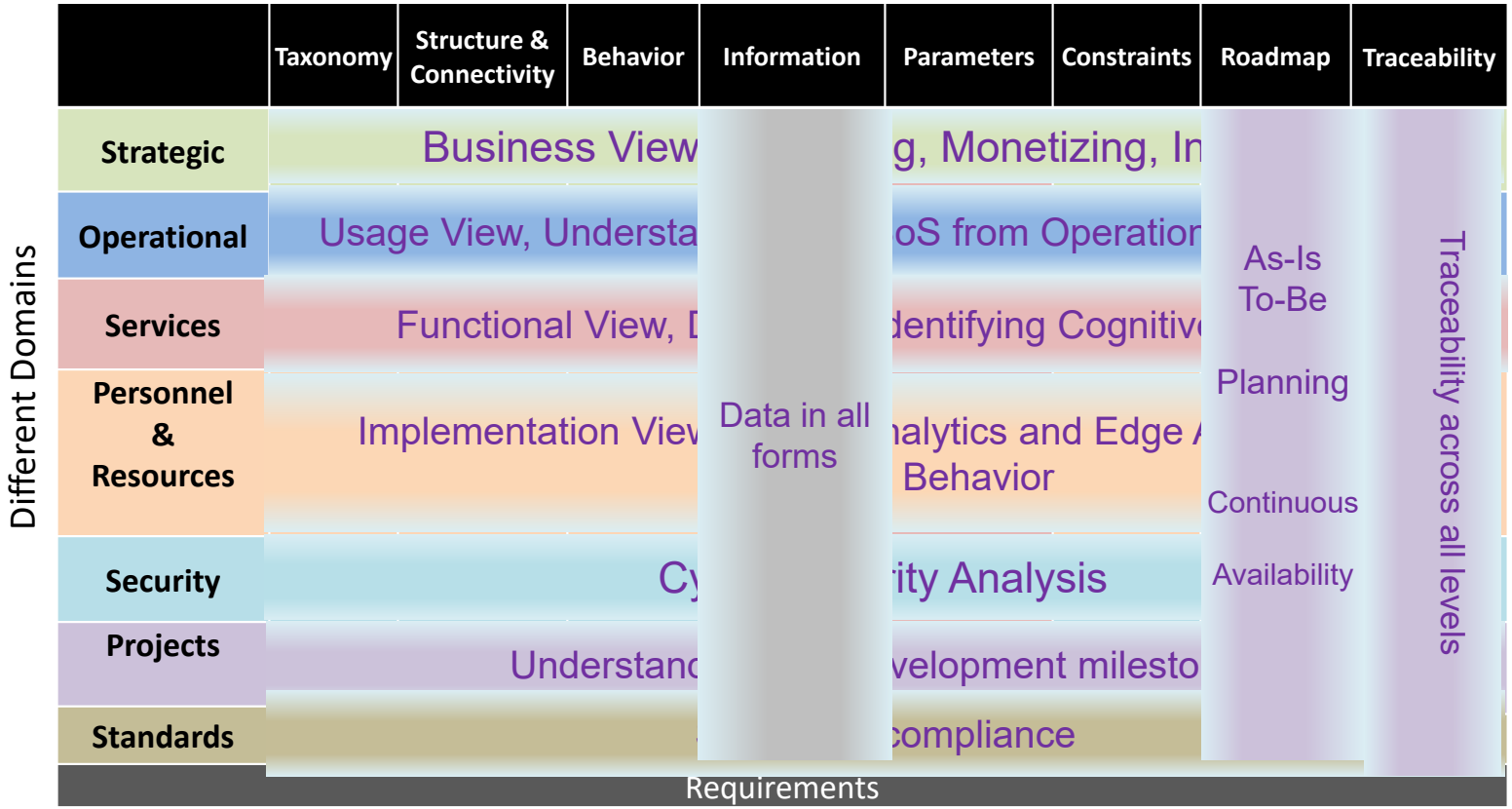
The Unified Architecture Framework Grid

Standard means of expression – model kinds



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	Taxonomy Tx	Structure Sr	Connectivity Cn	Processes Pr	States St	Interaction Scenarios Is	Information If	Parameters Pm	Constraints Ct	Roadmap Rm	Traceability Tr
Metadata Md	Metadata Taxonomy Md-Tx	Architecture Viewpoints [a] Md-Sr	Metadata Connectivity Md-Cn	Metadata Processes [a] Md-Pr	-	-	Conceptual Data Model, Logical Data Model, Physical schema, real world results	Environment Pm-En, Measurements Pm-Me	Metadata Constraints [a] Md-Ct		Metadata Traceability Md-Tr
Strategic St	Strategic Taxonomy St-Tx	Strategic Structure St-Sr	Strategic Connectivity St-Cn	-	Strategic States St-St	-			Strategic Constraints St-Ct	Strategic Deployment, St-Rm Stategic Phasing St-Rm	Strategic Traceability St-Tr
Operational 0p	Operational Taxonomy Op-Tx	Operational Structure Op-Sr	Operational Connectivity Op-Cn	Operational Processes Op-Pr	Operational States Op-St	Operational Interaction Scenarios Op-Is			Operational Constraints Op-Ct	-	-
Services Sv	Service Taxonomy Sv-Tx	Service Structure Sv-Sr	Service Connectivity Sv-Cn	Service Processes Sv-Pr	Service States Sv-St	Service Interaction Scenarios Sv-Is			Service Constraints Sv-Ct	Service Roadmap Sv-Rm	Service Traceability Sv-Tr
Personnel Pr	Personnel Taxonomy Pr-Tx	Personnel Structure Pr-Sr	Personnel Connectivity Pr-Cn	Personnel Processes Pr-Pr	Personnel States Pr-St	Personnel Interaction Scenarios Pr-Is			Competence, Drivers, Performance Pr-Ct	Personnel Availability, Personnel Evolution, Personnel Forecast Pr-Rm	Personnel Traceability Pr-Tr
Resources Rs	Resource Taxonomy Rs-Tx	Resource Structure Rs-Sr	Resource Connectivity Rs-Cn	Resource Processes Rs-Pr	Resource States Rs-St	Resource Interaction Scenarios Rs-Is			Resource Constraints Rs-Ct	Resource evolution, Resource forecast Rs-Rm	Resource Traceability Rs-Tr
Security Sc	Security Taxonomy Sc-Tx	Security Structure Sc-Sr	Security Connectivity Sc-Cn	Security Processes Sc-Pr	-	-			Security Constraints Sc-Ct	-	-
Projects Pj	Project Taxonomy Pj-Tx	Project Structure Pj-Sr	Project Connectivity Pj-Cn	-	-	-			-	Project Roadmap Pj-Rm	Project Traceability Pj-Tr
Standards Sd	Standard Taxonomy Sd-Tx	Standards Structure Sd-Sr	-	-	-	-			-	Standards Roadmap Sr-Rm	Standards Traceability Sr-Tr
Actuals Resources Ar		Actual Resources Structure, Ar-Sr	Actual Resources Connectivity, Ar-Cn	Simulation [b]					Parametric Execution/ Evaluation [b]	-	-
Dictionary * Dc											
Summary & Overview SmOv											
Requirements Rq											

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Example Automotive Factory Model

- **Problem Statement: Powerhouse Engines (PE Inc.) is an automotive supply company providing internal combustion engines. PE Inc. finds that it has gradually become less competitive over the years largely due to their outdated technology and largely manual processes. Foreign and domestic competitors have started to cut into their business and the stakeholders are concerned that the company's loss of market share will accelerate and that they will eventually become insolvent. To combat this, the shareholders have proposed an investigation into strategies and technologies such as Augmented reality, Robotic assembly systems, 5G, AI, Additive manufacturing, outsourcing of select manufacturing and IT systems, Battery technology, Data analytics, Hybrid/electric engines, etc. These technologies will be rolled out over a 3-phase technology deployment plan.**

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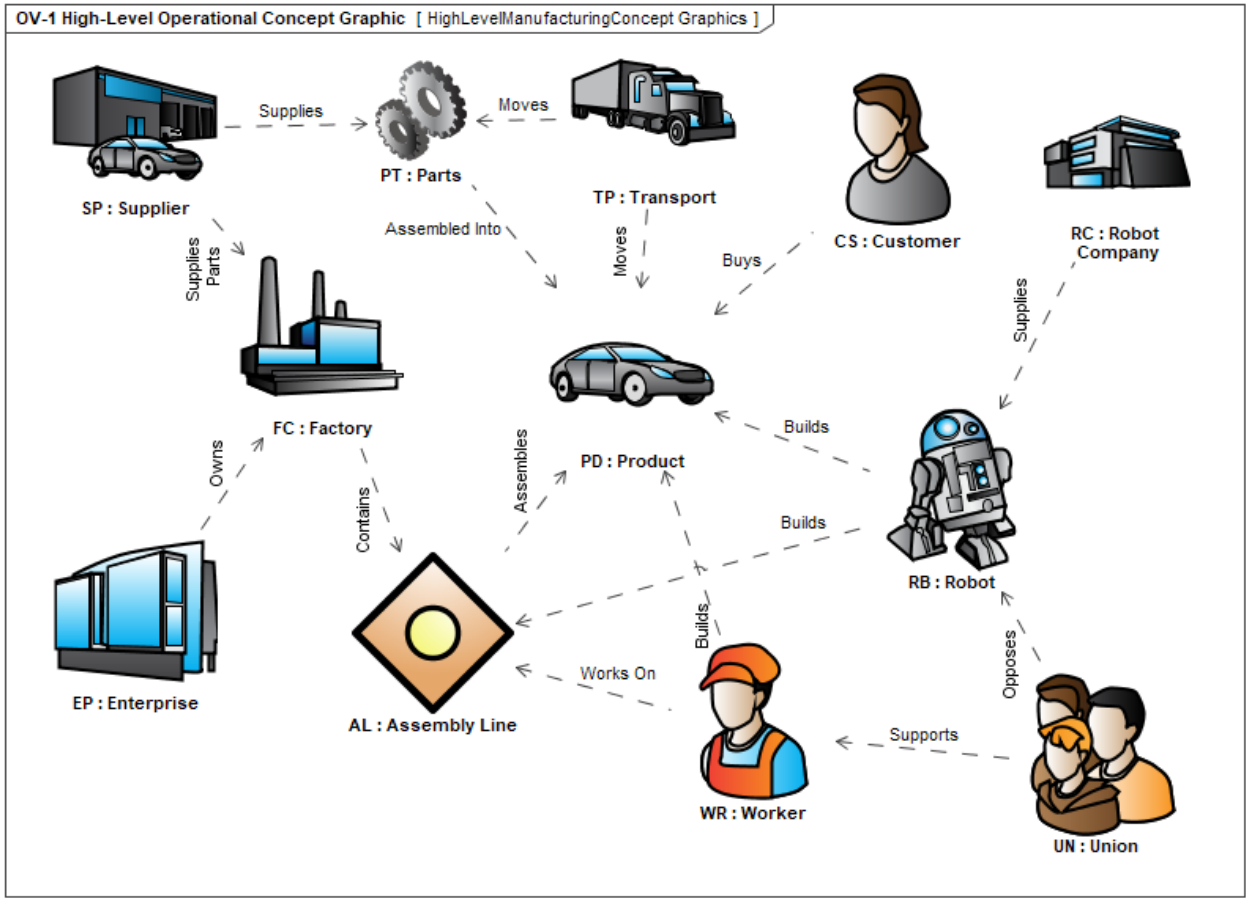
High Level Manufacturing Concept for Powerhouse Engines

- Solution independent concepts in the architecture
- The part supplier could be an external company, an internal casting department, or an in-house 3D printer.
- All supply parts, and each has advantages and disadvantages regarding supply chain delays, cost, flexibility, etc.
- All 3 will be deployed over the 3 phases of technology introduction.



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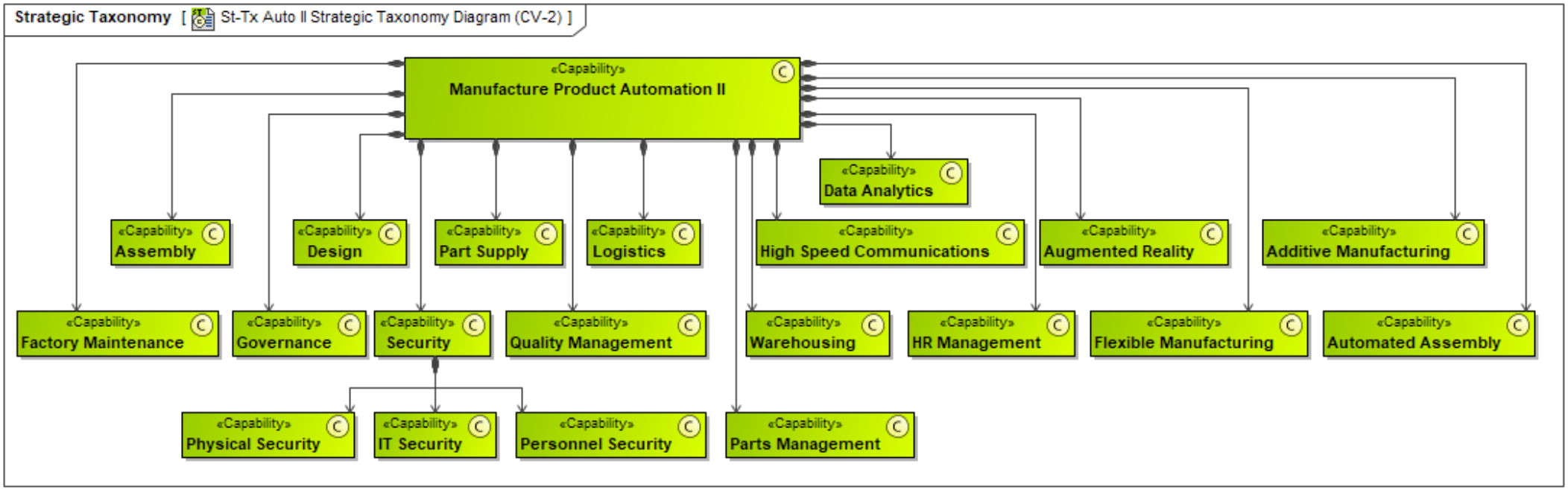
Powerhouse Engines Enterprise Capabilities

- Defines what the enterprise can do, not how it does it.
- Linked to effects that implementing systems accomplish



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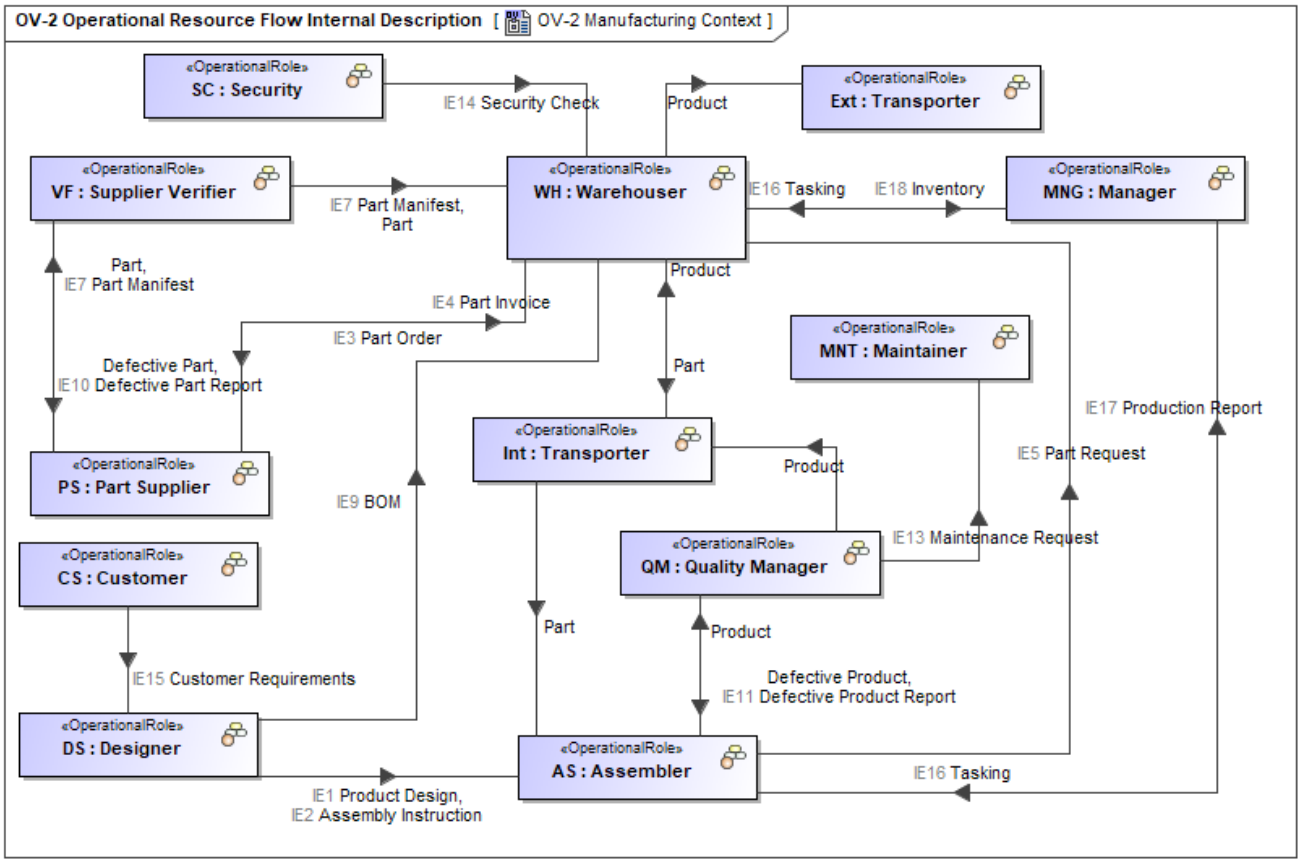
Manufacturing Logical Performers

- Operational activities are grouped together to define operational performers
- Deriving performers from their activities concentrates on behavior before structure
- Helps prevent “Solutioneering”



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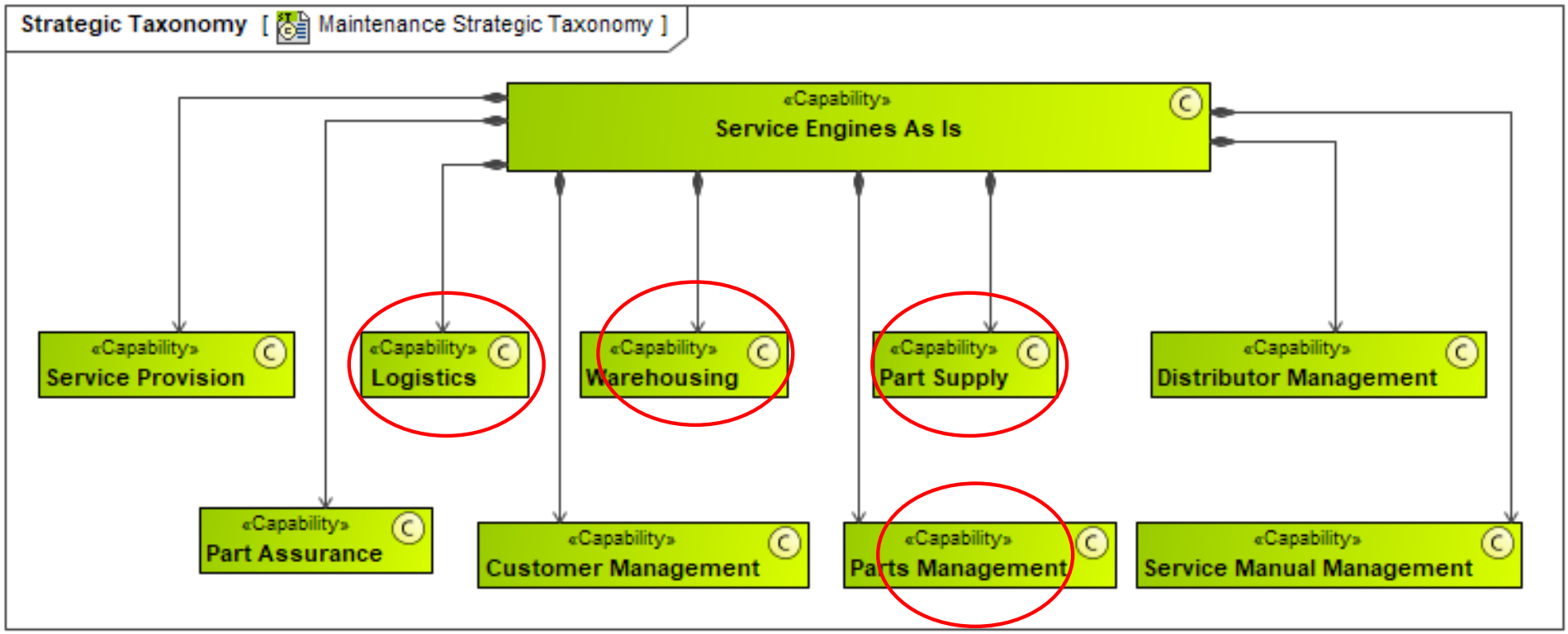
Servicing Capabilities



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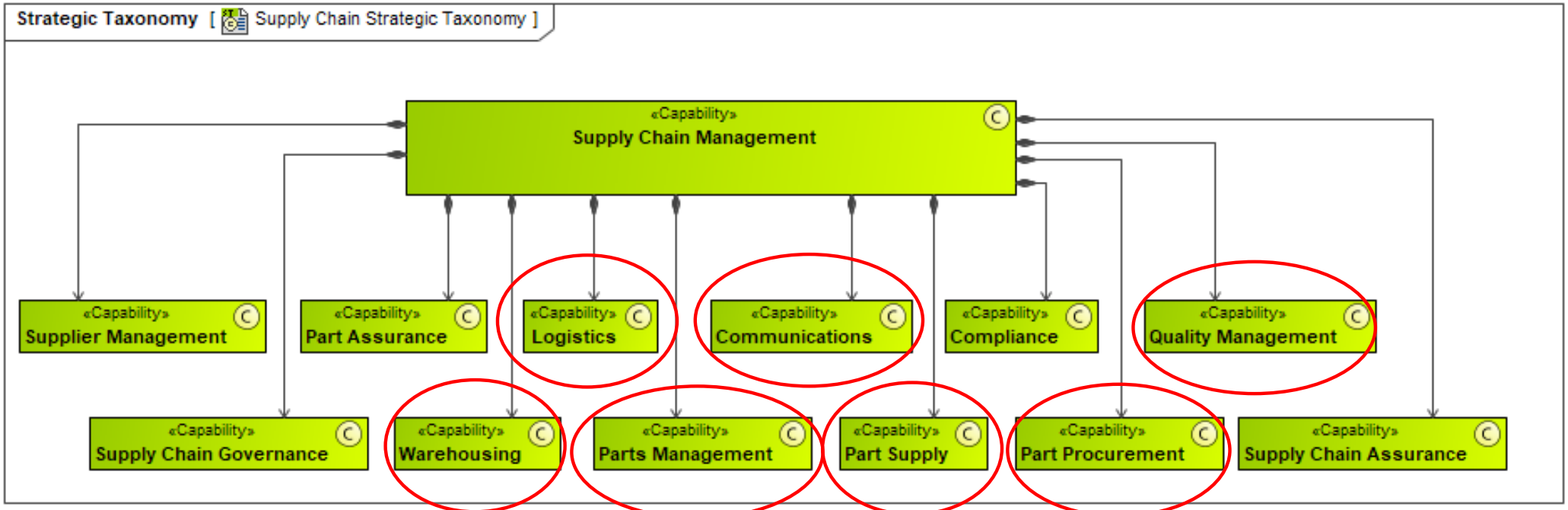
Supply Chain Management Capabilities



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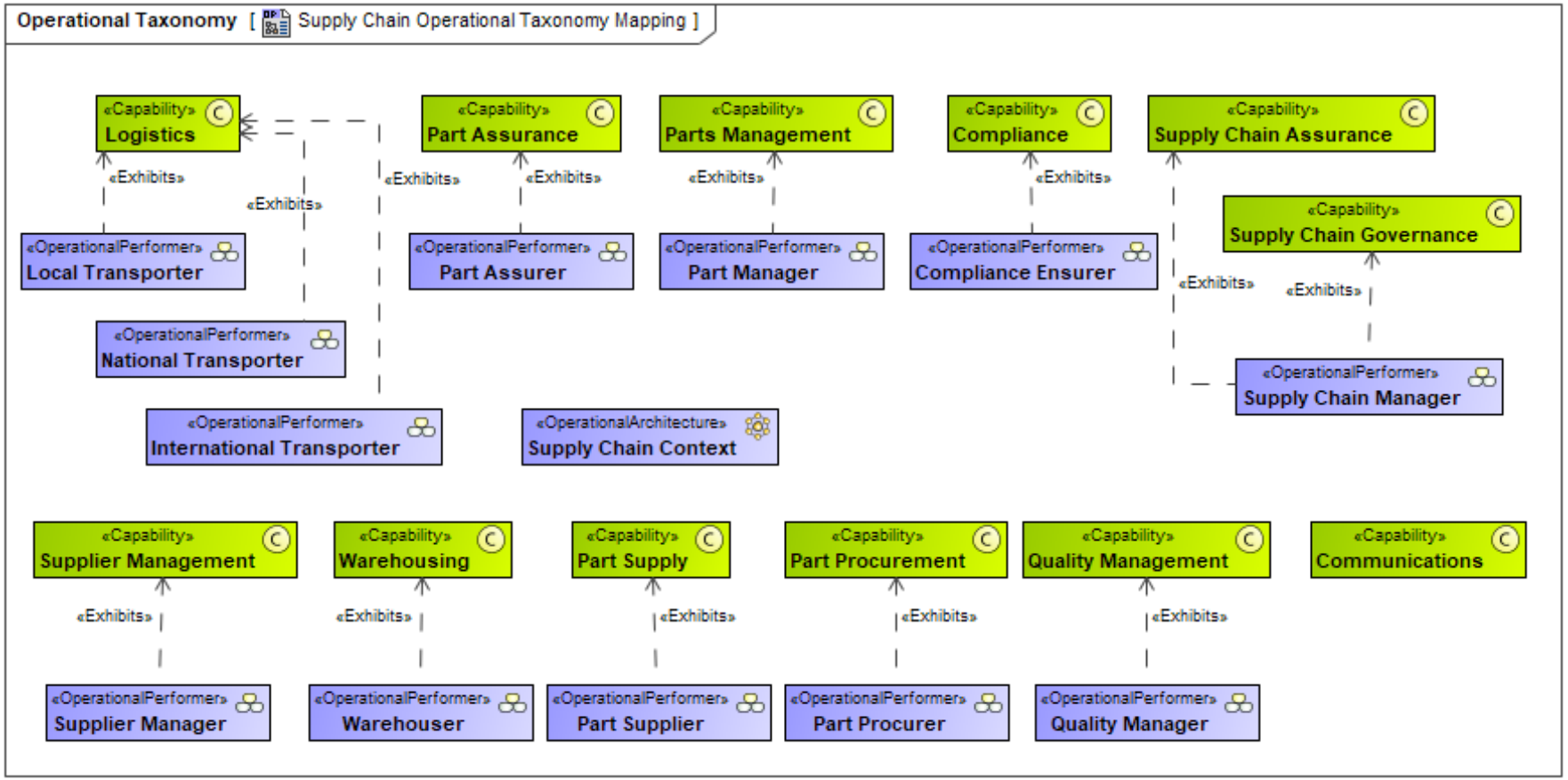
Supply Chain Operational Performers



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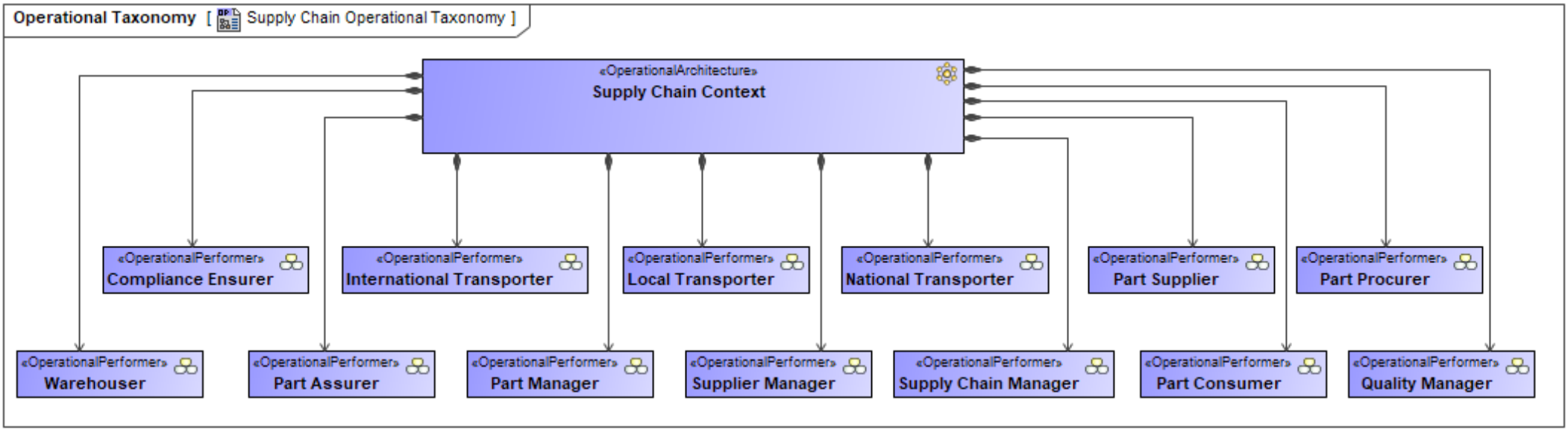
Supply Chain Structure



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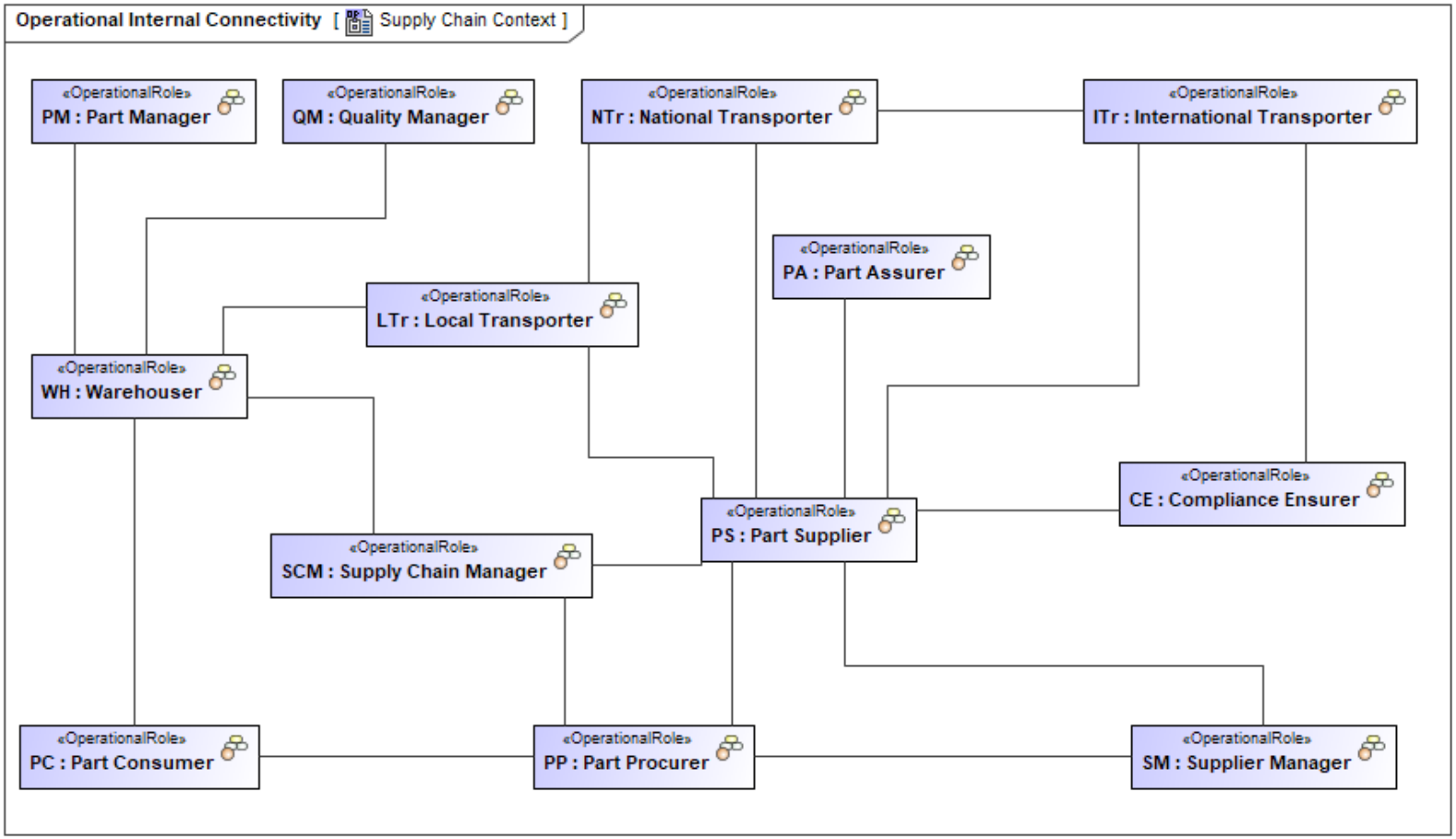
Supply Chain Interactions



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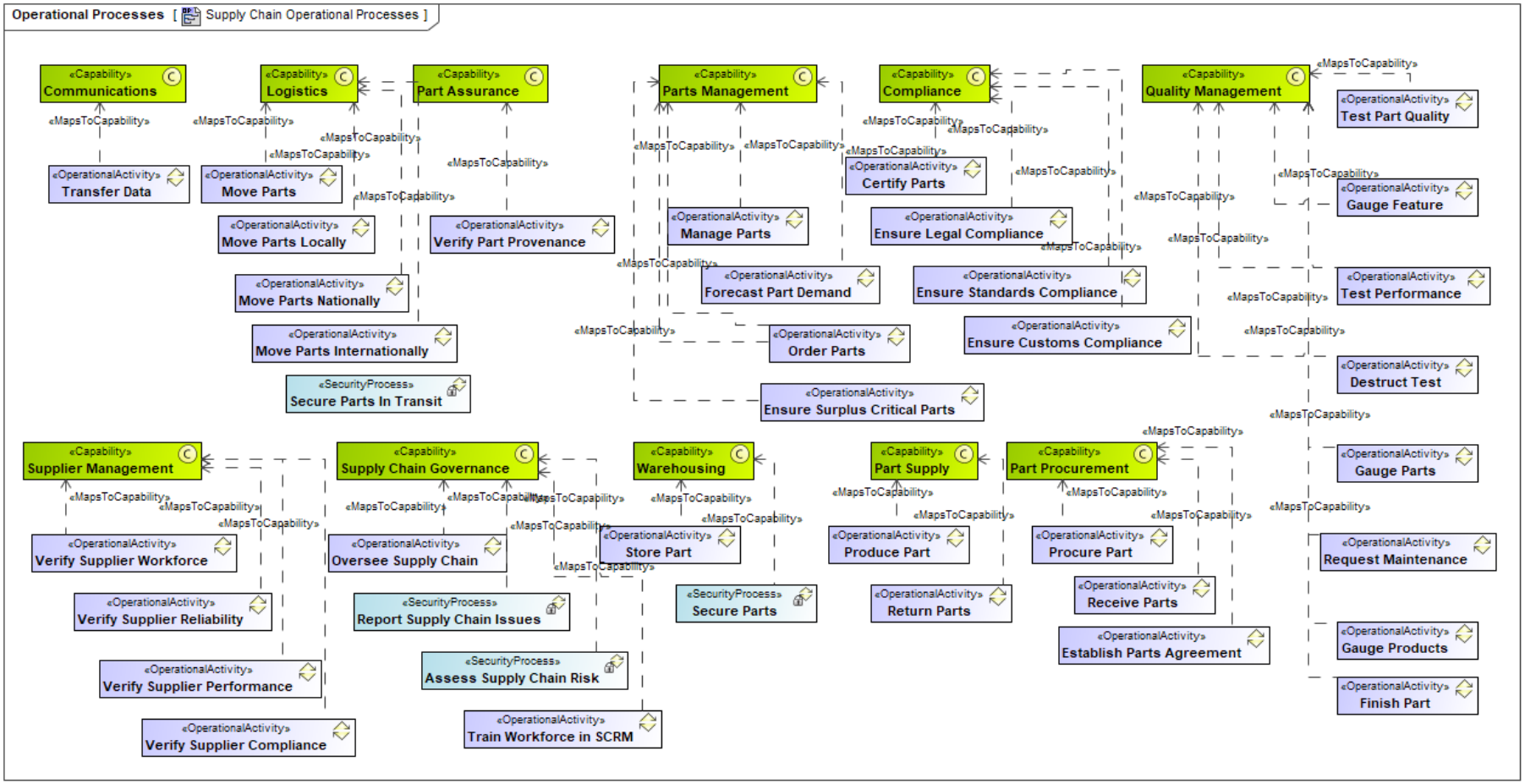
Supply Chain Activities



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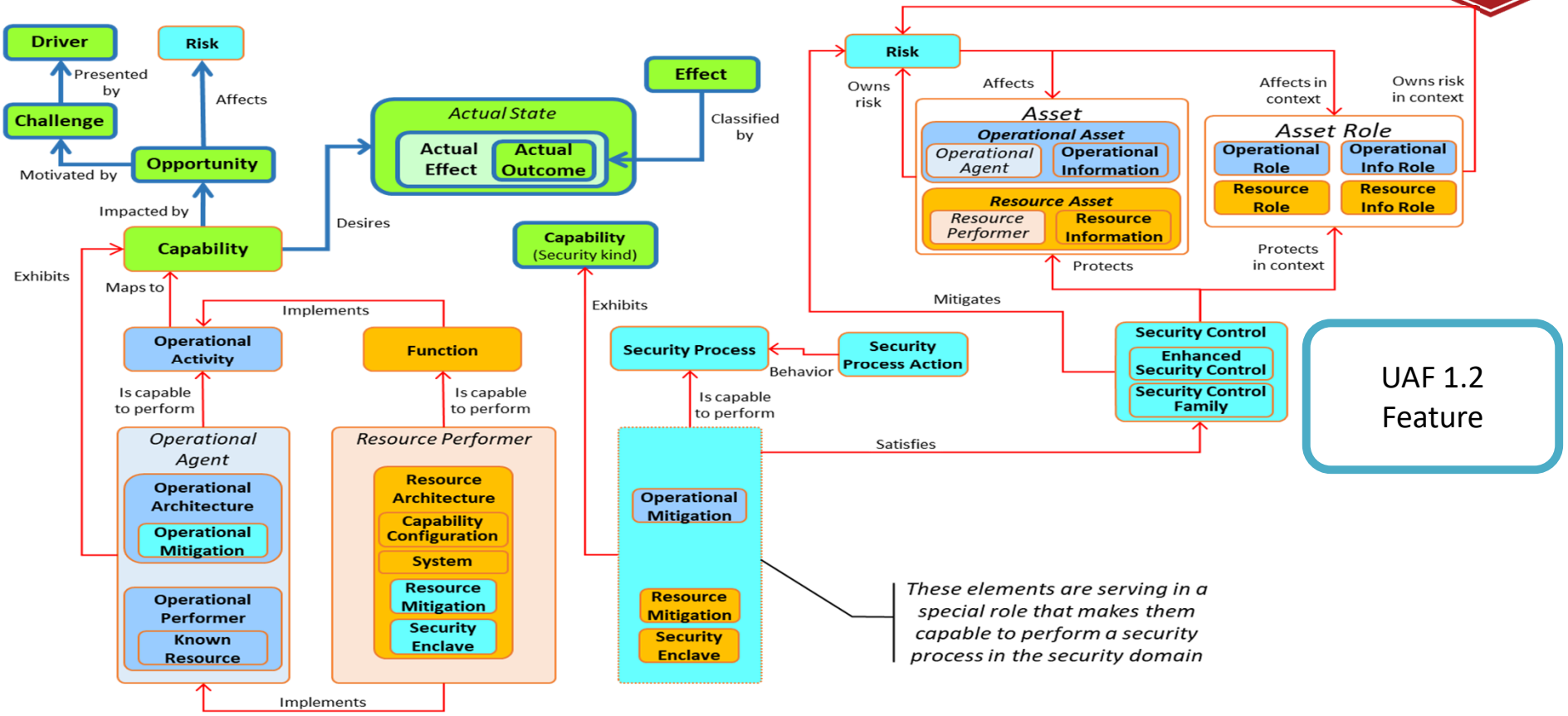
UAF Security Views Conceptual Meta-Model



UAF 1.2 Feature

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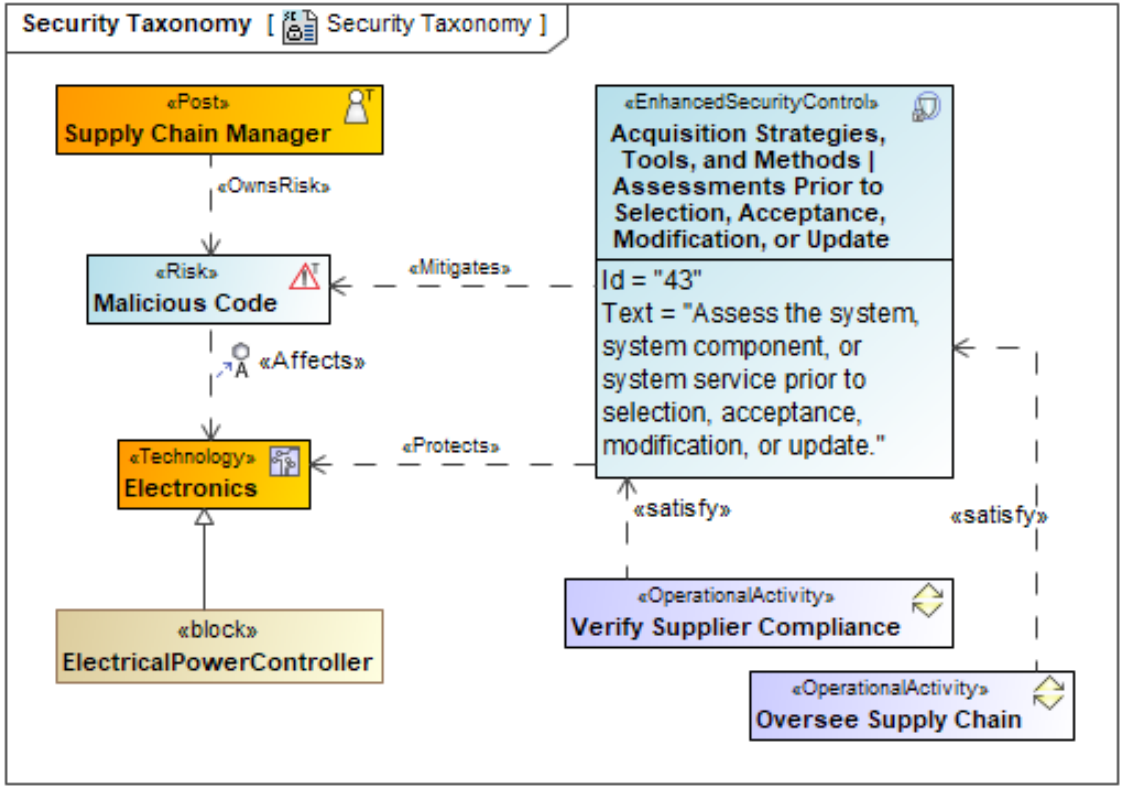
Sc-Tx Security Taxonomy

- **This figure shows the taxonomy for some of the security elements**
- **Risks are the possibility of an adverse effect and its likelihood of occurrence**
  - Risks affect resource artifacts, capability configurations, etc.
- **Security Controls are a management, operational, or technical control (e.g., safeguard or countermeasure) which Protects an asset.**
  - They mitigate risks and protect assets
- **Resource Mitigations are a set of performers established to manage operational or resource Risks.**
  - They are represented as an overall strategy or through techniques (mitigation configurations) and procedures (Security Processes)and other assets to satisfy security controls



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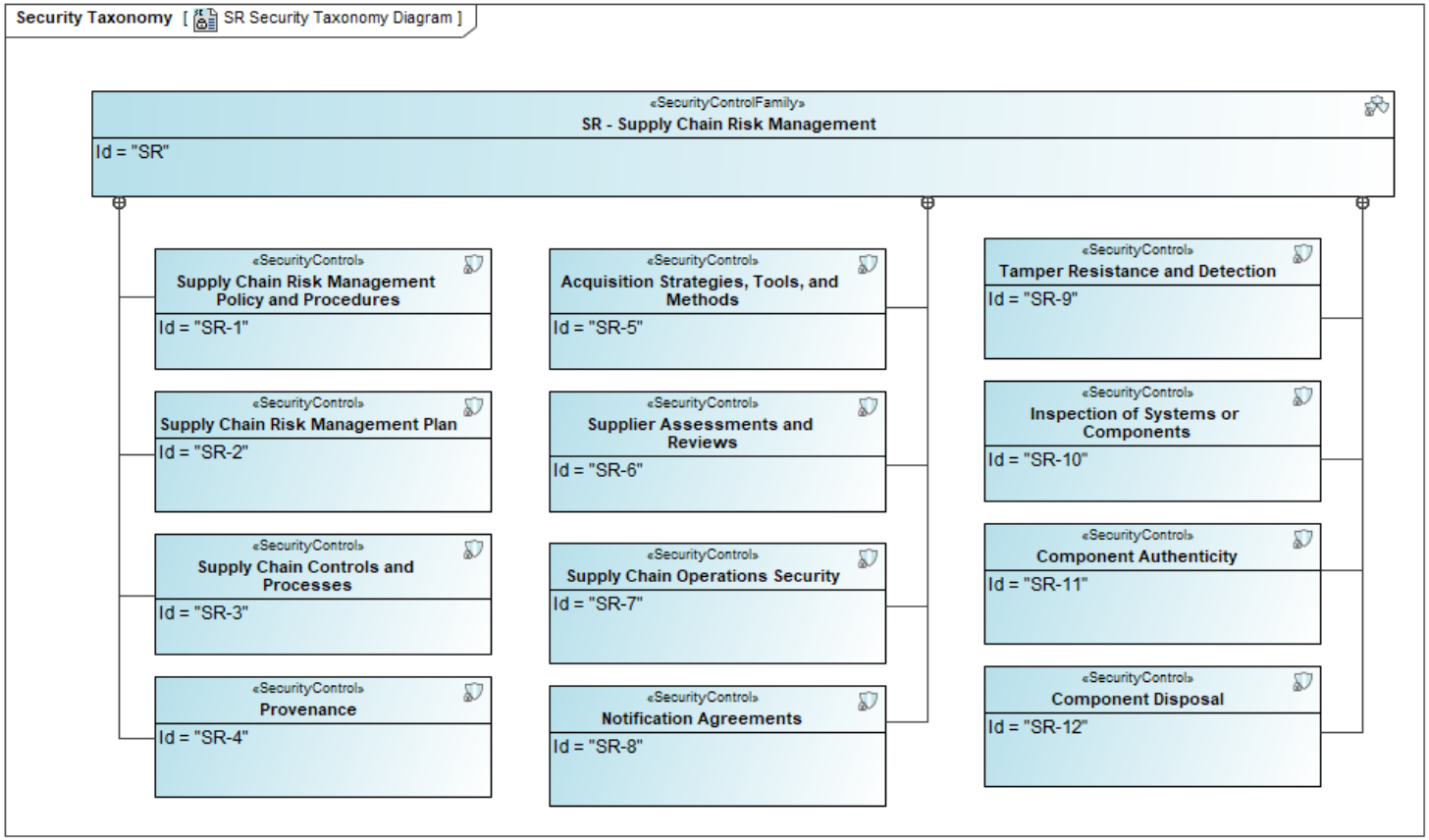
NIST SP 800-53 Security Controls Library

- UAF Reference Library
- Captures Security Controls, Families, Enhanced, Etc.
- Can combine with risks, mitigations, to find solutions



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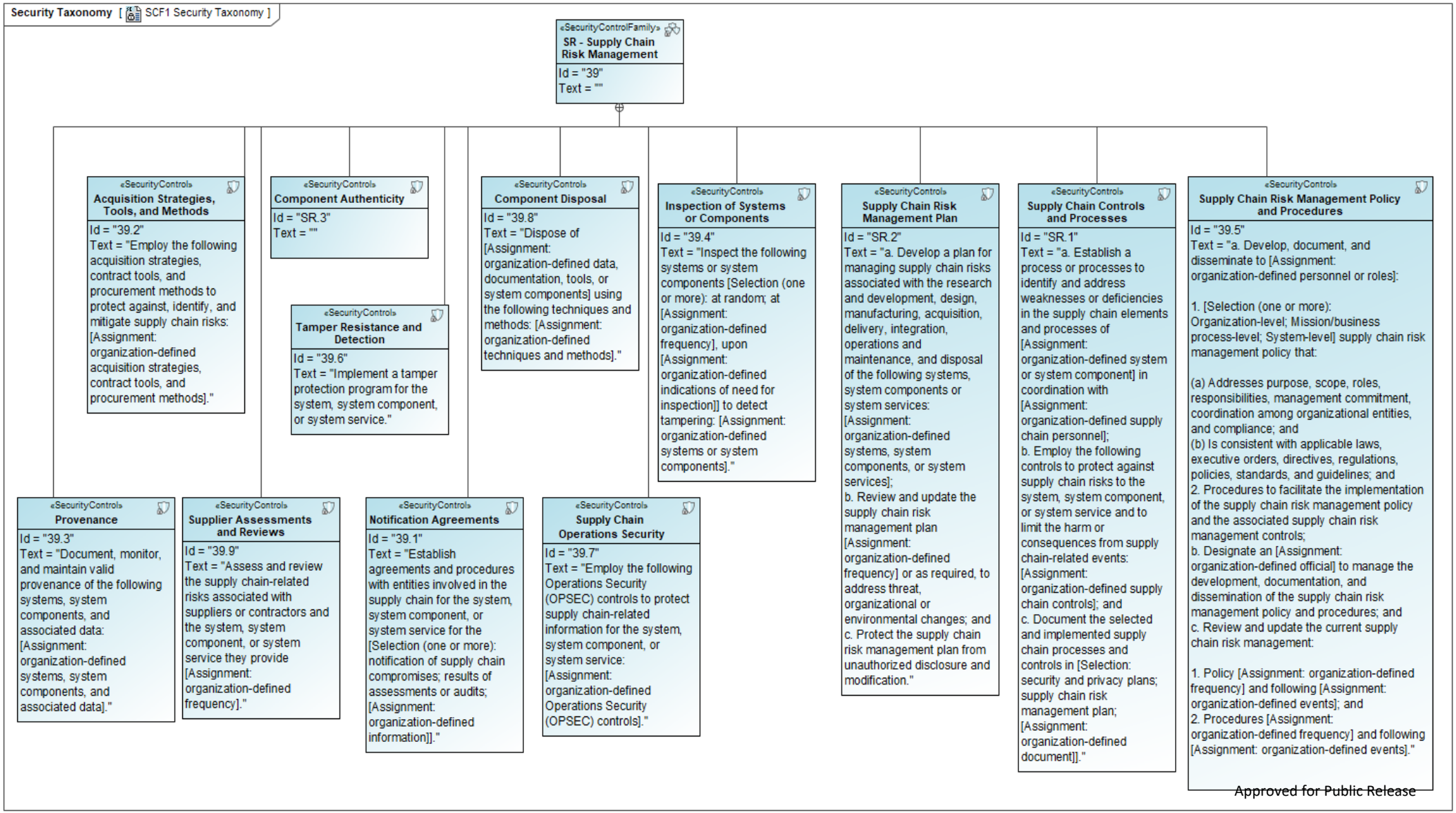

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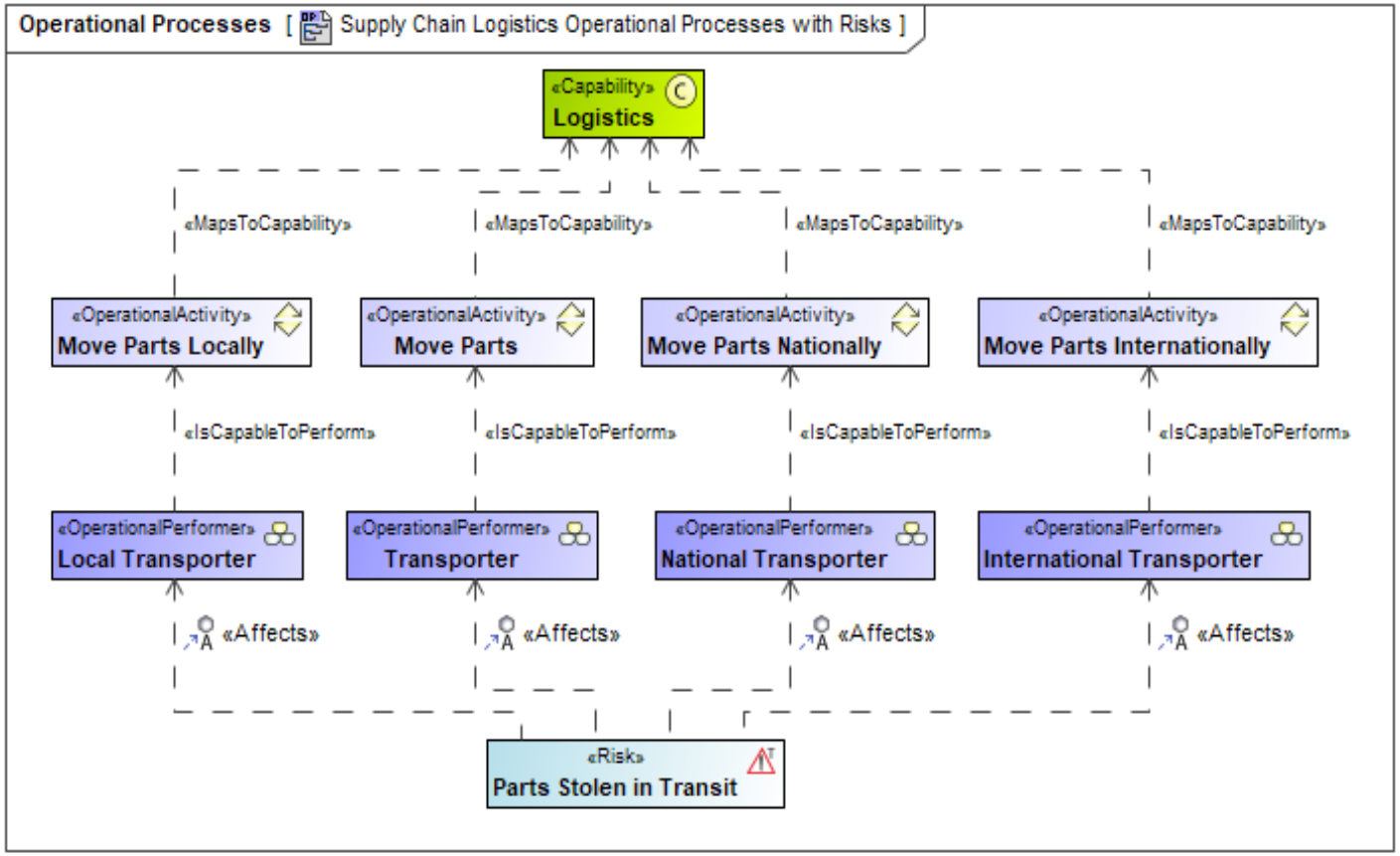
Example Risk and Affected Element

- The risk of Parts Stolen in Transit affects the Transporters
- These eventually map to the Logistics capability



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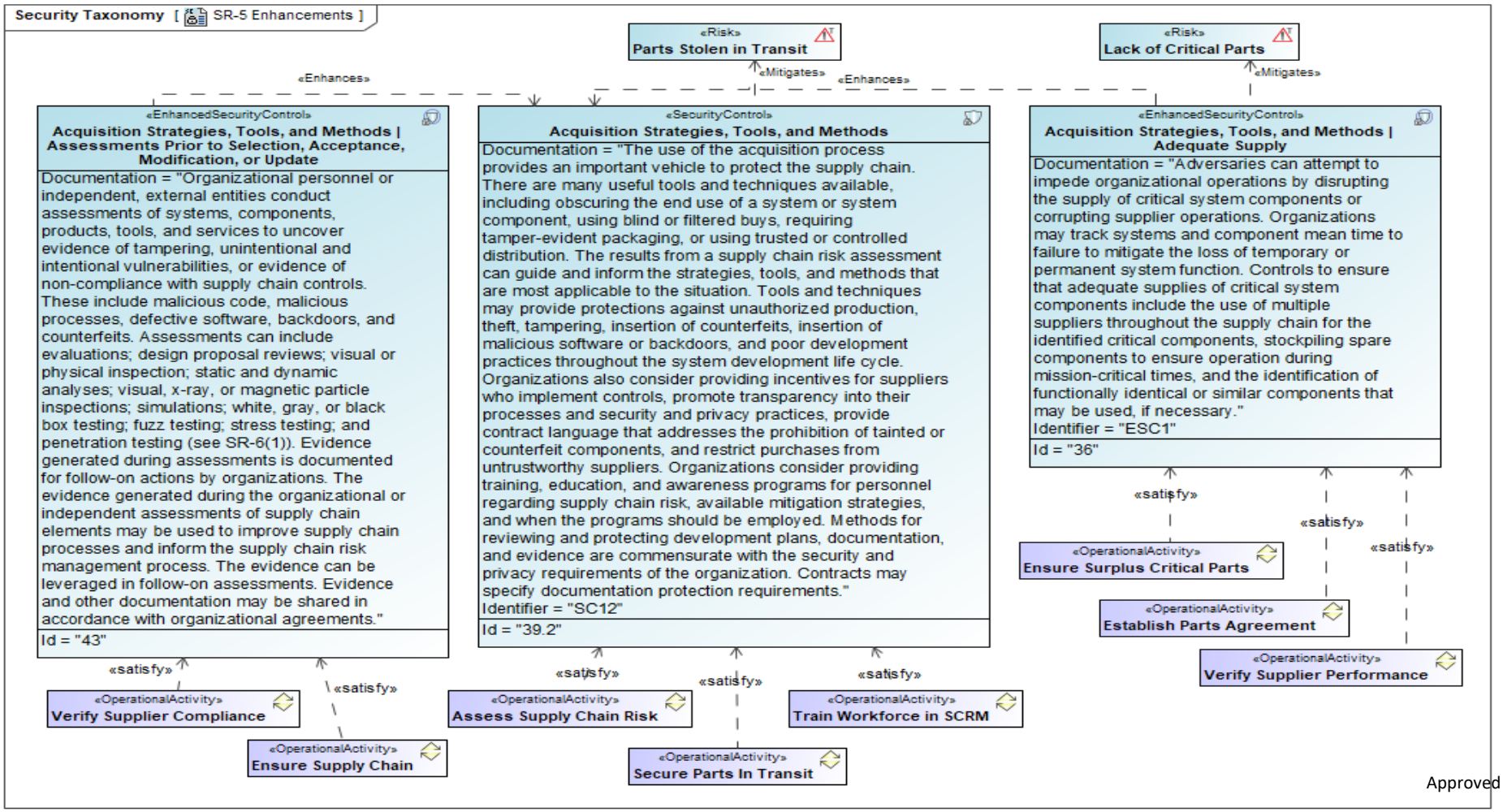
Additional Supply Chain Risk Mitigations and Activities



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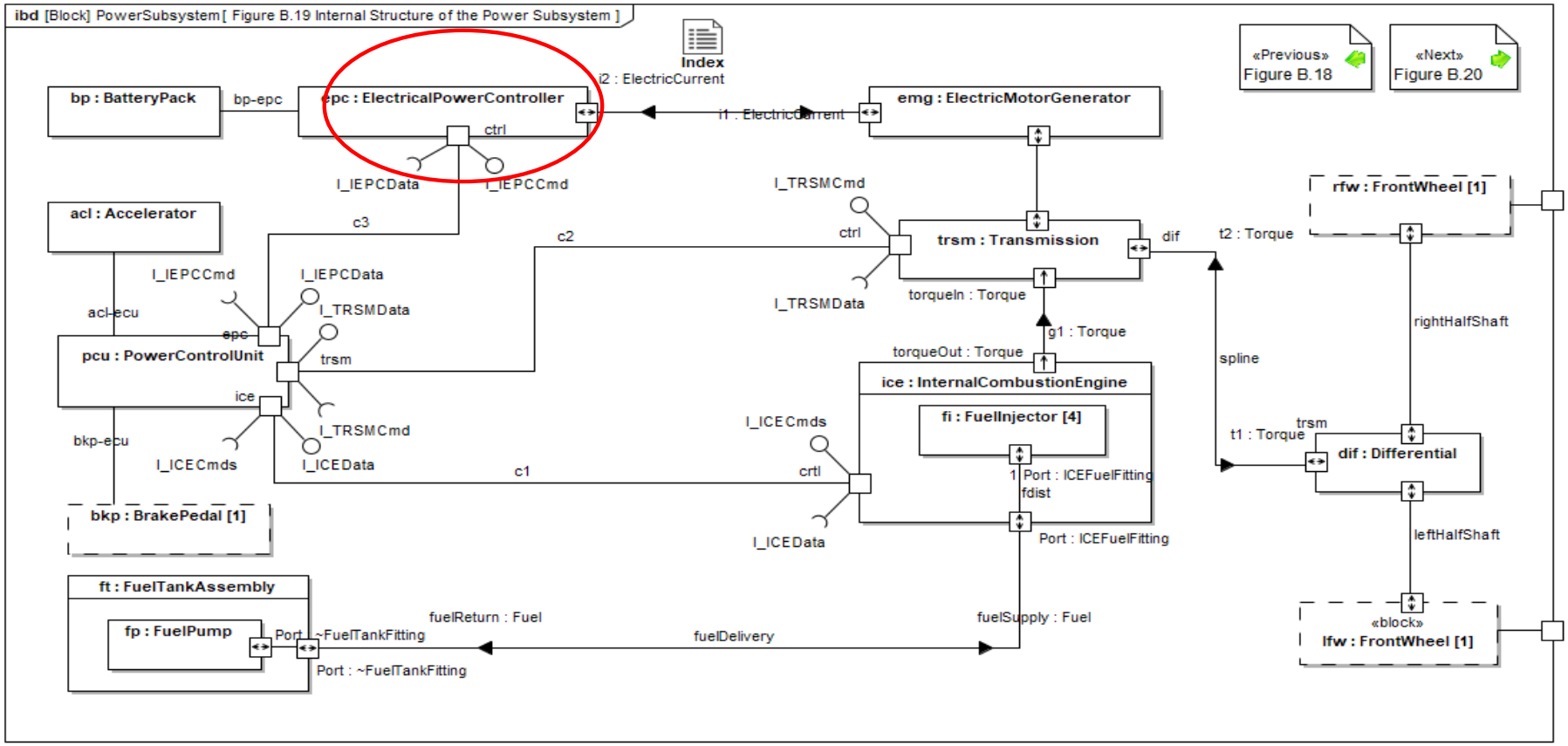
Traceability from the System Design



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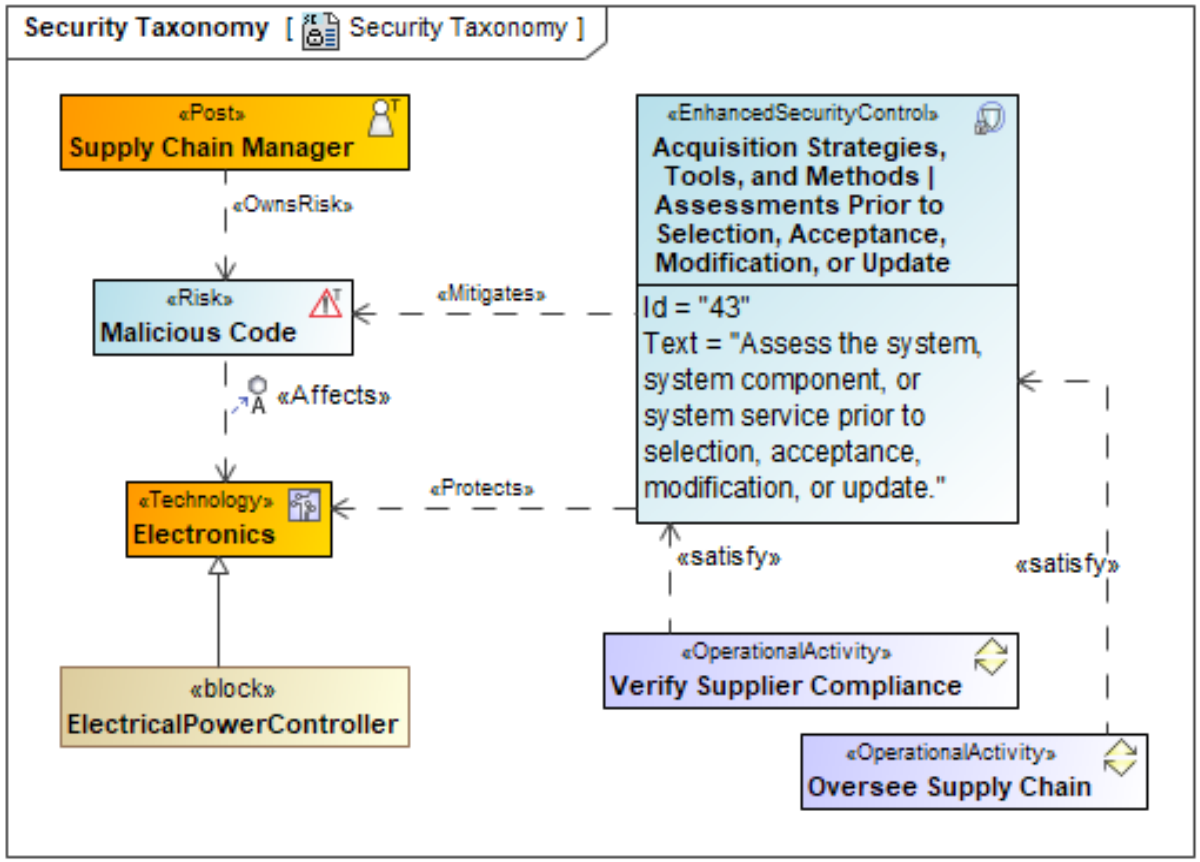
Links From the SysML Elements to Supply Chain

- The Electrical Power Controller is a type of Electronics.
- The Risk, Security Control, Mitigating Elements and Satisfying Processes define the necessary Supply Chain processes.



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Why is This Useful?

- Although supply chain simulation software exists, a SoS POV is still useful
- Looking outside the existing contexts is always helpful
- Provides SCRM earlier in the cycle

MH&L Material Handling & Logistics

GLOBAL SUPPLY CHAIN

80% of Supply Chain Not Accounted for in Current Digital Decision Models

Digital models are missing the vast majority of the supply chain environment.

MH&L Staff

Digital models are missing the vast majority of the supply chain environment, according to analyst firm Gartner.

This incomplete view of the supply chain results in digital trade-off analysis failing to improve decision makers' outcomes, despite the potentially transformative capabilities of these new tools. Digital trade-off analysis includes things such as what-if analysis, scenario modeling, or simulations. Digital trade-off analysis offers improvements in analytical power and clarity when processes are adhered to and enabled with high-quality data.

"The 'digital-to-reality gap' will continue to hamper supply chain performance

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Future Work

- Create additional risks and mitigations
- Add RAAML relationships to verify assurance case
- Create supply chain simulation and process diagrams
- Trace additional system parts to the supply chain
- Generate traceability tables for SysML parts list
- Further investigation of Supply Chain Tools for gap analysis
- Decompose existing controls into atomic controls or requirements
- Add links to standards and guidance

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Questions?

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