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Using a Model-Based Systems Engineering (MBSE) Approach for Human-Centric Design

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ABSTRACT

This research explores the integration of model-based systems engineering (MBSE) practices with human-centric design principles to enhance enterprise operations. The primary focus is on incorporating personnel data into digital SE environments to improve human resource management and project outcomes. Utilizing the Unified Architecture Framework (UAF), the study develops a model that captures the complex relationships between organizational structures, resources, and human factors. A production line system (PLS) serves as a case study to demonstrate how MBSE tools can simulate and optimize human interactions within the operational environment. Key findings include improved traceability of personnel competencies between individual persons and proper resource allocation based on capabilities. The research concludes with a recommendation further studies to include performance requirements, personnel and resource roadmaps, and the consideration of organizational and societal influences on employees.

Keywords: Model-based systems engineering, Human factors engineering, Enterprise architecture, Organizational structure, UAF, Human-centric design, Digital thread

INTRODUCTION

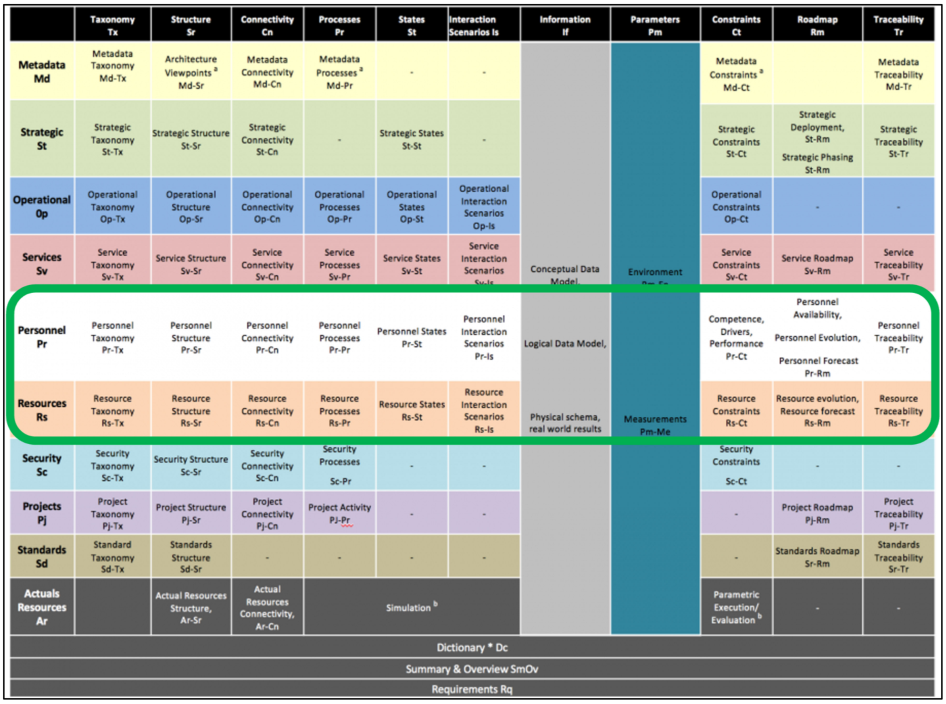
This research is motivated by the desire to extend typical systems engineering (SE) models to provide detailed information regarding employees within an enterprise. The case study was conducted with the goal of answering the following questions: (1) How can personnel data be captured in a digital environment conducive to SE processes? (2) Does capturing project management information within an engineering model assist with human resource management and decisions?

Model-Based Systems Engineering (MBSE)

As model-based systems engineering (MBSE) tools become increasingly integrated into the digital thread during product design and development, additional approaches and methods have arisen. For the proper implementation of MBSE practices, a modeling language, tool, and approach must be defined and documented (Delligatti, 2014). Several graphical modeling languages that support the International Organization of Standards (ISO) 15288 - *Systems engineering processes* are available to assist with product development and design at the system, subsystem, and component levels. The Unified Architecture Framework Modeling Language (UAFML) extends expected capabilities of the Unified Modeling Language (UML) and the Systems Modeling Language (SysML) to provide similar solutions for enterprises and system-of-systems (SoS).

The framework itself encompasses a multitude of management concepts in addition to technical necessities. Given the increase in available model elements within UAFML, the flexibility of an MBSE approach is enhanced for more project-specific deviations to include parameters and constraints such as schedule, cost, and resources. UAF produces models and views to develop an understanding of the complex relationships that exist between organizations, systems, and end users. The UAF profile to enable practitioners to express architectural model elements and organize them in a set of viewpoints, aspects, and view specifications (OMG, 2022).

The profile has a domain metamodel to guide the modeler through the process shown in Figure 1. Each row of the grid represents a domain within the UAF. The columns are different views (i.e., diagrams) that can be created for the domains. This paper will focus on the *Personnel* domain and traceability to the *Resource* domain.



	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	-	-			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 Strategic Phasing St-Rm	Strategic Traceability St-Tr
Operational Op	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	Conceptual Data Model,	Environment	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	Logical Data Model,		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	Physical schema, real world results	Measurements Pm-Me	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 Activity PJ-Pr	-	-			-	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											

Figure 1: UAF grid.

For each domain, packages in the containment tree construct the UAF and direct the process as shown in Figure 2.

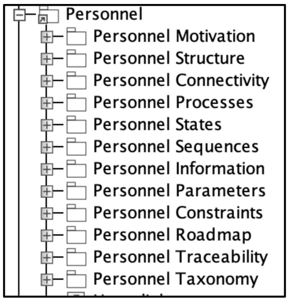


Figure 2: Personnel domain package structure.

The goal of the *Personnel* domain is to understand human resources and the interactions between them to better define the necessary human factors characteristics. Table 1 shows the subset of views constructed for the *Personnel* domain (OMG, 2022).

Table 1. UAF personnel domain views.

Personnel View	Concern	Purpose
Taxonomy	Organizational personnel types	Defines inheritance hierarchy of organization, posts, and persons
Structure	Organization structure used to support capabilities	Defines organizational structure
Processes	Functions executed by organizational personnel	Defines the functional flow of organizational interactions
States	Capture state-based behavior of organizational personnel	Defines possible states of the organization and responses to various events and actions
Sequences	Interactions between organization personnel (i.e., roles)	Defines time-ordered interaction between resources
Constraints	Show personnel abilities defined by knowledge, skills, and aptitude	Defines measurements for personnel-level artifacts

The goal of the *Resources* domain is to define resources by providing defining resources required for implementation of successful enterprises [i.e., system-of-systems (SoS)]. Model elements originating in the *Personnel* domain are re-used here to architect human-machine interfaces (HMI).

Human Factors Engineering (HFE)

The main objective of human factors engineering (HFE) [i.e., human factors and ergonomics) is to understand the interactions between people and the environment to optimize the human well-being and overall system performance (Salvendy, G., 2022). Human factors (HF) design should account for failure to match requirements of a task with operator capabilities

(Jankovich, J.P., 1973). HF seeks to support systems development through the systematic and reasoned design of human-computer interactions (HCI) [Dowell, J. & Long, J].

In addition to HF evaluations, task and activity analysis is included in human-systems integration, where a task is a prescription to operators and an activity is what people do (Boy, 2017). According to Perrow, C., 1983, organizational context and social influence should be included in HFE analyses of the operations. This presents a need to integrate SE and HFE to satisfy requirements of mapping human users with tasks they are capable of accomplishing.

RESEARCH METHOD

This research is focused on ways resource management integrates into a digital environment to provide a more complete model. UAF includes a particular focus on resources, associated requirements, their unique attributes, technical capabilities, areas for improvement, and allocated tasking. This information assists analysis of resource workload, dependencies, constraints, and parameters which leads to simulation capabilities for a production line while maintaining a human-centric approach. This research evaluates how capturing resource information in a digital environment serving as a single source of truth benefits a standard production system and an organization's employees. The information to create at least one recommended diagram for the views identified in Table 1 will be modeled within an MBSE tool. After data capture, the views will be constructed and evaluated for usefulness. A simple production line system (PLS) will be modeled with the following attributes:

- Five (5) workstations
- Seven (7) required human resources

Figure 3 is a high-level graphic of the PLS with orders scheduled for input and complete assemblies as output to the customer, workstations, and operator(s) assigned to each station. Note this example is not an optimized manufacturing design.

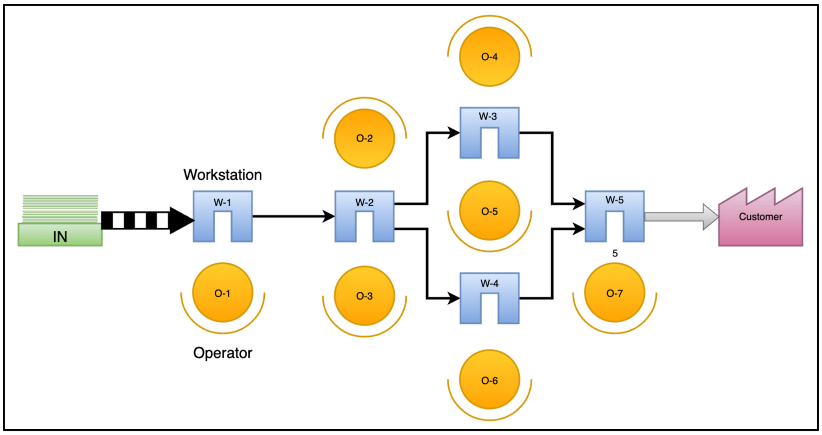


Figure 3: Production line system of interest.

Starting with *Personnel Taxonomy*, *posts* were created for all operational roles shown in Figure 4.

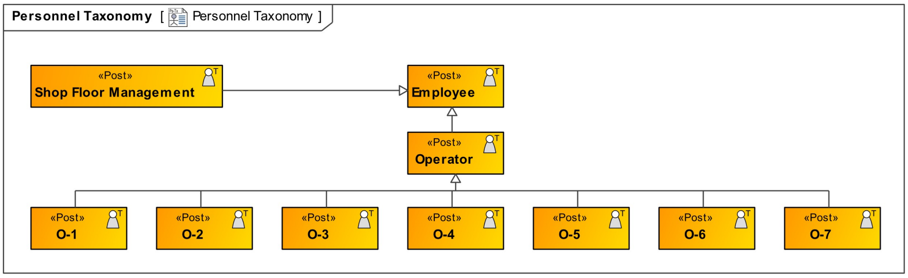


Figure 4: PLS personnel taxonomy diagram.

Competencies necessary for these posts were added to the *Personnel Structure* shown in Figure 5.

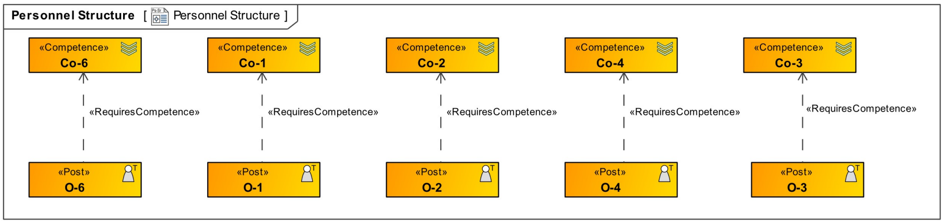


Figure 5: PLS personnel structure diagram.

As shown in Figure 6, a *Personnel Process Flow* diagram was built to demonstrate the functions performed by posts in the PLS and the resource information exchanged between them. Executing this flow within the MBSE tool demonstrates the sequence of events that transpires to transform the inputs to the desired output at a high-level.

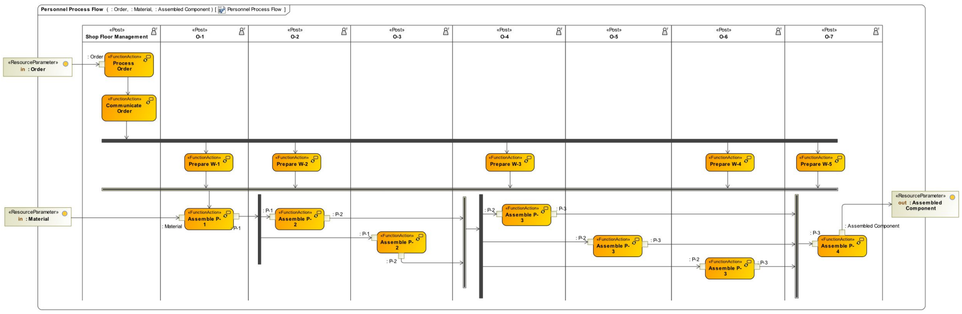


Figure 6: PLS personnel process flow diagram.

The *Personnel* domain states were identified in alignment with the PLS process flow shown in Figure 7.

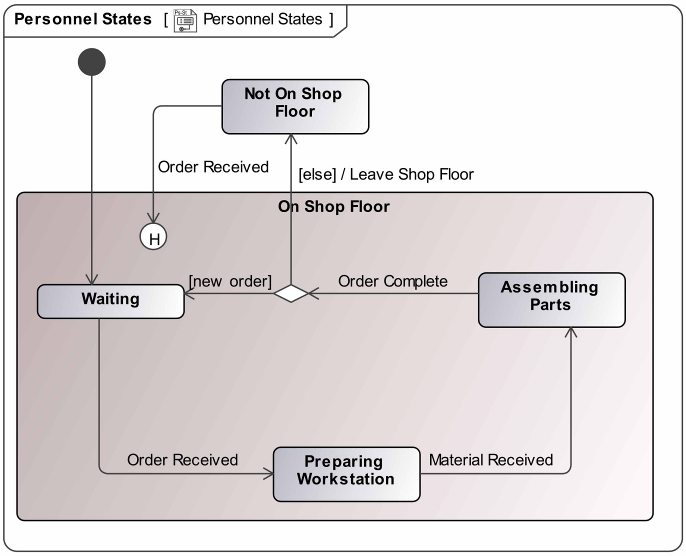


Figure 7: PLS personnel states diagram.

The *Personnel Constraint Definition* diagram can now be produced to realize actual posts and actual persons to fill the posts. Ten alternative operators have been added with dependencies to show the posts each can hold. The actual persons are then allocated to the competencies. A subset of these relationships is shown in Figure 8.

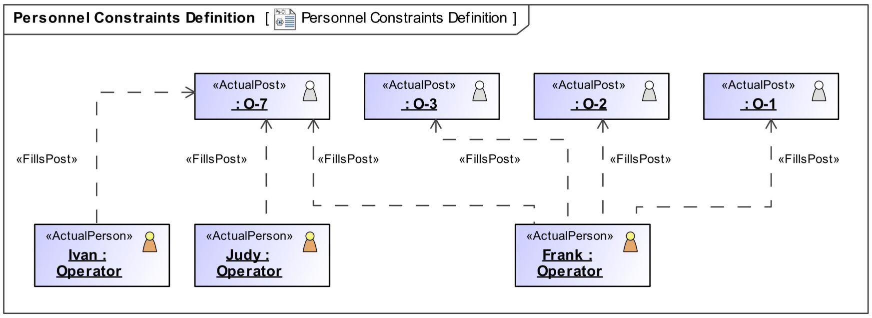


Figure 8: PLS constraint definition diagram.

Within the SE model, traceability is now be shown between the *actual person* model elements acting as operators and their individual competencies shown in Figure 9.

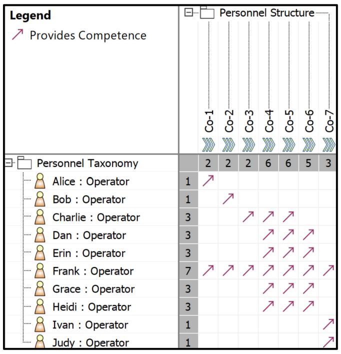


Figure 9: Matrix of operator competencies.

The *Resources* domain defines resources that are required for implementation of successful enterprises [i.e., system-of-systems (SoS)]. Model elements originating in the *Personnel* domain are re-used here to architect human-machine interfaces (HMI).

Table 2. UAF resources domain views.

Resources View	Concern	Purpose
Taxonomy	Resource types	Defines the inheritance hierarchy of resource-level elements
Structure	Resource structure, connectors, and interfaces in a specific context	Defines the SoS structure and physical resources
Connectivity	Interactions between resources	Defines internal resource exchanges of the enterprise
Processes	Capture activity-based behavior and flows	Defines functional flow of resource-level elements
States	Capture state-based behavior of a resource	Defines SoS states
Information	Capture operational, resource, and strategic information for resources	Defines resource-level information exchanged between system-level elements
Parameters	System performance	Defines measurements of resource-level artifacts
Constraints	Define limitations, constraints, and performance parameters for resources	Defines structural or functional resource implementation
Roadmap	Resource structure changes over time	Defines dependencies between resources, resource tasking, and schedules

The workstations that comprise the PLS were added to the *Resource Taxonomy* view as *systems*. The *Resources Structure* diagram realizes a more complete view of the architecture with the consideration of human-in-the-loop in the manufacturing floor context. Figure 10 shows the introduction of relationships forming between the *Personnel* and *Resources* domains. Explicit connections showing resource information exchange items are created between ports owned by organizational resource roles.

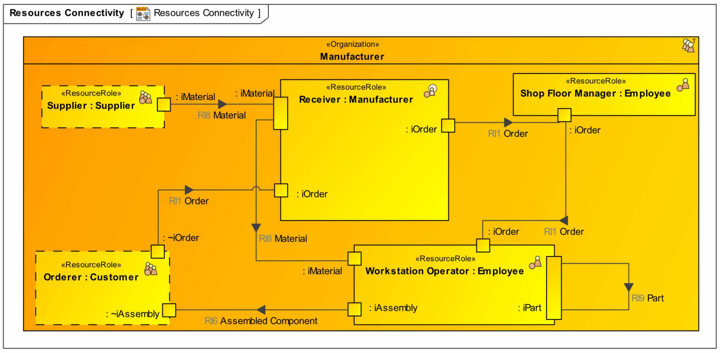


Figure 10: PLS resource connectivity diagram.

RESEARCH RESULTS

The allocated attributes of model elements can be traced to multiple other domains, increasing insight into human resource management. Research question (1) has been answered throughout this paper with the use of *Personnel* and *Resources* domain practices and the resulting views. Figure 11 shows a dependency matrix of relationships between the actual persons, *post* allocations, and assigned competencies within the digital environment. This view shows discrepancies between the allocated operator *posts* assigned to the *actual persons* and the *actual persons* competencies. In this example, Bob should not be responsible for the O3 position since the associated competency is not allocated. Charlie should not be sourced to the O2 position, and instead assigned to either the O3, O4, or O5 stations.

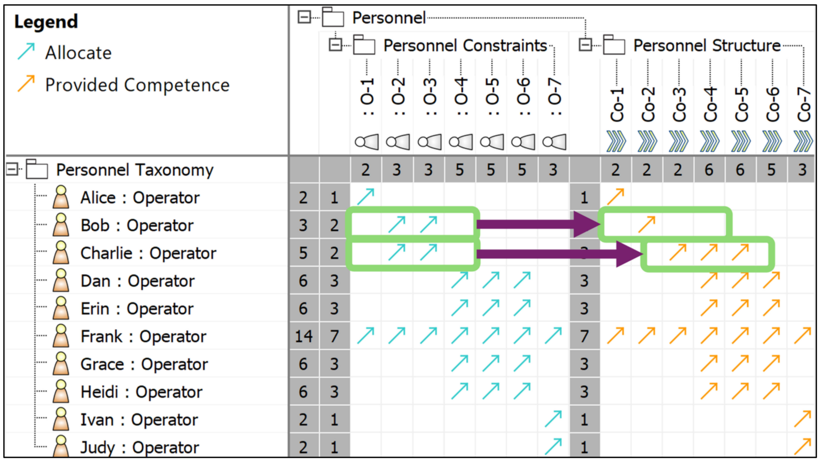


Figure 11: Human operator constraints and competencies.

RESEARCH CONCLUSIONS

Although the PLS is not representative of an enterprise, the common application of UAF, this domain subset of the framework proves to be helpful in capturing information to analyze and improve human-centric designs. By focusing on capabilities and necessary competencies of human resources, transparency is built between management and other types of employees. Structured expressions can be used to query the SE model and ensure performance requirements are being met for human operators. Results from these queries shown in generic dependency matrices within the model assist with providing optimized allocation of human resources.

FUTURE RESEARCH

Additional research for the effects of an SE model with a framework for a human-centric enterprise can build from the initial effort to include, but not limited to, performance requirements, personnel and resource roadmaps, risk, and evaluation of individual persons' competencies. Organizational and societal influences should also be accounted for in future research endeavors.

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