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Task Analysis: A Model Based Human Systems Engineering Approach

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ABSTRACT

Model-Based Systems Engineering (MBSE) utilizes digital modeling to support system design, analysis, and validation throughout the system lifecycle. However, traditional MBSE approaches often overlook critical aspects of human-system interaction. Human Systems Engineering (HSE) addresses these gaps by focusing on human factors, safety, training, and other human-centric elements. Model-Based Human Systems Engineering (MBHSE) integrates these two disciplines, leveraging the strengths of MBSE while incorporating detailed analyses of human tasks and interactions. A key component of MBHSE is the Mission Task Analysis (MTA), a systematic approach to analyze operators interact with systems in specific mission contexts. This paper presents a novel approach to MBHSE that utilizes SysML to conduct and capture MTA data, focusing on enhancing existing MBSE models with detailed human-centered information. The approach demonstrates how a comprehensive MTA can inform system design and improve overall system performance.

Keywords: Human systems integration, Systems engineering, Systems modeling language, Model based systems engineering

INTRODUCTION

Model-Based Systems Engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases (INCOSE, 2007). Human Systems Engineering (HSE) encompasses various elements, including human factors engineering (cognitive workload, ergonomics), safety (hazard analysis, risk mitigation), training (skill development, knowledge transfer), survivability and force protection, habitability, manpower, personnel, and human centered engineering. Traditional MBSE can overlook how operators interact with complex systems, which can lead to designs that are inefficient, unsafe, or difficult to use. MBHSE is the intersection of the two disciplines (Figure 1). MBHSE aims to address the shortfalls of MBSE to adequately include humans.

Model Based Mission Task Analysis

Mission Task Analysis (MTA) systematically analyzes how operators interact with systems within the context of specific mission goals and operational environments. It provides a structured approach to understanding human performance requirements and identifying potential design issues. MTAs have proven successful in a number of previous programs across the DOD.

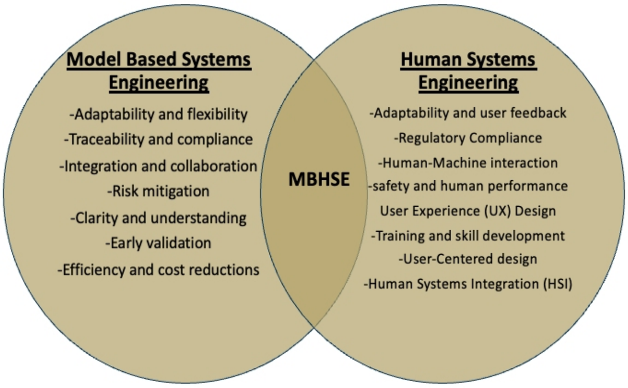

Figure 1: Model based human systems engineering.

Conceptually, MTA operates on three levels, missions, functions, and tasks. At the level of missions, the goal is to identify system requirements that map to human performance requirements. At the level of functions, the goal is to identify and decompose system functions and allocate functions to the operator or the system. At the task level, the goal is to identify specific behaviors, information needs, interaction dynamics and task performance statistics that are needed to assess conformance with requirements and specifications, estimate workload, and Evaluate potential errors. The MTA starts with a thorough assessment of key capability and requirement documents (Figure 2).

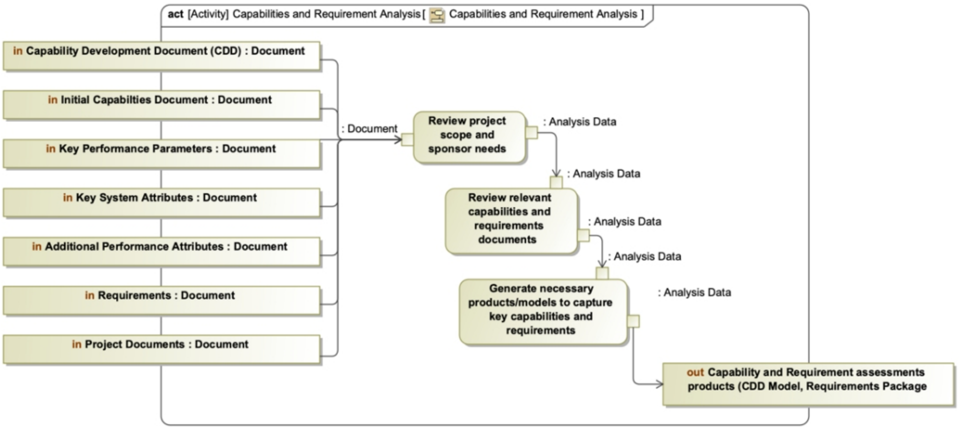

Figure 2: Mission task analysis inputs.

Mission Level Analysis

The primary activity in conducting a mission level analysis is the development of reference scenarios and CONOPs that define the operational context that drives the sequence of user actions and system functions required to achieve mission objectives and sub-objectives. The inputs to the mission level analysis are capability documents, requirement documents, and other appropriate programmatic documents; the outputs are use cases, a Mission Element Matrix (MEM), and design references scenarios or CONOPS (Figure 3). The mission element matrix contains "mission elements" in the rows and references scenarios or CONOPs identifiers in the columns. The MEM defines which mission elements are contained in each scenario and helps ensure full coverage of all mission elements in the analysis (Figure 4).

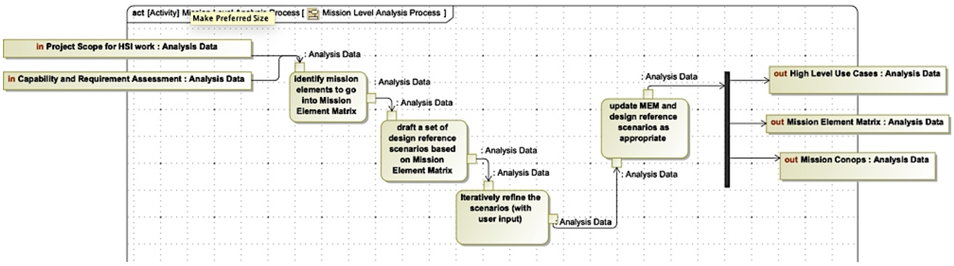

Figure 3: Mission level analysis process.

MISSION ELEMENTS	Scenario Number (TBD)											
	1	2	3	4	5	6	7	8	9	10	11	12
EO/IR												
Radar												
ESM												
SEI												
AIS												
IFF												
Tactics												
Directed by tasking authority; with in flight re-tasking												
At the discretion of aircrew												
Significantly constrained by political standoff												
Communications												
Common Data Links (e.g., Link 16)												
Common Voice Comms (UHF/VHF)												
Failures												
Mission Computers (degraded)												
Communications degradation												
C2 Link Failure												
Sensor system degradation (mission relevant)												
Shot Down / Forced Down / Ditch (with self-destruct) with accelerated launch replacement												
Flight Controls												
Engine Failure w/restart												
Fuel												
Mission Crew Workstation												
Divert to alternate site												

Figure 4: Mission element matrix (MEM).

The design reference scenarios and CONOPs should focus on frequent scenarios, scenarios that significantly stress users or the system, scenarios that significantly impact mission outcomes, failure and exception scenarios, scenarios that include critical functions, scenarios that include new functions, and scenarios that include interactions-of-interest between the user, the system, or external systems (Friedenthal et al., 2014). The reference scenarios will illustrate requirements and capabilities across a broad range of mission elements that include a variety of performance, environmental, mission, and operational conditions. Following the mission level analysis, the function level analysis is completed.

Mission Task Analysis Model

The mission task analysis model uses structural (e.g., blocks), strategic (e.g., UAF capabilities), or other appropriate model elements to represent mission elements and reference scenarios. These elements are then traced to capabilities and requirement documents, requirements, and other task analysis outputs. This provides comprehensive traceability of individual task analysis elements to high-level tactical, operational, and strategic level capabilities, requirements, and other items of interest.

Function Level Analysis

The function level analysis examines the system at the next lower level. The functions are analyzed and operator roles in each function are defined. The inputs to this process are the mission elements, design reference scenarios, and CONOPs; the outputs are a functional analysis and definition, functional decomposition, and functional allocation (Figure 5). The first step in the function analysis is the generation of a list of functions. Sub-functions are identified for each higher-level functional breakout element. Each function is identified and defined operationally. Operational definitions provide consistency, reduce ambiguity and overlap, and are necessary preparations for subsequent operator task analysis activities.

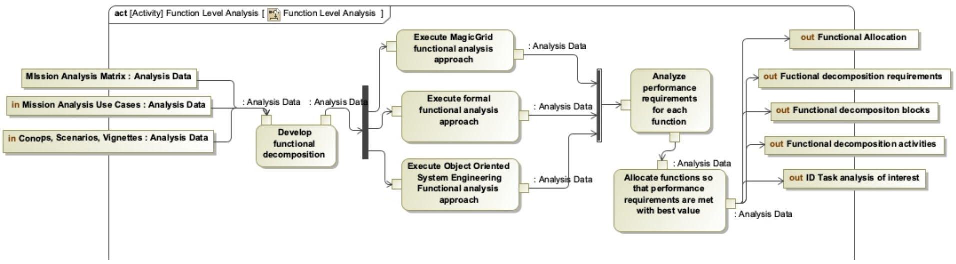

Figure 5: Function level analysis process.

Function allocation is the assignment of the defined system functions. Functions are allocated to software, operators, automation/AI, or to a combination of all three. The process of designating who (i.e., operator) or what (i.e., software or hardware) will perform a given function is a critical engineering activity. On modern systems, allocation of a given function is often dynamic. The function analysis identifies when an allocation should be dynamic in order to achieve an operational goal and identifies the necessary conditions that would allow the system to reallocate the function dynamically, and then return to default allocation states. For example, in an optionally piloted vehicle, the function “maintain situational awareness” could be dynamically allocated between the human pilot and an AI-powered sensor fusion system, depending on factors like visibility, pilot workload, and threat level.

During any function allocation process, designers must have access to a reliable approach for assigning an appropriate level of automation. The most appropriate roles for human and software/hardware components must be determined. A combination of approaches and perspectives are used to categorize autonomous functions: (a) dependency and authority – which agent/operator assumes the lead and which is in support for a specific task (Guyton et al., 2022); (b) information processing implications – this may include variable assignments of different levels of automation to specific functions and states; (c) situational awareness levels – the ability to perceive, understand, and project elements of the operational environment within a given time and space; and; (d) distinctive roles and function characteristics, which dynamically assess roles across goals, intentions, actions, perception, and analysis (O’Neill et al., 2022).

Function Level Analysis Model

The function task analysis model uses activities, activity diagrams, state machine diagrams, block definition diagrams, and traceability matrices to capture the structure, behavior, operational states and modes, and allocation of system functions. There are conventional techniques such as MagicGrid (Aleksandraviciene & Morkevicius, 2021), Object Oriented Systems Engineering Method (INCOSE, 2023; Friedenthal et al., 2014) or other well established systems engineering approaches that can be leveraged to conduct the function level analysis within the MBSE tool.

Task Level Analysis

Following the function level analysis, the task analysis is performed for all functions allocated to human operators and automation. These tasks are analyzed in the context of the system functions the they interact with. The task analysis identifies and describes operator or maintainer tasks associated with each function, with emphasis on tasks related to system operations. Often the list of tasks can be derived directly for the function analysis by adding operator tasks to each lowest-level function. The descriptive component of the task analysis consists of a brief description of operator activities required to perform each specific task.

Table 1: Task analysis categories of interest for identified tasks.

1	General	Mission Function List
1	General	Mission function criticality (Mission specific)
1	General	Decision(s) required to accomplish mission function(s)
2	Information	Information presented (by SS/component)
2	Information	Information/Cues that initiate mission functions
2	Information	Method to gather information required for task
2	Information	Type of information that is gathered

Continued

Table 1: Continued

2	Information	Information available to user
2	Information	L1 Information requirements (data)
2	Information	L2 Information requirements (understanding)
2	Information	L3 Information requirements (prediction)
2	Information	Difference between required/available information
2	Information	Modality information is conveyed
3	Information processing	Information processing (IP): Workload VCAP
3	Information processing	IP: Decision Evaluation Process
4	Task performance	Performance consequences of each task to SSS, overall system, and mission
5	Decision	Possible Decisions that could be reached
5	Decision	Responses to information/cues and combinations of information and cues
5	Decision	Self-initiated Responses
5	Decision	Cues that support decision logic
6	Workspace	Workspace envelop required for all possible actions
6	Workspace	Workspace available
6	Workspace	Location of user within the workspace with relation to task interfaces
6	Workspace	Location/condition of work environment
7	Actions	All possible actions
7	Actions	Frequency
7	Actions	Tolerance/acceptable values (performance)
7	Actions	Feedback
7	Actions	Tools/equipment required
7	Actions	Concurrent tasks and associated workloads/attentional considerations.
7	Actions	Impact of operating and maintaining equipment with PPE
7	Actions	Modality of action to system
7	Actions	Body Movements required to execute task
8	Personnel	# personnel required
8	Personnel	Personnel KSAOs, ranks, ratings, etc.
8	Personnel	Job aids, training, references required and their timely availability (also action)
8	Personnel	Personnel interactions where more than one person is involved
8	Personnel	Performance limits of personnel
8	Personnel	Sense modalities required
9	Error	Consequences and severity of human error
9	Error	Potential for error recovery
9	Error	Errors of omission
9	Error	Errors of commission
10	Communication	Communications required
10	Communication	Type of communication
11	Safety	Hazards involved
11	Safety	Other Safety items of interest
12	System	Operational limits of hardware/software and associated user interfaces

Continued

Table 1: Continued

13	Automation	Levels of automation
13	Automation	Stages of automation
13	Automation	Automation candidate functions
13	Automation	Automation TRLs and HRL compatibility and projections
13	Automation	Data required to support levels of Automation for various L3 info requirements
14	Other	HCI principles/Guidelines
14	HMI	HMI required
14	HMI	HMI Available
14	HMI	HMI Ideal
14	HMI	Control Needs
14	HMI	Display Needs
15	Other	HCI principles/Guidelines

There are various categories of interest related to each task can be investigated depending on the specific research questions of interest (Table 1). Categories include goals, information parameters, information processing parameters, decision parameters, workspace parameters, action parameters, personnel parameters, communication parameters, system parameters, HMI parameters, and automation parameters.

Information requirements are identified for each task. From the static task analysis, we can identify nominal requirements (i.e., statements about what the operator is expected to do). From the design reference scenarios, qualitative (i.e., as least enough for a reference) and quantitative (i.e., with some specified degree of accuracy or precision, or within some defined time period, or above or below some specified threshold) performance requirements are defined. Interviews and stakeholder discussions with experienced personnel may lead to documentation of further information requirements that can be incorporated into the design.

Task Level Analysis Model

Completing the task analysis in the model expands on the function level analysis model completed in the previous step. The inputs to the task analysis are all previously discussed documents and the function level analysis, and when possible, identified and tailored task parameters of interest (Table 1). Figure 6 displays a basic model of tasks allocated to the operator and functions allocated to the system. This is a basic version of a function level analysis output model. Now that operator tasks are assigned in the model, the task analysis model will analyze each task. A SysML block is created with value properties representing the selected task parameters of interest from Table 1.

An instance of this block is created and the analysis is executed and task data is entered through the model instance. MBSE tools allow for a tabular view and manipulation of this data through an instance table which can be exported to excel for non-MBSE consumers of the information. This method allows for traceability across all impacted system elements, communication across stakeholders, and provides a single source of truth (Figure 7). The tabular analysis is augmented by, or augments, additional diagram-based models that support visualizations and modeling of task-related data.

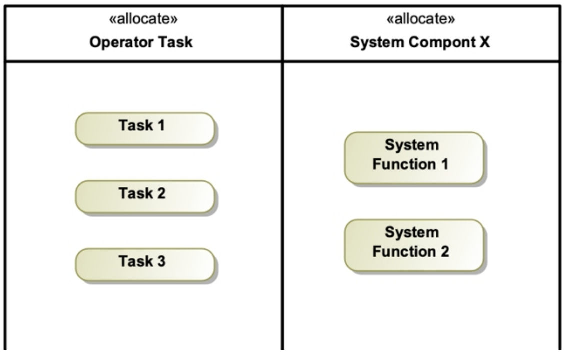

Figure 6: Function level analysis output.

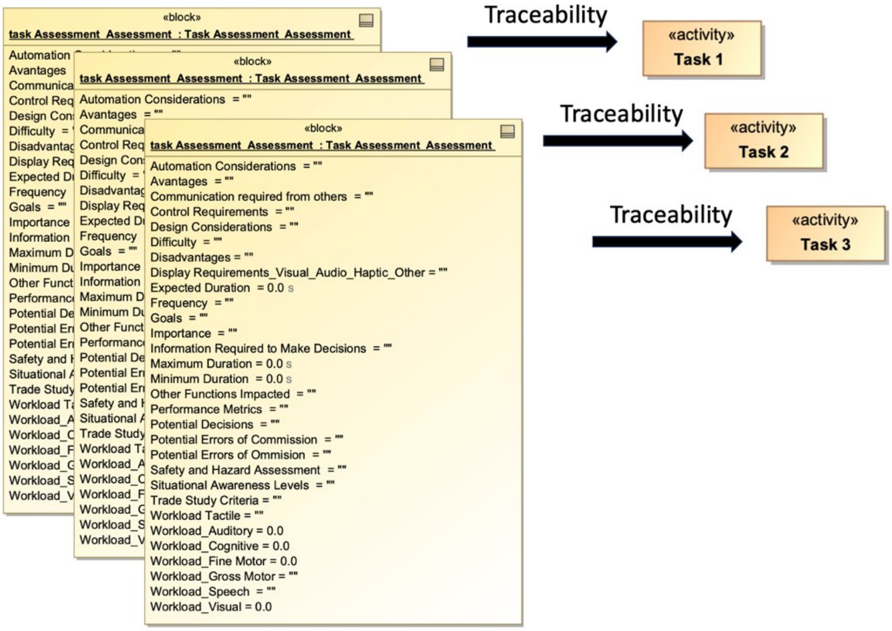

Figure 7: Task instance traced to operator task.

Additional research is often required for automation. Behavioral diagrams including the activity diagram, state machine diagram, and sequence diagram can be used to capture how a task could be performed at various levels of automation (Sheridan & Verplank, 1978). These diagrams can convey human-automation interaction variables of interest such as contextual automation reliability, information delivered by automation, automation confidence rating, automation decisions, level of information aggregation, how automation is calculating or making a conclusion, decisions or recommendations, and level of situational awareness. Figure 8 provides A high-level representation of this. The sequence diagram is used to convey task-related exchanges between the different actors in the exchange.

The approach shown in Figure 8 demonstrates an event in the operational environment triggering the system to make a settings adjustment.

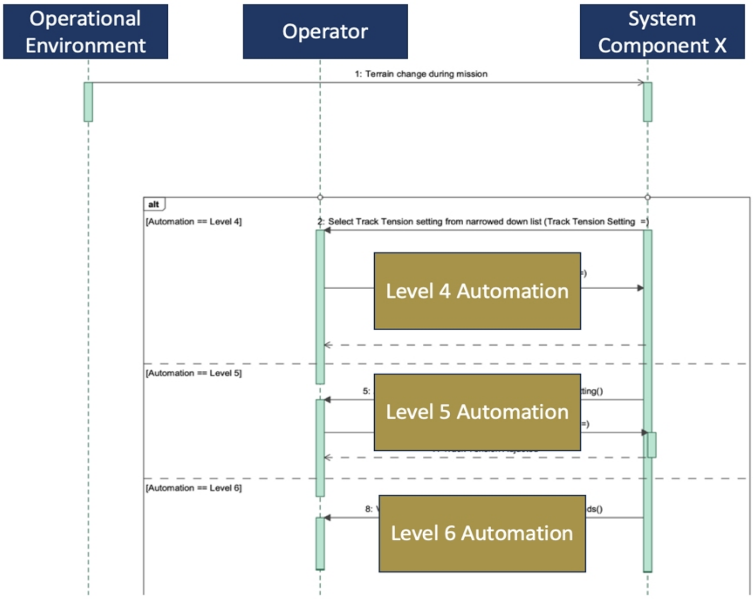

Figure 8: Automation analysis sequence diagram.

The diagram shows the system providing the user with three options at different levels of automation to adjust the same setting. At the level 4 option, the system provides the user a list of two choices, the level 5 automation provides the user a single recommendation, and the level 6 automation gives the user 5 seconds to veto before the system makes the recommended setting adjustment. This information could also be represented into three distinct sequence diagrams for clarity. The human system engineer and MBSE team will ultimately decide on the best approach for modeling specific task-related content. SysML has the capability to provide dynamic configurations and automation models interconnected through different state machine, activities, and sequence diagrams.

CONCLUSION

This paper introduced a novel approach to Model-Based Human Systems Engineering (MBHSE), leveraging SysML to conduct and capture Mission Task Analysis (MTA) data. By integrating detailed human-centered information into existing MBSE models, this method addresses critical gaps in traditional systems engineering practices. The approach demonstrates how a comprehensive MTA can systematically analyze operator-system interactions, informing system design and improving overall performance. This work contributes to the field by structuring how human factors are incorporated into the MBSE process, enhancing traceability, and fostering collaboration among stakeholders. The resulting models enable a more comprehensive understanding of system behavior by accounting for both technical and human elements, ultimately supporting more effective design decisions.

REFERENCES

Aleksandravičienė, A., & Morkevičius, A. (2021). *MagicGrid® Book of Knowledge: A Practical Guide to Systems Modeling using MagicGrid from Dassault Systèmes* (2nd ed.). Kaunas, Lithuania: No Magic, Inc. ISBN: 978-609-454-554-2.

Friedenthal, S., Moore, A., & Steiner, R. (2014). *A practical guide to SysML: The systems modeling language* (3rd ed.). Morgan Kaufmann.

Guyton, Z., Pierson, K., Garay, T., Novitzky, M., McLaughlin, A., Rovira, E. (2022). The Impact of Role Authority and Communication Initiative on HAT Outcomes. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Volume 66, Issue 1.

International Council on Systems Engineering. (2007). MBSE Initiative.

International Council on Systems Engineering. (2023). *INCOSE systems engineering handbook: A guide for system life cycle processes and activities* (5th ed.). John Wiley & Sons.

O'Neill, T. A., McNeese, N. J., Barron, A., & Schelble, B. (2022). Human–autonomy teaming: A review and analysis of the empirical literature. *Human Factors, 64*(5), 904–938.

Sheridan, T. B., & Verplank, W. L. (1978, June 19–21). *Human and computer control of undersea teleoperators* [Paper presentation]. 14th Annual Conference on Manual Control, Cambridge, MA, United States.