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Assessing Human Performance for Model-Based Engineering

PRESENTED BY

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Human Factors
integrating the human with the system

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Summary

The Model Authorized Product Realization (MAP-R) project is designed to characterize and analyze the differences between a traditional drawing-based design and manufacturing process versus a model-based design and manufacturing process.

As part of MAP-R, the Sandia National Laboratories (SNL) Human Factors Engineering (HFE) team was asked to collect and analyze human performance data.

This presentation describes the HFE data collection activities, analyses performed and the results for the MAP-R project and how they can be used to further the understanding of the benefits and challenges of implementing an MBE process for DOE engineering and manufacturing.

Why MBE?

The model-based engineering (MBE) approach uses models rather than documents as the data source for all engineering activities throughout the product life cycle. The core MBE tenet is that models are used to drive all aspects of the product lifecycle and that data is created once and reused by all downstream data consumers.

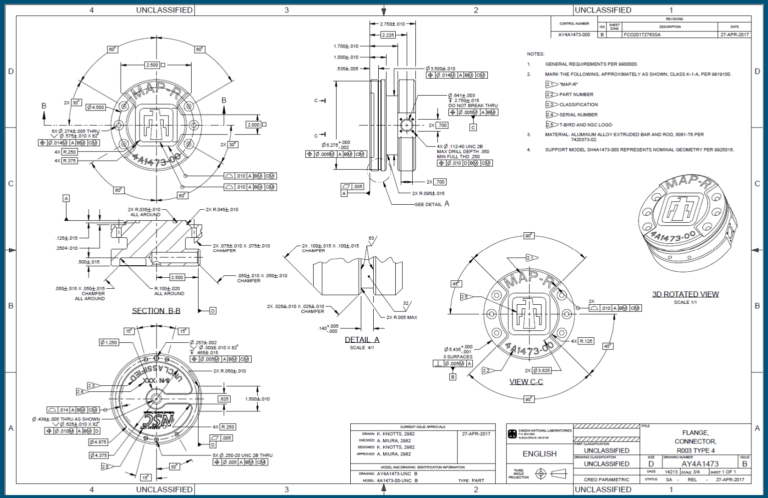
SNL has determined it will pursue the possible integration of an MBE approach for design and manufacturing – why?

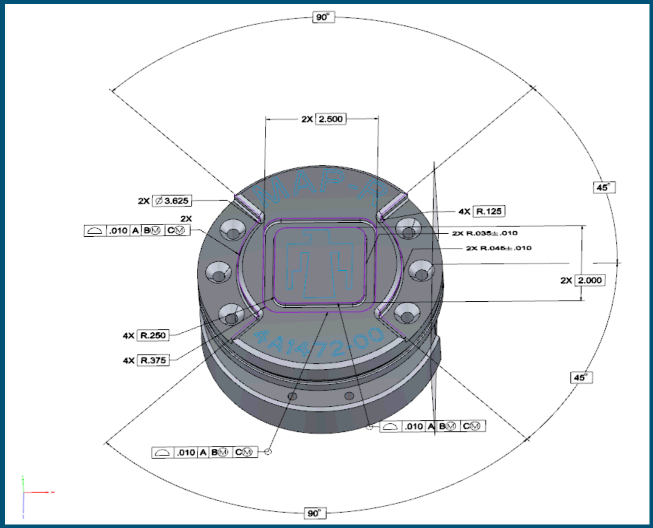
- Imperative need for greater speed, responsiveness, & innovation
- Complexity of the product
- Efficient Application of additive manufacturing
- Unsustainability of 70+ years status-quo of drawing-based practice

The MAP-R Project

The MAP-R project is designed to advance the ability to quantify the differences between the current drawing centric/drawing-based process and a product centric/model-based process

MAP-R will identify the key business benefits of the model-based product centric process using quantifiable data





MAP-R Process

The drawing-based (2D) and model-based (3D) process were compared across the following use cases:

- **Product Definition** – creation of the 3D model, 2D specification drawing, and design data
- **Package for Manufacturing** – assembling all required models and data for manufacturing
- **Manufacturing**
  - Engineering Analysis – creation of manufacturing materials by the contractor
  - Turning – initial computer numerical control (CNC) shaping of the part and simple features
  - Milling – detail CNC of the more complicated features
  - Coordinate Measuring Machine (CMM) – digital measuring of part and feature tolerances
  - Inspection – manufacturers inspection for part quality
- **Quality Assurance Inspection Procedure (QAIP)** – final customer inspection and acceptance of part

MAP-R HFE Analyses

Problem statement: which process (drawing-based vs. model-based) requires more cognitive workload over time?

- Assumption: cognitive workload levels are tied to the use of the reference materials
- Cognitive workload levels can be a predictor of performance (Yerkes, Dodson, 1908; Swain, 1964; Paas, 1992)

Human factors analysis methods used to generate the data for answering the problem statement

- Cognitive Walkthrough
- Ethnographic Analysis
- Workload Analysis
- Situation Awareness Analysis

Cognitive Walkthrough and Ethnographic Analysis

Cognitive Walkthrough

- A cognitive walkthrough is a detailed evaluation procedure that aims to simulate and map an operator's problem solving process at each step of a task (Lewis et al. 1990; Nielsen 1995)
- Cognitive walkthrough allows for understanding of tasks and subtasks, with a focus on the cognitive elements of the tasks performed

Ethnographic Analysis

- Ethnography is the process of collecting data about users or tasks in their normal environment (Fetterman 1998)
- Ethnographic observations are field-based and holistic, in which the analyst observes users and tasks to gain a full understanding of the group being studied
- Onsite ethnographic observations were performed in-situ for the analyzed use cases

Cognitive Walkthrough and Ethnographic Analysis Data

The cognitive walkthrough data and the ethnographic observations resulted in detailed task flows for the analyzed activities

Task/ST#	Sub-Task/MT#	Notes/Micro-Task	Micro-Models
Milling Setup and Cut			
1	Prep milling machine for OP 30		
	1	Attach CNC vice to milling machine	Insert CNC vice to the milling machine part holder
	2	Measure position of vice	Use micrometer to measure the precise location of the vice
	3	Program in position into the vice	Modify program in milling machine interface.
2	Create program to cut jaws for OP30		
	1	Open jaw cutting program in GibbsCAM	Walk to computer, open GibbsCAM and retrieve a old program to modify
	2	Modify jaw program	Use GibbsCAM to modeify old program and create a new one for the part jaws - consulted drawing 3 times. Create 10 dimensions to cut (typing and cross referencing)
3	Create program for OP30		
	1	Import engineering model to GibbsCAM	
	2	Make modifications to OP30 program in GibbsCAM	Align model in program with CNC machine info. Add reference dimensions to model. Review reference drawing 3 times. Review toolset. Add cuts for each tool. Save programs. There are 10 tools.
	3	Design custom tool for OP30	Spec and order tool to be CNC'ed to cut small holes. Which includes calculating features, writing out on paper and walking over to the tool maker
	4	Create OP30 program text file	Output program into a .txt file. Manually modifying .txt to transfer to CNC machine - deleting lines and carriage returns that aren't needed
	5	Transfer OP30 program to CNC machine	Transfer program via memory stick to Wi-Fi computer, then upload it to the CNC machine via Wi-Fi

Workload Analysis

Measuring workload allows for better understanding of the performance demands of given tasks, which improves prediction of operator and system performance (Cain 2007)

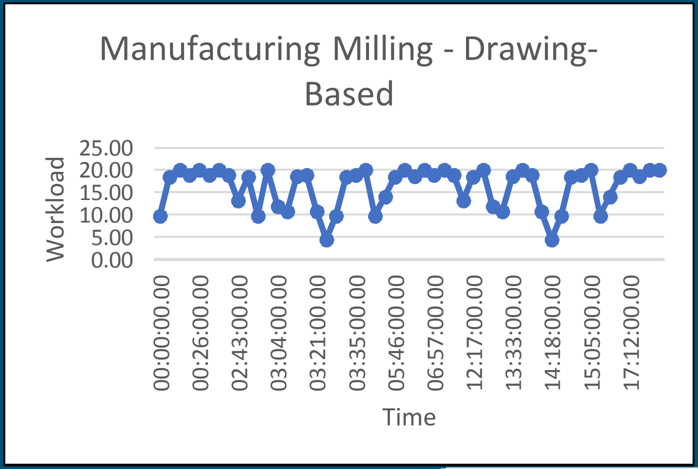
For this project, the mental workload of the engineers and technicians was analyzed using data collected via the cognitive walkthroughs and ethnographic observations to construct workload models, as well as data collected from validated questionnaires

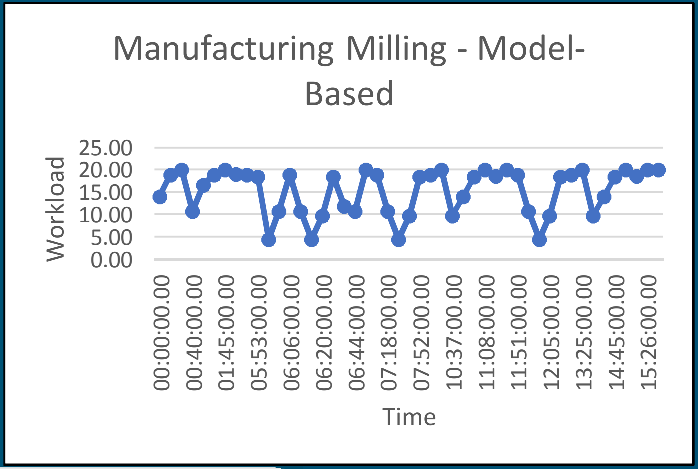
- **Discrete event simulation modeling – multiple resource theory** (Wickens and Yeh, 1986)
- **National Aeronautics and Space Administration (NASA) Task Load Comparison (TLX)** (Hart and Straveland, 1988)

Workload Analysis Data

Workload models

- Data were generated from the models that allowed for comparison of the use cases across processes and thereby answering of the problem statement





Time at Workload Level for Manufacturing Milling – Drawing

Low	Med	High
0-14	15-18	19 - 21
1:33:00	0:00:00	16:22:00

Time at Workload Level for Manufacturing Milling – Model

Low	Med	High
0-14	15-18	19 - 21
1:43:00	0:15:00	13:58:00

Most use cases showed differences in workload levels

Workload Analysis Data

NASA TLX

- NASA TLX data help pin point tasks or process activities where the task performer might be experiencing workload issues
- These results were used for follow up questioning

Milling Drawing			Milling Model	
Demand	**Tally**		**Demand**	**Tally**
Mental Demand	3		Mental Demand	3
Physical Demand	0		Physical Demand	2
Time Demand	4		Time Demand	1
Performance	5		Performance	5
Effort	1		Effort	4
Frustration Level	2		Frustration Level	0
Rating Category	**Task Ratings**		**Rating Category**	**Task Ratings**
MD	20		MD	30
PD	0		PD	30
TD	40		TD	30
PE	30		PE	5
EF	50		EF	25
FR	20		FR	20
Final Score	30.66666667		**Final Score**	20.33333333

No use cases showed significantly high workload levels

Situation Awareness Analysis

At a high level, Situational Awareness (SA) can be understood simply as "what is going on" (Endsley, 1995)

It is generally accepted that more demanding activities (i.e. high workload) will negatively impact the participant's SA of non-critical activities in a specific process. (Selcon and Taylor, 1989; Endsley, 1998; Vidulich, 1992)

The Situation Awareness Rating Technique (SART; Taylor 1989) was administered following either the ethnographic observations or the cognitive walkthrough interviews

Situation Awareness Analysis Data

SA data generated from the SART was used as anecdotal information to support the workload models

Data was used much like the NASA TLX, to identify use cases or activities where the could be workload issues

SART Data for the Manufacturing Milling Process

	Drawing	Model	Questions
Instability (D)	4	1	How unstable is the situation? (high = unstable, low = stable)
Complexity (D)	5	2	How complicated is the situation? (high = complicated, low = uncomplicated)
Variability (D)	3	1	How many variables are changing with the situation? (high = lots of variables, low = few variables)
Arousal (S)	6	5	How alert are you in the situation? (high = alert, low = not alert)
Concentration (S)	6	3	How much are you concentrating on the situation? (high = lots of concentration, low = little concentration
Division (S)	6	5	How much is your attention divided in the situation? (high = more divided, low = less divided)
Mental Capacity (S)	4	5	How much mental capacity do you have to spare in the situation? (high = lots of reserve, low = little reserve)
Information (U)	4	5	How much information have you gained in the situation? (high = lots of information, low = little information)
Familiarity (U)	5	4	How familiar are you with the situation? (high = familiar, low = new to me)
SA (39 to -15)	19	23	Level of SA

Level of SA was fairly high and mostly equivalent across processes

Overall Data

Conclusion – the data collected did demonstrate a sizable difference between the cognitive workload exhibited by task performers between the drawing-based and model-based processes

Total Execution Time	
Drawing-based	Model-based
89:23:14	83:50:11

Time in Low Workload	
Drawing-based	Model-based
19:56:31	18:22:28

Time in Med Workload	
Drawing-based	Model-based
5:24:38	12:08:38

Time in High Workload	
Drawing-based	Model-based
64:02:05	53:19:05

The model-based process demonstrated less cognitive workload over time for the same use cases

Results support the pursuit of an model-based effort over the traditional drawing-based effort for DOE design and manufacturing

Next Steps

Perform more detailed experiment(s) using the reference materials to determine if a statistically significant difference in performance can be observed between the two processes

Analyze the model-based reference material to improve usability

Establish a human performance analysis procedure for future process comparisons

Questions