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Multidimensional Task Analysis (MTA): A New Design Method for Human Factors Practitioners

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In this practice-oriented paper, we describe Multidimensional Task Analysis (MTA). MTA encourages researchers, designers, and evaluators to perform a range of focused task analyses when working with, or toward, a product, process, or system. While some forms of task analysis are well known – e.g., behavioral and cognitive task analysis – MTA suggests that there are many other task analyses that could be performed. Each additional analysis helps the practitioner identify important design constraints and opportunities. As a case-study, we discuss one form of analysis in depth: Emotional Task Analysis (ETA). ETA allows and encourages practitioners to make explicit emotional aspects of a task. We briefly present other new forms of task analysis, including Information Task Analysis, Decision Task Analysis, Attention Task Analysis, and Teamwork Task Analysis. We also suggest a wide range of other forms of task analysis.

INTRODUCTION

One of the important roles that human factors professionals play is helping to discover *design constraints* and *design opportunities*. Whether it is identifying the size to make a chair (*physical constraint*), the frequency to make an alarm (*perceptual constraint)*, or the best way to present information (*cognitive constraint*), human factors experts are there to help. As a profession we have collected a "toolbox" filled with a range of knowledge, tools, approaches, heuristics, and methods. Our toolbox has everything – from anthropometrics to biomechanics, to card-sorting, to task analysis, to usability testing. As a profession we have dozens of tools that can be used to uncover a wide range of constraints and opportunities across a vast range of domains - from simple physical products to highly complex systems and processes.

One of the standard methods we employ is task analysis (TA). TA is, at heart, the systematic decomposition of a high-level task into its constituent parts (or sub-tasks). Variations of this approach are used in domains as diverse as product design, interface design, process design, and training (Shipley, Stephen and Tawfik, 2018). Several authors have traced or discussed the roots of task analysis (Hoffman and Militello, 2008; Militello and Hoffman, 2008).

Task analysis has proved incredibly useful in a wide range of human factors endeavors. A task analysis is typically an important precursor to various other human factors activities: everything from identifying potential risks/hazards to developing better tools/processes, to crafting automation strategies, to creating training programs or instructional/assistive materials.

Early forms of task analysis focused on the *physical* aspects of a task: the steps involved in accomplishing some overall (physical) task. For example, one could perform a task analysis of baking bread or building a brick wall. Later, perhaps fueled by the "cognitive revolution" in psychology, task analyses began to focus more explicitly on *cognitive* aspects of a task – and thus "cognitive task analysis" was born.

Additionally, many of the task analyses we perform are aimed at the decomposition of a main task into smaller tasks that might then be further broken down into smaller tasks. This approach is known as hierarchical task analysis (HTA) and it is a descriptor that cuts across other forms of task analysis. Practitioner could do a hierarchical physical/behavioral task analysis or a hierarchical cognitive task analysis, etc.

Physical and cognitive task analyses have served as important methodologies for decades. However, there are numerous other forms of task analyses that can serve valuable roles in the human factors toolkit. Here we present a broader framework and method: Multidimensional Task Analysis (MTA). MTA can, from our perspective, include or subsume all other forms of task analysis. And, additionally, MTA empowers the practitioner by expanding the range of possible task-analyses they might perform at any point in their research, development, or assessment project. Here we lay out our MTA framework and briefly discuss several of the TAs possible within MTA - including an in-depth presentation of our method of Emotional Task Analysis (ETA).

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PRACTICE INNOVATION

The MTA framework highlights and urges on the broad and open nature of task analysis. At the same time, the term is meant to connote something like a "layers" approach like that used in modern mapping software (see Figure 1).

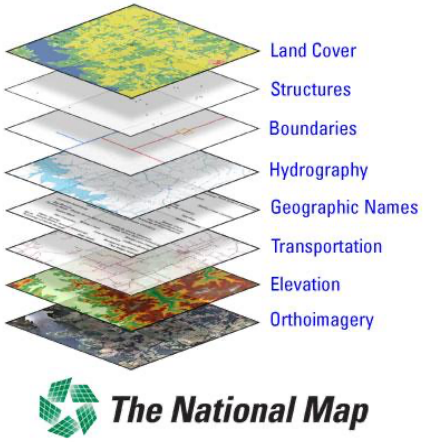

Figure 1 – Example map layers (U.S. Geological Survey, 2012)

If looking at a modern online map, one can choose to show or hide many different layers: topography, buildings, streets, traffic, weather, income levels, temperature, rainfall, sunlight, etc. Similarly, in multidimensional task analysis (MTA), one can choose which dimensions (layers) to analyze. And, the different dimensions can add valuable insights to (and help elucidate constraints and opportunities in) any design challenge.

In each of the various forms of task analysis discussed below, the human factors professional begins by decomposing the task into steps (as small as required). These steps might be more in the physical domain or in the cognitive domain – in some sense the traditional forms of task analysis (physical and cognitive) are akin to the "basemap" used in mapping systems. The other layers (dimensions) can be added atop the base map. Shortly we will describe many new task analyses (or layers) and how/when they might be selected. But, we begin with a presentation of Emotional Task Analysis (ETA) as an example of how such dimensions might be analyzed and used to inform subsequent activities. Although we have been using and presenting ETA for over four years in our teaching and presentations, it is worth noting that another form of ETA was independently developed by Crowson et al (2020).

Emotional Task Analysis (ETA) After performing a traditional task analysis (PTA or CTA), you then identify any emotions that might be evoked (or desired) during (or before/after) each step. For example, for a system to onboard a new user, there will be several steps where the new user might feel uncertain ("start date?"), confused ("role?"), suspicious ("social security number?"), or happily surprised ("welcome aboard – look for your prize"). Once these emotions are mapped they become important constraints/opportunities for the designer. For example, the designer might want to add features (information, icons, sounds, or other mechanisms) to either alleviate these emotions, such as the various trust icons used on websites, or to accentuate them, such as text alerts that congratulate you for creating an account. The world of behavioral economics and nudge theory has a raft of potential design solutions that can then come into play, once the emotional landscape is explicitly mapped.

While this approach is clearly important for designing tools and systems like websites (particularly commercial ones), it plays perhaps an even larger role in the realm of social robotics. For example, if designing a "social robot" to assist with home healthcare, an emotional task analysis is vital. It might reveal, for example, that when the robot attempts to wake a client, the patient might be confused or upset. This additional design constraint/opportunity might lead the designer to have the robot say or do something to increase calm and trust. Or, if the robot is working with a patient who has mild cognitive impairment, the designer might need to acknowledge the near constant confusion and add requirements to design features that moderate every action. Perhaps the robot should play music? Or perhaps the robot should have a face that can be used to convey emotional states more rapidly?

In a class at Tufts University (ENP162: Human-Machine System Design), students use emotional task analysis (ETA) to design a social robot. One student, Mikayla Rose, used ETA to help inform the design of a shopping-assistant robot (S3: Sally the Shopping Sidekick). Figure 2 shows a portion of her ETA. The white boxes are user actions/inputs, blue boxes are from the behavioral task analysis (BTA), purple boxes are from the decisional task analysis (DTA - see below), and yellow boxes are from the ETA.

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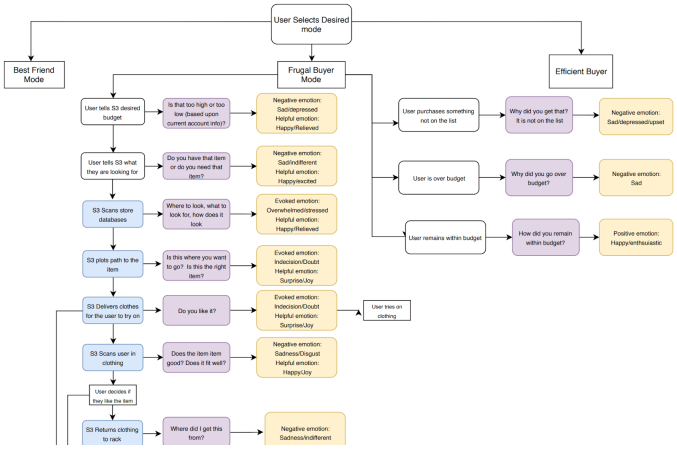

Figure 2 – A portion of an Emotional Task Analysis (ETA) created by Mikayla Rose.

The student uncovered numerous emotional constraints/opportunities to inform the robot design. This student (a dual major in Human Factors Engineering and Studio Art) even crafted an icon set (Figure 3) that could be used to achieve the design constraints (faces to evoke desired emotions) revealed by her ETA.

Figure 3 – Faces to address constraints revealed by the Emotional Task Analysis (ETA) in Figure 2. Images created by Mikayla Rose.

Each year students in this class design about a dozen different social robots that are deeply informed by ETA. Some recently designed systems include:

- "Driver's EDward" – a social robot that teaches student drivers and makes their learning less stressful
- "Wheely" – a social robot that helps wheelchair users have a more enjoyable (and safe/informed) journey
- "Arthur" – a social robot designed to help children on the Autism-Asperger spectrum to develop stronger social skills
- "Jumbo" – a social robot tour guide for Tufts University campus visitors.

In all these cases, clearly the end-user of the system will potentially experience a range of emotions as they go through their primary tasks (learning to drive, using a wheelchair, interacting in groups, or taking a tour). In all cases, the designers completed standard hierarchical task analyses (behavioral and cognitive) and then completed an emotional task analysis to ensure that the designed system met the emotional needs of the end-users. Note: at this point most of our ETAs have been based on introspection, interviews, and empathy. One could, of course, move to more quantitative methods.

Other Types of Task Analysis

As noted above, MTA is a framework/method that can encompass and encourage a wide range of task analyses. In some sense most of us have already been practicing a very low-dimensional form of MTA where we have been examining only two dimensions (physical and cognitive). There is a vast number of other task analyses that a human factors professional might reasonably perform. Each of these may bring to the forefront (and make explicit) a different dimension of an overall task. The advantage of this approach is in that it makes these other dimensions/layers explicit and forces the practitioner to focus exclusively on this one aspect of the task. Some examples should help clarify this approach.

Decisional Task Analysis (DTA). After performing a traditional cognitive task analysis, one might identify any decisions required during (or before/after) each step. The output of such a DTA would be an MTA "layer" of decisional space showing who, what, where, why, when, and how different kinds of decisions need to be made. While cognitive task analyses typically include such data, it is often buried within the minutia of the overall analysis. When one performs a DTA all the decision points become explicit. It then is much easier to identify challenges and opportunities (e.g. for decision-assist tools - c.f. Baxter et al, 2005) in the overall task flow. It is worth noting that such decision-assist tools might incorporate expert-system or machine-learning-based algorithms. In fact, we have found DTA to be a very useful method in designing human-machine systems that incorporate machine-learning (ML) in meaningful ways. For example, the designers of systems like Amazon and

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Spotify have identified moments of decision (product choice or song choice),and they now help users make these decisions more easily by using a range of ML decision support tools. Many of our students have used DTA to evaluate and iterate on commercial websites: identifying the numerous and specific moments-of-decision the customer faces, analyzing them, and developing innovations to guide customers through the decision space.

Informational Task Analysis (ITA). In an ITA the HFE practitioner identifies where information is created, transformed, transmitted, or used to some end. For example, often information is essential when making a decision – hence one reason ITA often accompanies a DTA. But, other human-machine systems might also benefit from creating a separate layer or map of how information "works" in the system. A variant and extension of DTA and ITA is our method of Dynamic Information Needs Analysis (DINA) – see Zamen, Drake, et al (2021) and Zamen, Roeca, et al (2021).

Attentional Task Analysis (ATA). In an ATA you identify where attention might be required to perform aspects of the task. For example, when driving a car, if it is time to take an exit ramp, you know the driver *should* have their attention directed towards the off-ramp. Or, when checking their blind spot, the driver's attention (and vision!) should likely be aimed at a mirror or camera display. Once the attentional distribution constraints/opportunities are understood, various options are available to the designer. For example, perhaps the overall process should be redesigned to re-allocate attention more appropriately. Or, perhaps attention should be strategically guided/deployed to make task accomplishment more likely. We are currently investigating the use of subtle spatialized audio cues in cars to orchestrate and direct attention during task performance.

Teamwork Task Analysis (TTA). After performing a traditional task analysis, you identify where teaming is an important aspect of the overall task performance. These moments of teamwork can then be analyzed (Who leads? Who follows? Who is responsible for what?) and new design constraints/opportunities will emerge to inform the overall system design.

Other Task Analyses. Some of the other forms, or dimensions, of task analysis that we have found valuable include dimensions taken from the world of marketing (e.g. brand task analysis, conversion task analysis, messaging task analysis, experience task analysis) or from the world of business (cost task analysis, profit task analysis, cooperation task analysis, innovation task analysis, or added-value task analysis). Six other dimensions we have found useful are those sometimes abbreviated through the acronym PESTEL – Political, Economic, Societal, Technical, Environmental, and Legal task analyses.

There are nearly limitless forms of task analysis waiting to be discovered and used by the modern human factors professional. Of course, the specific methods required to fully elucidate any of these task analyses still need deeper specification and expansion: Where do we get the qualitative and quantitative data to support a detailed analysis? What tools can help us understand these dimensions? It is our hope that over time others will develop additional methods to help professionals perform the task analysis variants they require.

FINDINGS

The myriad of task analysis varieties that we include under the umbrella of Multidimensional Task Analysis have proven useful across a wide range of design challenges. We have used these approaches for systems ranging from websites to store design, to social robots, to automotive displays, to workplace interventions, to marketing campaigns.

DISCUSSION

Multidimensional task analysis – as a framework and as a methodological and philosophical approach – is a very useful extension of traditional forms of task analysis (physical and cognitive). Here we demonstrated the broader concept of multidimensional task analysis through a discussion of emotional task analysis. Of course, all these new types of task analysis are not a radical departure from traditional forms of task analysis. However, the *explicit* focus on important dimensions of a task (or even a system, more broadly) allows us to reveal specific, explicit, and novel constraints and opportunities. We have found that this approach allows for more focused design and seems to nurture creative innovations that otherwise might have been hidden within the broad remit of traditional forms of task analysis.

PRACTITIONER TAKE-AWAYS

Multidimensional task analysis can provide insights into design constraints and opportunities that are not available by other methods.

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● **Traditional forms of task analysis often merge multiple dimensions**. When human factors professionals perform "overall" task analyses, often the information needs, decision points, emotions (evoked or desired), collaboration, social impacts, legal constraints, and dozens of other dimensions get either ignored altogether, left implicit and vague, or just merged together into a generic high-level analysis.

● **Focusing on individual dimensions can reveal new constraints and opportunities.** If human factors professionals identify important/relevant dimensions of interest, they can then perform far more focused task analyses.

● **Task analysis can be focused and re-focused to allow for greater exploration discoveries.** One need not be locked into any particular set of dimensions. Why focus or limit our research into the purely physical or cognitive aspects of a task? Rather, the human factors practitioner should be free and empowered through multidimensional task analysis. A new dimension might well be waiting just around the corner – and this new dimension, when analyzed deeply and systematically, might help reveal fundamental and important insights, constraints, and opportunities for design and innovation.

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