Human-Automation Allocations for Current Robotic Space Operations

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Motivation

Future human space exploration missions will shift the manner in which space operations are conducted. These missions will have one or more of these new operational constraints:

- Fewer crewmembers,
- Longer duration missions,
- Limited Earth-return opportunities,
- Variant, intermittent communication delays,
- Crew autonomy with limited ground support.

In order to support these missions, NASA must build upon and go beyond its existing human spaceflight operational experience, which has heavily relied on ground control support. NASA will have to develop and infuse new *automation and robotic technology* into safety-critical areas in order to enable these exploration-class missions.

The Risk of Inadequate Design of Human and Automation/Robotic Integration (HARI) aims at conducting research to support successful human-systems performance with complex automation and robotic systems. Successful crew performance significantly depends on the correct allocation between human, automation, and/or robotics. Thus, NASA needs methods and guidelines for identifying human-automation/robot task information needs, function allocation, and team composition for future long duration, long distance space missions. An initial step is to achieve this is to **assess the current state-of-the-practice of existing function allocation methods at NASA** and their extensibility for future mixed-agent HAR systems.

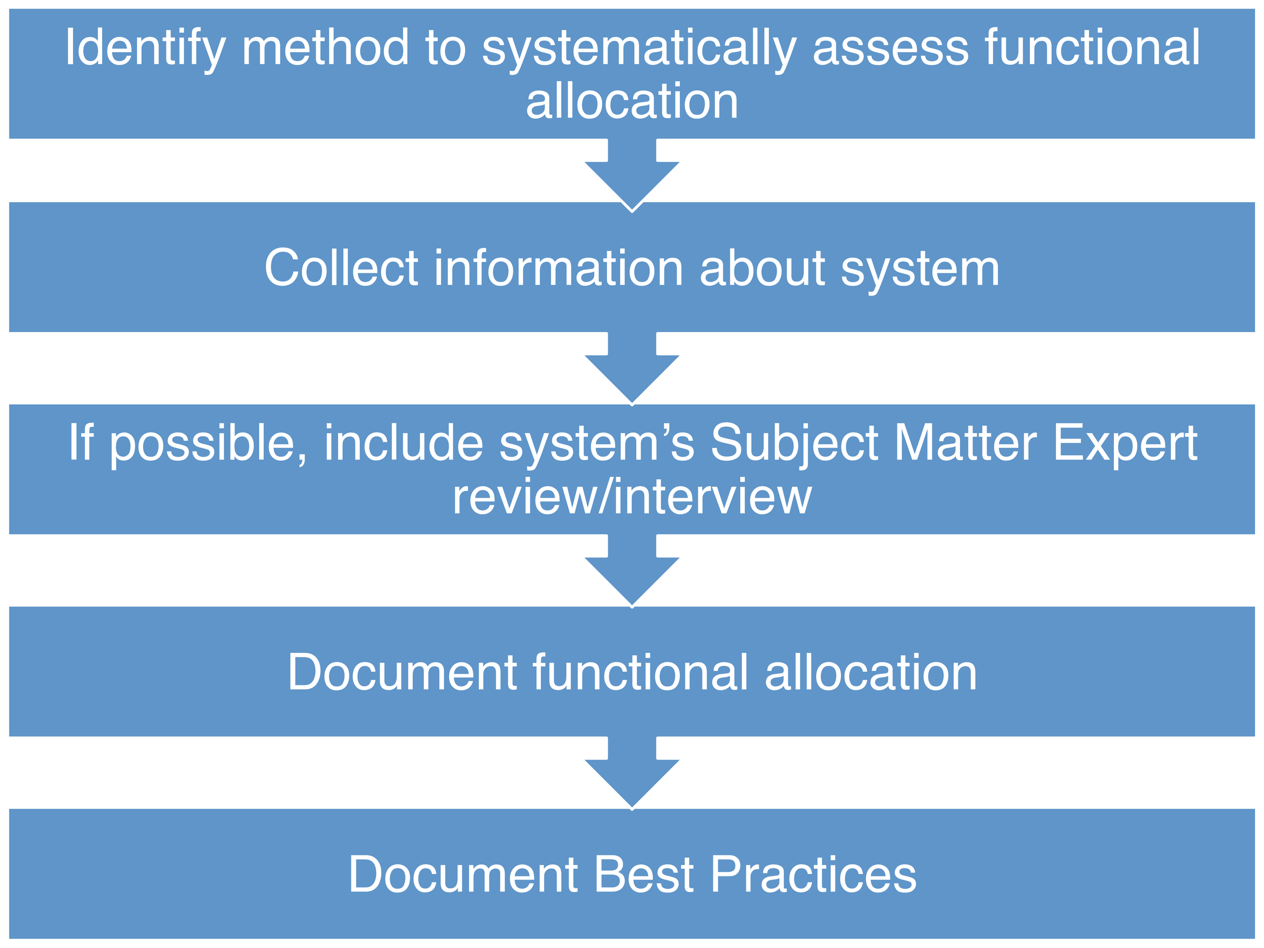
Objective

This project's objective is to provide Human Factors and Behavioral Performance (HFBP) a systematic documentation of human-automation-robotic allocations in existing, operational spaceflight systems, specifically robotic arm and robotic explorers rover systems. This was completed by gathering existing practices and/or standards in these role assignments, from spaceflight operational experience of crew and ground teams that may be used to guide standards development for future systems.

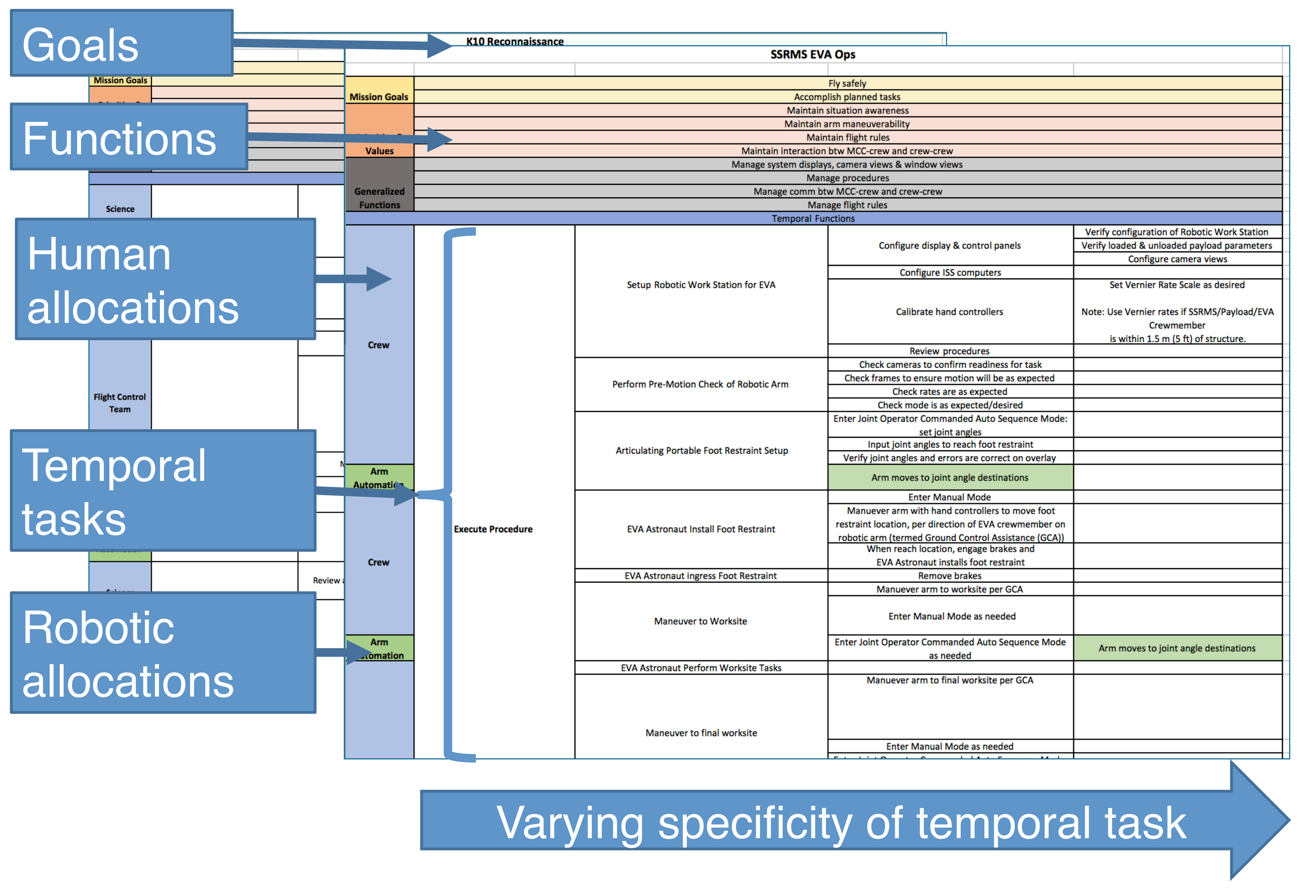
The **robotic systems** selected are those that are currently used in spaceflight operations:

- Heavy-Lift Robotic Arms
  - Space Station Robotic Manipulator System (SSRMS) & Japanese Robotic Manipulator System (JRMS)
  - European Robotic Arm (ERA) [*not operational in space*]
- Robotic Exploring Rovers
  - Mars Exploration Rovers (MER) & Mars Science Laboratory (MSL)
  - K-10 Rovers [*not operational in space*]

Methodology



Assessing Functional Allocations



Hierarchical Task Analysis + Pritchett, Kim, & Feigh (2013, 2014) functional allocation framework, including: temporal functions, actions, parent generalized function, priorities/values, mission goals, strategy, resources, and decision & time scale.

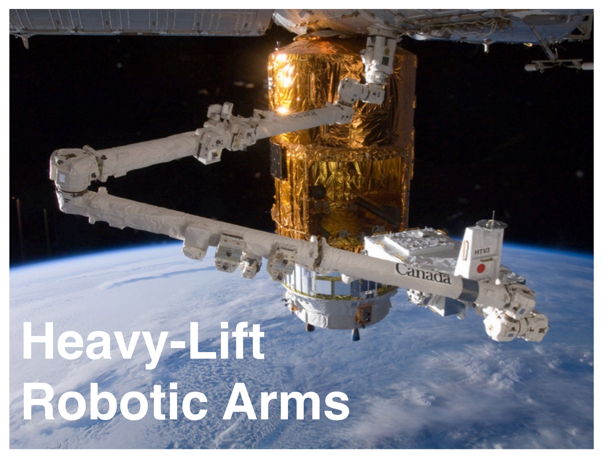
Documented Functional Allocations

Summaries of Japanese Robotic Manipulator System and European Robotic Arm based on literature review. With sufficient data (literature, access to operators, review with SMEs), several Hierarchical Task Analyses developed:

- SSRMS (2): visiting vehicle/free-flyer ops & EVA ops
- MER (1): Mars exploration operations
- MSL (1): Mars exploration operations
- K10 (2): reconnaissance ops & follow up ops

Pritchett, A. R., Kim, S. Y., & Feigh, K. M. (2013). Measuring human-automation function allocation. Journal of Cognitive Engineering and Decision Making, 1555343413490166.
Pritchett, A. R., Kim, S. Y., & Feigh, K. M. (2014). Modeling human–automation function allocation. Journal of Cognitive Engineering and Decision Making, 8(1), 33-51.

Operational Spaceflight Robotic Systems



Functional Allocation Practices at NASA

- How were allocation decisions made in the early stage of design of the human-machine system?
  - Surprisingly, little evidence found on how allocation decisions were made for the systems assessed.
  - Did not identify a method of evaluation, though that is not to say analysis was not completed (just wasn't documented).
- Were effects on human performance considered or taken into account during function allocation?
  - Did not identify if any of the robotic systems completed sensitivity analysis with regards to allocation decisions, if these decisions were sensitive to safety and/or reliability of system, nor if these allocation decisions were done for individual functions or as a whole.
  - There is **significant** amount (most) of task allocation assigned to human operators. Tasks assigned to crew (for SSRMS) seems adequate. High reliance on ground.
  - Did not capture all the planning that occurs before execution, which **heavily relies** on a team ground operators.
- Are there any recommendations that may improve effective operation of integrated human-machine systems?
  - Once function allocations are determined, robotic systems are not flexible enough to change to different (better) allocation decisions between humans and systems.
  - K10 is a successful case study that allows investigating and assessing varying human-robotic allocations.
  - Focusing on improving planning phase of human-robot task execution might be fruitful as operators spend significant amount of effort here.

Conclusions

NASA needs a systematic method to evaluate functional allocation of human-automation-robotic tasks. When automation/robotic systems are being designed and built, NASA should consider and evaluate the impact on crew performance based on task function allocation. In lieu of flexible systems, different human-automation-robotic function allocations can be evaluated in prototype, research test beds.

Acknowledgements

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