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**IMPACT 1.0—Task Impairment: A Novel Approach for Assessing Impairment during Exploration-Class Missions**

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**Abstract**

Exploration-class and International Space Station (ISS) missions have significantly different levels of associated medical risk for crewmembers. The Integrated Medical Model (IMM), the probabilistic risk assessment tool used for ISS medical trade-space analyses, uses a Functional Impairment (FI) metric to determine quality time lost should a crewmember be afflicted with a medical condition. While IMM-based FI has been successful for ISS operations, it has limitations when applied to exploration-class missions. As the National Aeronautics and Space Administration (NASA) looks ahead to Gateway, Artemis, and Martian missions, a novel, dynamic, and mission-appropriate impairment paradigm is necessary for accurate contingency planning. This paradigm, Task Impairment (TI), fulfills that need by utilizing mission-specific tasks. TI will allow future capability for a loss of mission metric, previously not available with IMM. TI serves as a replacement metric for FI within IMPACT, the next-generation trade-space analysis tool suite created to replace the IMM. IMPACT significantly increases the fidelity of probabilistic risk assessment for exploration-class missions. The Human Exploration of Mars Preliminary List of Crew Tasks (MTL, a source of 1100+ exploration-class mission-specific tasks for crewmembers) was used to calculate TI. Using the Task List, 18 individual Human System Categories were identified as being required to perform each task (e.g., Cardiopulmonary, Cognitive, etc.). Each of the 1200+ tasks were mapped to the Human System categories listed in the Task List. The total number of tasks in each category were tallied to determine how many tasks required each Human System. Lastly, each of the 120 medical conditions from the IMPACT condition list were mapped to the Human System categories to complete the TI calculation. NASA subject matter experts across five medical specialties established consensus for the mapping of each condition. The resulting total tasks impaired by each condition were used to calculate discrete TI values. This process was repeated for each of the four severity/resource utilization variants of each condition, and for each of the three phases of clinical care. Through this process, discrete TI values were calculated for each of the 120 IMPACT medical conditions and their variants. The Task Impairment metric provides higher fidelity, dynamic utility, and quicker analysis of medical impairment compared to the previous Functional Impairment metric used for the Integrated Medical Model. TI will be used for higher fidelity medical impairment analysis and contingency planning during Lunar, Martian, and other long-term exploration-class missions. **Keywords:** task impairment, IMPACT, exploration-class mission, functional impairment

**Acronyms/Abbreviations**

NASA—National Aeronautics and Space Administration

ISS—International Space Station

IMM—Integrated Medical Model

FI—Functional Impairment

TI—Task Impairment

AMA—American Medical Association

ADLs—Activities of Daily Living

ICL—IMPACT 1.0 Condition List

IMPACT—Informing Mission Planning via Analysis of Complex Tradespaces

CP—Clinical Phase

BC—Best Case

WC—Worst Case

Tx—Treated

Utx—Untreated

MTL—Mars Task List

HSTC—Human Systems Task Category

CTT—Condition Task Total

TMT—Total Mission Tasks

**1. Introduction**

With the advancement of spaceflight since the early 1960s, humanity has strived to make space travel as safe as possible. Despite the various technological improvements in launch, flight, and landing systems, the human system has remained relatively unchanged. Space agencies can select the healthiest possible spaceflight candidates and train them exceptionally well, however, the human system is dynamic and the risk of medical conditions occurring in spaceflight will always exist [1].

Over the course of spaceflight history, crewmembers have developed a range of medical conditions (Table 1).

Table 1. Example medical conditions which have arisen during spaceflight [1].

|  |  |  |
| --- | --- | --- |
| Date | Mission | Description |
| 12/1972 | Apollo 17 | Back strain |
| 8/1976 | Soyuz 21/Salyut 5 | Crewmember illness—related to environmental control systems problem |
| 11/1982 | Salyut 7 | Acute abdominal pain, probable kidney stone |
| 9/1985 | Soyuz T-13 | Hypothermia and CO2 Toxicity |
| 11/1985 | Salyut 7 | Prostatitis and urosepsis |
| 1987 | Mir 2 | Persistent tachydysrhythmia |
| 1995 | Mir 18 | Traumatic eye injury resolved with onboard treatment |

These conditions ranged in severity, and as such required varying amounts of on-board resources. As crewmembers develop medical conditions, their productivity and ability to perform mission tasks decreases. Simultaneously, ill crewmembers increase medical resource utilization [2].

With the introduction of orbital space stations, long-duration missions in microgravity increased in frequency. Long-duration missions have a different medical risk profile compared to short-duration missions. To help quantify this risk, NASA created the Integrated Medical Model (IMM).

*1.1 The Integrated Medical Model*

The IMM is a Monte Carlo simulation-based tool specifically designed to quantify the probability of medical risks and potential consequences astronauts could experience during a mission. It uses dozens of variables as inputs into its algorithms, including mission type, mission duration, crew complement, and crew medical history, among others. The IMM was validated on several occasions and has been used extensively by NASA and their flight surgeons/engineers to build relevant medical systems for the International Space Station (ISS) [2].

The primary purpose of the IMM is to quantify medical risk specifically during ISS-based missions. For this purpose, it has proven immensely successful. However, while the IMM excels at its primary purpose, extending its use to exploration-class missions highlights several limitations. The IMM determines functional impairment (FI) through the utilization of the *American Medical Association* (AMA) *Guides to the Evaluation of Permanent Impairment, Sixth Edition* [3]. While these guides are useful for terrestrial applications, in microgravity they present several shortcomings, which in turn reduce the fidelity of the IMM for exploration-class missions. The AMA Guides utilize terrestrial activities of daily living (ADLs) to determine relevant functional impairment; ADLs in microgravity are categorically different from terrestrial ADLs. Daily activities during exploration-class missions are of a significantly higher complexity. Additionally, the AMA Guides are static, preventing real-time changes in functional impairment assessment based on changing mission parameters or objectives. Lastly, the AMA Guides assume permanent impairment; this is not useful for short-duration medical conditions (e.g. tension-type headache), which while not permanent, still confer some level of functional impairment [4].

Despite the limitations of the AMA Guides, as mentioned previously, the IMM has functioned exceptionally well for ISS-based missions. As human spaceflight continues to advance, NASA is now planning both crewed Lunar (Artemis) and Martian missions. These exploration-class missions carry a medical risk profile which is entirely different than ISS-based mission medical risk, necessitating a new probabilistic medical risk quantification tool. This new tool needs to improve upon the limitations of the IMM for exploration-class missions, and utilize a higher-fidelity method for determining functional impairment. These improvements will lead to better medical risk assessment, medical system development, flight rule development, and mission success.

*1.2 Informing Mission Planning via Analysis of Complex Tradespaces*

IMPACT is a novel tool suite being developed by NASA which includes next-generation probabilistic risk assessment capabilities to conduct evaluations of human health and performance system options, inform research prioritization, and provide trade study support, all based on evidence, risks, and systems engineering principles [5]. This tool suite can be used to better calculate medical risk for exploration-class missions. A critical component of IMPACT is the ability to determine functional impairment from potential medical conditions which may arise during exploration-class missions. IMPACT is addressing this need with a novel approach to functional impairment.

*1.3 Existing Approaches to Functional Impairment*

Aside from the AMA Guides, several other tools exist for assessment of functional impairment. The *Walter Reed Functional Impairment Scale* and *Veterans Affairs Disability Rating for Anxiety and Depression* are both American military-based tools for assessing FI, and have similar limitations as the AMA Guides [6,7]. The *Guide to Determining Impairment and Compensation* is another effective terrestrial tool for FI determination, developed by the Australian military. Unfortunately, it too has similar limitations as the AMA Guides. The *Global Assessment of Functioning Tool* assesses functional impairment strictly from a mental illness perspective; while useful for that realm of medicine, it cannot be extrapolated to other medical conditions, which limits its utility for spaceflight [8]. Overall, the above tools are either similar to the AMA Guides in their limitations, specific to a small number of medical conditions, or are not generalizable to the astronaut population. These limitations further highlight the need for a novel approach to the assessment functional impairment.

*1.4 Task Impairment*

A solution to NASA’s need for a high-fidelity novel approach to the assessment of functional impairment is Task Impairment (TI). Task Impairment is a novel metric used within IMPACT to replace the previous functional impairment metric used in the IMM. It improves upon the FI used in the IMM by increasing overall fidelity, allowing dynamic changes in real-time as mission tasks are added or changed, simplifying the development process, and by providing a basis for this process to be entirely automated in the future.

**2. Methods**

Existing methods for functional impairment assessment were evaluated and compared to the needs for exploration-class mission medical risk assessment. As none of these existing methods met the needed requirements, a novel approach was necessary.

*2.1 Mars Task List*

The Mars Task List (MTL) is a list of approximately 1100 tasks crewmembers will likely perform during a Martian mission [9]. The MTL was created by several NASA operational personnel for the Human Factors and Behavioral Performance Element of the Human Performance Program located at NASA’s Johnson Space Center (JSC) in Houston, Texas. The list was then validated by a combination of active and former Flight Directors and astronauts. The approximate 1100 tasks encompass twelve distinct phases of flight, from Launch to Low-Earth Orbit and Mars Surface Descent, to Mars Surface Operations and Earth Surface Descent. Each individual task is highly specific, describing a given action, how to perform it and with what equipment, to achieve a particular end result (Fig. 1). These tasks are extremely spaceflight-specific and can serve as spaceflight-based ADLs; these are the tasks astronauts on Martian missions will be performing on a daily basis throughout the duration of their missions. With these spaceflight ADLs in place, we were able to then begin determining which medical conditions would impair the ability of astronauts to actually perform the tasks on the MTL. This medical impairment is termed Task Impairment (TI), as it directly stems from the tasks on the MTL.

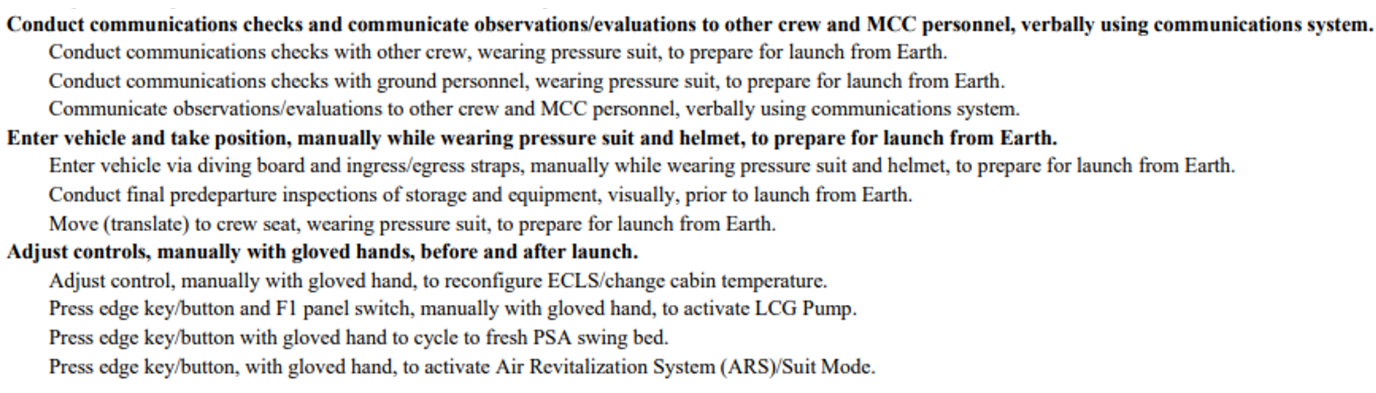


Fig.1. Example tasks from Mars Task List

*2.2 Determining Task Impairment*

After deciding the MTL was the best tool to use as a basis for determining impairment, we then created a five-step process to complete the calculation of TI (Fig. 2, see Additional Figures and Tables).

*2.2.1 Step 1: Identification of Human System Task Categories on the Mars Task List*

The first step was to create eighteen separate Human System Task Categories (HSTCs) in which the MTL tasks can be assigned (Table 2, see Additional Figures and Tables). These HSTCs in large part mirror the various human organ systems (e.g. Vision, Cardiopulmonary, Gastrointestinal), but also include spaceflight-specific categories (e.g. Translation/Stabilization in Microgravity, Pressure Operations, Don/Doff Equipment).

*2.2.2 Step 2: Assigning Tasks to Human System Task Categories*

Once the HSTCs were established, we then assigned each individual task on the MTL to the relevant categories. For example, the task “Conduct communications checks with other crew, wearing pressure suit, to prepare for launch from Earth”, requires the use of two HSTCs: Cognitive Complex and Communications. Because both human systems are required to perform the task, the task was assigned

to both HSTCs. This process was applied to all the tasks on the MTL.

*2.2.3 Step 3: Tally Total Tasks Across All Human System Task Categories*

After applying the above process to each of the approximate 1100 tasks on the MTL, the total numbers of tasks assigned to each HSTC were determined (“HSTC Total”). These totals were then combined to determine the “Total Mission Tasks” (TMT) across all HSTCs (Fig. 3). There are 3763 TMT. TMT will serve as the denominator for the TI% calculation in Step 5 (See section 2.2.5).

*2.2.4 Step 4: Mapping ICL 1.0 Conditions to Human System Task Categories*

With Steps 1-3 completed, the 120 medical conditions on the ICL 1.0 were then mapped to the relevant HSTCs. These medical conditions range from simple lacerations to appendicitis, stroke, dental conditions, and psychological conditions; as such, the conditions were mapped to multiple HTSCs. For example, the appendicitis condition would impair all tasks that require the use of the Cognitive Complex system, Hand Dominance (e.g. piloting or operating critical systems), Pressure Ops, and more. To assist with the determination of which categories conditions were assigned to, six specific criteria were used as guidelines (Fig. 3).

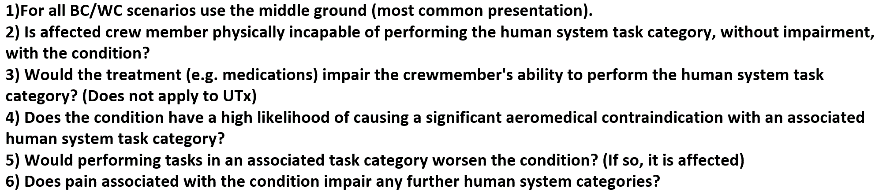


Fig. 3. Criteria for Assignment of Conditions to Task Categories

*2.2.4.1 Clinical Phases*

To further increase the fidelity of medical impairment assessment, the Impact Condition List (ICL) 1.0 medical conditions were separated into three distinct clinical phases. Clinical Phase 1 (CP1) assumes 100% impairment, as this is the diagnostic phase and the severity of a medical condition has not yet been established; during CP1 a crewmember would not be performing tasks of any kind. Clinical Phase 2 is the active treatment and immediate recovery phase of a given medical condition. Using the appendicitis example, this phase would include pain medications and definitive treatment modalities, along with the ensuing recovery period. Clinical Phase 3 (CP3) is defined as the maximal resolution phase. In CP3, the crewmember has recovered to the best of his/her ability, and any resulting impairment is permanent (or cannot be further improved during a given mission).

*2.2.4.2 Severity and Treatment Variants*

In addition to separating each condition into the three clinical phases, each was also separated into two variants of itself: Best-Case Scenario (BC) and Worst-Case Scenario (WC). These were then sub-divided into Treated (Tx) and Untreated (Utx). This was necessary to account for both the natural variations in medical condition severity and to determine the differences in potential outcomes based on whether the resources are present to actually treat a given medical condition.

*2.2.4.3 Subject Matter Expert Validation*

To determine which HSTCs were affected by a given condition (including each clinical phase and severity/treatment variant), a panel of NASA subject matter experts (SMEs) was convened to provide input and reach consensus. The SMEs had a diverse assortment of medical board certifications: Preventive Medicine (Aerospace Medicine), Emergency Medicine, Physical Medicine and Rehabilitation, Family Medicine, Internal Medicine, and Sports Medicine. Each medical condition and associated clinical phase, along with the associated severity/treatment variants, was mapped to the relevant HSTCs.

*2.2.5 Step 5: Calculate Discreet Task Impairment Percentage*

After SME consensus on all components of Step 4 was achieved, the number of tasks impaired by a given condition (the sum of all affected HSCT Totals), known as the “Condition Task Total” (CTT) was determined for each condition (and condition variant, e.g. CP and severity/treatment variant). With the appendicitis example, during Clinical Phase 2 (CP2), for the BC, if Treated, the resulting CTT for this variant of appendicitis is 2518 tasks. The CTT is then used as the numerator, with the TMT from Step 3 (3763) as the denominator, to calculate a definitive TI%. This calculation becomes 2518/3763, resulting in a definitive TI% of 66.9% in CP2 for a best-case treated appendicitis. This was repeated for all possible variants of each of the 120 ICL 1.0 medical conditions, for CP2 and CP3 (recall CP1 assumes 100% impairment for all conditions).

**3. Results and Discussion**

The above processes produced four discrete TI percentages for each clinical phase of the 120 medical conditions in the ICL 1.0 list (1. Best-case scenario treated, 2. Best-case scenario untreated, 3. Worst-case scenario treated, 4. Worst-case scenario untreated). When previously using the IMM and associated AMA Guides, resulting functional impairment presented a range of potential values to account for uncertainty in the model. This range for some conditions varied from 0%-100% impairment. Such a broad range reduced the clinical and dynamic mission-planning capabilities of the IMM. The approach described above calculates a discrete value of percent task impairment, and relates it directly to verified tasks astronauts are likely to perform during exploration-class missions. Uncertainty is accounted for elsewhere in the IMPACT 1.0 model.

Using a discrete metric to define task impairment provides numerous benefits to personnel associated with mission planning and operations. It enables efficient planning for required treatment capabilities and medical supply inclusion. Operationally, changing mission parameters and expected tasks, especially if initiated after a given mission has started, would require real-time updates to the IMM functional impairment metric; the IMPACT 1.0 task impairment metric and associated calculation process enables such dynamic updates.

*3.1 Limitations*

The TI metric is limited by the scope of each task on the MTL. If an entirely novel task is added to a planned mission, Steps 2-5 of the process outlined in the Methods section above would need to be undertaken to recalculate task impairment for all conditions. If an added task falls under an already existing task on the MTL, this process will not need to be repeated. The majority of work needed to calculate TI% is assigning tasks to HSTCs, as well as mapping conditions to HSTCs; after this is complete, updating TI% based on changing tasks is straightforward and can potentially be automated in the future. Finally, multiple steps in the determination of TI% require input from SMEs, which is intrinsically subjective.

*3.1 Future Directions*

Given the extensive use of Microsoft Excel in the calculation of TI%, the above processes are amenable to automation. Automating these calculations would increase the overall utility and dynamic capabilities of TI%.

**4. Conclusions**

The development of TI% as a novel metric for functional impairment serves as an important next step in exploration-class mission medical planning. The added utility and flexibility of TI% eases the difficulties of planning and operating such advanced mission types.

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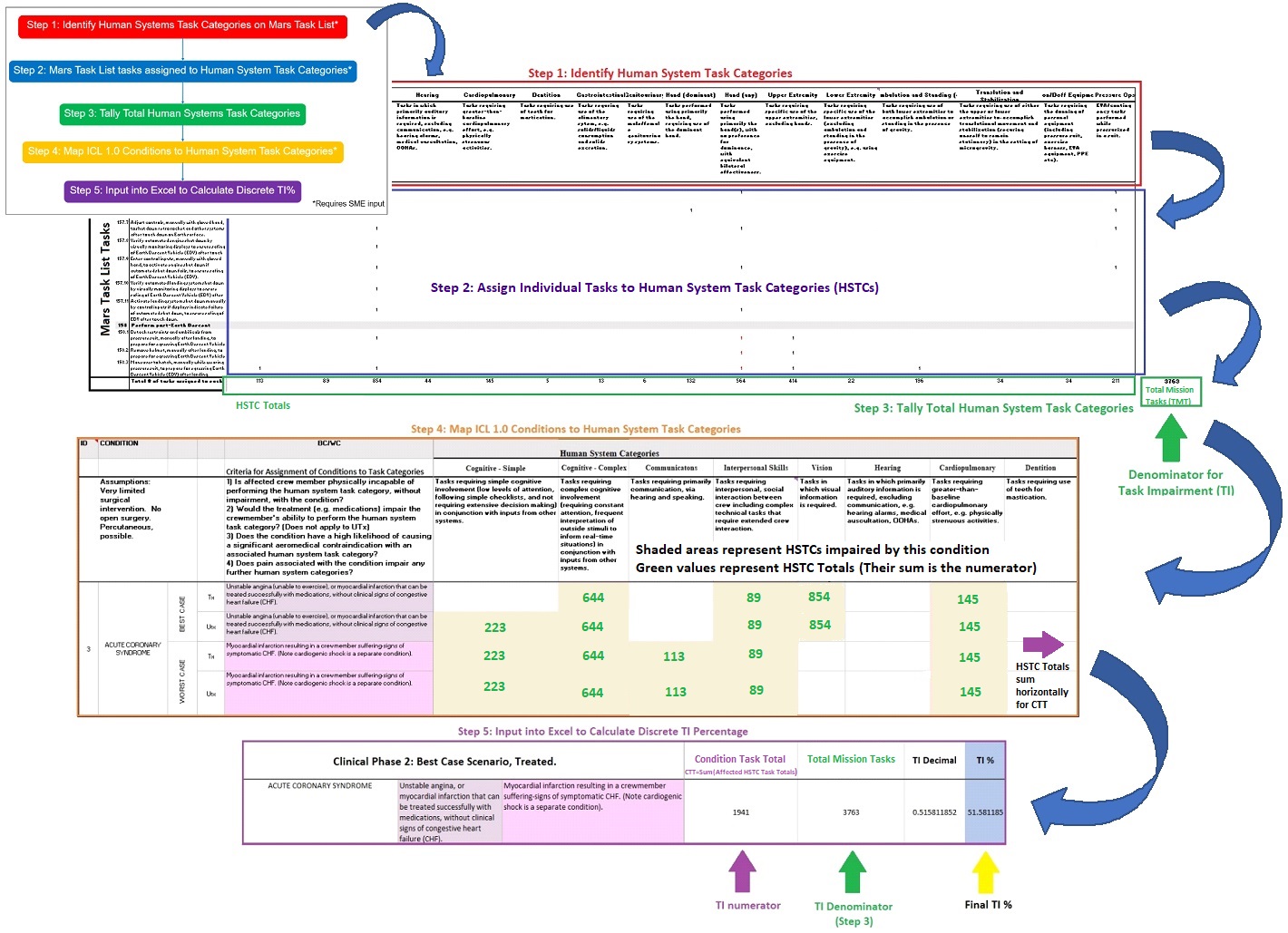
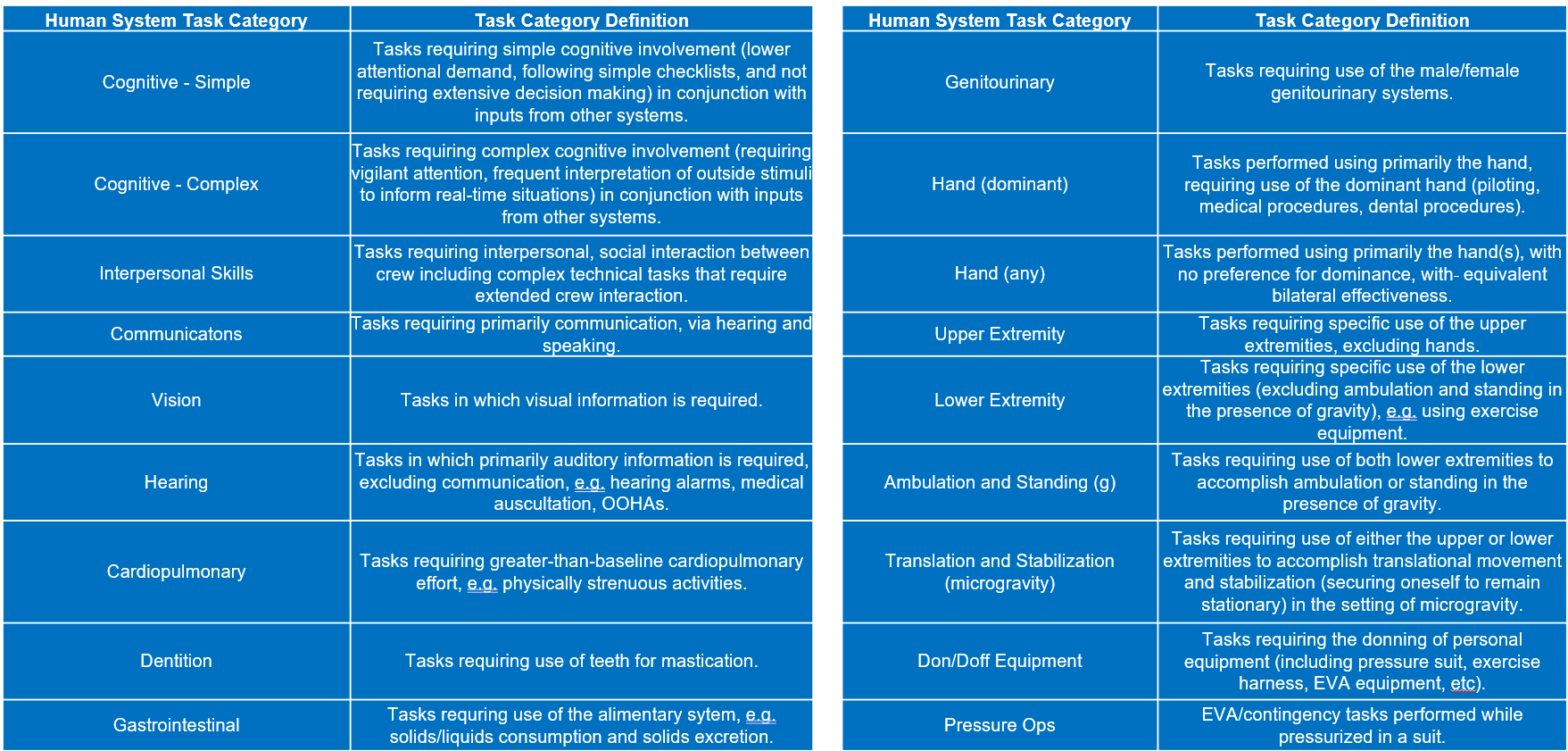
**5. Additional Figures and Tables**

Fig. 2. Task Impairment calculation complete overview.

Table 2. Human System Task Categories.

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