Robot Operator Specifications Derived from the Occupational Information Network

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The use of robots in aviation is widespread, for use as targets, decoys, remote sensing, reconnaissance, and increasingly for combat missions. Robots come in all forms and capabilities, from handheld micro air vehicles to hypersonic versions capable of high altitude long distance missions. At the same time, ground-based robots have proven effective for both military and civilian applications such as manufacturing and remote sensing / manipulations. Certainly, Talon and Packbot robots have proven their worth in battle conditions. Just as there is great variance in the type of robot being developed and utilized, so too is there tremendous variation operator requirements. Thus, it is essential the individual possess the requisite knowledge, skills, abilities and other characteristics to do so. Our work specifies the requirements for a prototypical robot operator through an examination of the U.S. Department of Labor/Employment and Training Administration's Occupational Information Network (O*NET). The applicable aviation occupations include UAV operations and also many other robots used in the aviation domain. Results yield the following for operator characteristics. *Knowledge*: The high frequency types are mechanical, production and processing, computers and electronics. *Skills*: high language component with high active learning, active listening and reading comprehension, critical thinking and mathematics. *Abilities*: Seven specific types cognitive ability are deemed important: problem sensitivity, information ordering, oral comprehension, deductive reasoning, oral expression, inductive reasoning, and written comprehension. Our paper documents the full operator profile that can be used for a variety of purposes including selection, training, and human factors design and specifications.

There is a long history for classification systems to be employed in describing worker characteristics and requirements for occupations in the United States. These specifications are important as they lead to standards for equipment design, human factors requirements, and training needs, among others. The U.S. Department of Labor successfully employed the *Dictionary of Occupational Titles* for many years, but in light of changes to occupations and the need to access and update this information in a timely fashion drove the development of a new system, the Occupational Information Network (O*NET).

O*NET represents a comprehensive assessment of various jobs and occupations found in the United States. The data about each occupation were gathered by taking both a job-oriented and a worker-oriented perspective for the requirements to perform work. This provides complete coverage of the knowledge, skills, abilities, and other worker characteristics required for successful job performance. The O*NET framework is presented in Figure 1.

Information in O*NET is very rich and meant to fulfill the needs of a variety of purposes, such as an older worker interested in changing occupations or locations, a young individual preparing to entering the workforce and wanting to know the skill requirements for various occupations, or a high school vocational counselor providing guidance to students.

We examine the O*NET database to glean a picture of the cognitive and task demands for a prototypical robot operator so that information might be used to address a variety of purposes ranging from selection and training to human factors. The information gleaned from O*NET can serve as one source of input into a taxonomy of cognitive and task demands for the warfighter robot operator. The other source of input is the scientific literature in general and the human-robot literature in particular.

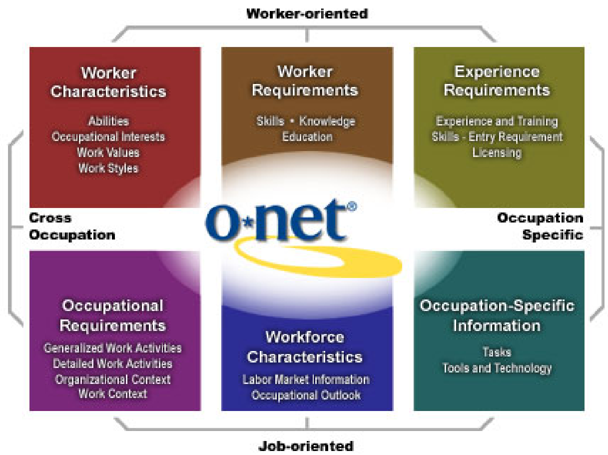

Figure 1. Content model of O*NET (figure reproduced from the O*NET Resource Center, used with permission. http://www.onetcenter.org/content.html#cm2).

The paper is organized as follows. First, a description of the O*NET coding scheme is given to provide an understanding of the hierarchy of jobs and occupations within the database (for a detailed description of any aspect of the construction and validation of O*NET, see the O*NET final report (Peterson et al., 1997). Second, the search strategy and occupations utilized is listed. Data from eleven different occupations was employed to generate the profile for the prototypical robot operator occupation. Third, a description of job knowledge, skills, and abilities as defined in O*NET is provided along with a summary for the robot operator occupation. Fourth, work activities defined by O*NET are provided and those that lead into our robot operator are listed. Although perhaps not as directly pertinent as knowledge, skill, and abilities for human factors specifications, information on work activities is still useful and informative. Finally, the prototypical robot operator occupation worker characteristics and task activities are listed by highlighting those that are most important across existing robot occupations.

*O*NET Occupational Code*

Each occupation requires a specific mix of knowledge, skills and abilities to accomplish the required tasks and activities. O*NET uses a set of descriptors and for each occupation and at the highest level there are six of these. They are expanded to 277 for which unique measurable information is gathered. The information about any one occupation in O*NET is linked in a relational database via an occupational code. The following quote from the O*NET website describes how the occupational classification scheme is applied.

"Each item in the hierarchy is designated by a six-digit code. The hyphen between the second and third digit is used only for presentation clarity. The first two digits of the SOC code represent the major group; the third digit represents the minor group; the fourth and fifth digits represent the broad occupation; and the detailed occupation is represented by the sixth digit. Major group codes end with 0000 (e.g., 33-0000, Protective Service Occupations), minor groups end with 000 (e.g., 33-2000, Fire Fighting Workers), and broad occupations end with 0 (e.g., 33-2020, Fire Inspectors). All residuals ("Other," "Miscellaneous," or "All Other"), whether at the detailed or broad occupation or minor group level, contain a 9 at the level of the residual. Detailed residual occupations end in 9 (e.g., 33-9199, Protective Service Workers, All Other); broad occupations which are minor group residuals end in 90 (e.g., 33-9190, Miscellaneous Protective Service Workers); and minor groups which are major group residuals end in 9000 (e.g., 33-9000, Other Protective Service Workers):

33-0000 Protective Service Occupations
    33-9000 Other Protective Service Workers
        33-9190 Miscellaneous Protective Service Workers
            33-9199 Protective Service Workers, All Other"

O*NET provides a readily accessible and searchable means for gathering information about thousands of occupation titles across hundreds of occupation titles in the US.

Occupational Relevance Score

The O*NET database contains hundreds of occupations and many thousands of jobs, with new ones being added daily. One of the primary advantages of the database is the ability to compare existing jobs to new job, or jobs in one occupation to those in another. To accomplish this comparison, O*NET employs a relevance score, which is defined as: **"**Relevance Score - The search strategy used in the keyword search employs a combination of occupational information, such as associated alternate titles, description, and tasks. A raw score is calculated based on the number of matches across the different data elements and their respective weights. This maximum score becomes the normalization factor. The scores are translated to a 0 to 100 relevance ranking by the following formula: relevance ranking = (score / maximum score) * 100. Thus, the occupation with the highest relevance ranking will be 100. Those occupational titles receiving less that the maximum score will receive a lower ranking. The lowest possible ranking is 0." (Occupational Information Network, 2009).

*KNOWLEDGE, SKILLS, ABILITIES and WORK ACTIVITIES as DEFINED in O*NET*

The knowledge, skills, and abilities definitions come from the O*NET website. See Occupational Information Network (2009) http://www.onetcenter.org, or Peterson et al. (1997) for complete information.

Knowledge

Success in any job depends on having a background set of knowledge. Thirty-three specific knowledge areas are defined in O*NET. Occupations are rated on the extent to which each specific type of knowledge is important to that occupation. knowledge area as defined in O*NET an organized sets of principles and facts applying in general domains. Examples from the 33 include: biology, computers and electronics, design, geography, mechanical, personnel and human resources, physics, and transportation.

Skills

As with knowledge, it is important to identify the extent to which particular skills are necessary in an occupation. O*NET defines six major categories of skills: Basic, complex problem solving, resource management, social, systems, and technical. Each category is elaborated from into one to eleven specific type of skill. The six categories are defined as follows. 1. *Basic Skills*: Developed capacities that facilitate learning or the more rapid acquisition of knowledge. 2. *Complex problem solving skills*: Developed capacities used to solve novel, ill-defined problems in complex, real-world settings. 3. *Resource management skills*: Developed capacities used to allocate resources efficiently. 4. *Social skills*: Developed capacities used to work with people to achieve goals. 5. *Systems skills*: Developed capacities used to understand, monitor, and improve socio-technical systems. 6. *Technical skills*: Developed capacities used to design, set-up, operate, and correct malfunctions involving application of machines or technological systems.

Abilities

O*Net defines four major categories of abilities: *cognitive*, *physical*, *psychomotor*, and *sensory*. Each category has from nine to twenty-one specific types. The list of *cognitive abilities* is very comprehensive – with twenty-one unique types identified and linked to occupations. They cover the gamut of cognitive functioning, ranging from the perceptual level (e.g., perceptual speed) through memorization, and higher-order processing such as that found in deductive and inductive reasoning, oral and written comprehension, and mathematical reasoning. *Physical abilities* are essential for jobs with a high physical component. These deal with gross physical characteristics (e.g., trunk strength) and are anticipated to be of little importance to the typical robot operator position. Physical abilities are defined as: Abilities that influence strength, endurance, flexibility, balance, and coordination. *Psychomotor abilit*ies are the third class of abilities utilized in O*NET to classify jobs. These deal with more micro-level abilities (e.g., control precision, finger dexterity) than the physical abilities class. As robot operators must interact with the robot through an operator control unit of some type (computer interface), it is anticipated these are more likely aligned with the prototypical robot operator occupation. Psychomotor activities are defined as those abilities that influence the capacity to manipulate and control objects. The final class of abilities in O*NET are *sensory abilities*. Although sensory abilities are important as they feed into higher level perceptions and cognitions, they are anticipated to play a smaller role in direct overall importance to the job than other skill classes. Sensory abilities are defined as abilities that influence visual, auditory, and speech perception.

Work Activities

The final set of O*NET descriptors used here is *work activities*. There are four major categories of work activities defined in O*NET: *information input*, *interacting with others*, *mental processes*, and *work output*. Each, as defined in O*Net is now listed. 1. *Information input*: Where and how are the information and data gained that are needed to perform the job. 2. *Interacting with others*: What interactions with other persons or supervisory activities occur while performing this job? 3. *Mental processes*: What processing, planning, problem-solving, decision-making, and innovating activities are performed with job-relevant information? 4. *Work output*: What physical activities are performed, what equipment and vehicles are operated/controlled, and what complex/technical activities are accomplished as job outputs?

Summary

O*NET provides a comprehensive approach for evaluating an occupation from the perspective of worker and job requirements. Our purpose is to employ the rich data of O*NET to determining the cognitive and task demands on a warfighter utilizing one of many different robots with various operator control units. This information, combined with that from the scientific literatures will help with the establishment of taxonomy of such demands. Once established, various human factors purposes can be served, such as: equipment design, workload reduction/optimization, interface development (scalability issues), and task specification (e.g., for collaborative technologies; individual vs. team issues).

Method

Three searches in O*NET were conducted, two focusing on robot occupations and, given the interface often used to interact with a computer, one search utilized the term computer. The robot occupational searches employed ‘robot operator’ ‘robot’ as search terms. Robot operator is clearly targeted at our interests, but a search was also conducted on robot as it is more general and would turn up specifics that might need further investigation. The two searches are summarized in the table below. The top ten occupations are the same regardless of which term is utilized—although the rank-order changes. Warfighters often control robots via a computer interface. Due to this, a search was conducted on a ‘computer operator’ occupation. In sum, for the knowledge, skills, abilities, and work activities for the prototypical robot operator job were identified based on a search employing three occupational terms (robot operator, robot, computer operator) which yielded eleven occupations. These are listed in Table 1.

Table 1. *Occupations, relevance scores, and rank orders for search terms*.

	Search =’robot operator’		Search=’robot’	
Occupation code and title	Relevance score	Rank order	Relevance score	Rank order
51-4122.00 Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	100	1	94	2
51-4121.06 Welders, Cutters, and Welder Fitters	97	2	68	6
17-3024.00 Electro-Mechanical Technicians	89	3	100	1
51-4011.00 Computer-Controlled Machine Tool Operators,	68	4	67	10
51-9031.00 Cutters and Trimmers, Hand	62	5	68	6
17-3023.03 Electrical Engineering Technicians	59	6	71	3
17-3027.00 Mechanical Engineering Technicians	59	7	71	3
17-3023.01 Electronics Engineering Technicians	58	8	71	3
49-2094.00 Electrical and Electronics Repairers,	57	9	68	6
27-1021.00 Commercial and Industrial Designers	55	10	68	6
43-9011.00 Computer Operators	15	15	<5	<5

Results

Specifying Requirements for a Prototypical Robot Operator Job

Now that the relevant occupations that can be used to pull data from have been identified, we proceed through the data examining the frequency each knowledge, skill, or ability type is mentioned for the jobs. That is listed in the following tables along with the percentage of occupations in our set requiring it. For evaluation purposes, a frequency of 5 which equates to a percentage of 45 to be significant enough to be considered an important characteristic for a robot operator. For example, mechanical knowledge is listed as a requirement for nine of the 11 jobs in our sample. This equates into it being a requirement for 82% of the sample jobs.

Prototypical Robot Operator: Knowledge, Skills, Abilities, and Work Activities

The ground work has been laid for developing the requirements for a prototypical warfighter who must operate a robot. These requirements are derived from the perspective of knowledge, skills, abilities, and work activities contained in the nations Occupational Information Network. O*NET includes information on worker and job requirements, and the extent to which jobs are related based on the profile of these requirements. Worker knowledge, skills, abilities, and work activities provided the data for the warfighter robot operator profile.

Knowledge refers to an organized set of principles and facts that apply in general domains. *Mechanical knowledge* is the most important and operators need to be able to understand the design, use, repair, and maintenance aspects of the robots. *Production and processing* is identified as important, but as it deals more with manufacturing is not as central to a warfighters understanding. *Knowledge of computers* and electronics is essential as well. Operators need to have an understanding of the hardware and software of the robots and perhaps some application programming. Similar to this is *knowledge of engineering and technology* where the warfighter operating a robot is able to apply principles, techniques and procedures for equipment design. Knowledge of the *English language* is essential, but all warfighters will have this and it is not unique to the robot operator. The final knowledge requirement is *mathematics* as it helps in many aspects of robot operation.

There are six major skill categories, but only two (basic and technical) contain specific skills important to the warfighter robot operator. Basic skills refer to the developed capacities that facilitate knowledge or its acquisition. The basic skill requirements are five: *active learning, active listening, reading comprehension, critical thinking,* and *mathematics*. *Active learning* deals with the ability to understand the implications of both current and future problem-solving and decision-making. This is clearly an important capability for the warfighter involved with operating a robot. *Active listening* is a skill where the individual gives full attention to what others are saying, taking time to understand the points being made, and not interrupting at inappropriate times. The third basic skill for the warfigher robot operator is the capacity to understand written sentences and paragraphs in work related documents – *reading comprehension*. A fourth basic skill requirement is *critical thinking* which involves the ability to use logic and reasoning to identify strengths and weaknesses of alternate solutions, conclusions, or approaches to problems. This seems almost intuitive as a required skill for a warfighter operating a robot. The final skill is *mathematics* and is useful for solving and considering alternative approaches to problems.

Technical skills are the second skill class important for the warfighter robot operator to posess. Technical skills are the developed capacity to design, set-up, operate and fix technological systems. Four are specifically required: troubleshooting, equipment maintenance, equipment selection, and operation monitoring. *Troubleshooting* deals with determining the cause of operating errors and deciding what to do about it. Clearly this is an important skill for a robot operator. *Equipment selection* and *equipment maintenance* are two skills focusing on managing tools and equipment for a job and for selecting the correct apparatus and maintaining it during use. Finally, *operation monitoring* is perhaps the most essential skill as it deals with the capacity to watch gauges, dials, and other indicators to ensure the robot is operating properly. This is important for both line of sight and non line of sight operation.

Abilities are the final worker-oriented attribute to assess for the warfighter robot operator. Of the four major categories of abilities in O*NET, three are important. Cognitive abilities are the most essential, at least in terms of number as seven separate ones are considered important. Cognitive abilities influence the acquisition and application of knowledge to problem solving. Beginning with *problem sensitivity*, this is the warfighter robot operators ability to tell when something is either wrong or likely to go wrong. It does not focus on solving the problem, but on the ability to recognize that there is a problem. Second is *information ordering* which involves the ability to arrange things in a certain order or pattern according to specific rules. *Deductive reasoning* is another required ability and it is the capacity to apply general rules to specific problems to produce answers that make sense. Similarly, *inductive reasoning* is also essential. Separate from deduction, inductive reasoning is the ability to combine pieces of information to arrive at general rules or conclusions. Other cognitive abilities focus on the oral and written. *Oral comprehension* states it is important for the operator to be able to listen to and understand information and ideas presented in spoken words and sentences. Similarly, the *oral expression* ability states the need to be able to communicate information and ideas in speaking so others will understand. Finally, the warfighter robot operator needs the ability to read and understand information and ideas presented in writing. This final ability is *written comprehension*.

Psychomotor abilities refer to the capacity of an individual to manipulate and control objects. For the warfigher operating a robot three psychomotor abilities are important: Arm-hand steadiness, control precision, and finger dexterity. *Arm-hand steadiness* is the ability to keep one's hand and arm steady while moving the arm or holding the arm and hand in one position. *Control precision* is the ability to work quickly and repeatedly adjust the controls of a machine or vehicle to one or more exact positions. The third psychomotor ability is *finger dexterity* which is the ability to make precisely controlled and coordinated movements of the fingers of the operator's hands to grasp, manipulate, or assemble objects. In looking at these three psychomotor abilities it is easy to see how they are important for the typical human-robot interface consisting of a joystick, mouse, or similar interaction controller.

Finally are sensory abilities which are those that influence visual, auditory, and speech perception. For the warfighter who is the operator of the prototypical robot, only near vision is considered essential. *Near vision* is the ability to see details at close range. While it is easy to understand how this ability is important to all operators, it is also acknowledged that other sensory abilities will be important depending on the particular robot or task. For example, if utilizing a 2D or 3D auditory interface, *auditory attention* (ability to focus in the presence of distracters) would be important when engaging in a targeting task. Another example is *hearing sensitivity* for the same type of interface.

Work activities are the final domain to be considered for our warfighter robot operator. There are four primary categories of work activities and each is considered for relevance to the warfighter. Information input, interacting with others, mental processes, and work output are all important for the robot operator. Functional levels of each are provided in our full technical report.

Summary

Our goal is to identify the cognitive and task demands for a warfighter who must operate a robot. There is, however, tremendous variance in the type of robots deployed and the interactional devices associated with robots. The strategy taken here is to leverage information and data available across thousands of workers, hundreds of jobs, and many occupations where workers interact with robots. These have been evaluated in O*NET for the knowledge, skills, abilities, and work activities that are essential for successful performance. By aggregating across jobs and then selecting those knowledge, skills, abilities and work activities that are most prominent it is possible to create a profile for a prototypical robot operator. The profiles can be used for a variety of purposes including input into a cognitive and task demand structure that feeds a variety of human factors needs and goals.

Acknowledgements

This work was supported by government contract number DAAD19-01-C-0065, task order 83. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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