# Using Competency Definitions to Adapt Training for Mission Success

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## ABSTRACT

U.S. military forces require personnel who are prepared for new missions, who are equipped to face ever-changing operating environments, and who are proficient in increasingly sophisticated, rapidly evolving technologies. To successfully support personnel, the training, operational, and personnel communities must be aware of the rapidly changing needs of those in the field and understand how decisions concerning the allocation of limited recruiting and training resources may affect their readiness.

This paper describes how competency definitions can support resource allocation decision-making by linking data on experience in the field with personnel and training data. Linking these data automatically allows training managers to quantitatively compare how tasks are trained in the schools with how tasks are executed in the field and to adjust training time and equipment resources accordingly. Competency descriptions with multiple levels of abstraction can be used to summarize data at the level appropriate for the decision-maker.

Complex competency definitions can be expensive to build and difficult to update. An automated approach to generating competency definitions that leverages standard reusable competency definition data models and existing taxonomies can reduce the development effort and speed up maintenance.

This paper provides an example where competency definitions are generated automatically using an ontology. The model has been used to integrate operational data on equipment used in the current operating environment, personnel data on driving accidents, and training data on equipment used for training. It allows decision-makers to compare operational risk in terms of the cost of accidents involving particular types of vehicles in the field with the investment in driver training time by type of vehicle at U.S. Army schools.

## ABOUT THE AUTHORS

**Geoffrey Frank** is a Principal Scientist at RTI International. He holds a PhD in Computer Science from the University of North Carolina at Chapel Hill. Dr. Frank is a member of the IEEE Learning Technology Standards Committee, and has contributed to the development of use cases for the IEEE Reusable Competency Definition Standard, P1484.20.1. He has led the training analysis of Web-delivered simulations for the Army Signal Center and is a co-author of the Signal Center Masterplan for Lifelong Learning.

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**Michael O'Bea** is a Military Analyst at TPIO-Virtual. He is a combat developer of virtual training devices for the Combat Support and Combat Service Support Soldier. His focus for the past year has been on the Virtual Combat Convoy Trainer, the Reconfigurable Vehicle Tactical Trainer, and the Common Driver Trainer. Mr. O'Bea is a retired Army Transportation Corps Lieutenant Colonel. He holds a BS in Environmental Health, and a master's in Education, both from the University of Georgia.

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## INTRODUCTION

Organizations like the U.S. military require personnel who are prepared for new missions, equipped to face ever-changing operating environments, and proficient in rapidly evolving technologies. To allocate limited recruiting and training resources effectively, the training, operational, and personnel communities must be aware of the rapidly changing needs of those in the field and understand how resource allocation decisions may affect them. Currently, competency definitions are used by these communities for planning and for communicating operational needs among themselves.

Traditionally, competency definitions have been composed of textual descriptions of tasks and performance measures organized by skill levels. However, manually managing competencies with large numbers of detailed, technology-specific task definitions is no longer practical in today's dynamic environment. The ongoing challenge is how to construct competencies so that automation can help to give decision-makers a better awareness of current and future operational needs.

This paper describes an approach to automating competency definitions by using an ontology. The ontology generates competencies consistent with the IEEE Reusable Competency Definition (RCD) draft standard and uses existing vehicle taxonomies. This approach is applied to U.S. Army driver training conducted by the branch schools. The resulting hierarchy of competencies is used to integrate vehicle accident data with driver training course information. The hierarchy aligns the data to identify gaps where the vehicles used for training differ from the vehicles that are causing accidents. The output is a decision aid for each branch and each level of the vehicle taxonomy that matches risks defined by aggregate accident costs against total driver training time on the class of vehicles.

## COMPETENCY DEFINITIONS

Competency definitions typically identify the knowledge, skills, and aptitude required for a job. Knowledge is associated with educational requirements or qualifying exams. Skills are defined in terms of tasks to be performed, the conditions under which those tasks are performed, and the standards to be achieved in performing the task.

For a driving competency, the knowledge definition would include the rules of the road. The aptitude definition would require the ability to read road signs, and the skills would be defined in terms of tasks such as preparing the vehicle for operation (making sure it has gas), driving, and basic vehicle maintenance.

The complexity of a competency results from the relationships between the different component definitions. For example, the driving competency knowledge is dependent upon the country in which the driving will take place (e.g., the rules of the road differ in England and the United States). This information is captured in the conditions component of the task definition.

## APPLICATIONS OF COMPETENCY DEFINITIONS

Competency definitions are a valuable planning tool for the operational, personnel, and training communities. This concept is illustrated in Figure 1, where each of the communities indicated by the intersecting circles has its own set of interests in competency definitions (denoted by the RCD at the center of the figure).

### Mission Planning

The Operational Community matches assigned missions against the competency models of their subordinate elements to organize for mission success. This is done in a top-down fashion that starts with Mission Essential Task Lists (METLs) at the highest

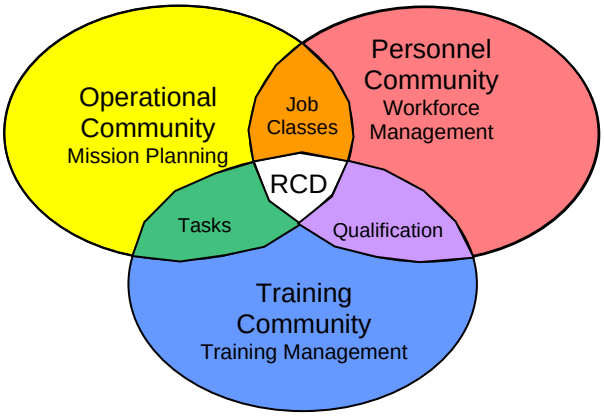


**Figure 1. Overlapping Competency User Communities**

level of abstraction and eventually identifies individual tasks at the lowest level of abstraction.

For example, a unit may be given a convoy task. The unit will determine the mix of trucks, high mobility multipurpose wheeled vehicles (HMMWVs), and Bradley fighting vehicles needed for the mission. Each of these vehicles will have a driver whose individual task is to drive the vehicle along the specified route. The unit has recently upgraded its HMMWVs with additional armor.

Mission competencies are critical in such situations. The unit tracks the readiness of its soldiers and vehicles and reports accidents involving vehicles as well as personnel and vehicle losses due to combat. The up-armored HMMWVs have a higher center of gravity and are more likely to turn over, increasing the rate of accidents in the unit. The unit commanders expect the new soldiers they receive to understand the dangers inherent in the up-armored HMMWVs and they need for the soldiers already in the field receiving the new equipment to be provided sustainment training.

**Workforce Management**

The Personnel Community is responsible for providing the right mix of skilled personnel to meet the missions of the organization. They use competencies to define jobs and track the personnel resources of the organization. They construct competencies by combining individual tasks, identifying required skill levels, and specifying the requirements to achieve a skill level rating. They track the number of personnel in each competency and skill level and compare operational needs with available personnel. They then use the competencies to devise strategies for recruiting or training people to fill the competency gaps.

Continuing the convoy example, the soldier driving an HMMWV may be a member of the Military Police (MP) branch or may be a Signal specialist. The MP branch includes driving skills as a basic competency, but the Signal branch does not. The Personnel Community supports the unit by determining how many MP and Signal soldiers are needed across the Army, as well as how many will be in training at any given time. The Personnel Community also decides whether different versions of equipment warrant different competencies.

**Training Management**

The Training Community is responsible for the transitions of personnel between competencies via training and certification of that training. They use the competencies to determine the time, personnel, and equipment resources needed for the training.

Continuing the convoy example, the MP soldier is assigned the task of guiding the convoy and driving one of the recently up-armored HMMWVs. The MP school supports the unit by training driving skills, and it has to decide which HMMWV models are relevant to the training and how much time should be spent in the different vehicles the soldier may be driving. The MP school has to plan the number of instructors and vehicles needed for the training based on the expected number of soldiers to be trained. In this case, the MP school has to decide whether to acquire up-armored HMMWVs for training or whether other training approaches and conditions are sufficient.

**Competency Definitions as Organizational Interfaces**

Mission descriptions provided by the operational communities of interest identify tasks, conditions, and standards of the competencies for the personnel and training communities. The operating environment (including equipment and terrain) identifies the conditions for the tasks. The Training Community must select from the range of operating environments an appropriate set of conditions for training. The Personnel Community must determine which combination of tasks, conditions, and

standards is appropriate for the competency defining a particular job.

The Personnel Community works with the Training Community and the Operational Community to determine the qualifications needed for a specific competency. These qualifications may be defined in terms of specific tests (e.g., a rules-of-the-road written exam (to assess knowledge) and a driving performance exam (to assess skills), or may be defined in terms of experience.

## COMPETENCY DATA MODELS

Each of the three communities shown in Figure 1 is building databases to support its decision-making. Competency data models have the potential for automating the connections between these databases, improving communications between the three communities, and reducing the decision-making cycle times.

### Reusable Competency Definitions

Competency data model standards such as the IEEE RCD draft standard have been evolving to provide more automation for these communities (IEEE LTSC, 2005). This standard encourages the definition of competencies by linking together component RCDs and adding information in the form of attributes to each component RCD (Frank et al., 2005).

Figure 2 illustrates such a network of competencies. The top-level RCD is assembled by linking component knowledge, skill, and aptitude RCDs. The component RCDs either reference or incorporate existing validated taxonomies. Using taxonomies that have been validated by the community simplifies the validation process for the competency.

The choice of taxonomies should reflect the desired use cases for the competency as an interface to the databases of the communities. Taxonomies are a source of terms for controlled vocabularies and index terms for the community databases. Explicit links in the RCDs to online versions of the taxonomies enable automatic identification of changes in the source taxonomy databases that may require updates to the competency, ensuring that the competency definitions stay current. This linkage can be implemented via hyperlinks in the definition portion of the RCD, as represented by the solid red lines in Figure 2. The green dashed arrows represent metadata links that tie the components of the competency (knowledge, skills, aptitude) to set locations within source taxonomy databases. The light blue triangles represent existing databases.

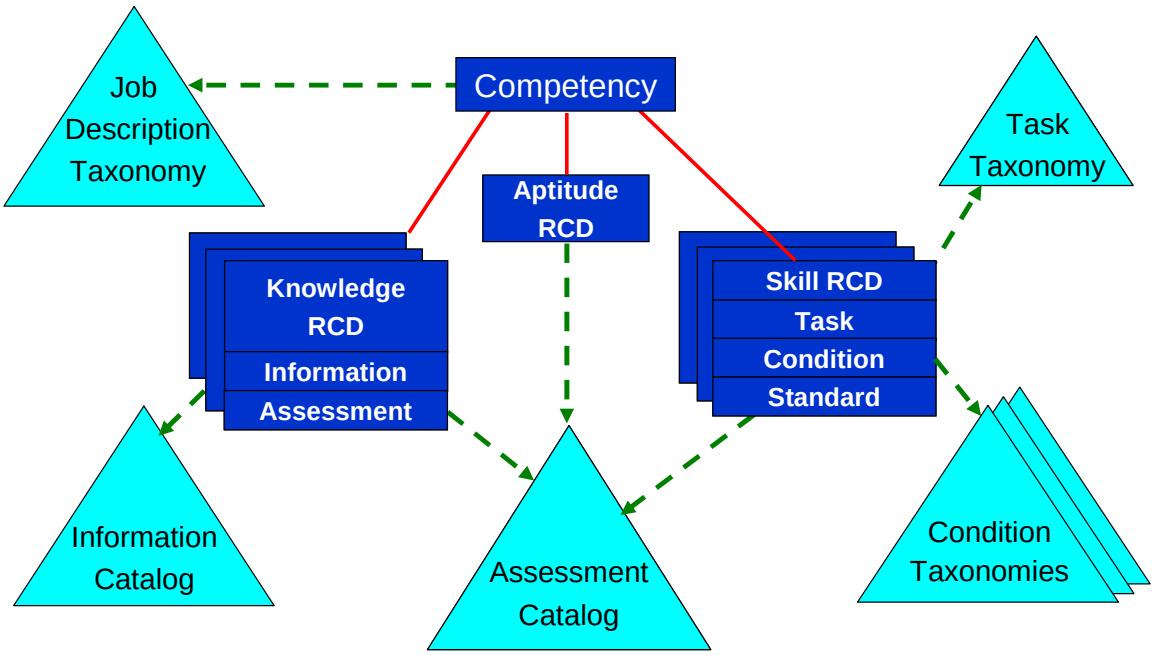


**Figure 2. A Vehicle Operator Task Competency Model That Uses Taxonomies**

**Benefits of Reusable Competency Definitions**

The decomposition of a high-level competency into a network of component RCDs allows several benefits for automation:

- **Database Searches**: Defining a competency in terms of a network of RCDs and existing taxonomies supports computerized searches and more general matching of database index terms. This allows automated metrics for ranking the matches, similar to the approach used by Internet search engines.

- **Gap Analysis**: The same metrics used for ranking matches can also be used to detect gaps. For example, gaps can be calculated between the resume of a job applicant and a job description when both are constructed around similar RCD networks.

- **Summarization**: Automation can be used effectively to traverse a network of RCDs and summarize data extracted from each node in the network. For example, given an hierarchical RCD network of vehicles and a database of accidents indexed by type of vehicle, accident cost data can be summarized up the hierarchy. A classic example of summarization is the reporting by the U.S. Bureau of Labor Statistics against the O*NET hierarchy of job descriptions.

- **Reuse**: Defining a competency in terms of a network of RCDs allows the component RCDs to be reused for multiple purposes. For example, the Operational Community will decompose a unit mission to individual tasks, each of which can have its own RCD. The Personnel Community can combine tasks from multiple missions and abstract those same basic RCDs to create a job description. Similarly, the Training Community can combine and abstract those RCDs to specify programs of instruction.

- **Localized Maintenance**: Automation can help to propagate changes made to a small portion of a large RCD network to the rest of the network. For example, if a new radio is fielded to the Operational Community, then the training courses for soldiers who will use this new technology can be updated by propagating information to all the programs of instruction using the radio, and the course length and instructor contact hours can be updated or reported as requiring course-level tradeoffs. This approach is even more valuable if the portion that is changed is reused across multiple competency networks. However, propagation depends on a tightly structured RCD network or one that has metadata that tags associated components across disparate parts of the network.

**Risks of Reusable Competency Definitions**

Developers of competency data models have to balance the benefits of an RCD network against risks. Complex unstructured RCD networks, such as software "spaghetti code," can be expensive to construct and hard to maintain. If the RCD network is too simple, it may not have the details needed to generate job descriptions or provide the links to community-of-interest databases. If the network does not rely on existing taxonomic databases, or if those databases do not exist, then ranking and gap analyses may be more difficult to accomplish. If the network is not inherently hierarchical, then the advantage of summarization may be lost.

The use of automation for interpreting the overall competency in terms of the network of RCDs places an increased burden on the validation of the model. Validation must not only consider the accuracy of the competency description, but also the accuracy of reports generated using the RCD network.

## AUTOMATING THE CONSTRUCTION OF REUSABLE COMPETENCY DEFINITIONS

The remainder of this paper describes an example of using the RCD structure, in particular using the combination of taxonomies as a way of constructing competencies. We focus on how to define critical tasks as a special case of competency definitions. We then show how this structure can be used to align data from different sources to support decision-making. The example is derived from a Joint Capabilities Integration and Development System (JCIDS) study addressing how to reduce driving accidents (O'Bea, 2005).

In the example, vehicle operator tasks are represented as a network of RCDs using an entity-relation model where each entity is a taxonomy or collection of taxonomies and a task relationship connects many of these taxonomies. This approach is illustrated in Figure 3, where the tasks related to operating a vehicle are captured by the competency description: Perform **SKILL** with **VEHICLE** under **CONDITIONS** to **STANDARD**. The abstract

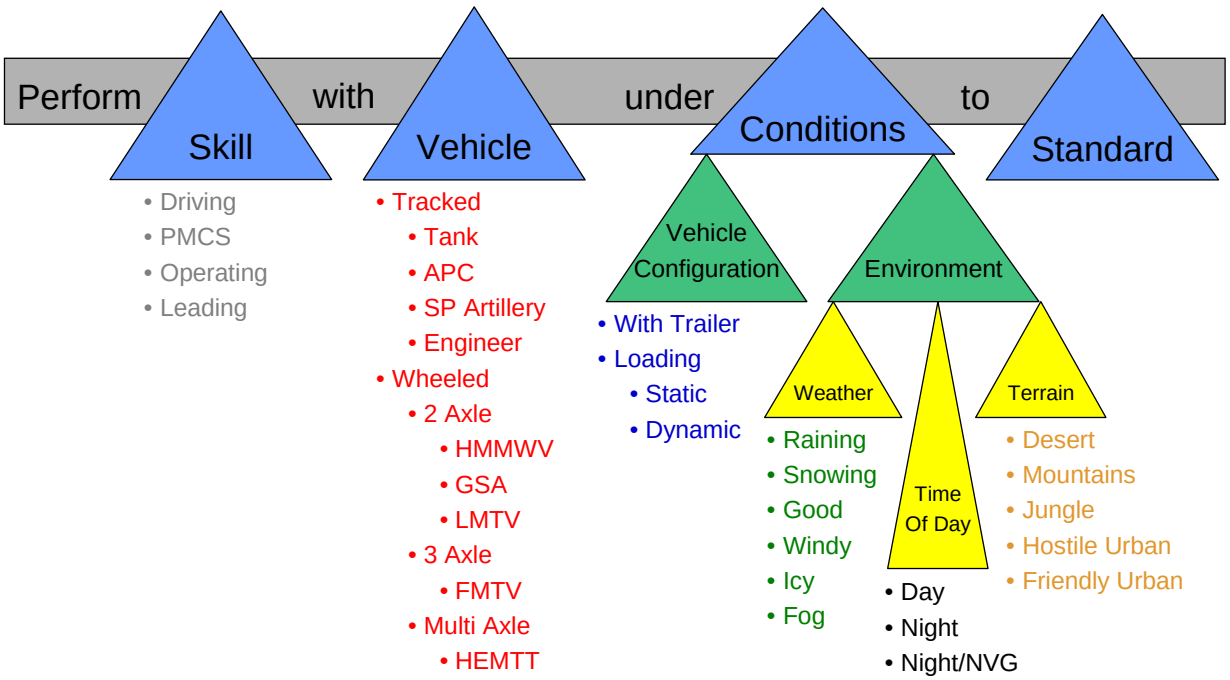


**Figure 3. A Vehicle Operator Task Competency Model That Uses Taxonomies**

relation is depicted by the gray rectangle across the top of the figure. The **VEHICLE** taxonomy is depicted by one of the blue triangles. The text under the **VEHICLE** triangle illustrates the structure of the taxonomy, distinguishing tracked and wheeled vehicles, then distinguishing wheeled vehicles in terms of the number of axles. Each node in the hierarchy is labeled using U.S. Army vehicle terminology, which is also used as a keyword in the accident reports and the training programs of instruction. Similarly, the **CONDITIONS** entity of the task abstract relation is defined in terms of the **VEHICLE_CONFIGURATION** taxonomy and an **ENVIRONMENT** taxonomy having **WEATHER**, **TIME_OF_DAY**, and **TERRAIN** components.

The skill taxonomy was extracted from Army Critical Task Lists for 31 Military Occupational Specialties (MOSs) for nine U.S. Army branches. The vehicle taxonomy was constructed from a combination of the Federal Highway Administration taxonomy for wheeled vehicles (Federal Highway Administration, 2003), the IEEE 1278-1 standard taxonomy for vehicles used in Distributed Interactive Simulations (IEEE Standards Association, 1995), and Army Regulation 600–55 (U.S. Army, 1994). The environment taxonomy is a combination of taxonomies from the Army Universal Task List (AUTL) (U.S. Army, 2003), extended for some Engineer Tasks that are included with driving in the general category of "operating a motor vehicle."

**Constructing the Competency Using an Ontology**

Ontologies are increasingly prevalent, in part due to the needs of the Semantic Web (Sicilia, 2005). They can be used to construct entity relationship models like the competency model depicted in Figure 3. Ontologies are defined in terms of entity-relationship models, the attributes associated with the entities, and class hierarchies of rules. The combination of entity relationships and attributes allows the ontology to communicate with source databases to obtain initial attribute values. The class hierarchies of rules allow the ontology to process hierarchical structures such as taxonomies. The rules of an ontology are used to compute derived attribute values and to determine under what circumstances the abstract relation is inherited to elements of the taxonomies connected by the relation.

For this driving-related ontology, we defined a class hierarchy of attributes and rules based on the vehicle taxonomy. All elements of the taxonomy have a common set of attributes. The ontology was constructed with the following distribution, rollup, and display rules applying at all levels of the vehicle taxonomy.

A distribution rule was used to allocate accident costs by an abstractly defined vehicle to MOS by assuming the same risk for all personnel expected to use the

vehicle. Another distribution rule was used to allocate training times by number of vehicles.

A rollup rule was used separately for each branch of the Army to sum allocated accident costs by vehicle type. Similar rollup rules were used to sum training times for each MOS, and to sum training times and allocated accident costs for each branch of the Army.

Display rules were developed to show allocated costs and training times for each branch and class of vehicles as bar charts to provide easy visual comparison by decision-makers. These display rules were used to generate the alignment displays shown in Figure 4.

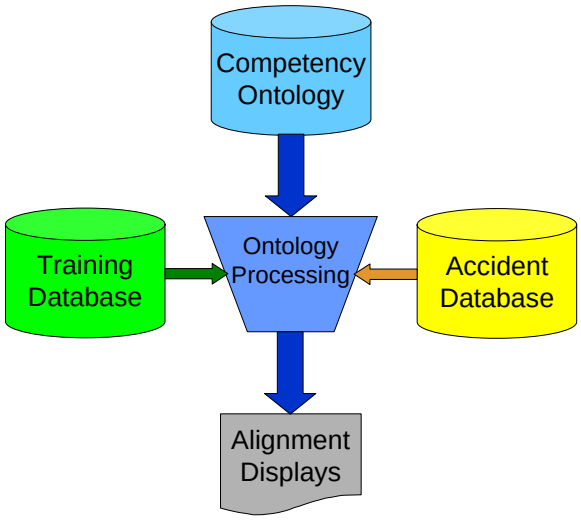


**Figure 4. Using the Competency to Align Data**

**Using a Competency Ontology to Align Accident and Training Data**

During a Functional Needs Analysis (FNA) for restructuring driver training to align it with the needs and constraints of the current operating environment (O'Bea, 2005), the authors surveyed nine U.S. Army branch schools and obtained accident data from the Army Combat Readiness Center (Army Driving Task Force, 2005). The data collected for the FNA was used to test the competency concepts described in this paper. Figure 4 shows the process used to generate alignment displays for each of the nine Army branch schools.

**The Training Database**

The training database was constructed from surveys taken of the nine U.S. Army branch schools covering 31 MOSs, as well as data exported from the Army Training Requirements and Resources System (ATRRS). Attributes associated with this database include: the vehicles used by the MOS, the driver training times for the MOS qualification courses, and the number of students for each MOS trained annually by the school. In some cases, data were available on the driver training times for the different types of vehicles. In other cases, only the total training time was available, so it was equally distributed across the different types of vehicles.

This database was indexed by MOS, Branch (proponent school), and level of instruction (Advanced Individual Training, Basic Noncommissioned Officer Course, Advanced Noncommissioned Officer Course).

**The Accident Database**

The accident database provided by the Army Combat Readiness Center (Army Driving Task Force, 2005) covered 524 reports of accidents from Iraq, Afghanistan, and Kuwait for 2003–2005.

Attributes associated with this database include: number of fatalities (military and civilian), a severity encoding, and a cost to resolve associated medical costs, damage claims, and vehicle repair or replacement.

The database was indexed by the type of vehicle involved, the branch of the Army of the person who was involved in the accident, and conditions (e.g., day or night and the country where the accident occurred). The reporting on the type of vehicle involved in the accident varied across multiple levels of detail. For example, one accident report might simply refer to a "Truck" as the cause of the accident, while another report might identify an M1078 LMTV Cargo Truck. The cost of the generically identified accident must be distributed across the different possible vehicles.

**Results from Aligning Accident and Training Data**

Accident data included 256 unique branch-vehicle pairs. Almost one quarter (61) of those pairs did not have a matching vehicle ID in the training records. After using the ontology, all but two of the records matched. These two (boat accident records) were not matched because the taxonomy did not consider Army water craft.

The vehicle taxonomy was implemented using Extensible Markup Language (XML) and its built-in hierarchical structure. The training data and the accident data were exported from relational databases into XML structures. XSLT software was used to merge the exported training and accident databases so that they aligned with the vehicle taxonomy. The ontology was used to match the data on training by branch and vehicle against the data on accidents by branch and vehicle, and finally to generate alignment reports in XML.

Figure 5 shows an alignment report from the ontology for one Army branch school. In this chart, the structure of the vehicle taxonomy is used to align data by using rules to roll up costs to allow "apples to apples" comparisons at each level. In this example, three levels of part of the hierarchy are shown. At the top level is Wheeled Vehicles (this branch does not used tracked vehicles). The next level of the taxonomy has two elements: Trucks and Wheeled Armored Combat Vehicles. The training and accident risk costs are balanced for Trucks, but the driving training time for the Wheeled Armored Combat Vehicles is relatively higher than the risks. For this branch of the Army, only two classes of trucks are relevant: four-wheeled (HMMWV) and six-wheeled (LMTV and other 2.5-ton) trucks. Four types of HMMWV are referenced in accident reports for this branch: utility, armament utility, expanded capacity, and up-armored, expanded capacity. The training uses only the expanded-capacity vehicles, but the accidents are distributed across all four types. The analysis suggests that this might be a valid training approach given limited training time and vehicle resources. Additional results indicated that personnel with many specialties in different branches were driving vehicles and being involved in accidents, but were not getting driver training.

## CONCLUSIONS

Reusable competency definitions can serve as an interface between databases by the operational, personnel, and training communities. By automating the alignment of data from these communities and presenting that information in a format that supports decision-making, RCDs can help speed up the cycle turning operational needs into practical training tailored to the personnel of the organization.

The construction of RCDs is a challenge if the RCDs are to serve the needs of multiple communities. RCDs need to provide high-level guidance in terms of job descriptions. However, they also need to track the detailed requirements of the current and future operating environments. They must rapidly adapt to the constant insertion of new technologies.

Automating the construction of RCDs is a viable strategy. The draft standard for RCDs being developed by the IEEE supports the use of existing

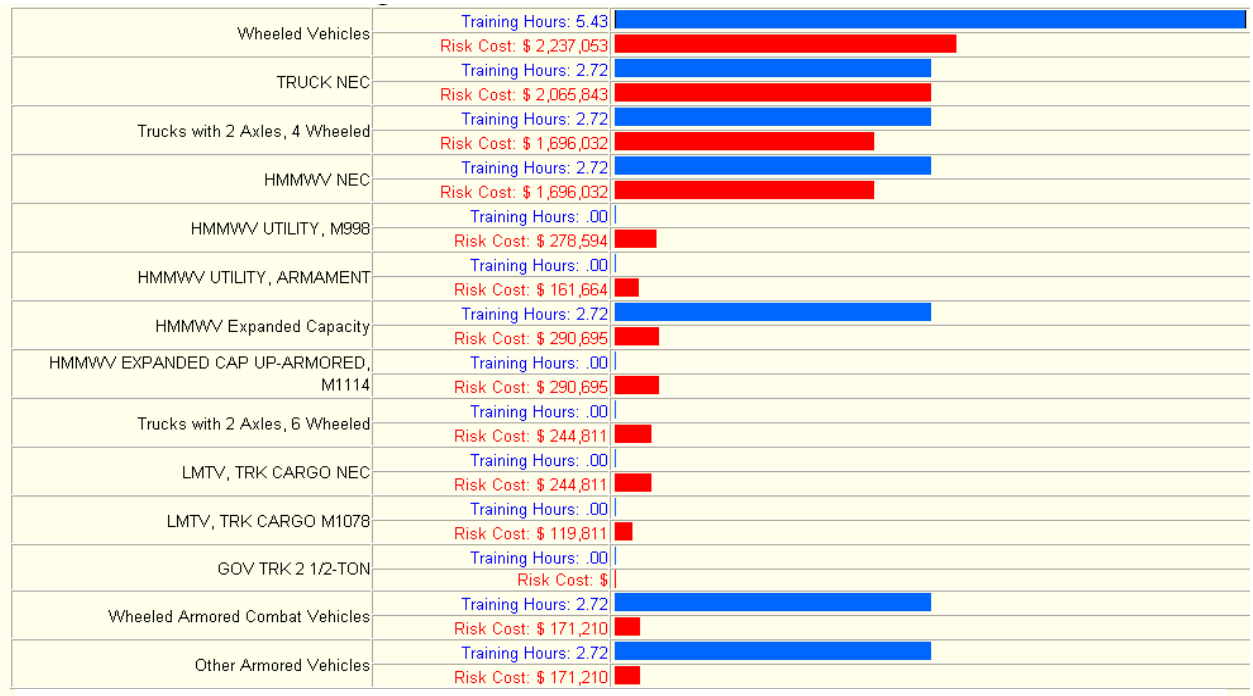


**Figure 5. Training and Risk Alignment Display for a Taxonomy of Vehicles**

taxonomies to construct competencies. This approach reduces RCD development time and effort, reduces the burden for validation of the competency models, and assists in maintenance of competency models. For example, use of existing taxonomies to identify competency dependencies on technology can identify gaps between current operating conditions and existing training.

Ontologies are an effective method for automating the construction of RCDs. The IEEE draft standard for RCDs encourages the representation of competencies as networks of component RCDs similar to the hyperlinked structure of Web pages. Ontologies are being developed as a technology for construction and maintenance of such networks.

This paper provides an example of the use of an ontology to automatically construct an hierarchical network of RCDs for operation of U.S. Army military vehicles. It uses existing taxonomies from the Federal Highway Association and the IEEE Distributed Interactive Simulation communities. The ontology was used to align accident data from the current operating environment with current training strategy. Select Army schools (Armor, Transportation, Engineer) have active driver training programs and are addressing key skills that were identified in the JCIDS process. In turn, the Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) is including performance attributes in its latest simulators to meet increased training requirements.

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