Development of the Joint Weigh-In-Motion and Measurement Reach Back Capability (WIM-RBC) – The Configuration and Data Management Tool for Validation, Verification, Testing and Certification Activities

By Robert K. Abercrombie, Ph.D., Frederick T. Sheldon, Ph.D., Robert G. Schlicher and Kristopher M. Daley

Introduction and Background

The United States Department of Defense must maintain the capability to rapidly project massive combat power anywhere in the world with minimum preparation time. Currently, personnel use portable individual wheel weight or fixed in-ground static scales, tape measures, and calculators to determine vehicle axle weights, total vehicle weight, and center-of-balance for vehicles and palletized cargo to be shipped via railcar, sealift, or airlift in support of military and humanitarian operations. The process of manually weighing and measuring all vehicles and cargo subject to these transshipment operations is time-consuming, labor-intensive, and, most importantly, prone to human errors that can result in safety hazards and inaccurate data.

Errors can result from inaccurate or incomplete identification of vehicles and equipment; misreading a scale or tape measure and manually recording data incorrectly; manually miscalculating the axle weight, total vehicle weight or center-of-balance; and transferring data from manually prepared work sheets into an electronic database via keyboard entry personnel. Many of these errors can greatly increase during stressful deployment times and adverse weather conditions.

> "Errors in determining weights and balances in military deployments as well as commercial air transport can be fatal."

Errors in determining weights and balances in military deployments as well as commercial air transport can be fatal. In June 2002 a special operations combat supply plane crashed in Afghanistan, killing several of the crew. U.S. Air Force accident investigators concluded that the crash was caused by "imprecise information" about cargo weight combined with a "get the job done" attitude. The aircraft crashed not because it was overloaded but because it was overweight for the location, 7,200 feet above sea level. **Army Times** reported that weighing cargo at such isolated airstrips was not practicable - the Air Force special operations crews were relying instead on weight estimates.[1]

A Weigh-in-Motion (WIM) system may have applicability in response to the National Transportation Safety Board's February 2004 recommendation that federal regulators and the airlines develop methods to weigh passengers and baggage to prevent overloading of airplanes.[2] The safety board had concluded that the crash of Air Midwest Flight 5481 on January 8, 2003 was caused by too much weight in the rear of the aircraft combined with a maintenance mistake. The United States military has recognized and documented a need for WIM technology,[3] further documented the requirement[4] and recommended a WIM technology solution for military applications in 2004.[5]

In this article we will concentrate on the configuration and data management aspects of military applications of WIM. We will discuss specific aspects of the United States Army/Oak Ridge National Laboratory (ORNL) WIM program, which will include the discussions of: 1) the configuration control of both the configuration of the WIM device and its software, 2) the data management of all weighing and measurement data collected from the ORNL WIM Gen II pre-production system, 3) the architectural components of the Joint Weigh-In-Motion and Measurement Reach Back Capability (WIM-RBC) Configuration and Management Tool itself, and 4) aspects of processing with respect to configuration and data management.

The lack of a standardized airlift-weighing system for joint service use also creates redundant weighing requirements at the cost of scarce resources and time. The process of determining the vehicle weight, center-of-balance, and individual axle weights for load planning and assets visibility consists of: staging and identifying the vehicle; determining the individual wheel weights; determining the axle spacing; calculating the total weight, center-of-balance and individual axle weights; marking the vehicle with its total weight and center-of-balance; accumulating the vehicle data for a group of vehicles; and, finally, entering the data into an electronic database to enhance military planning and visibility capabilities. Presently, the entire process is performed manually using a large static truck scale or multiple individual portable wheel weight scales, tape measures, calculators and clipboards. The process is very time consuming, manpower intensive and prone to human errors. The WIM system, shown in Figure 1, can greatly reduce the time required to perform this operation and eliminate the human errors that result from the manual nature of these measurements, calculations, and data input.

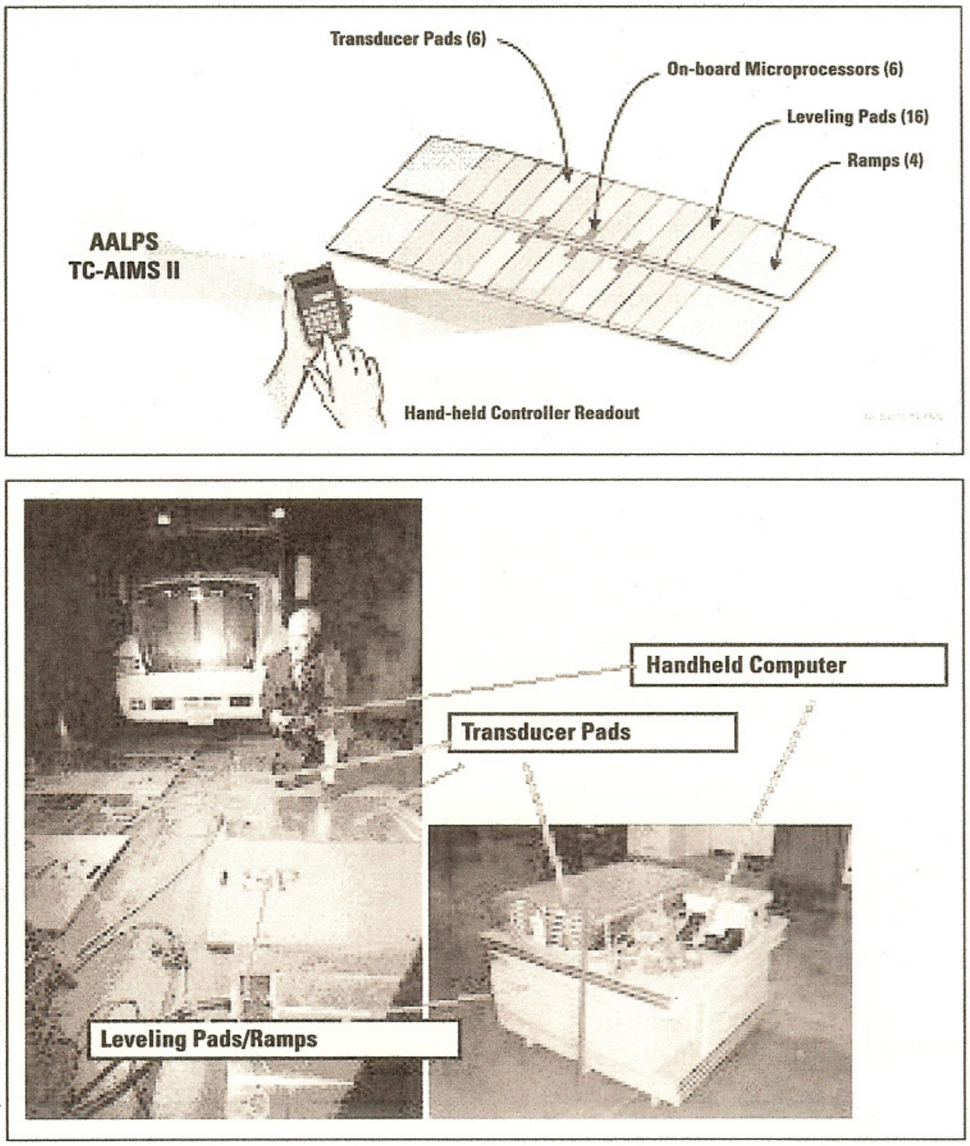


Figure 1
(Top Panel) WIM Gen II Artist Conception and (Bottom Panel) Actual WIM Gen II Assembled and Disassembled

Key Features of WIM-RBC

The objective of the WIM-RBC is to provide a secured, Web-enabled, and central data and service repository for configuration and data management processing that is used to continuously analyze and improve the WIM system. The WIM-RBC stores and retrieves disparate types of system, logistics, and technical information in the form of text, data, images, and video using relational Structured Query Language-based data sources, flat files and external Web services as required. All of this is readily accessible through a simple Web browser User Interface (UI). The information storage and access is executed immediately over the Internet.

Figure 2 provides a high-level system design of the WIM-RBC. WIM fielded and test equipment push information to the WIM-RBC over the Internet using eXtensible Markup Language (XML) that includes the schema (format) and contents for: (1) the Deployment Equipment List (DEL), (2) detailed WIM scale data, (3) images (such as jpegs) of vehicles, (4) additional conveyance information, (5) measurement and timing data,

(6) weather data, and (7) video as required. The XML is validated, processed and committed to the database through the WIM-RBC Web Services interface. The detailed WIM scale data includes the "raw" data from each pad for each weight measurement. This data is used for further analysis to identify efficiencies, improvements and performance correlations. By design, all information concerning WIM operations and equipment, including equipment manufacturer, serial number, model and specifications, are stored in the WIM-RBC data repository.

In addition to storing configuration, operational and test information, the WIM-RBC also hosts the configuration control for the WIM software using Subversion, the Next-Generation Open Source Version Control source code version control from the CollabNet Open Source community.[6] The versioned WIM software includes the source code for the WIM scale micro-processor and WIM Host microprocessor (Windows XP operating system), Handheld Controller (Windows Pocket PC operating system) user software, the Local WIM Relay Host and the WIM-RBC software.

For the user WIM-RBC provides a secured Web browser UI that is used to access and manage the services and data repositories from anywhere on the Internet. The UI was designed to be simple to allow authorized users to submit information, query, edit/update, produce reports, and produce tabular formed data for follow-on analysis and processing.

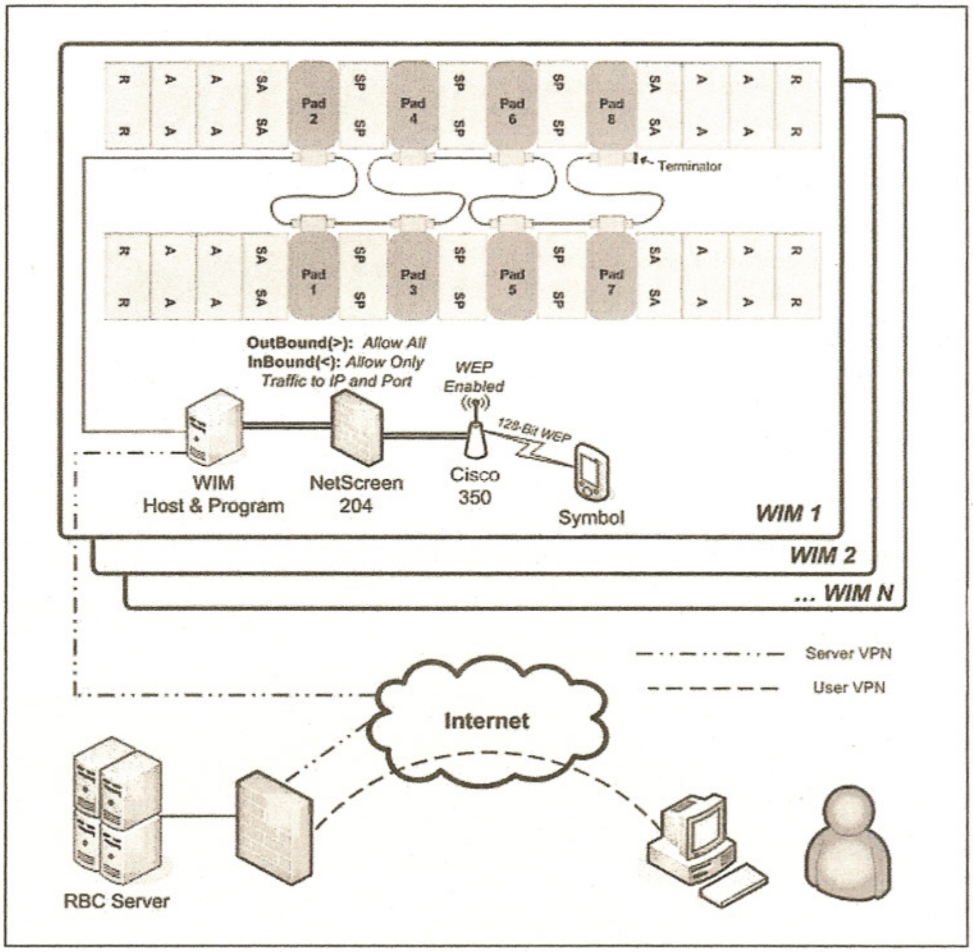


Figure 2
WIM-RBC High-Level System Design

WIM-RBC Data and Processing

The WIM-RBC information is modeled using two complementary forms: the Unified Modeling Language (UML) and the WIM-RBC XML Schema. UML is the standard object-oriented notation that facilitates modeling the structure, architecture, and behavior of systems, software and data. An XML Schema describes the structure or format for an XML document for such things including the contained elements, the order of the elements it contains, and the quantity and relationship of each element.

Figure 3 illustrates an overview of the WIM-RBC UML structural or class diagram. Note that the attributes and cardinality have been filtered in this view for clarity. The UML class diagram is divided into four main sections: (1) DEL Model, (2) WIM Scale Details, (3) Vehicle Details, and (4) Vehicle Tracking.

The DEL model is used to store all the elements for Military items that are planned for movement and measured by the WIM System for load planning. In addition to this relational model primarily used for query and reporting, the DEL, in its raw text-based format, is stored in the file system. The WIM Scale details model provides the storage and access for the data collected during a weight and measurement session for a particular vehicle. Although the DELTransport class identifies vehicles, a separate vehicle class is provided in the Vehicle Details model for those vehicles that are measured during a non-Military or non-DEL exercise and testing. Such activities are part of the on-going verification process for the WIM system involving laboratory evaluations and commerce operations. Finally, the

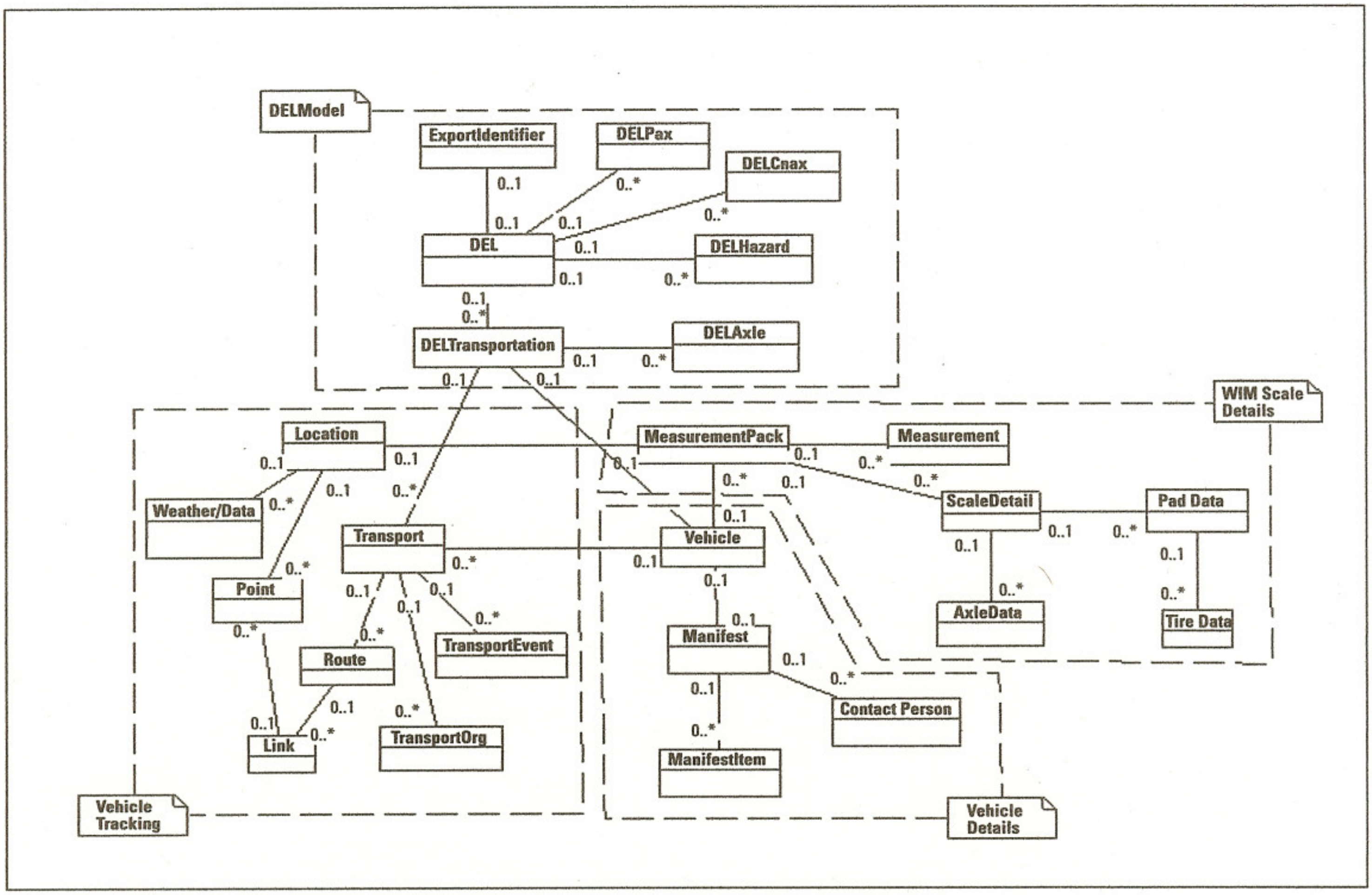


Figure 3
WIM-RBC UML Class Diagram Overview

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
<xsd:element name="DEL" type="DELType"/>
<xsd:complexType name="DELType">
<xsd:sequence>
<xsd:element name="RecordType" type=" xsd:string "/>
<xsd:element name="PlanId" type="xsd:integer"/>
<xsd:element name="PlanLegId" type="xsd:integer"/>
<xsd:element name="PlanName" type="xsd:string"/>
<xsd:element name="POECode" type="xsd:string"/>
....
</xsd:sequence>
</xsd:complexType>
...
</xsd:schema>
```

Figure 4
A Portion of the WIM-RBC XML Schema

Vehicle Tracking model is a Route design pattern that is used to record the movement of a vehicle with respect to the WIM Systems that may be used in its transport path. This is particularly useful in commerce and inter-modal, multi-leg transports where a vehicle crosses one or more states in the continental United States or country jurisdictions.

All measurements for vehicles, including but not limited to weights, detailed weights, cube data and images, are stored in the WIM-RBC repository. In Figure 3 each vehicle can have many measurement packages (called MeasurementPacks) such that vehicle measurements can be stored if measured many times during a single loading session.

For the WIM-RBC the XML Schema directly reflects the UML model including not only the attributes of each class but also the relationships among the classes. Figure 4 provides an example of the schema that describes part of the UML in Figure 3.

The UML is used to drive the storage repository design. To complement this the XML Schema is used to drive the message format design for communications to the WIM-RBC and among the WIM software components. This schema serves as the foundation for a common communications protocol and any authorized fielded or test system that posts data that conforms to the XML standard. In this way, posts are saved to and made available to the WIM-RBC service.

Summary

The development of the WIM-RBC embodied in the current WIM Gen II system demonstrates a configuration and data management strategy that ensures data integrity, coherence, and cost effectiveness during the WIM and Measurement systems validation, verification, testing and certification activities. The WIM-RBC is based on a Web services architecture implemented using commercial off-the-shelf products, through the best practices of software design with the UML and XML Schema. Fielded WIM and measurement systems and XML-compliant messages are engaging the WIM-RBC to store collected data in the WIM-RBC information repository. Through a Web browser authorized users securely access this repository, generate reports and obtain separate tabular data for follow-on custom analysis. The WIM-RBC intends to store all collected measurement data that will ultimately be used to determine the life-cycle cost of the WIM measurement systems (including related measurement systems such as volumetric and center of balance).

End Notes

1. Rolfsen, B., *Weight of Cargo Cited in Crash of MC-130H*, **Army Times**, December 9, 2002, *http://www.armytimes.com/archive paper.php?f=0-ARMYPAPER-1340371.php.*
2. Levin, A., "Airlines Should Weigh Passengers, Bags, NTSB Says; Agency Finds Overloading Was Factor in N.C. Crash," *USA Today*, February 28, 2004, p. 8A.
3. Keane, J.M., *Commander, XVIII Airborne Corps Validation of the Requirement for a Portable Vehicle Weigh-in-Motion (WIM) System in Accordance with the Operational Need Statement*, Official Correspondence to US Army Training and Doctrine Command, March 14, 1996.
4. Coats, Jr., J.E., Abercrombie, R.K., Beshears, D.L. and Honea, R.B., *Weigh-In-Motion Technology for Military Operations, Developing a Portable, Safe, and Accurate System*, Transportation (TR) News, Transportation Research Board of the National Academies, Transportation Research Board Publications Office, Number 231, March-April 2004, p. 16-18.
5. Coats, Jr., J.E., Abercrombie, R.K. and Honea, R.B., *Weigh-in-Motion (WIM) Technology for In-Theater Applications*, 83rd Annual Meeting of Transportation Research Board Military Transportation Committee – AT035, January 14, 2004.
6. CollabNet Enterprise Edition, Open Source Software Engineering Tools, Subversion Project home, *http://subversion.tigris.org/.*

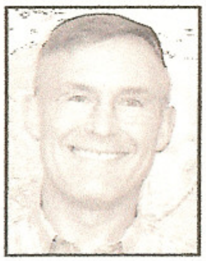
Reference

1. Abercrombie, R.K., Beshears, D.L., Scudiere, M.B., Coats, Jr., J.E., Sheldon, F.T., Brumbaugh, C., Hart, E. and McKay, R., *Weigh-In-Motion Research and Development Activities at the Oak Ridge National Laboratory*, Fourth International Conference on Weigh In Motion, Taipei, Taiwan, National Science Council, National Taiwan University Publications (ISBN 986-00-0417-X), 02/20/2005-02/23/2005, p.139-149.

Authors' Biographies

Robert K. Abercrombie, Ph.D. has over 25 years of experience in the fields of computer science and logistics. He currently is a senior program manager at ORNL. Formerly, he was an adjunct professor at the University of Tennessee in Computer Science, and has been a senior research staff member and group leader at Department of Energy's Oak Ridge Reservation. He received his doctorate from the University of Tennessee, Knoxville, his master's degree from the University of Missouri, Columbia and his bachelor's degree from The College of William & Mary, Williamsburg, Virginia. He has been a recipient of National Science Foundation, National Institutes of Health (NIH), and Alfred P. Sloan pre-doctoral research fellowships, and a NIH NLM (National Library of Medicine) post-doctoral fellowship in bioinformatics and computer science. He is a current member of SOLE - The International Society of Logistics and a past member of American Association for the Advancement of Science, Military Operations Research Society, Institute for Operations Research and the Management Sciences, and Armed

Forces Communications and Electronics Association. He has published over 300 technical reports and numerous papers in various journals and international conferences. He has extensive experience in all phases of program and project life cycle management from requirements definition through retirement and closeout of system(s). Additional strengths include technical management of research and development multidisciplinary complex endeavors. His research interests include wired and wireless high performance information infrastructures technologies with respect to logistics, Information Assurance, and security requirements.



Frederick T. Sheldon, Ph.D. has over 22 years of experience in the field of computer science. He currently is a senior research staff member at ORNL. Formerly, he was assistant professor at the Washington State University, the University of Colorado, and research staff at DaimlerChrysler, Lockheed Martin, Raytheon and NASA Langley/Ames. He received his doctorate/master's degree from the University of Texas at Arlington in 1996/1989, and has two degrees from the University of Minnesota in computer science and microbiology. He founded the Software Engineering for Secure and Dependable Systems Lab in 1999. He is a Senior Member of the Institute of Electrical and Electronics Engineers, Inc. (IEEE) and member of the Association for Computing Machinery, the International Association of Science and Technology for Development, the American Institute of Aeronautics and Astronautics, the Tau Beta Pi and Upsilon Pi Epsilon honor societies, and has received the Sigma Xi award for an outstanding dissertation. He has published over 60 papers in various journals and international conferences. His research has been concerned with developing and validating/testing models, applications, methods, and supporting tools for the creation of safe, secure and dependable software/systems.

Robert G. Schlicher has over 18 years of experience developing software. He is currently an enterprise architect at EigenSoft and has established a broad and successful career designing large-scale, distributed software systems using UML, patterns, cyber security, and developing and integrating systems using Java, C/C++, Python, and Perl. His primary areas of expertise are distributed computing and enterprise integration, large-scale/volume systems, peer-to-peer, and agent-based networks. Mr. Schlicher is currently engaged in developments involving Web services for J2EE, multi-player game servers, rule engines, and integrating legacy systems. He has specified and built systems for the U.S. Department of Defense, Department of Energy, and Fortune 1000 companies in the Insurance, Finance, Logistics, and Entertainment markets. Mr. Schlicher has been an IEEE member for 18 years. He did his masters studies in electrical engineering at Boston University and received his bachelor's degree in electrical engineering from Mississippi State University.

Kristopher M. Daley is a cyber security researcher with the Cyber Security and Information Infrastructure Research group that is under the Computational Sciences and Engineering directorate at ORNL. He provides cyber security hardware and software

support to secure both new and current projects within the group. He is also involved in the development and research of new security technologies. He participates in proposal and quality assurance plan authoring, project planning, website construction and maintenance, programming, and publishing efforts. Previously, he was a systems security designer for the National Security Agency (NSA). At the NSA he worked as an information systems security engineer, performing information systems security design and review for civil agencies. During his college career he was part of the University of Tulsa's Center for Information Security (CIS), a designated NSA Center of Excellence and Faculty Development Center, reporting directly to CIS founding members Director Dr. John Hale and Dr. Sujeet Shenoi.