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The NOνA module factory quality assurance system

Alex Smith for the NOνA Collaboration*

University of Minnesota, 116 Church St. S.E., Minneapolis, MN 55404, USA

Abstract

The NOνA experiment will measure neutrino oscillations using a long-baseline beam, a ~220-ton near detector and a ~15-kiloton far detector. Production of ~12500 modules to build these detectors is an industrial scale operation requiring careful quality assurance to meet the stringent technical specifications. Unlike a typical industrial operation, this project will use primarily a *part time* labor force of ~200 University of Minnesota undergraduate students managed by a small team of full time employees. The quality assurance system is involved in nearly every aspect of the production: assembly, scheduling, training, payroll, materials, machine maintenance, test data, and safety compliance. The quality assurance data collected during the assembly process allows us to quickly identify and correct any problems that arise.

neutrino; oscillation; quality assurance; production

1. Introduction

NOνA is a long-baseline neutrino oscillation experiment, which uses muon neutrino/anti-neutrino beams from the Fermilab Main Injector. In transit to the far detector, some muon-type neutrinos may oscillate into electron-type neutrinos. Neutrino composition of the beam is measured at distances of 1 km and 810 km using a ~220-ton near detector at Fermilab and a ~14-kiloton far detector at Ash River in northern Minnesota [1]. The detector elements are PVC plastic tubes filled with liquid scintillator and a loop of wavelength shifting fiber, which is read out by one pixel of an avalanche photo-diode array at one end of the tube [2]. In practice, the tubes are produced as sixteen-cell extrusions. In the first step of module assembly, two of these extrusions [3] are glued side-by-side to make a 32-cell module. The remaining process steps involve stringing the wavelength shifting fibers down the 16 m length of each cell, attaching injection molded PVC plastic parts to route the fibers through an optical connector, facing the optical connector, and attaching the covers to make a liquid-tight seal. The readout end of the module is shown in an exploded view in Fig. 1 (a). A two-adhesive solution is used to make the liquid-tight seals, as shown in Fig. 1(b). An inner seal is made with adhesive known to be inert in liquid scintillator, and an outer seal is made using an adhesive that is very strong, but known to interact with liquid scintillator. In total, almost 100 individual parts are added to the module before it is shipped to the far detector site. A prototype detector has been assembled and is being operated [4] in a beam halo at Fermilab.

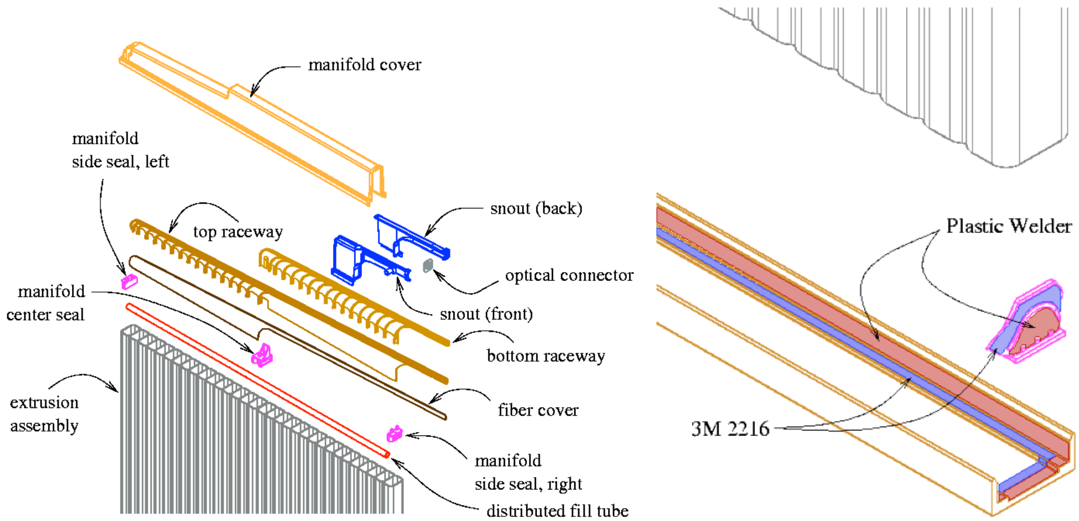

Fig. 1. (a) This shows the main components of the readout end of the module in an exploded view. (b) The module liquid seals are made with two adhesives: an inner seal adhesive which is known to be inert in scintillator, and an outer seal adhesive which is very strong, but known to interact with scintillator. This figure shows how adhesive is applied to the non-readout end of the module.

2. Challenges

The PVC plastic modules that form the structure and liquid scintillator containment for the detector are produced in a factory operated by the University of Minnesota, using primarily part-time University of Minnesota students to perform assembly work. There are several challenges involved in making use of this labor pool. Students work an average of about 12 hours per week and schedule their own hours. At peak production approximately 250 students will be in our employ, with as many as ~70 in the factory at a time. A small team consisting of two senior factory managers and only six full time employees manages these students.

There is a very tight tolerance on the leak rate of oil from the assembled detector. The leak test is performed by first pressurizing the test module and a functionally identical reference module with air. Then, the two volumes, each about 1 m^3, are connected through a flow meter and, after a long equilibration time, the flow rate can be determined. This flow is required to be less than 3.3 std. cc/min---a change of only ~3 parts per million per minute.

The wavelength shifting fibers are easily damaged during handling and must be checked for light transmission at several stages in the process. The total failure rate for modules must be kept below two percent, as that is the number of spare parts ordered. The fibers are tested a five different stages of assembly, so that damaged fibers can be detected and replaced while they are still accessible. The modules have stringent tolerances on length, square, and flatness. They are required to be flat within 0.5

mm and have an area of more than 20 m^2. A small robot accomplishes the flatness measurement while driving down the length of the module, reporting data to the quality assurance system over the wireless network.

The modules are quite large, 16 m x 1.3 m x 7 cm, and weigh approximately 450 kg. Production of a single module is spread over five days in order to accommodate overnight adhesive curing and two overnight leak tests. At peak output of 30 modules per day, there will be 150 modules in production at a time. Thus, a delay in any step in the assembly sequence will likely cause production to stop due to space constraints within the factory.

There are many items to keep track of in this operation. Incoming parts and materials must be checked for defects and dimensional tolerances. Defects are possible at all stages in the assembly, and may include misaligned or missing parts, adhesive where it should not be, and damage to parts. The process involves a large number of complex machines, including fourteen two-component bulk adhesive dispensers, lifting fixtures, robots, and a host of other custom-built devices. The assembly process itself depends critically upon proper employee training and the ability to identity where retraining is needed.

3. Quality assurance system

The quality assurance (QA) system hardware consists of a local application server cluster and database cluster with high availability failover capabilities, as shown in Fig. 2. Approximately fifty client computers are located at assembly stations throughout the factory. These communicate with the server machines over a wireless network. Employees interact with the system primarily by using wireless Bluetooth scanners or touch screen panels connected to the client machines. Data is generated by several custom devices throughout the factory, which are used to perform such tasks as testing for leaks, testing wavelength shifting fiber transmission, facing the optical connector, measuring module flatness, or performing machine maintenance. Control and data collection from these devices is fully integrated with the QA system.

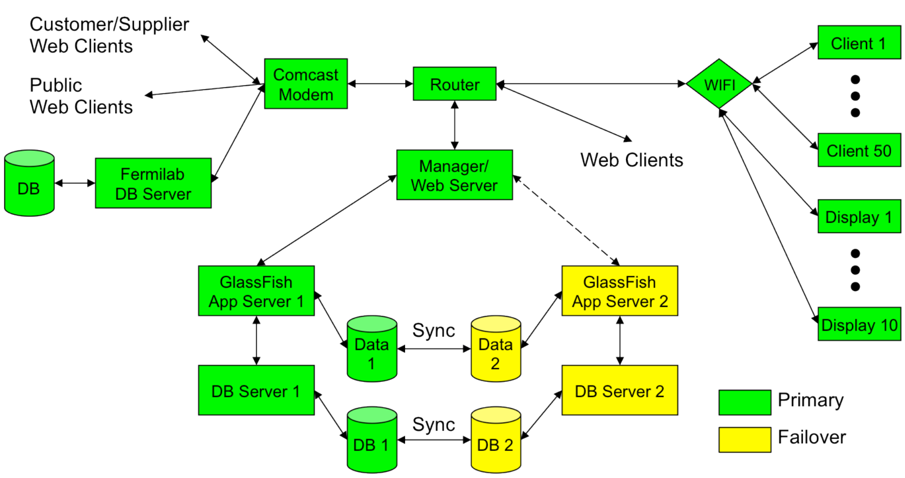

Fig. 2. The key components of the QA system are the application server, database server, web server, and client computers. There is a redundant failover server branch with will automatically take over when either the primary application server or the database server fail. The database and data files are continuously synchronized to maintain a hot backup.

3.1. Goals of the system

The QA system is being used for nearly every aspect of module production in order to ensure that we produce modules meeting the tolerances and on schedule. Having real-time tracking of the assembly process is essential to meeting these ends. The software has been designed with the following goals in mind:

- Ensure that all tolerances are met.
- Collect data during assembly process to allow us to quickly identify, diagnose, and fix any problems that arise.
- Interface with test devices:
  - Interpret, summarize, and archive data
  - Provide pass/fail feedback to employees
  - Centralize calibration data
- Guide assembly process to prevent mistakes.
- Provide management tools:
  - Online self-scheduling of employees
  - Web-based views of data
  - Employee training management
  - Allocation of labor
  - Incoming material inventory and quality assurance
  - Machine maintenance enforcement, guidance, and data collection
  - Enforcement of compliance with safety standards
  - Reporting of progress and labor expenditures to project management
- Provide data to collaborators

3.2. Software framework

The system has three functionally distinct software components: scanning and data collection, web interface, and alarm system. All systems are built on free software.

The scanning and data collection system is the core component and includes the client and server side code and the database. The system is a multi-tiered enterprise application written in Java Enterprise Edition and is deployed on two GlassFish application servers, which connect to a PostgreSQL database. A database hot backup is maintained on a separate server and failover of the application server or database is supported in the event of a failure of either. The client side graphical user interfaces are written in Java Swing and provide a user-friendly interface at assembly stations throughout the factory.

An alarm system is displayed on large panel televisions at key locations in the factory. These displays can be configured with information that is relevant for each location, as shown in Fig. 3. Options include color-coded alarm tiles and information alerts, as well as station-specific data. This package is written mostly in PHP.

The web interface is written primarily using Java Servlets and runs on a separate web server. This interface provides detailed views of data collected in the assembly process, as shown in Figs. 4-5, as well as an interface for student employees to self-schedule.

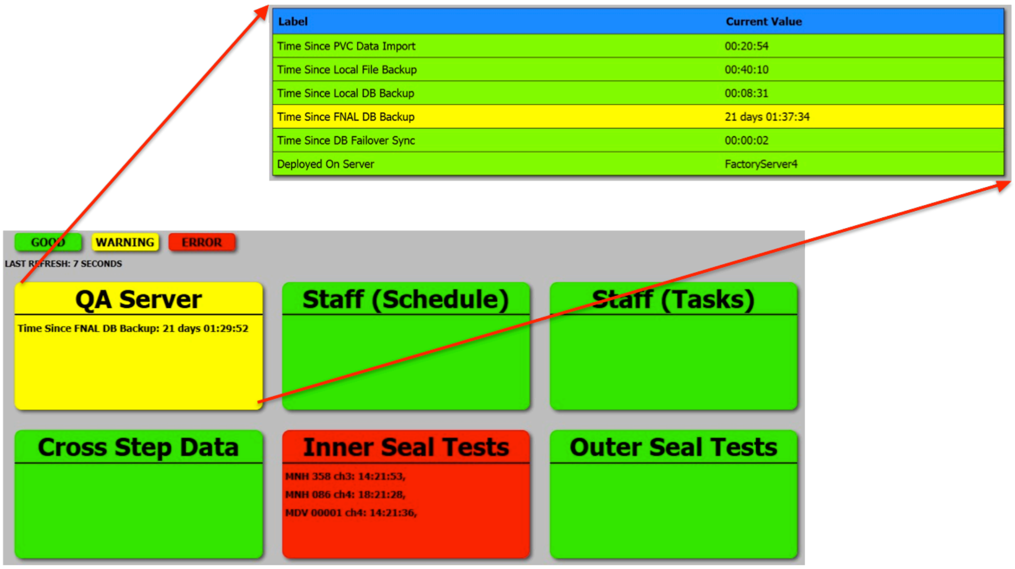

Fig. 3. The alarm system displays relevant color-coded tiles on large-format LCD televisions at key locations in the factory. Users can click on a tile to view the details of the alarm.

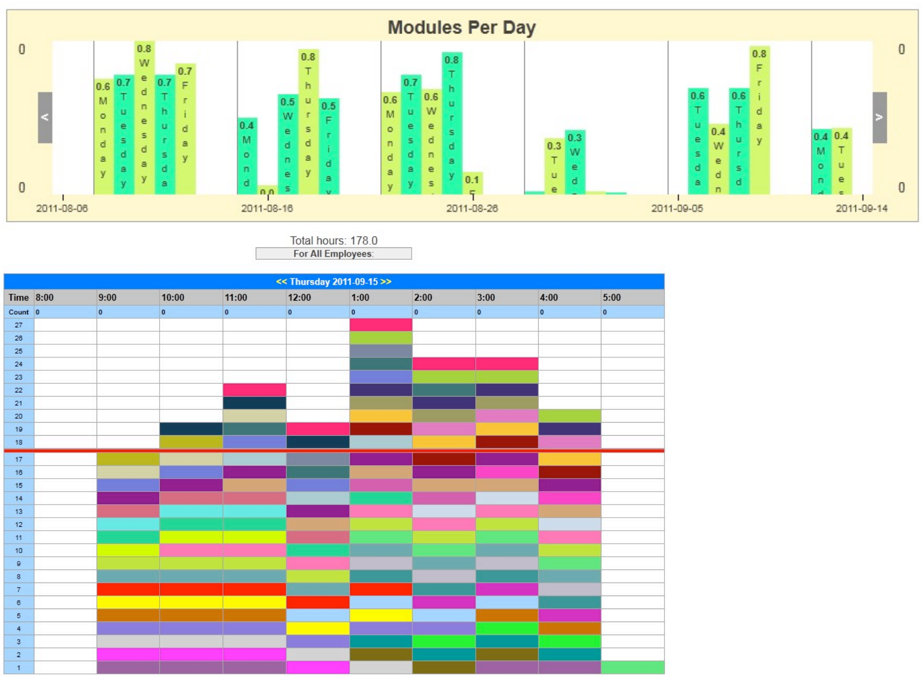

Fig. 4. The web interface provides useful views of nearly every aspect of the module production, such as (a) module production progress and (b) the labor profile for each day.

4. Examples of operation

4.1. Joining two 16-cell extrusions to make a 32-cell module

The first assembly step is to join two of the 16-cell PVC plastic extrusions into a 32-cell structure that forms the base structure of the module. The user begins by scanning their employee identification bar code, then a code identifying the assembly step to be performed. The panel shown in Fig. 6 (a) prompts the user to scan bar codes identifying the adhesive dispenser, shown in Fig. 6 (b), lifting fixture, and the two extrusions. Bar code stickers corresponding to the next module in the sequence are automatically printed. The user is then reminded to put their respirator mask on to prevent exposure to fumes from the adhesive and prompted to scan a bar code to acknowledge. The user is prompted to acknowledge after the glue joint is clamped to start a timer, which alerts the user when the adhesive has cured. Several checks are performed by the quality assurance system during this procedure:

- Are extrusions within tolerance?
- Is there any missing QA data from the extrusion supplier?
- Are the two extrusion heights compatible with each other?
- Does the employee have a respirator assigned?
- Are the employee's respirator cartridges within the exposure threshold?
- Are the module vacuum lifter, gantry, and hoist current on their scheduled service and inspection?
- Is the adhesive dispenser current on its maintenance and glue component ratio calibration?

If any of these conditions are not met, the user is alerted.

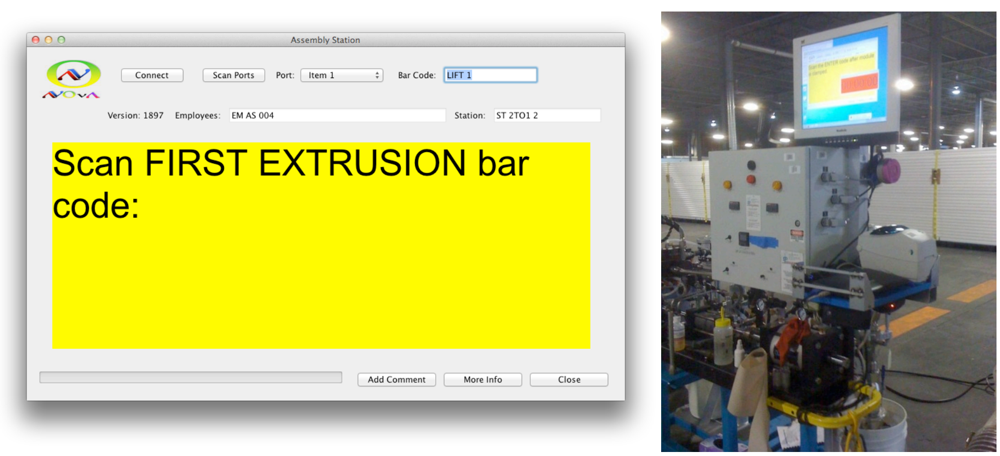

Fig. 6. (a) This is an example of a client interface panel used for the first assembly step of joining two sixteen-cell extrusions to make a thirty-two-cell module. (b) A quality assurance client mounted on a bulk adhesive dispenser.

4.2. Leak test of module

Modules must be leak tested overnight in order to achieve the required leak sensitivity. Like all assembly steps, the process is initiated by the employee scanning their identification badge bar code and the bar code corresponding to the type of leak test task. The panel shown in Fig. 7 (a) is displayed on the touch screen monitor. The user is prompted for the bar code of the pressure containment shield that goes around the module cover, the bar code on the pressure connector for the channel connected to the module, and the module bar code. The button corresponding to this channel on the touch panel monitor becomes active and changes to “Fill”. When that button is pressed the module is automatically filled to the appropriate test pressure, the user is prompted to close the valve which bypasses the flow sensor, the system is allowed to equilibrate for a preset time and finally, the button becomes activated and its text gets set to “Start”. Pressing that button begins the test. While the test is running, the database and web site get refreshed with data and plots every 10 minutes, so that progress can be monitored from a remote location. When the test is complete, pressing “End” will guide the user through final verifications of the hardware functioning, shown in Fig. 7 (b) and commit the final data to the database.

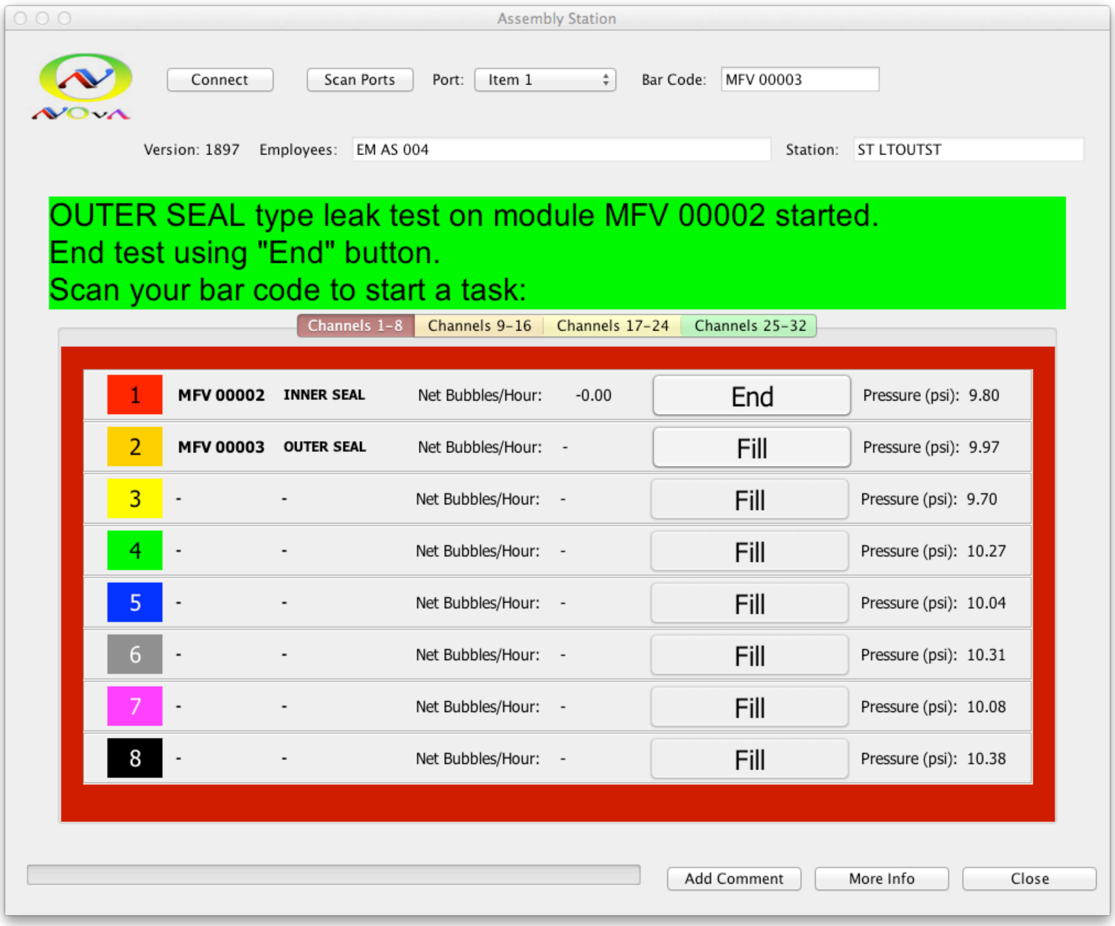

Fig. 7. (a) This is an example of the leak test interface panel.

Fig. 8. A 32-channel leak tester is shown. The device measures leaks by counting bubbles as air flows from the reference module (not shown) to the test module.

Conclusions

The NOνA module factory QA system is a comprehensive framework for managing production and quality of modules that will be used to build the near and far NOνA detectors. The system was used for the production of modules for a prototype detector, currently in operation at Fermilab. The system is designed to be flexible and expandable, should issues in production require additions or changes. Indeed, experience in production of the prototype detector modules has guided the direction of development for the far detector module production. Because of its success, this system is being used as the basis for a QA system for assembly of the far detector at Ash River.

Acknowledgements

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References

[1] D.Ayres, et al., NOνA Proposal to Build a 30 Kiloton Off-Axis Detector to Study Neutrino Oscillations in the Fermilab NuMI Beamline, http://arxiv.org/abs/hep-ex/0503053 (2005).

[2] S. Kasahara, NOνA Data Acquisition System, in: Technology and Implementation in Particle Physics 2011 (these proceedings), 2011.

[3] S. Phan-Budd, Construction of PVC Extrusions for NOνA Near and Far Detectors, in: Technology and Implementation in Particle Physics 2011 (these proceedings), 2011.

[4] M. Muether, Initial Performance from the NOνA Surface Prototype Detector, in: Technology and Implementation in Particle Physics 2011 (these proceedings), 2011.