The NOvA Module Factory Quality Assurance System

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for the
NOvA Collaboration
NOνA Physics Goals

- $\sin^2(2\theta_{13})$
- Determine neutrino mass hierarchy using MSW matter effects
  - Possible because NuMI can provide both neutrino and antineutrino beams
- Limit parameter space of $\delta_{\text{CP}}$
- Precise measurement of $\sin^2(2\theta_{23})$
- Potential to observe neutrino flux from galactic supernovae
**NOvA Detector Module Design**

- Wavelength shifting fiber looped through tube filled with liquid scintillator
- Many custom injection-molded PVC parts required to route 64 fiber ends and seal each module
- Two adhesive seals
  - “Inner”: a buffer that does not react with scintillator, but moderate strength
  - “Outer”: about as strong as PVC itself
- Modules assembled 12 across and 12 high at FD site
A Matter of Scale and Cost…

- Industry-scale production operation:
  - ~12,000 modules
  - ~500 outgoing semi-truck loads of modules
  - Up to ~150 truck loads stored in factory
  - 125,000 sf production space

- Cost per module is critical
  - Student labor
  - Low reject rate: <2%
    - ~$5000 for each rejected module

- Many part-time employees
  - Up to 200-250 student employees at a time (up to 70 in the factory at a time)
  - 400-500 total employees for ~2.5 year duration of production
Assembly Challenges

- Build ~12000 far detector modules
- Large *part-time* University of Minnesota student work force
  - ~70 part-time employees in factory at a time during peak
  - Small full-time crew of two senior managers and five full-time managers
- Material handling
  - Modules are 16 m x 1.3 m x 0.7 m and weigh about 450 kg (1000 lbs)
  - Production of a single module spread over 5 days
  - Work on up to 150 modules at a time
  - Delay in any assembly step quickly leads to traffic jam
- Stringent technical requirements:
  - Liquid leak rate (tested with air)
    - Test: detect air leak of ~3.3 std. cc/min from a ~1,000,000 cc volume
    - 12 hour minimum test duration to reach this sensitivity
  - Flatness requirement of 0.5 mm over more than 20 m²
  - Wavelength shifting fiber light transmission
    - Fibers easily damaged
    - Three different tests to check for damage
- **Real-time tracking of assembly process is essential**
Goals of Quality Assurance Software

• Ensure that modules meet specifications before shipping
• Collect data during the assembly process to allow us to quickly identify, diagnose, and fix any problems that may arise.
• Interface with test devices to collect data
  – Interpret, summarize, and archive data
  – Centralize calibration data
• Guide assembly process to prevent mistakes
• Provide tools to:
  – Manage large number of part-time employees with a small team of full-time employees
  – Manage training of employees
  – Ensure quality and manage inventory of parts and materials
  – Guarantee maintenance and proper functioning of the large number of machines
  – Ensure compliance with safety standards
  – Ease reporting to safety agencies
  – Simplify reporting to project management
Software Framework

- Built on Java Enterprise Edition (Java EE)
  - Multi-tiered enterprise application
- Deployed on GlassFish application server cluster
  - Two servers
  - Failover
- PostgreSQL database
  - Two servers
  - Sync to hot failover
- Web tier
  - Based on Servlets, PHP, and JSF
- Client tier
  - Java GUI application clients
  - Started from Java WebStart
    - Downloads installs code if needed
    - Auto update of code if changed
  - Provide interface to employees
    - Instructions
    - Error alerts
    - Audio and voice feedback
  - Receive input primarily from Bluetooth bar code scanners and touchscreen panels
Employee Management

- Login/logout to track actual hours
- Online scheduler
  - Students schedule themselves
- Employees scan into their tasks
- Safety equipment tracking

EM AS 004 logged in.
Respirator exposure 4 hours.
Scan your bar code.
Labor Allocation and Training

- Managers use “Day Planner” tool to decide how to allocate the day’s work force
- Employee training is indicated for each assembly process group
  - Training defined for each group of assembly procedures
- We plan to add algorithms to choose starting labor allocation based on selected priorities
Reporting and Compliance

- Many workers and machines to keep track of

- Safety Compliance
  - Data to demonstrate compliance with safety standards is collected
    - Respirator usage and maintenance
    - Gantries and lifting device maintenance

- Expenditure reporting to project management
  - Employees track their work by scanning corresponding bar codes

- Payroll
  - Required data is collected to automate payroll
  - We plan to switch to automated timesheet generation soon
Inventory Management

- Shortage of part or supply could have serious impact on project schedule
- Some injection molded parts have lead times on the order of months
- Adhesives have limited shelf life
  - Cannot be ordered too far in advance
  - Shelf life must be checked before use
- Many small items to track
  - Adhesive mixing nozzles
  - Bar code labels
- Alarm system alerts management when inventory drops below configurable warning and error thresholds
- Tools for receiving and checking out parts
Alarm Systems and Displays

- Can be configured with relevant information for each factory location

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Inventory</th>
<th>Warning</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Raceway Insert</td>
<td>100</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Bottom Raceway</td>
<td>51</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>WLS Fiber</td>
<td>-325</td>
<td>100</td>
<td>40</td>
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<tr>
<td>Fiber Retaining</td>
<td>7038</td>
<td>6400</td>
<td>3200</td>
</tr>
<tr>
<td>Optical Connector</td>
<td>368</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Bottom Raceway</td>
<td>260</td>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>
Configurable Alarm Displays

Location of stacks

Extrusion details

Extrusion Stack
- Location: Bay 4, Row 2, Col 5 (4/15 11:54 AM)
- Location: Bay 4, Row 1, Col 5 (4/15 10:22 AM)
- Location: Bay 4, Row 3, Col 4 (4/15 10:24 AM)

Inventory
- WLS Filter: 325 (Threshold: 40)
- Top Recessed Insert: 100 (Threshold: 100)
- Bottom Recessed Insert: 55 (Threshold: 100)

QA Server
- Time Since DB Failover Sync: 00:51:29

Staff
- Rob Skorlitz: No Task for 06/24/26
- April Staggens: No Show
Assembly Tracking and Checks

Example: Joining two extrusions:

• The scanner interface panel guides the employee through assembly process
• Scans capture ID of employees, gluing jig, adhesive dispenser, extrusion ID’s, lifting fixture.
• Checks:
  – Does employee have a respirator assigned?
  – Are respirator cartridges within the exposure threshold?
  – Are extrusions within tolerance? Any missing data?
  – Are two extrusion heights compatible with each other?
  – Are module lifter, gantry, and hoist current on their scheduled service and inspection?
  – Is the adhesive dispenser current on its maintenance and ratio calibration?
• Automatically determines next module ID from database and prints bar code labels
• Starts adhesive cure timer when module is clamped and sounds bell when ready.
Assuring Module Flatness

- Flatness of module impacts strength of detector structure
- Custom robot drives down module to measure flatness of the module
  - Employee is alerted if module is out of tolerance
- Alarm is displayed on factory monitor panel
- Data is uploaded to the database and is viewable on the web

Ends of fit to each extrusion must fall within tolerance

Flatness measurement made for each cell at 5 locations along length of module
Installation of WLS Fibers

- Added extra fiber tests based on prototype detector experience
  - Throwing away a module costs >$5000
  - Test fibers as early as possible when they can be replaced
  - Test at several stages of assembly
- Fiber loops are pulled down cells using semi-automated pulling device
  - Control and feedback through touch screen panels
- Tension measured and controlled
  - Alarm if tension threshold exceeded
- Fiber transmission measured during pull
  - Alarm if insufficient or sharp drop in transmission
- Fibers threaded through guide channels and optical connector
Additional QA of WLS Fiber

Open-End Laser Test Robot
- Shine laser on exposed far end of fiber loop
- Compare light output against expected output

Closed End Test
- Measure reflected and transmitted light from each end while illuminating other end
  - Use camera to measure light
Closed Module Fiber Test

- Plot transmission intensities from each end of fiber
  - Apply $4\sigma$ cut
  - Reject outliers as bad
  - Refit and apply $4\sigma$ cut

- Continue until no fibers are rejected

- Perform same analysis using reflected intensities
Module Leak Test

- Tester measures flow by counting bubbles passing between equalized test module and reference
- Up to 32 modules per tester
- 12 hour test duration
Conclusions

• System was used to build NOvA prototype detector
  – Added additional QA steps based on experience
• Currently being used for first steps of far detector assembly
• This system is key to meeting the challenges ahead of us
  – Build ~12000 far detector modules
  – Meet stringent tolerances
  – Manage large part-time work force with small full-time crew
• Ongoing development to address new needs and concerns as they arise