*Proceedings of the 2002 Winter Simulation Conference*
*E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.*

# A SIMULATION STUDY OF HIGH POWER DETONATOR PRODUCTION TRANSITION

Johnell Gonzales-Lujan
Robert J. Burnside
George H. Tompkins

Technology Modeling & Analysis Group
Los Alamos National Laboratory
Los Alamos, NM 87545, U.S.A.

## ABSTRACT

Due to changes in production requirements the current facility was no longer adequate. A simulation study was conducted to help quantify the impacts of additional capacity, when that capacity should be brought online, and how to manage production in the interim before the new facility is available.

## 1 OVERVIEW

Los Alamos National Laboratory has performed detonator development and fabrication since the mid-1940s and continued the testing and development of Los Alamos-designed detonators after the war reserve (WR) production mission moved to the facility at Mound, Ohio. In 1993, the Mound facilities were closed, and the WR production mission was transferred to Los Alamos. The WR production mission was to "preserve the capability," which required production of only several hundred detonators per year. However, the projected WR workload has increased by at least a factor of 10, to between five and eight WR-certified lots to be in simultaneous production each year from FY 2002 to FY 2008. In addition to production for stockpile systems, detonators are fabricated for Joint Test Assemblies (JTAs), dynamic tests and experiments, and the Department of Defense. Surveillance inspections and testing are performed on detonators removed from stockpile systems using facilities used for production. R&D on advanced detonators is performed in these facilities. This projected workload cannot be accommodated without additional production facilities.

Consequently, The High Power Detonator Facility (HPDF) Project was initiated to (1) provide the facilities and infrastructure needed for HPD fabrication and surveillance and (2) to house process equipment and systems required for the continued reliable fabrication of WR detonators for stockpile systems. This project will add facility space and increase the number of workstations available for production; it is planned for operation in 2004 time frame. Until then, Los Alamos will be operating in a transition mode to meet short-term production schedules and prepare for increased capacity.

This paper summarizes a study of the high-power detonator production processes at Los Alamos during the transition from the current capability to the upgraded/expanded capability. The following options were analyzed and evaluated: (1) the capacity of the current facility to meet schedules, (2) the location and effects of bottlenecks in the production processes, (3) the effects of the expanded facility coming on line in 2004 vs in 2003, (4) the effects of outsourcing some of the production, and (5) the utilization of the firing stations.

The study uses a discrete-event simulation model constructed with EXTEND™ software from Imagine That Incorporated. This modeling technique allows the user to capture the time-based behavior and interrelationships of the system components. This study has provided operational data used to structure the conduct of operations until the expanded capacity is available. The study also confirmed that the proposed workstation suite will support the planned detonator production schedule.

### 1.1 Production Process

Detonator production includes the following major activities: (1) inspections, (2) high explosive (HE) pellet pressing, (3) low-density HE pellet pressing in plastic headers, (4) high-density HE pressing into metal cups, (5) slapper and cable production, (6) laser welding of electrical contacts, (7) detonator assembly, (8) radiography, (9) component testing, (10) detonator cable assembly, and (11) surveillance.

Detonators are handled in small batches called trays. The tray size depends on the physical size, cable size, and hazard category of each type of detonator. A tray never contains more than 50 detonators and can contain less than that. As inspections identify bad detonators, they are removed from the tray. Inspections are done at the completion of every production/assembly activity. Sometimes, the inspection is complete; other times, sampling inspection is performed. The trays are moved manually among the workstations in the manufacturing buildings. The current layout arranged workstations for one kind of activity in one room of a building.

Certifiable WR production requires a four-phase quality process to complete a build of detonators. Phase I completes the development of the processes. Phase II is a process prove-in (PPI) activity. Phase III is an engineering and quality activity. The last phase, IV, is the production of the WR build for stockpile use. The four-phase certification process increases production 3 to 4 times that needed to meet the stockpile requirements. This level of production contributes to the need for expanding facilities to meet WR production requirements. After certification, a small lot of detonators must be fabricated every 6 months to keep production processes certified.

Detonator manufacturing is an intricate process using one set of resources for up to 11 different categories of detonators. Each category of detonator contains from one to four detonator types and several categories often must be fabricated simultaneously. The sequence of production steps for each category of detonator is different. Production of WR detonators is schedule-driven; Los Alamos receives parts/components from other Nuclear Weapon Complex (NWC) sites, assembles the HE components, and then sends the detonator to another NWC site for installation or use. Therefore, the capacity must be available to meet the schedule, prebuilds cannot be used to level production because components from other suppliers are not available until scheduled times.

## 2 SIMULATION MODEL DESCRIPTION

The discrete-event model of detonator production operations developed in EXTEND™ simulates all of the functions described in the previous sections. The model tracks the progress of individual detonators from initial activities through production, inspection, assembly, back to inspection, and finally either to test firing or to shipping.

The data for the model were collected from the detonator production subject matter experts. The data consist of two parts: (1) workstation operational parameters and (2) the production schedule. The workstation operational parameters, time to do activity, reject rates, and efficiency are maintained in a spreadsheet model file. The operational parameter input files for the EXTEND™ model are prepared automatically from the spreadsheet.

The model can analyze the nature of boundary conditions and various aspects of production system performance, including (1) workstation performance, availability, and reliability; (2) bottleneck identification and analysis; and (3) overtime and multiple-shift influence on production output. The principal operating parameters required by the model are production start date, production quantity, unit process times, and reject rates.

The model is constructed in a hierarchical fashion. The top level shows all of the pertinent resources and input constructs of the model. The detonator production activities (e.g. reject streams, assembly processes, scheduling, routing and information gathering) are modeled on the lower levels of the hierarchy. Figure 1 shows the top level of the model and Table 1 lists the activities in each location.

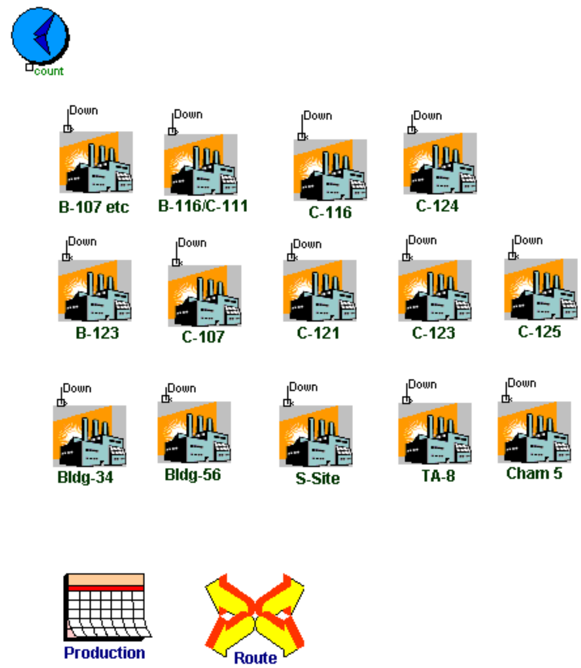


Figure 1: Top Level of the Detonator Simulation Model

As a detonator lot completes production, it is sent to the Final Products H-block which records the arrival time of each lot. The arrival time is used to perform the analysis described in Section 3.

## 3 PRODUCTION OPERATIONS EVALUATION

The model has been used to help evaluate the effects of production capacity on meeting production schedules. The overall production capacity has two components. The first component is the current capacity with the current equipment suite. The second is the capacity with the expanded facility and the additional equipment that is planned to be operational in 2004. The expanded capacity allows WR and R&D production to be segregated. As the additional equipment will not be available until 2004, scenarios were investigated to identify beneficial conduct-of-operations options that would meet production schedules during the transition from the current capacity to the expanded capacity. The capability of the various operational options is done by determining the number of detonators that meet the production schedules compared to the number that are late.

Table 1: Factory Icon List

| ***Building or Room*** | ***Activity*** | ***Equipment*** |
|---|---|---|
| *Manufacture & Fabrication* | | |
| B-107/111/115 | Fabricate Cables | Table & Equipment |
| B-116/C-111 | R&D pressing | Pressing Equipment |
| C-116 | Inspection | Computer Inspection Equipment |
| C-124 | Gluing/Potting | Work Tables |
| B-123 | Clean AL Cans | Tables and Cleaning Equipment |
| C-107 | Assemble Detonators & Cables | Laser Welders |
| C-121 | Pressing | Manual Pressing Stations |
| C-123 | Assemble Pressings | Work Tables |
| C-125 | Assemble Shot Board | Work Tables |
| *Testing & Certification* | | |
| Building 34 | Testing | Explosive Testing Equipment |
| Building 56 | Fabricate Shot Stands | Fabrication (Wood) Equipment |
| S-Site | Surveillance | Surveillance Equipment |
| TA-8 | Radiography | Radiography Equipment |
| Chamber 5 | Testing | Explosive Testing Equipment |

### 3.1 Study Assumptions

The following assumptions were used in the analysis of the detonator operations. The workday is 8 h a day, 5 days a week. Equipment and personnel availability is assumed to be 75%. The 25% reduction accounts for quality audits, security, training, tours, breaks, standard operating procedure (SOP) reviews, maintenance, and qualification exercises that are counted as nonproductive time from a manufacturing perspective. The production day is then 6 h long.

Second-shift efficiency is estimated to be 75% of the day shift. This estimate is comparable to industrial standards for multiple-shift operations involving hazardous materials and incorporates additional downtime caused by workstation reconfiguration as needed for the second-shift operations. This means the second shift has a production period of 4.5 h.

The third-shift production period is assumed to be the 4.5 h, the same as that of the second shift. Reconfigurations and handling of hazardous materials will affect the third-shift operations in the same way as for the second shift.

The equipment suites for evaluating operations are described below. Operators are required to be in attendance during all operations. Inspection workstations typically use computers to analyze components, but some inspections are visual examinations by trained personnel.

Most of the current equipment suite is shared by both WR and non-WR production. Rooms and equipment must be reconfigured to maintain the quality requirements for the WR products. Equipment quantities and types are shown in Table 2. The pressing and assembly workstations are physically segregated between WR and R&D production because of the risk of inadvertently intermixing components among detonators.

The workstation suite for the new facility is shown in Table 3. The workstations are segregated, except for the inspection and laser welding functions, to ensure that quality requirements are maintained. The inspection and laser welding functions can be shared because there is very little risk of intermixing components between WR and non-WR production.

Table 2: Current Workstation Suite

| ***Production Activity*** | ***Workstation Quantity*** |
|---|---|
| High Explosive Pressing | 9 |
| Detonator Assembly | 3 |
| Inspection | 2 |
| Laser Welding | 2 |
| Gluing/Potting | 1 |
| Shot Boarding | 1 |

The expanded workstation suite should support the estimated detonator production. The additional workstation requirements were determined from a previous study (Burnside, 1999). Operators were not modeled directly in the simulation because of the one-to-one correspondence between workstations and operators.

The time period for the evaluation is from 2001 through 2006. The past 2 years of production are included as input to the model to properly fill the detonator production lines. The input schedule is based on the schedule as known in early 2001for all detonators.

### 3.2 Current Workstation Evaluation

The current workstation suite evaluation analyzed the capacity of the current facility and workstations to meet the production schedules under the following four operational scenarios (See Table 4). The first scenario evaluates the current single-shift mode of operation, the second scenario is a two-shift operation, the third scenario comprises two 6-h shifts, and the fourth scenario is three-shift operation. The current workstation suite is not adequate to meet the production schedule without a three-shift operation. Although the three-shift scenario has an acceptable on-time

Table 3: Expanded Capability Workstation Suite

| *Production Activity* | *Non-WR Production* | *Shared* | *WR Production* |
|---|---|---|---|
| High Explosive Pressing | 5 | | 5 |
| Detonator Assembly | 2 | | 3 |
| Inspection | | 8 | |
| Laser Welding | | 2 | |
| Gluing/Potting | 1 | | 3 |
| Shot Boarding | 1 | | 3 |

Table 4: Effect on Production Deliveries with Current Workstation Suite

| *Scenario* | *Early/On Time* | *1-10 Days Late* | *11- 20 Days Late* | *21-30 Days Late* | *Greater than 31 Days Late* |
|---|---|---|---|---|---|
| Single Shift | 20% | 4% | 9% | 8% | 59% |
| Double Shift | 77% | 3% | 1% | 1% | 18% |
| Two 6-h Shifts | 85% | 2% | 2% | 1% | 10% |
| Triple Shift | 91% | 2% | 1% | 1% | 5% |

delivery of detonators using 24-h-a-day production, it does preclude performing preventive maintenance and other support functions during the week and probably the weekends. This is not a viable long-term mode of operation. In the short term, working overtime has been sufficient to meet the production schedules, but that mode of operation cannot go on indefinitely as the analysis of the production schedules indicates.

## 3.3 Bottleneck Operation During Transition

Detonator production during the period from 2001 until the expanded facility becomes available is a concern. This transition period will need to be managed carefully to ensure that production requirements are met. This section provides guidance for operating stratagems during the transition period. Inspection, assembly, and gluing/potting were identified as bottlenecks.

### 3.3.1 Inspection

Because of the number of inspections required for each detonator, inspection will always be a bottleneck. Figures 2 and 3 show the inspection backlog behavior for one-shift and two-shift operation, respectively. The graphs show the backlog of trays, not detonators, where each tray is 50 detonators (or a few less because of rejects). The single-shift operation has such a large backlog that it affects production even when the expanded capacity comes on line. Transition to the expanded workstation suite occurs at 1825 days in both cases.

### 3.3.2 Assembly

Assembly is not expected to be a bottleneck. The five assembly workstations were used between 52 and 62% over the simulation period. Both WR and non-WR workstations had the same use. The exception was the additional non-WR workstation that had a use of 20%.

After transition, there are two periods where WR product accumulates waiting for assembly workstations to become available. Detonator assembly will be a bottleneck during the transition period, but with the capacity to do one non-WR system and three WR systems after transition this condition will disappear. A little less than a year after transition, a backlog occurs, and workstations take approximately 75 days to work off the backlog. The other backlog occurs about 200 days later and takes about 50 days to work off.

### 3.3.3 Gluing/Potting

Gluing/potting is currently a pinch-point. An additional workstation is needed to support the production schedule before the expanded facility is on line. A second shift is not sufficient to keep up with production requirements. In a two-shift simulation using two workstations, a backlog begins to accumulate about 2 years into the simulation and takes almost a year to work down. There are a two other times when backlogs accumulate, but they are worked down in a matter of 1 or 2 months. There are no serious backlog accumulations after the new workstation is in place. Figure 4 shows the backlog behavior for two shifts and two workstations over the simulation period. Using fewer workstations or less production time only increases the backlog during the transition period.

## 3.4 Effects of Expanded Capacity Availability

The availability of expanded production capacity is dependent on the approval, design, and construction processes. Consequently, a study was conducted for two availability dates: one at the beginning of FY 2003 and the

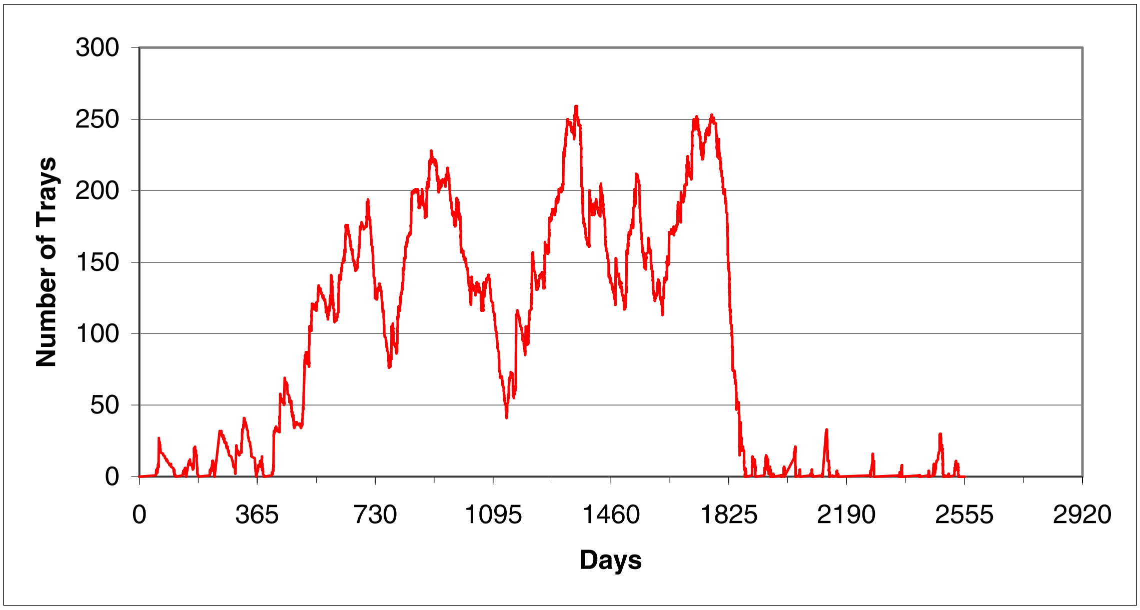


Figure 2: Inspection Backlog with Single-Shift Operation

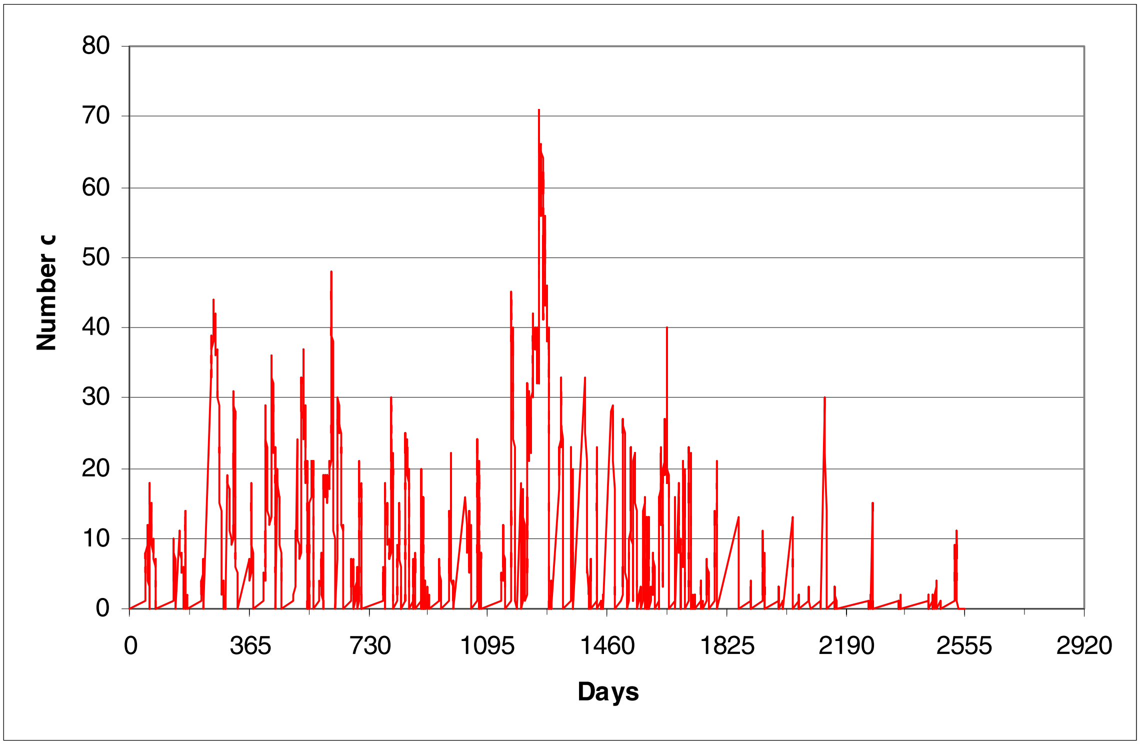


Figure 3: Inspection Backlog with Two-Shift Operation

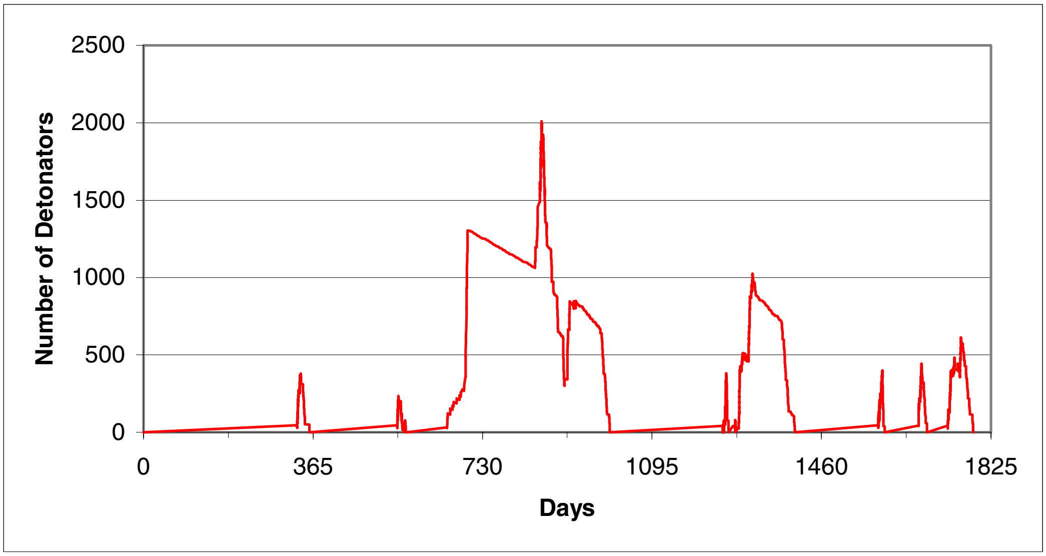


Figure 4: Gluing/Potting Backlog Before Transition with Two-Shift Operation

other at the beginning of FY 2004. The results of the study are discussed below.

Three different shift scenarios were considered in this evaluation. The first is single-shift operation. The second is two-shift operation during the transition period but single shift after the expanded capacity is available. The third is two-shift operation.

### 3.4.1 2003 Availability Date

Table 5 shows the amount of product that can be delivered on time if the expanded capability is available at the beginning of 2003.

### 3.4.2 2004 Availability Date

Table 6 shows the amount of product that can be delivered on time if the expanded capability is available at the beginning of 2004. Generally speaking, a 2004 availability date vs a 2003 date appears to not affect the on-time-production output adversely. However, working around the clock is not the best long-term strategy to produce quality detonators. If the expanded capacity is not available until 2004, it means that the "before transition" production is in an overtime mode of operation to meet the production schedules a year longer. Obviously, detonator production is best served by having the expanded capability available as soon as possible.

## 3.5 Effects of Outsourcing Timers

The Laboratory has completed a make/buy evaluation to ascertain what production can be shifted to outside vendors without affecting critical capabilities. The most likely candidates for outsourcing were the timer detonators; therefore, the effect of outsourcing these systems was investigated, and the results are shown in the Table 7. The transition to the additional capacity occurs in 2004. The effect of outsourcing the timers has a small benefit in production (2 to 5% increase). This was expected because the resources used by timers are much less than for all of the other WR detonators. Because of the stochastic parameters used to account for process variables, such as downtime and reject rates, differences from 1 to 2 % can occur in production over the simulation time period.

The outsourcing of timers does provide some help and will be pursued aggressively by Los Alamos to ensure timely delivery of detonators. However, the need for additional production capacity is still present.

Table 5: Early or On-Time Production for a 2003 Availability Date

| | *Work Shift, Hrs/Day* | | *All Detonators % Completed On Time* | | *WR Detonators % Completed On Time* | |
|---|---|---|---|---|---|---|
| *Case* | *Before Transition* | *After Transition* | *Before Transition* | *After Transition* | *Before Transition* | *After Transition* |
| 1 | 6 | 6 | 22 | 48 | 33 | 32 |
| 2 | 10.5 | 6 | 74 | 60 | 48 | 48 |
| 3 | 10.5 | 10.5 | 73 | 85 | 48 | 80 |

Table 6: Early or On-Time Production for a 2004 Availability Date

| | ***Work Shift, Hrs/Day*** | | ***All Detonators % Completed On Time*** | | ***WR Detonators % Completed On Time*** | |
|---|---|---|---|---|---|---|
| ***Case*** | ***Before Transition*** | ***After Transition*** | ***Before Transition*** | ***After Transition*** | ***Before Transition*** | ***After Transition*** |
| 1 | 6 | 6 | 14 | 72 | 19 | 56 |
| 2 | 10.5 | 6 | 73 | 71 | 52 | 60 |
| 3 | 10.5 | 10.5 | 73 | 90 | 51 | 80 |

Table 7: Effect of Outsourcing Timer Detonators

| ***Scenario*** | ***% Completed with Timers*** | ***% Completed without Timers*** |
|---|---|---|
| Single Shift | 25 | 27 |
| Double Shift Before 2004<br>Single Shift After 2004 | 72 | 77 |
| Double Shift | 76 | 80 |

### 3.6 Firing Station Utilization

Test fire capacity was analyzed using a large detonator throughput scenario (the two-shift case). Table 8 lists the quantity and utilization of the test-fire workstations from the model.

Table 8: Test Fire Workstations and Use

| | **Workstation** | **Use** |
|---|---|---|
| **Building 34** | Workstation A (WR) | 0.47 |
| | Workstation B (WR) | 0.47 |
| | Workstation C (WR) | 2.0 |
| | Workstation D (Non-WR) | 0.91 |
| **Chamber 5** | | |
| | Chamber 5A | 0.84 |
| | Chamber 5B | 0.11 |
| | Chamber 5C | 0.11 |

#### 3.6.1 Building 34

Building 34 fully used four test-fire workstations during the simulation. Workstation C was not shut down for nights or weekends. Consequently, it did the equivalent work of two workstations operating for two shifts. Workstations being used over 85% is a single-point failure in the manufacturing process because any workstation failures or downtime can drastically affect production. Summing, the use totals to 3.85 or 4 workstations with an average use of over 96%. Therefore, the results reported here indicate that five test-fire workstations would be needed to support production. Under one shift operation, the number of workstations would increase by a factor of 1.75 to approximately 7 workstations to support the production schedule.

#### 3.6.2 Chamber 5

As seen in Table 8, the overall use required is 107%; therefore, the one current workstation is overloaded to support the production schedule. Chamber 5 will support detonator production with two workstations. Under one-shift operation, the number of workstations would increase by a factor of 1.75 to approximately 4 workstations to support the production schedule.

## 4 SUMMARY AND CONCLUSIONS

### 4.1 Workstation Suites

The current workstation suite is inadequate to support WR production at Los Alamos even using second-shift operation. Reasonable support for the production schedule can be provided by using three-shift operation. However, considering quality requirements, peak production periods, and concurrent production schedules, a dedicated production line for WR detonators is required.

The evaluations completed in the transition study verified that the proposed workstation suite provides enough capacity to meet the planned detonator production schedule, as well as, a dedicated WR production line. The proposed workstation suite will support the planned 2004 production requirements and beyond with some judicious overtime to account for peak production periods.

### 4.2 Personnel

The operating staff must be increased and trained to support the expanded workstation suite.

### 4.3 Transition Operations

Additional capacity will be required by Los Alamos to meet the WR scheduled production requirements. The transition period operation will require overtime to meet production schedules. Even double-shift operation will not provide the required workstation suite to support concurrent production of three detonator systems. Stratagems such as outsourcing noncritical WR systems can help increase the availability of production resources.

The expanded capability needs to be available as soon as possible to provide a quality and minimum-risk production environment. The transition operating stratagems will work to meet the production schedule until 2004, but in FY 2004, there is a jump in the number of concurrent systems needing production support that is beyond the capability of the current workstation suite.

### 4.4 Workstation Bottlenecks

During transition operation before the additional capacity is on-line, at least one more workstation will be needed in gluing and potting. Whenever and wherever there is space, additional workstations should be considered for inspection and assembly.

### 4.5 Test-fire Stations

The study has indicated that the test-firing workstations, Chamber 5 and Building 34, will not support the planned production schedule. A study is recommended to give some specific guidance as to what options should be pursued to provide the required test firing capacity.

## ACKNOWLEDGEMENTS

LA-UR-02-2807

## REFERENCE

Burnside, R. 1999. Projections of High Power Detonator Production Requirements. Technical Report No. LA-CP-99-240, Los Alamos National Laboratory, Los Alamos, New Mexico.

## AUTHOR BIOGRAPHIES

**JOHNELL GONZALES-LUJAN** is a Technical Staff Member in the Technology Modeling & Analysis Group (D-7). Since joining the Lab in 1992, she has performed systems analysis of material processing and manufacturing operations for defense and commercial applications. She received her Masters of Business Administration in Operations Research and Management Science and her Bachelors of Business Administration in Business Computer Systems from the University of New Mexico.

**ROBERT BURNSIDE** is a Technical Staff Member in the Technology Modeling & Analysis Group (D-7). His current interests are in modeling fabrication and process lines. Since coming to Los Alamos, he has been involved with developing simulation models of the defense production process. He received his Masters in Nuclear Engineering from Carnegie-Mellon University and a Masters of Business Administration from the University of Washington.

**GEORGE TOMPKINS** is a Technical Staff Member in the Technology Modeling & Analysis Group (D-7). His interests include output analysis and agent modeling techniques. Before coming to Los Alamos he was a consultant for SAS Institute Inc. He received a Ph.D. in Industrial Engineering from Kansas State University.