The Effects of Ergonomic Stressors on Process Tool Maintenance and Utilization

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Abstract: This study examines ergonomic stressors associated with front-end process tool maintenance, relates them to decreased machine utilization, and proposes solution strategies to reduce their negative impact on productivity. Member company ergonomists observed technicians performing field maintenance tasks on seven different bottleneck tools and recorded ergonomic stressors using SEMaCheck, a graphics-based, integrated checklist developed by Sandia National Laboratories. The top ten stressors were prioritized according to a cost formula that accounted for difficulty, time, and potential errors. Estimates of additional time on a task caused by ergonomic stressors demonstrated that machine utilization could be increased from 6% to 25%. Optimal solution strategies were formulated based on redesign budget, stressor cost, and estimates of solution costs and benefits.

Keywords: Ergonomics, Maintenance, Cost Analysis, Overall Equipment Effectiveness, Equipment Productivity Analysis

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1 EXECUTIVE SUMMARY

1.1 Purpose and Methodology

The purpose of this study was to identify the most significant physical and cognitive ergonomic stressors associated with front-end tool maintenance, estimate their negative impact on productivity and the cost of ownership, and propose strategies to reduce the impact. A method to gather actual, objective field data was developed by Sandia National Laboratories (SNL) using a graphics-based integrated checklist, SEMaCheck. The Project Technical Advisory Board (PTAB) members collected stressor data at their respective sites. Because time and resources did not permit a large survey of all processing equipment, an inclusion score was developed for targeting specific machines that had high downtime, cost, repair complexity, and number of machines in the field. Seven "bottleneck" tools were ultimately selected for the study. Six ergonomists observed 28 of the least favored maintenance tasks on the seven bottleneck tools and recorded 250 observations of instances where ergonomic stressors contributed to task difficulty, increased task duration, or increased the likelihood of human error. SNL, with help from the PTAB, developed a combined score for each observation based on multi-attribute utility theory. Each attribute was weighted to represent its relative importance and combined in a mathematical formula to model the combination of perceived costs. The factors combined were inclusion score, frequency of the task, task difficulty, additional time required, and error consequence.

1.2 Results

After examining the highest scoring 25 stressors, similar items were combined, resulting in the following list of the top ten stressors:

Ergonomic Stressor

1. Difficult enclosure panel removal
2. Kneeling, prolonged standing with knees bent
3. Arm lifting, one and two arms
4. Reaches, over the shoulder, etc.
5. Difficult component access
6. Poor body access, trunk twist or flex
7. Inadequate visual access or lighting
8. Inadequate arm/hand/finger access
9. Two-person lifting, no weight labels on heavy objects
10. Pinch grip, manipulating small objects

Eighty-two of the 250 observations were judged to involve stressors that increased the duration of a task, for a total of 777 additional minutes. When computed as a proportion of additional time divided by summed nominal task lengths (as estimated by the maintenance technicians doing the work), a percentage of additional time resulting from ergonomic stressors was obtained:

$$\frac{777\,\text{min.}}{2924\,\text{min.}} \times 100 = 26.6\%\ \text{additional time}$$

Of the individual machines, the Nikon Steppers had the highest percentage of additional time at 53%, while the SVG Micrascan had the lowest at 1%. The table below lists the additional time, nominal task length, and percentage of time wasted for the seven machines studied.

Machine	Add'l	Task	Percent
Applied 5000	63	210	30%
Applied 9500	80	180	44%
Eaton	235	510	46%
SVG Micrascan	4	410	1%
Nikon	37	70	53%
Novellus	62	196	32%
Varian	296	1348	22%

The negative impact of the ergonomic stressors on productivity was estimated by examining the cost of ownership (COO) equation and identifying the impacts on its factors. Maintenance costs mostly affect the sum of recurring costs in the numerator. However, when a tool is installed, the types of tasks that are performed are very similar, if not identical, to maintenance tasks. Therefore, benefits brought to recurring costs in the form of less time spent, fewer technicians needed, reduced opportunity for errors, etc. can be applied to the portion of fixed costs associated with tool installation. The scrap factor might be affected positively if the reduced probability of errors in machine calibration helps to avoid processing wafers out of tolerance. In the denominator of the COO equation, lifetime, throughput rate, and yield remain unaffected by ease of maintenance. However, utilization can increase as a result of reduced maintenance time, especially for tools with low utilization. For instance, if utilization for a tool is nominally 0.80, and maintenance time is reduced 25%, as suggested is possible from the results, utilization can increase (1.0–.8) x .25 = .05, to .85, a 6% improvement. If a tool with lower utilization (e.g., 0.65) were to benefit from the kind of reductions in maintenance time found in the two implanters studied (45%), the increase in utilization can be substantial (1.0–.65) x .45 = .157, or 25%.

A simulation using Two Cool software calculated the savings possible in a low pressure chemical vapor deposition (CVD) tool with only 5 hours maintenance per week. The baseline calculation for COO was $3.49 per wafer-layer. With a 30% reduction in maintenance time, the COO was reduced to $3.45. If the labor force were reduced by one maintenance technician, another $0.05 was saved, causing the COO to decrease by a total of $0.09. This reduction multiplied by six layers and 20,000 wafers a month for 12 months adds up to $129,600 per year or $648,000 over five years. This is not an insignificant figure when combined with potential savings from multiple machines of the same type or other types of tools.

Various solutions are suggested, consisting of recommendations made by the maintenance technicians performing the work, the observing ergonomists, and group consensus recommendations offered by the PTAB. Suggested strategies to reduce ergonomic stressors emphasize combining cost-effective means of simplifying panel removal, using guide-locating devices such as pins to help support parts while fastening, improving physical and visual access to tool components, reducing lifting requirements, and using captive fasteners. Estimates of solution effectiveness and cost were entered into an optimization algorithm that generated

solution strategies for graduated levels of spending (see Appendix J). The notion of reducing tool footprint as a cost-savings tactic is revisited, given the inverse relationship with ease and cost of maintenance.

Based on field experience, the SEMaCheck checklist was revised for enhanced usability in the field. Member companies can use SEMaCheck to further examine ergonomic stressors associated with maintenance activities in their fabs; supplier companies can use it in equipment design cycles to identify and avoid potential ergonomic stressors in their machines' projected maintenance scenarios.

1.3 Conclusions

This study has demonstrated that machine design issues and related stressors present major impediments to efficient maintenance activities and that ergonomic solutions have the potential to improve machine utilization significantly. Machine users are encouraged to demand enhanced serviceability with fewer physical and cognitive stressors. Suppliers are encouraged to put more emphasis in the ergonomic design of their products to help them be more competitive and to meet the additional maintainability requirements of their customers.

2 INTRODUCTION

2.1 Background

The genesis for this study was a meeting in May 1996, at which several ergonomists from member companies met to discuss the state of ergonomics in the microelectronics industry with representatives from SEMATECH's Environment, Safety, and Health (ESH) thrust area. Among the outcomes of this meeting was a list of potential topics for research, a recommendation not to do another cumulative-trauma-disorders (CTDs) study, and a resolution to translate any study results or industry impacts in terms accessible to industry executives. As a result of that meeting and subsequent correspondence, discussions, and negotiations on a statement of work, Sandia National Laboratories (SNL) partnered with SEMATECH in November 1996 to investigate the impact of ergonomic stressors on wafer processing. For the purposes of this study, ergonomics is defined as follows:

> ***ergonomics*** [also called human factors engineering] discovers and applies information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use (Sanders and McCormick, 1987, after Chapanis, 1985).

Two literature searches preceded the finalized statement of work; however, very little useful literature was found addressing ergonomics in cleanroom operations. See Appendix A for a summary of the findings of the two literature searches.

The first PTAB meeting for this project was held January 28–29, 1997, in Austin. In addition to project managers from SEMATECH and SNL, ergonomists from member companies participated. One major decision was to concentrate on *productivity* issues and de-emphasize factors relating to work-related CTDs and their associated costs. This decision was based on examination of the cost-of-ownership formula and the realization that a small improvement in

machine utilization would far outweigh any decrease in labor-related expenses associated with lost work days. Another project-defining decision was to study ergonomic factors associated with *maintenance* activities. This decision was based on the recognition that operator efficiencies are difficult to measure and improve, while machine downtime is a universal fact of life in fabs and is relatively straightforward to measure.

2.2 Purpose

The purpose of the study was to identify the most significant physical and cognitive ergonomic stressors associated with front-end tool maintenance, estimate their negative impact on productivity and the cost of ownership, and propose a strategy to reduce the impact. Stressors are defined as any external or internal forces that cause bodily or mental tension, i.e., stress (Swain and Guttmann, 1983). Ergonomic physical stressors include forceful exertions, repetitive motions, awkward postures, temperature extremes, inadequate lighting, etc. Examples include prolonged crouching, repeated lifting, extended reaching, and the like. Cognitive stressors cause stress by forcing the maintenance technician to engage in difficult perceptual or thinking activities. Examples of cognitive stressors include poorly labeled displays, difficulty in diagnosing a fault in the machine's software because of inadequate job aids, and the lack of a checklist or system documentation to help remember all the steps in a maintenance task.

3 APPROACH – TASKS AND DELIVERABLES

Because objective field data were preferred over subjective estimates, a method of field data collection had to be developed. Also the PTAB members themselves decided to collect ergonomic-stressor data at their respective sites. SNL developed the field observation techniques and tools for them to use and analyzed the data after collection. The following tasks formed the basis for a project plan:

1. Conduct a literature search
2. Define target activities, and stressor types
3. Identify candidate tools for field observation
4. Develop a field checklist and protocol for use
5. Assign PTAB members to specific tools in their fabs
6. Collect data
7. Analyze data
8. Create prioritized list of stressors
9. Calculate impact of stressors using cost-of-ownership formula
10. Develop a generic solution strategy for tool designers
11. Refine the checklist based on field experience and make available to member companies
12. Deliver tool-specific results to suppliers

The major SNL deliverables for the study were identified by the PTAB as follows:

1. A questionnaire/survey tool to help identify ergonomic stressors in the field
2. A prioritized list of physical and cognitive stressors found in front-end tool maintenance
3. A statement about the relationship between the stressors and fab productivity
4. Strategies to address the reduction of the top stressors

4 METHOD

4.1 Tool Selection

To target specific machines and maintenance tasks, the PTAB members returned to their fabs with a set of questions to help identify candidate tools for study. Since "bottleneck" tools had the most severe impact on fab productivity, each member sought help in identifying these tools were in their fabs. A bottleneck tool was defined as one that had a relatively short mean time between failure (MTBF) or long mean time to repair (MTTR) and that was on the critical path to successful wafer processing (i.e., no substitute processing paths were available). A formula was developed to rank the tools based on characteristics of unavailability, exposure, and repair complexity. The formula was later revised and is shown as Equation 1:

Equation 1. Machine Inclusion Score = (100-a)m(1+c/10)(1+v/$3.5M)n

where:
a = machine availability as a %
m = number of machines at PTAB member's site*
c = estimate of tool complexity** (0,1, or 3)
v = estimated cost of new tool
n = number of PTAB member companies that use the tool

* 1–4 tools, m = 1 9–15 tools, m = 3
5–8 tools, m = 2 >15 tools, m = 4

**Deposition, c = 1 Implant, c = 3
Track, c = 1 Stepper, c = 3
Etch, c = 1

PTAB members calculated their own scores for candidate tools so that data about the numbers of tools at any given site would not have to be shared with other member companies. The eight tools with the highest inclusion scores are shown in Table 1.

Table 1 Targeted Tools and Their Inclusion Scores

Tool	Inclusion Score
1. Applied CVD 5000	1960
2. Novellus Concept One	1344
3. Varian Implanter V500	976
4. Nikon Stepper	936
5. SVG Micrascan Stepper	600*
6. Eaton Implanter 200	432
7. Applied Implanter 9500	292
8. Genus Implanter	224

*estimated with incomplete data

4.2 Tool Assignment

Data were collected with enough overlap to assure coverage of all tools and repeated measures on most. Tool assignments are shown in Table 2.

Table 2 PTAB Tool Observation Assignments

PTAB Member	Member Company Site	Tools
1	A	Varian SVG
2	B	Varian Applied 9500 Genus
3	C	Varian Nikon Eaton
4	D	Varian Applied 9500
5	E	Nikon Eaton SVG
6	F	Applied 5000 Nikon
7	G	Applied Novellus

4.3 Site Protocol

SNL developed a process to identify the most ergonomically demanding maintenance tasks. It started with sending PTAB members general information on data-collection techniques, including the questionnaire, the personal interview, the focus group interview, and five types of direct observation (see Appendix B for the complete information). The PTAB decided to use the focus-group technique with maintenance personnel to identify the most ergonomically challenging scheduled and unscheduled maintenance tasks (see Appendix C for materials used by

the PTAB in this process). This was followed by direct observation for real-time field identification of ergonomic stressors within the tasks. The process for identifying candidate tasks included the following:

1. Scheduling a focus group meeting with maintenance supervisor(s)
2. Explaining the project and types of data to be collected
3. Giving examples of desired data and undesired data
4. Creating a list of challenging maintenance tasks
5. Voting on the most difficult tasks and ranking the list

The PTAB member then waited for the next scheduled (or unscheduled) opportunity to observe one of the top tasks identified in the focus group and used the checklist to record observed physical and cognitive ergonomic stressors. Videotapes were made of the most difficult tasks if the equipment was available and management approved. All data were sent to SNL for analysis.

4.4 Checklist

Checklists are typically used as memory joggers, preventing wanted activities from being inadvertently forgotten. Most critical, lengthy industrial tasks employ checklists to help workers remember each task segment or perform tasks correctly. To avoid additional equipment downtime in the member company fabs, maintenance tasks had to be observed "over the shoulder" in "real" time. The literature was searched for an acceptable existing instrument, but none was found. Consequently, a data-recording checklist was developed that met the following criteria:

1. Observation of on-task behaviors, not preparatory tasks
2. Real-time observation and quick-access recording
3. Non-invasive, non-intrusive to maintenance personnel
4. Include all significant physical and cognitive stressors
5. Used by qualified, experienced users
6. Worst stressors emphasized, minor ones not recorded
7. Time inefficiencies and potential acute injuries emphasized
8. Recording step or task segment associated with stressor
9. Recording ergonomic difficulty of task (stressor severity)
10. Recording additional time spent on task due to stressor
11. Recording potential errors and severity of consequences
12. Timed non-servicing activities such as rest breaks
13. Recording suggested solutions to stressors
14. Record by exception – not a task or functional analysis

Existing ergonomic checklists were also consulted for content, but none were designed for microelectronics manufacturing or had all of the features needed. Several ergonomic checklists were examined for style and usability, but many were too wordy to use effectively in a time-critical environment. It was also decided that a graphics-based checklist would be best for quick access and recognition of items.

The checklist developed contained 210 individual stressors, 137 of which were depicted with individual graphical figures portraying the physical or cognitive ergonomic stressor (see Appendix D). The checklist was named SEMaCheck, for Sandia Ergonomic Maintenance Checklist. Unlike most ergonomic checklists designed to identify stressors that contribute to long-term work-related CTDs, the stressors in SEMaCheck could potentially slow down the work or cause acute injury (which could also slow down the work). An experienced ergonomist would note that many more benign stressors, usually addressed in office or shop-floor ergonomic worksite evaluations, were not included in SEMaCheck. The stressors were also compared for consistency with the ergonomic advice given in SEMATECH's *Application Guide for S2-93 and S8-95*. The ten topical "chapters" of the checklist are as follows:

1. Diagnosis and Computer Interaction
2. Documentation and Specifications
3. Maintainability Design and Work Flow
4. Clearance and Access
5. Lifting and Loading
6. Push, Pull, and Torque
7. Posture, Reach, Sitting, and Wrist
8. Hardware, Controls, and Displays
9. Grip, Dexterity, Tools, and Couplers
10. Repetition, Impact, and Vibration

Each chapter or group of related stressors was collected in sequential order within the checklist booklet. A table of contents or "Stressor Roadmap" page preceded the ten groups and served as a quick-reference guide to help the user find the appropriate chapter in the field. The "Roadmap" included large graphics, chapter headings, and large numbers identifying the locations of the ten groups. Large numbers in the headings of the checklist pages corresponded to the numbers in the "Roadmap". The ten groups were listed by order of appearance in a typical maintenance task, i.e., beginning with diagnosis and documentation and ending with fine motor-control activities and repetitive motions. Each group (except 3 and 5) was subdivided into blocks of like stressors. For instance, Group 1 (Diagnosis and Computer Interaction) had three blocks: Diagnosis, Input Devices, and Computer Interaction. Likewise, Group 7 comprised Posture, Sitting, Reach, Lying, and Wrist blocks. In addition to graphics, text-based descriptions were used for each item in the checklist. Not all stressors had their own graphic; several were shared.

The format of the checklist was designed for rapid recording of recognized stressors. Next to the figure/text descriptor, three check boxes of graduated size were used to capture the difficulty or severity of the stressor. Adjacent to the boxes, a line was provided for describing the problem or the step in the maintenance procedure. Following the line was a space for recording additional time spent on a task because of the ergonomic stressor. Following that line was a space for recording any potential errors that could result from the poorly designed task. Only errors of consequence were to be recorded. If an error had an obvious, immediate recovery path, it was not recorded. On the far right of the page three graduated-size boxes were available for recording the severity of the consequence of the potential error. The draft checklist was reviewed with the PTAB in May 1997 and revised before field use.

A cover page containing questions about the task and session was used to document the following data provided by the maintenance technician:

1. Frequency of task
2. Typical duration
3. Task segment duration
4. Time pressure (5-point scale)
5. Prior training on task
6. Person providing training
7. Times task performed
8. Most recent task performance
9. Ideas for task improvement

The following session information was provided by the ergonomist on the cover page:

1. Observer
2. Machine
3. Task performed
4. Unscheduled/scheduled maintenance
5. Auxiliary equipment needed/used
6. Maint. Techs—in-house vs. factory vs. contractor
7. Current shift hours
8. Session date
9. Session start time and end time
10. Task steps covered by checklist data

After all data were collected, the PTAB reviewed SEMaCheck again and suggested improvements based on field experience (see Appendix E)**.** The version of SEMaCheck shown in Appendix F has been revised to address redundancies, omitted items, and difficulty in quickly accessing the correct pages in time-critical field observations. See the conclusions section for a more complete discussion of SEMaCheck performance and revisions.

5 RESULTS

Ergonomic stressor data were collected from all targeted machines, except the Genus implanter. Six ergonomists from the PTAB successfully observed maintenance tasks and recorded ergonomic stressors found in 28 different tasks associated with seven machines. The tasks shown in Table 3 were selected by maintenance technicians as the most difficult and were either directly observed or demonstrated in enough detail so that stressors could be identified.

The data in the raw form were checklists that had entries describing observations of stressors, complemented by two videotapes and 32 digital photographs. There were 250 observations over 28 tasks, averaging 8.9 stressors per task (see Appendix G for the complete data set). Potential errors were recorded for 49 of the observations, while 83 of the observations incurred additional time because of the stressor. Twenty-nine of the 250 observations had both additional time and potential errors associated with them. Ninety-seven of the 210 checklist items were used in

making observations. The average score for time stress was 2.5 on a 1–5 scale. All but three of the 28 tasks were performed by in-house technicians. The three exceptions were performed by factory technicians. Several of the observed stressors typical to the maintenance work are shown in Figure 1. The stressors of kneeling, limited accessibility, reaching, and lifting were major contributors to the data collected.

Table 3 Maintenance Tasks Observed

Tool	Observed Procedures
1. Applied CVD 5000	Beam line PM Clean Chamber Remove extraction electrode PM
2. Novellus Concept One Dep	Clean gate assembly valve Scrub heater block Rebuild spindle
3. Varian Implanter V500	Replace air bearing Beam dumpliner, scan deflector, dipole liner Solenoid failure Change-out manipulator Post accel. Plate change Remove source bushing PM Remove/replace mass slit assembly Change source
4. Nikon Stepper	Particle on chuck Clean & lube lead screws
5. SVG Micrascan Stepper	14-day PM Focus Change lamp Liftarm on longstroke and relay pack
6. Eaton Implanter 200	Source, extractor exchange Source housing PM Semiannual PM Post accel. Electrode Ebara pump
7. Applied Implanter 9500	Scrub MRS and source chamber Remove/replace source Remove/replace beam stop

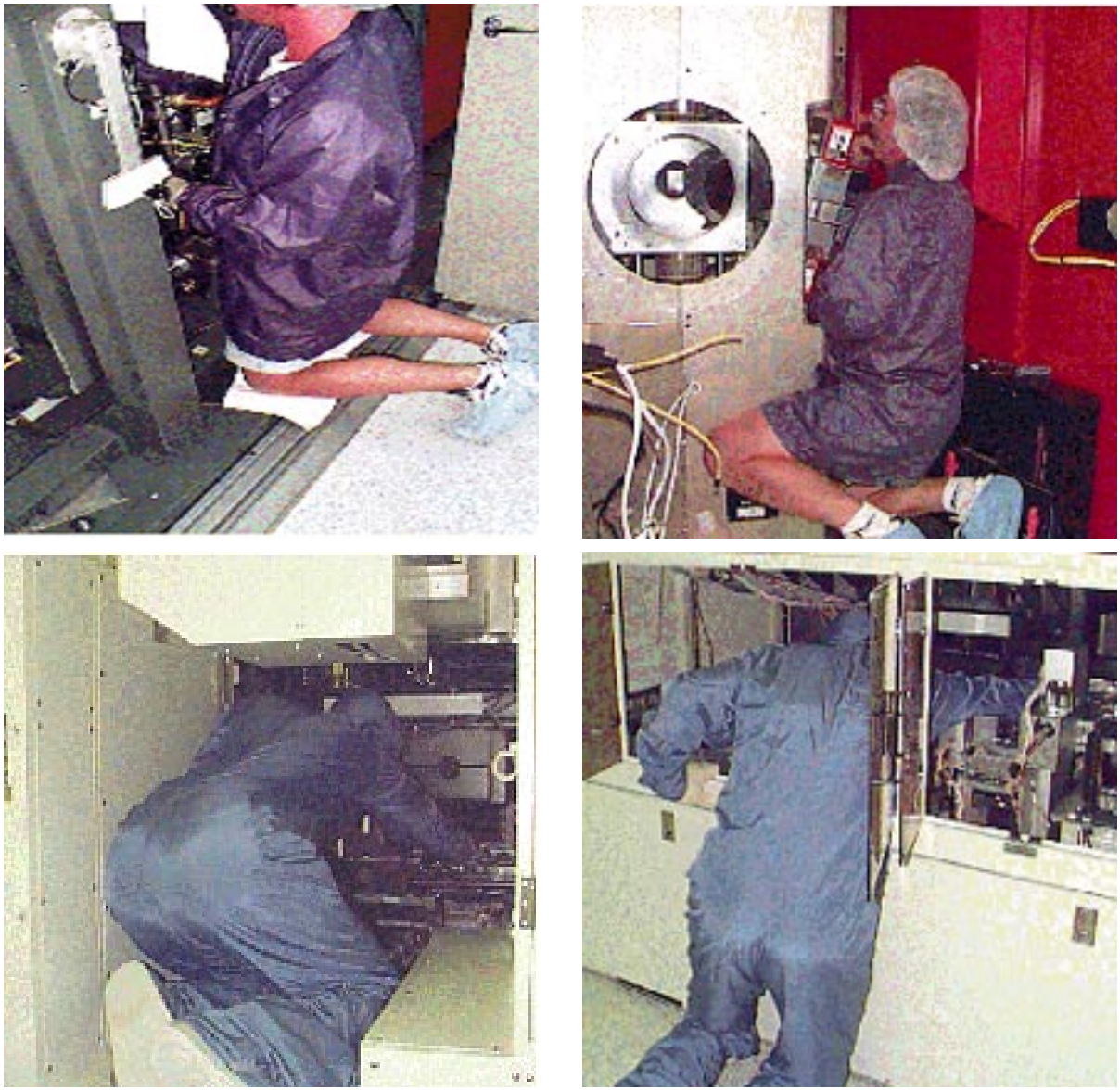

Figure 1 Examples of Typical Physical Stressors Experienced in Maintenance Tasks

5.1 The Most Significant Ergonomic Stressors

One way of assessing the most significant, or "worst" stressors, is to count the number of times the same stressor is observed over the 250 observations. Since the checklist includes groups (major categories or chapters of the checklist), blocks (subdivisions of the groups), and items (specific stressors), frequency analyses can be done for the three different levels of specificity. For example, the Pareto diagram in Figure 2 shows that the most frequently observed group was group 7—posture/reach. The next most frequently observed group was a tie between groups 4 and 5—clearance/access and lifting/loading. These three are followed by group 9—dexterity/tools, group 3—maintainability/work flow, and group 1—diagnosis/HCI (human-computer interaction). No observations were made in group 8.

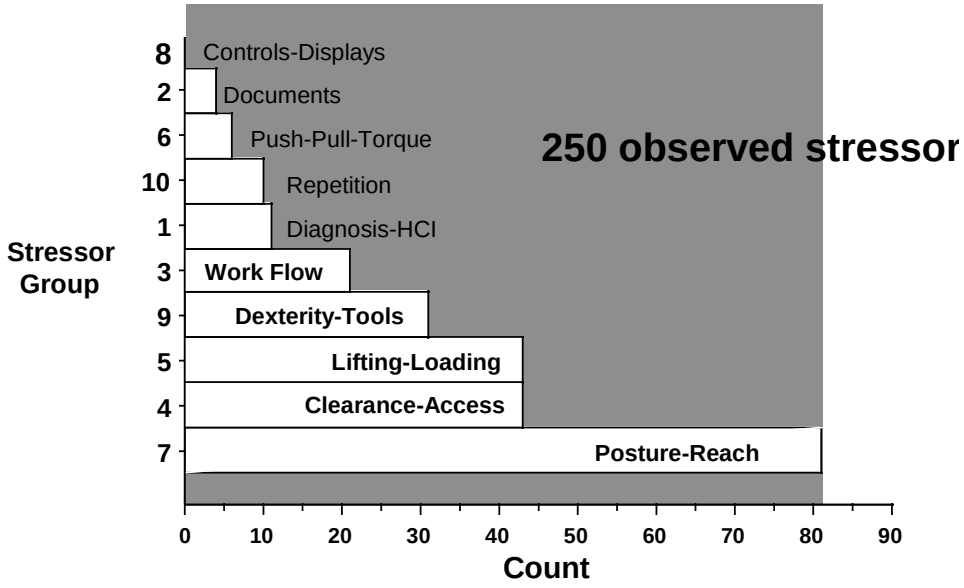

Figure 2 Pareto Diagram of Stressor Groups for All Observations

Another way of assessing worst stressors is by looking at those that can induce errors with significant consequences. Figure 3 is a Pareto diagram of the most frequent groups of stressors associated with the 49 error-likely observations. It should be noted that the top six groups are identical to those shown in Figure 1; however, the order differs slightly.

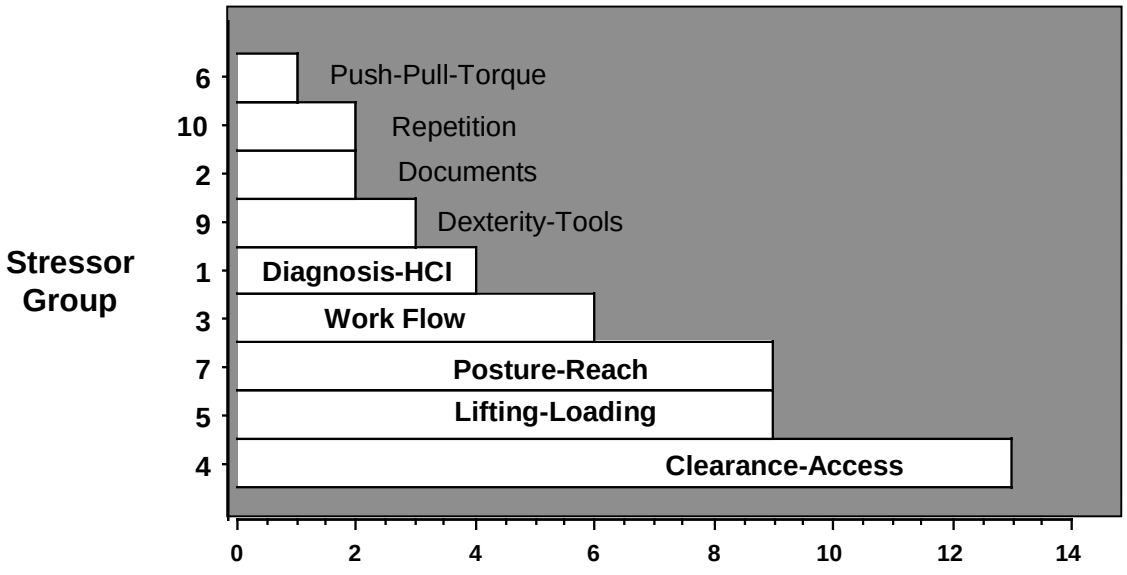

Figure 3 Pareto Diagram of Stressor Groups for Error-Likely Observations

Figure 4 shows an analysis by sub-groups or blocks. The blocks represent related sets of individual items. Twenty-seven of the 33 blocks were used in identifying stressors in the field. The top ten blocks are included in Figure 3. It should be noted that groups 3 and 5 consisted of only one block each (3–1 and 5–1).

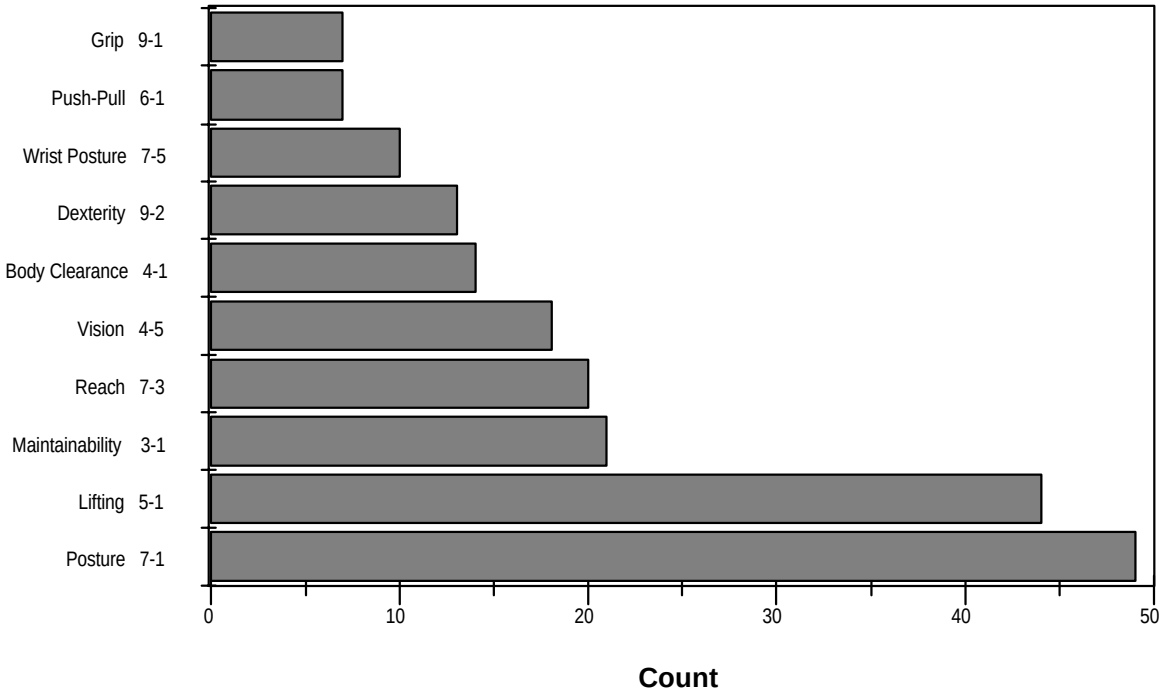

Figure 4 Pareto Diagram of Stressor Blocks

Figure 5 shows a similar Pareto diagram for the most frequently observed individual items. Here kneeling is the most frequent, followed by inadequate visual access, trunk flexion, and arm lifting.

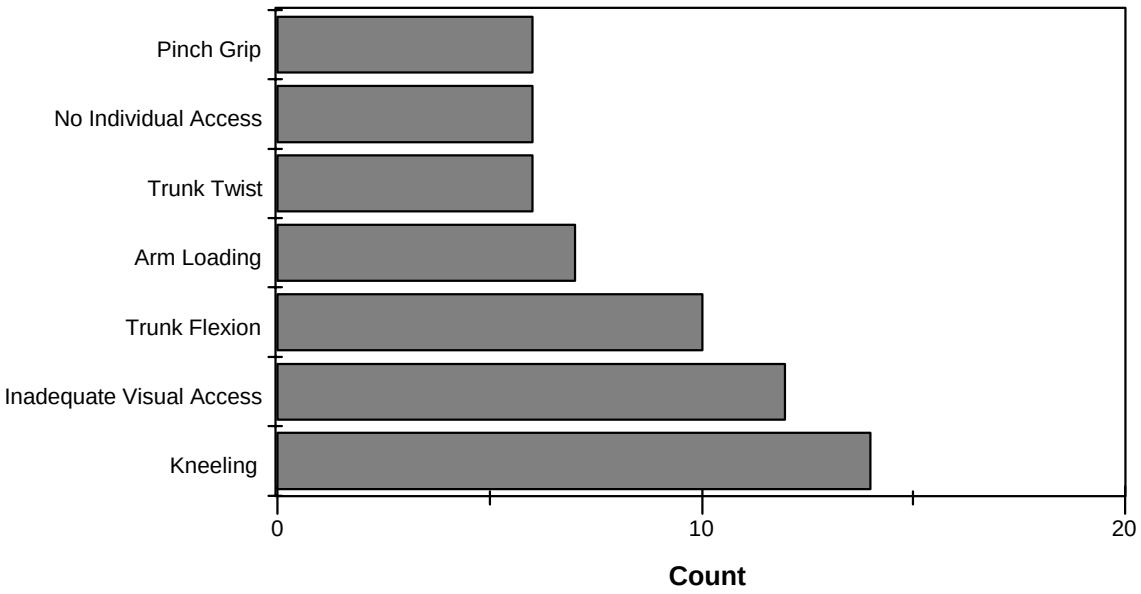

Figure 5 Pareto Diagram of Most Frequently Observed Items

Yet another way of assessing "worst" stressors is by the additional time they incur on maintenance tasks. The top individual-item stressors in terms of total additional time (multiple observations) are listed in Figure 6.

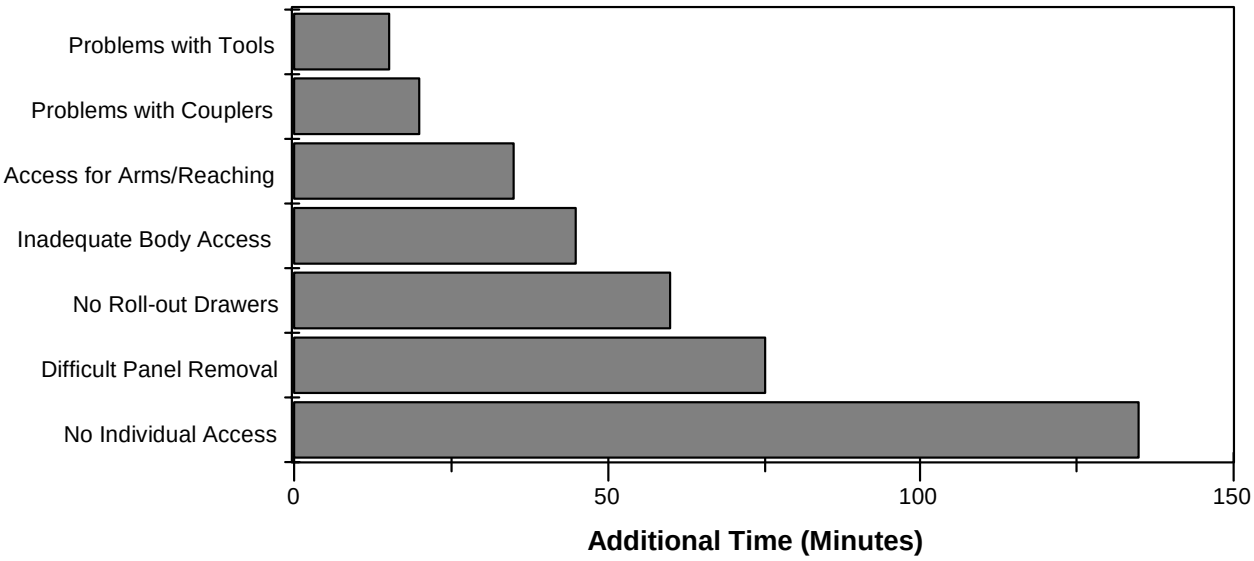

Figure 6 Pareto Diagram of Stressors Causing Most Additional Time

5.2 Combined Cost Scores

A review of the previous five analyses shows some overlap but does not clearly present a prioritized list of stressors. The order of the list changes based on the metric of interest and the interpretation of what is worse—frequency, additional time, or error potential. Because a single metric that can adequately characterize the overall negative impact on maintainability for each observation (data point) was needed, a combined score was developed for each observation based on multi-attribute utility theory. Human perceptions and decisions are usually based on the combination of several factors. The individual attributes, if measurable, can be combined in a mathematical formula to model the combination of perceived attributes. Each attribute, or factor, has a weight associated with it to represent its relative importance in the formula. This approach led to the development of a formula that combined the following attributes:

Machine Inclusion score—calculated earlier for each tool, based on availability, cost, complexity, and exposure (popularity). Tools with high inclusion scores are bottleneck tools that tend to be expensive, are difficult to repair, have a lot of down time, and are plentiful in the industry. Thus a high inclusion score points to tools that are costly and tend to hurt overall productivity.

Frequency of task—estimated metric collected from the maintenance technician while servicing the tool. It is also a measure of cost in that frequent repairs lead to higher cumulative downtimes.

Task difficulty—estimate of impact of the observed ergonomic stressor, also a measure of cost.

Additional time—estimate of additional time on task due to the stressor, also an obvious measure of cost.

Error consequence—damage done by making a potential error in the task due to ergonomic stressors, also a measure of cost.

These five attributes were converted into scaled factors and combined in a formula to represent the overall cost of each observed stressor. The formula, which was changed slightly at the final PTAB meeting to reflect improved relative weighting of the factors, is represented by Equation 2:

Cost score = (Inclusion score/250)(1+freq./20)(difficulty)(1+30(add'l.time/nom.time))(1+conseq./1.5)

Each of the five factors in Equation 2 was scaled based on perceived relative importance by the PTAB members. The inclusion score was scaled down to a 1 to 10 range to keep the cost scores less than 1000. The frequency factor was similarly constructed to handle a large range of raw data but also to generate a number between 1 and 10. The time factor was developed as a proportion of extra time over nominal task length to weight more heavily those tasks whose additional time was a significant portion of the entire task length. Difficulty did not need any alteration; however, the error consequence factor was perceived as less reliable and less important than the difficulty and time factors and hence its range was condensed. Table 4 lists the ranges of the numeric values for the raw data as collected in the field and the associated ranges of values for the resulting formula factors.

Table 4 Ranges of Cost Score Formula Factors

Dependent Variable	Data Min-Max	Factor	Min-Max
Inclusion score	292–1960	Inclusion score/250	1.17–7.84
Frequency (per yr.)	.5–170	1+freq./20	1.02–9.5
Difficulty	1–3	Difficulty	1–3
Additional time (min.)	0–120	1+30(add'l.time/nom.time)	1–16
Error consequence	0–3	1+conseq./1.5	1–3

The cost score metric proved to be robust to minor changes in the factor weights. For instance, the original formula used Inclusion score/50 and a logarithmic factor of frequency because of a very large range in frequency data. When two data points were excluded at the final PTAB meeting because they were not tasks performed by maintenance personnel, the range of frequency data decreased dramatically and the frequency factor was changed to a linear factor. The pairwise correlation of cost scores for the 250 observations before and after the formula change was 0.89. Similarly, in an earlier modification of the formula, the inclusion score was removed completely and a correlation of 0.78 obtained. All the current factors have a minimal value of 1 or more and have monotonic, linear relationships with cost. A correlation matrix for the five cost score factors is shown in Table 5. The highest correlation coefficient is 0.264, indicating very little covariance among the five factors and ensuring that the cost score formula factors are metrics of different underlying dimensions.

Table 5 Correlation Matrix of Cost Score Factors

Correlation Matrix

	Weighted Incl. Score	Freq.Factor	Diff Factor	Time Factor	Conseq Factor
Weighted Incl. Score	1.000	.041	.116	.102	–.134
Freq. Factor	.041	1.000	.013	–.081	–.124
Diff Factor	.116	–.013	1.000	.144	.066
Time Factor	.102	–.081	.144	1.000	.264
Conseq Factor	–.134	–.124	.066	.264	1.000

250 observations were used in this computation.

The cost scores calculated for the 250 observed stressors ranged from 1.197 to 746.928; they are plotted as a frequency distribution in Figure 7 (scores above 400 are not shown). The mean score was 43.11, and the distribution was highly skewed in the positive direction.

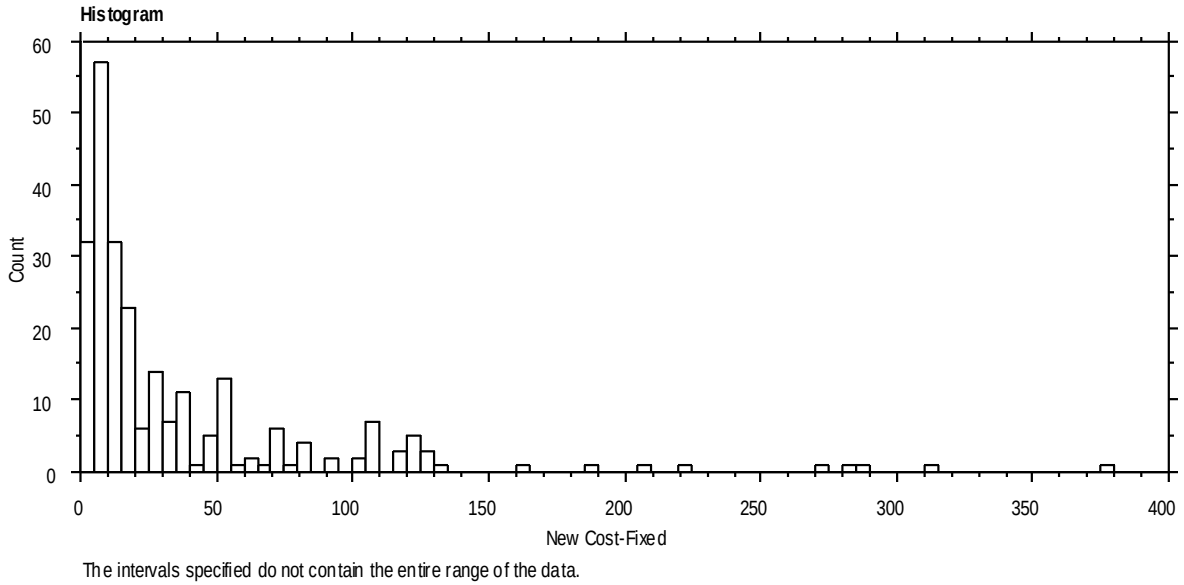

Figure 7 Frequency Distribution of 250 Cost Scores

Top Ten Ergonomic Stressors The cost scores were analyzed by checklist items, summing the scores of identical items. The process yielded a ranked list of the 97 items by summed cost scores. Looking at the top 25 items, similar items were combined to construct a list of the top ten stressors (see Table 6).

Table 6 Top Ten Ergonomic Stressors

Ergonomic Stressor	Number	Sum Score
1. Difficult panel removal	5	1474
2. Kneeling, standing, legs bent	33	1182
3. Arm lifting, one and two arms	12	1028
4. Reaches, over shoulder, etc.	16	977
5. Difficult component access	8	813
6. Poor body access, trunk twist/flex	20	727
7. Inadequate visual access/lighting	17	714
8. Inadequate arm/hand/finger access	7	613
9. Two-person lifting, no weight labels	9	279
10. Pinch grip, small objects	6	236
Totals	133	8043

There was some concern that the top ten represented only a small portion of the entire set of stressors. However, the sum of cost scores for the top ten combined list is 8043, representing 75% of the grand total of cost scores (10777) as indicated in Figure 8. The 133 observations

represented in the top ten combined list represent 53% of the total 250 observations, as shown in Figure 9.

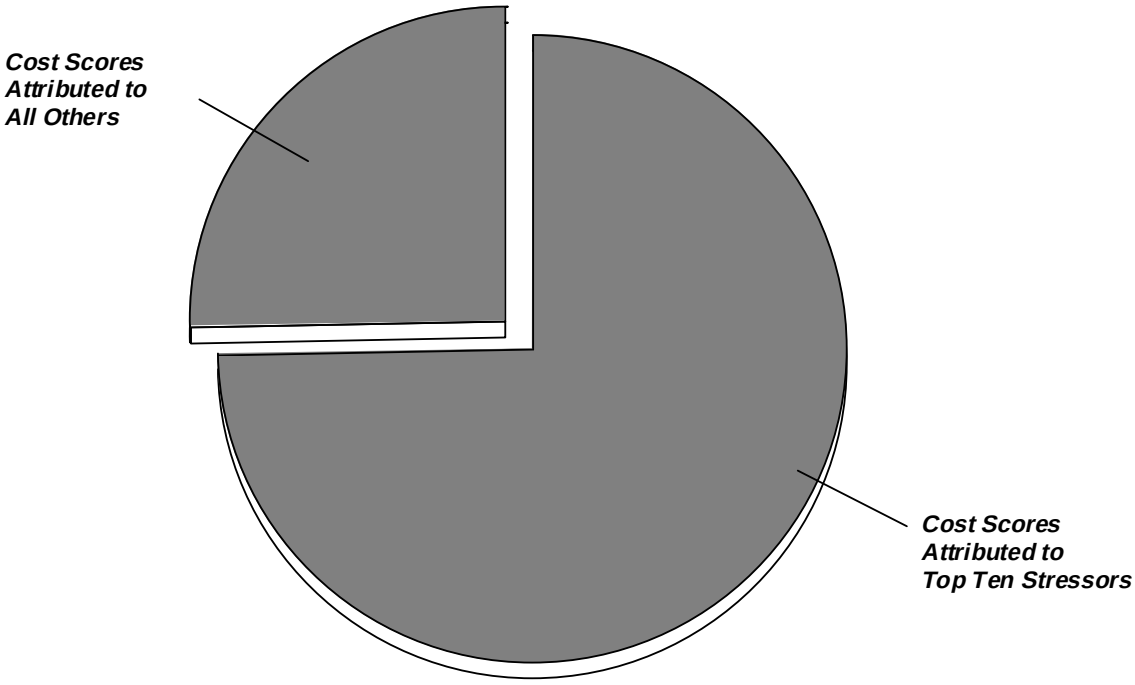

Figure 8 Cost Scores Attributed to Top Ten Stressors

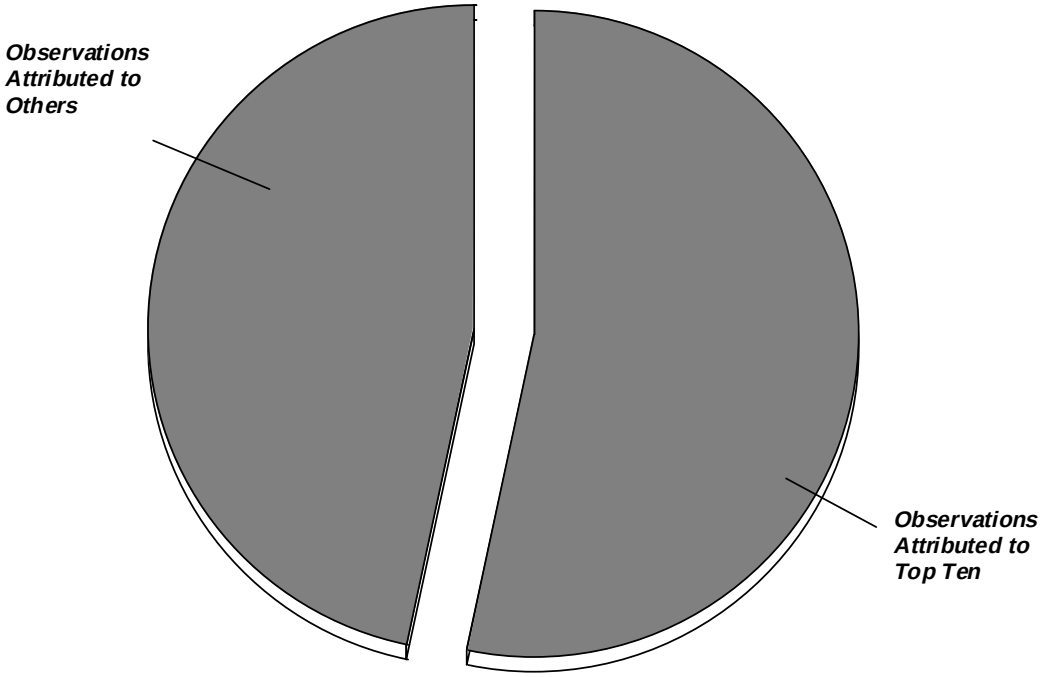

Figure 9 Observations Attributed to Top Ten Stressors

5.3 Worst Tools

Another analysis of the cost scores can reveal which tools (or types of tools) seem to have more severe maintenance-related stressors than others. Because the number of tasks sampled per tool was not controlled and the exposure to observations of stressors differed across the tools, the sum of scores is not a fair metric of comparison. However, a look at mean cost scores for all of the observations on any given tool or tool type yields some differences. Figure 10 lists the mean cost and number of observed stressors for the seven tools. Notice that the Applied 5000 CVD had the highest mean score at 103, with the Nikon steppers second at 82. The tool with the most observations was the Applied 9500 implanter with 75, observed over only three tasks. However the ergonomist collecting the data on the 9500 did not rate the stressors as costly as most of his colleagues. Table 7 lists the mean cost scores by PTAB member. Note that observer 2, who made the observations on the 9500 had the most number of observations, but by far the lowest mean score per observation. Observer 6, on the other hand, had the highest mean score at 106.9. The differences across PTAB members' cost scores are obviously significant, indicating large variability in using the various data provisions in the checklist. Table 8 lists the machine scores split by PTAB member-observer. Except for observer 2, there does not appear to be any strong consistencies in PTAB scoring behavior across machines, lending some credibility to the notion that differences found across machines are due to design and are not an artifact of the observers' individual scoring styles.

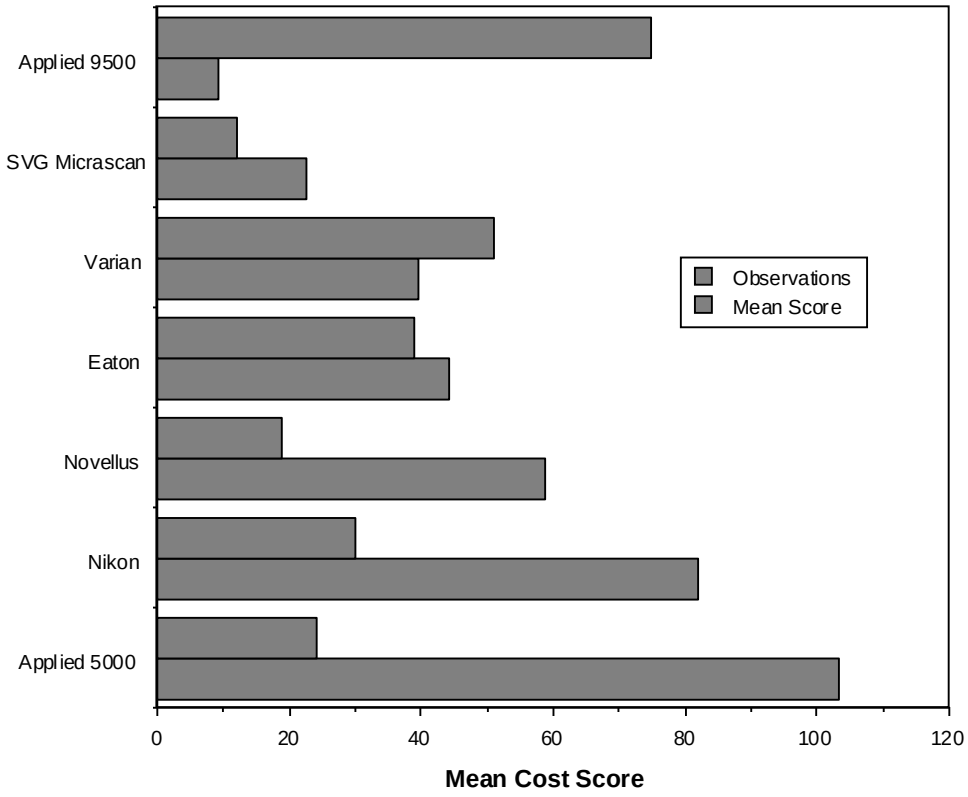

Figure 10 Mean Cost Scores and Number of Observed Stressors for the Seven Machines

Table 7 Mean Cost Scores by PTAB Member

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
Cost Score, Total	43.111	79.465	5.026	250	1.197	746.928	0
Cost Score, 1	45.186	49.522	7.004	50	6.246	289.766	0
Cost Score, 2	9.114	9.298	1.1015	84	1.197	52.034	0
Cost Score, 3	48.018	105.968	14.161	56	1.901	746.928	0
Cost Score, 4	77.858	165.311	47.721	12	18.739	602.112	0
Cost Score, 5	76.527	69.048	12.020	33	3.802	273.715	0
Cost Score, 6	106.938	107.950	27.873	15	34.496	379.456	0

Table 8 Mean Cost Scores Split by Observer and Machine

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
Cost Score, Total	43.111	79.465	5.026	250	1.197	746.928	0
Cost Score, 1, MICR	64.480	47.250	27.280	3	37.200	119.040	0
Cost Score, 1, NOV	58.922	67.423	15.468	19	11.544	289.766	0
Cost Score, 1, VAR	33.799	30.760	5.813	28	6.246	124.28	0
Cost Score, 2, 9500	9.190	9.812	1.133	75	1.197	52.034	0
Cost Score, 2, MICR	8.480	2.427	.809	9	6.000	11.520	0
Cost Score, 3, EAT	8.700	9.075	1.780	26	1.901	48.470	0
Cost Score, 3, NIK	82.093	136.524	24.926	30	8.611	746.928	0
Cost Score, 4, CVD	97.564	189.283	63.094	9	25.088	602.112	0
Cost Score, 4, VAR	18.739	0.000	0.000	3	18.879	18.739	0
Cost Score, 5, EAT	115.583	70.795	19.635	13	3.802	273.715	0
Cost Score, 5, VAR	51.140	56.055	12.534	20	4.294	221.357	0
Cost Score, 6, CVD	106.938	107.950	27.873	15	34.496	379.456	0

Looking at cost scores grouped across the three different types of machines—deposition tools, implanters, and steppers—although the implanters had by far the highest number of stressors at 165, the deposition tools had the highest mean cost score (see Table 9). Implanters were second highest, with steppers having the lowest overall cost scores, on the average.

Table 9 Mean Cost Scores by Machine Type

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
Cost Score, Total	43.111	79.465	5.026	250	1.197	746.928	0
Cost Score, DEP	83.759	114.756	17.500	43	11.544	602.112	0
Cost Score, IMPL	26.930	42.929	3.342	165	1.197	273.715	0
Cost Score, STEP	65.061	119.200	18.393	42	6.000	746.928	0

5.4 Worst Stressors for Each Tool Type

Another analysis of the cost scores partitioned the scores by blocks of stressor items within tool type. A finer-grained analysis of individual stressor items is not realistic because of the paucity of data points within each stressor item. Therefore, the five blocks containing the highest sums of cost scores for the deposition, implant, and stepper tools are shown in Table 10.

Table 10 Highest Cost Stressor Blocks for Each Tool Type

	Block Title	Block #	Sum	Obs.
Deposition	Maintainability/Work flow	3–1	774.6	3
	Reach	7–3	408.9	4
	Couplers	9–4	379.5	1
	Lifting/Loading	5–1	318.2	9
	Posture	7–1	316.6	6
Implanters	Lifting/Loading	5–1	1051.9	34
	Maintainability/Work flow	3–1	906.7	13
	Posture	7–1	569.7	27
	Reach	7–3	366.7	11
	Body access	4–1	291.8	10
Steppers	Maintainability/Work flow	3–1	912.1	5
	Posture	7–1	625.5	16
	Vision	4–5	331.0	5
	Arm access	4–2	284.1	1
	Body access	4–1	251.6	3

5.5 Additional Time

Additional time on tasks was estimated for each observed stressor. Only 82 of the 250 observations included a non-zero additional time; however, they summed to 777 additional minutes overall. When computed as a proportion of additional time over nominal task length, a rough measure of additional time caused by ergonomic stressors can be estimated (Equation 3). There were 28 tasks whose nominal task lengths (as estimated by the maintenance technicians doing the work) summed to 2924 minutes.

Equation 3: $777/2924 \times 100 = 26.6\%$

Looking at individual machines, the Nikon had the highest percentage of additional time at 53%, while the SVG Micrascan had the lowest at 1%. Table 11 lists the additional time, nominal task length, and percentage of time wasted data for the seven machines studied.

Table 11 Overall Percentage of Time Wasted for Each Machine Studied

Machine	Add'l (min)	Task (min)	Percent
Applied 9500	63	210	30%
Applied 5000	80	180	44%
Eaton	235	510	46%
SVG Micrascan	4	410	1%
Nikon	37	70	53%
Novellus	62	196	32%
Varian	296	1348	22%

Table 12 shows percentages when machines are grouped by machine type.

Table 12 Overall Percentage of Time Wasted by Tool Type

Machine Type	Add'l (min)	Task (min)	Percent
Deposition	142	376	37.8%
Implanter	594	2068	28.7%
Stepper	41	480	8.5%

5.6 Recommend Solutions to Stressors

Several labeled blanks in the checklist provided space for the ergonomist-observer to write in potential solutions to the ergonomic stressor. Appendix H lists the solutions by machine and task/task segment. The PTAB also constructed a list of solutions to the top ten stressors at the final PTAB meeting (see Appendix I).

Return on investment (ROI) is the product of decrease in cost of ownership multiplied by the number of wafers affected, divided by the cost of the upgrade, as shown in Equation 4.

Equation 4: $ROI = \Delta COO\ (\Sigma\ wafers)/Cost\ of\ upgrade$

Although the numbers to calculate ROI were unavailable, relative costs and relative positive impacts of the solutions can be estimated from which to develop solution strategies. The list of solutions in Appendix I, when considered as individual solutions, can be used as input to an optimization algorithm for determining the best sets of solutions for various levels of spending. Other inputs include weighting by stressor sum scores (1474-236), subjective estimates of relative benefits (1-10), and estimates of relative cost (1-10). Some logical operations obtained in the analysis prevent illogical combinations of solutions, such as eliminating fasteners and designing captive fasteners to improve enclosure panel removal. The results of the optimizations are shown below. The assumed total capital for spending was 153 points, the total of the solution costs. Each optimization analysis takes a fraction of that number as the spending limit, and the algorithm selects the most advantageous set of solutions that in combination can be afforded within that spending limit. For instance, the best set of solutions for a spending limit of 30%, or 50 points, is shown in Table 13. Additional solution sets are broken out by spending limits

ranging from 20 to 70 points in Appendix J. The solutions and their relevance to a strategy to overcome the stressors found in maintenance tasks are discussed the conclusions section.

Table 13 Optimal Solution Set for Budget of One-Third of Total Cost

Stressor	Solutions
1. Difficult Panel Removal	Eliminate fasteners, use snap fit or hanging panels Use lighter panels and add handles in appropriate locations for lifting User provides storage space for removed panels somewhere near the equipment
2. Kneeling, standing with legs bent	Use fatigue mats inside enclosures Provide folding stools or sit-stand supports
3. Arm lifting	Improve body access so that lifts are closer to torso Use guide-locating devices such as pins to help locate and support components while fastening Provide supports or hoists for parts over 50 #
4. Long reaches 5. Poor component access 6. Awkward postures	Provide light extension handles for tools Enlarge footprint conservatively and strategically to increase body access space within enclosure
7. Poor visual access	Increase local illumination to 100 ft.-c. Increase access openings in bulkheads Use captive fasteners on parts difficult to see
8. Poor arm, hand, or finger access	Enlarge access ports in panels and bulkheads Provide special tools to reach into tight quarters
9. Heavy lifting	Provide handles for two-person lifts
10. Pinch grip, small objects	Provide tools with larger diameter handles

5.7 Checklist Revisions

After data collection was complete, the PTAB reviewed SEMaCheck again, based on field experience. The version of SEMaCheck shown in Appendix F has been revised to address redundancies, omitted items, and difficulty in quickly accessing the correct pages in time-critical field observations. The most significant improvement was the addition of data-recording or response lines in the “Stressor Roadmap” section, now two pages long. The design now allows using only the roadmap section in the field and completing the detailed stressor identification afterwards. This will reduce page-flipping to a minimum. The intended use is as follows: First, the observer becomes familiar with the kinds of stressors enumerated in the reference section at the back of the checklist. Then, in the field, task information on the first page is filled in using information gathered from the maintenance technician who knows the task. Third, the task is observed and the response lines are filled out according to the instructions at the front of the

checklist. Later, in the observer's office, the described stressors are looked up in the reference section and identified by stressor code numbers. If no corresponding stressor code exists, the apparent stressor can be dropped or it can remain a write-in.

In addition, the following improvements were made:

1. Instructions are included under the first response line on each page.
2. Previously redundant stressors now appear in only one location.
3. Response-line data field labels were updated to be more descriptive.
4. More figures were used in the roadmap.
5. More stressor category names were used in the roadmap.
6. A landscape page layout was used to lengthen the response lines.
7. "Minutes" was added to the clock in the response line for clarity.
8. Navigation graphics were added to the bottom of each page of the reference section to help users find their way to different sections.
9. Stressor descriptions in the reference section were clarified.
10. An explanation of a modified cost score formula was added so that users could calculate relative scores for the various observed stressors.
11. Since the response lines are limited to the first two pages, the overall checklist length was shortened from 17 to 12 pages.
12. Write-in items from this study were added to the list of stressors.
13. Landscape page layout was used in the reference section for consistency.
14. The task information header page was reworked for consistency.
15. A title page was added.

An instructions page was added for users downloading SEMaCheck.

6 CONCLUSIONS

6.1 Were the Methods Effective?

The contributions of member company ergonomists in this study proved very effective. They observed tasks that an outsider probably could not have. They also could protect the member company's interests during information exchange. The observation protocol worked well, and the revised checklist should improve observations significantly. Digital photos and video tapes of portions of the tasks also helped elucidate what work was being performed and what stressors were taking their toll on that work. These tools should be used to complement future uses of the checklist. Results can be difficult to interpret. A cost score that combined the data in ways that were meaningful was used. Future investigators can develop their own weighting schemes and evaluation metrics based on their particular interests and goals.

6.2 Generalizing to Other Process Tools

The collected data reflect maintenance problems within a small subset of front-end processing machines. Care should be taken in extrapolating the findings to fab machines in general. The

machines and tasks chosen for study were worst-case bottlenecks and the least favored maintenance tasks. It was known that these machines and tasks had problems. The study explored the magnitude of the problems to see if they had significant impacts on productivity. Another approach could have been to randomly survey maintenance tasks for ergonomic stressors; those results would have been representative of fab machines in general. Nevertheless, the approach used herein has proven successful and would be advisable for any member company intent on looking for the critical maintenance problems that need solving.

6.3 Industry Use of SEMaCheck

It is hoped that the current form of SEMaCheck can be used by people with no formal training in ergonomics. However, for best results, SEMaCheck should be used by ergonomists, industrial engineers, or safety/health workers with some ergonomics training or experience. SEMaCheck should be implemented in software so that observers can use a portable computer to document ergonomic stressors in maintenance tasks. That would necessitate customization based on the technology chosen. Features such as automated computation of cost scores and automated optimization of solution strategies would make SEMaCheck an extremely useful tool. SEMaCheck can be used as a design guide for engineers in supplier companies. Avoiding physical and cognitive stressors from the outset is the best way to improve efficiency of maintenance tasks and improve tool utilization.

The revised version of SEMaCheck is available on the world wide web for unlimited member company use. Since SNL holds the copyright for SEMaCheck, any modifications or other uses must be approved by SNL's legal department.

6.4 The Most Significant Stressors

The current study identified the most significant physical and cognitive ergonomic stressors associated with front-end tool maintenance, as shown in Table 6. The cost scores are the most reliable and robust measures of negative impact on operational effectiveness when compared to frequency, time, or error consequences. The cost scores reliably return the same set of top ten stressors (albeit in slightly different order), even when the weighting of the formula factors are manipulated or eliminated. The top ten stressors tend to address accessing components, lifting, reaching, assuming awkward postures while standing, and having poor visual access. These impediments to work appear to agree with more casual observations of fab maintenance procedures. The tools are typically built to take advantage of the smallest possible footprint and consequently pack as much as possible into a small space, leaving little room for a person to access to components. Items that were least frequently observed by the PTAB members were problems with documentation and poorly designed controls and displays. No observations of stressors in Group 8 (Controls and Displays) were recorded in this study. The fact that very few maintenance technicians use documentation after their first few experiences explains the first of these results. The fact that the PTAB members were corporate ergonomists, trained and experienced in looking for physical problems in the workplace, explains the second.

6.5 The Cost of Stressors

The cost of ergonomic stressors on productivity can be estimated by examining the COO equation and identifying the impacts on the individual factors within that equation (see Equation

5). For instance, anything that can reduce the factors in the numerator—i.e., fixed costs, recurring costs, and scrap product—can reduce the COO.

$$\text{Equation 5:} \quad COO = \frac{\Sigma \text{ fixed costs} + \Sigma \text{ recurring costs} + \text{scrap}}{\text{lifetime} \times \text{throughput rate} \times \text{utilization} \times \text{yield}}$$

Maintenance costs mostly affect the sum of recurring costs. However, when a tool is installed, the types of tasks that are performed are very similar, if not identical, to maintenance tasks. Therefore, benefits brought to recurring costs in the form of less time spent, fewer technicians needed, reduced opportunity for errors, etc. can be applied to the portion of fixed costs associated with tool installation. The scrap factor might be affected positively if reduced probability of errors in machine calibration helps to avoid processing wafers out of tolerance. But mostly, the recurring costs will be reduced with faster, more reliable maintenance tasks. How much? It is difficult to estimate. If maintenance work time is reduced significantly across the entire fab by 10 to 20%, fewer technicians may be needed per shift, thereby reducing labor costs proportionately. Another recurring cost that can affect the numerator is the cost of lost work days due to cumulative trauma disorders (CTDs) and loss of efficiency in performing maintenance tasks due to CTDs that are not severe enough to keep a worker home.

In the denominator of Equation 5, factors that can be increased will reduce COO. Tool lifetime, throughput rate, and yield remain all but unaffected by ease of maintenance. However, utilization can increase as a result of reduced maintenance time, especially for tools with low utilization. For instance if utilization for a tool is nominally 0.80, and maintenance time is reduced 25%, as suggested is possible from the results section, utilization can increase (1.0–.8) x .25 = .05, or 6%. If a tool with lower utilization, say 0.65, were to benefit from the kind of reductions in maintenance time possible found in the Applied 9500 and Eaton implanters, the increase in utilization can be substantial (1.0–.65) x .45 = .157 or 25%. A recent simulation using Two Cool software calculated the savings possible in a low pressure CVD tool with only 5 hours maintenance per week. The baseline calculation for COO was $3.49 per wafer layer. With a 30% reduction in maintenance time, the COO was reduced to $3.45. If the labor force were reduced by one maintenance technician, another $0.05 was reduced, reducing the COO by a total of $0.09. The nine-cent reduction multiplied by six layers and 20,000 wafers a month for 12 months adds up to $129,600 per year or $648,000 for five years. This is not an insignificant figure, when considered with the combined potential savings from multiple machines of the same type or other types of tools.

6.6 Solution Strategies

The best engineering solutions for reducing human-related maintenance problems are to reduce the need for maintenance, automate the maintenance with robotics, and use wholesale modular design. The solution strategies outlined in Appendix J (and Table 13) demonstrate how many of the recurring stressors observed in maintenance activities can be partially reduced or, in some cases, eliminated through more conventional, affordable engineering practices. Some of these solutions are admittedly “Band-Aids.” Examples include using fatigue mats, providing hoists, and redesigning special tools used on the job. Others use sound engineering and are intended for major redesign cycles, such as using guide pins, roll-out chassis drawers, modular design, and hinged subassemblies. It is hoped that the suggested solutions are appropriate technologies for semiconductor manufacturing equipment.

The most advantageous engineering solutions are relatively inexpensive to implement, and they get results (see Appendix I). One is eliminating fasteners or using captive fasteners where applicable so that maintenance technicians do not need to handle or worry about losing nuts and washers. Others are redesigning panels to weigh less and providing convenient handles so that technicians can lift and carry them easily. Using guide-locating pins to help with mounting and dismounting heavy components or those needing alignment is a consistent winner in the optimization algorithm. One surprising result was the solution to conservatively and strategically enlarge the footprint to allow physical access to the interior of the tool enclosure. This, of course, must be weighed against the cost per square foot of clean fab space. Other add-on solutions such as increasing illumination, altering tooling, and adding fatigue mats, also present themselves frequently in the optimization results.

6.7 What Can Suppliers Do?

To help suppliers, machine-specific stressor data were culled out of the database. Narrative descriptions of the tasks observed, most prevalent stressors identified, and suggested solutions are collected in Appendix K. A more exhaustive list was sent to the appropriate representatives of the six supplier companies to alert them to design-for-maintainability issues.

Suppliers are encouraged to get data for design needs by talking to maintenance technicians and the design staff. Wherever factory maintenance technicians are employed, it is strongly advised that suppliers tap into their knowledge. Maintenance technicians can also be a good source of ideas on how to solve the problems. A visiting observer may be even more effective at discerning work-related stressors than the workers themselves, because the workers, being habituated to the stressors, may not usually perceive them as being unusual or unacceptable. SEMaCheck can be used as a baseline to establish criteria for stressors that can negatively affect maintenance efficiency.

6.8 What Can Users Do?

Most of the tasks observed in this study were performed by in-house maintenance technicians. This means that users have employees who can identify (perhaps with the help of SEMaCheck) inefficiencies in maintenance tasks caused by inadequate ergonomic design. In addition to increased machine utilization, workload and injury rates can be reduced by sound ergonomic design. Users' tool purchases are influenced by more than just economics; the long-term health and well-being of their maintenance technicians should also be a factor. SEMATECH's member companies can provide the necessary market pull to change the way processing tools are designed.

Currently, processing tools are designed for minimal footprint. Considering the extremely high cost of fab architecture, this seems reasonable. But have all of the real costs associated with compact footprints been accounted for? Many of the stressors observed in this study are directly related to or are artifacts of inadequate access to a tool's internal components. The economics of reducing the stressors through better design-for-maintainability have been demonstrated in section 6.2. The total costs of designing tools for minimal footprint should be subject to further study.

7 REFERENCES

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3. Swain, A.D. and Guttmann, H.E., *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, NUREG/CR 1278, SAND80-0200, Washington, 1983

4. Miller, D. P. and H. O. Whitehurst, *Preventing User-Hostile Interfaces in IC-Fab Equipment: Ergonomic approaches for preventing ten frequent user-interface problems*, SEMATECH Technology Transfer #92091299A-ENG, November 1992.

APPENDIX A
Literature SEARCH

Before the purpose of this study was refined, any documents addressing cleanroom ergonomics were of interest. The following conclusions were drawn from reading the documents listed below:

Summary Conclusions

1. Minienvironments are inherently cheaper than ballroom designs and can span several device generations. Operators can be in class 10,000 while product is in class 1. However, minienvironments need to be made user-friendly. They are also awkward to break down and clean.
2. Particle counts are increased by loadlock doors, cassette rotation, distance from doors, and garments made with short fibers.
3. A disk-handling tool redesigned using TOME model reduced droppage, handling time, and wrist deviations.
4. Robotic systems can replace operators in handling heavy, expensive wafer cassettes.
5. Projection microscopes can be effective in visual inspection if designed well.
6. There are systematic techniques for evaluating production effectiveness of new fabs.

Literature Sources Consulted

Title: **Designing a friendlier workplace through cleanroom ergonomics**
Author: Scott, George L.
Corporate Source: Jacob's Engineering Group's, Portland, OR, USA
Source: Microcontamination v 13 n 1 Jan 1995. p. 5

Title: **Norcross project. Investigating the relationship between ergonomic factors and particle addition in manual-access minienvironments**
Author: Muller, P.; Silverman, S.; Bostwick, J.; Rothman, L.; Miller, R.J.; Wang, R.D.; Van Sickle, P.M.; Tanaka, M.; Costa, J.
Corporate Source: IBM, Burlington, VT, USA
Source: Microcontamination v 12 n 10 Oct 1994. pp. 39-43

Title: **Class 10 chair controls contamination, static in cleanroom operation**
Author: Anon
Source: Microcontamination v 11 n 8 Aug 1993. p. 44

Title: **Upgrading a Class 100 fab through use of manual-access microenvironments**
Author: Grande, Wendy C.
Corporate Source: Northern Telecom
Source: Microcontamination v 11 n 1 Jan 1993. pp. 25-28, 63

Title: **Minienvironments and Their Place in the Fab of the Future**
Source: Solid State Technology September, 1993, p. 49

Title: **Design and evaluation of an optical disk handling tool for a cleanroom environment**
Author: Vora P V; Reynolds J L; Corl K G

Source: Applied Ergonomics, 1992, 23 (6) pp. 414-424

Title: **How to design a validation program for cleanrooms**
Author: Thibeault, Anita
Source: Medical device and diagnostic industry, v.17, n.5 May 1995, p. 6

Title: **Effects of a visual task with cognitive demand on dynamic and steady-state accommodation.**
Author: Iwasaki, T.
Source: Ophthalmic-&-Physiological-Optics, vol 13, no. 3, July 1993, pp. 285-90

Title**: The model-E projection microscope-a tool for visual inspection of wafers in microelectronic circuit manufacture.**
Au: Knupffer, H.; Bonnke, H.
Source: Jena Review no. 2, pp. 66-9

Title: **Impact of minienvironments of facilities cost**
Author: Barnett, William; Schneider, R.K.
Source: Proc. of IEEE/CPMT Int'l Electronic Manuf. Tech. (IEMT) Symposium 1995, IEEE, Piscataway, NJ 1995, pp. 286-291

Title: **Intrabay automated material handling**
Author: Pierce, Neal
Source: Proc. Inst. Envir. Sci. vol. 1 1993 pp. 529-537

Title**: Studies on sizing and counting particulate contaminate in and on clean room garments**
Author: Hayakawa, I. et al.
Source: 1985 Proc. 31st Annual Mtg. Inst. Envir. Sci. Improve your odds with sound basic science and creative engineering.

APPENDIX B
Data Collection Techniques

The following information was sent to PTAB members on March 10, 1997, before a teleconference to discuss how the data were to be collected.

Questionnaire—effective method for getting data from many people, can be anonymous, can be easy to score, has structural consistency, and open-ended questions can be used for workers to express difficulties.

Disadvantages—many people are Q'd out, which leads to bad attitudes, low return rates, sabotaged answers, etc. Also can't follow up for explanations unless you know who answered. Impersonal. Difficult to anticipate all possible responses, so can miss important information. Difficult to assure reliability in answers without rewording and repeating questions. Worst data in terms of validity.

Personal Interview—allows for more detailed explanations, no colleague bias or bandwagon effects, provides 2nd best data, task difficulties can be expressed by participant.

Disadvantages—not as consistent as Q, unless carefully scripted, time- inefficient, difficult to record/analyze data, can't be anonymous—social bias. A variation of this, called the 'Critical Incident Technique' was used by Engineering Psychologists in the mid-forties to identify ergonomics problems with flying aircraft during the war. The interviewer would ask "Tell me about some error or mistake you have made in using the ____ machine" and collect answers from several operators (pilots) to cross-validate. Advantages were getting right to the rough spots quickly, while disadvantages include forgetting, and having trouble combining data from several sources.

Focus Group Interview—typically held with 2-20 people, more time efficient than personal interview, general results available rapidly, lots of data can be recalled on specific issues, 3rd best data, task difficulties can be expressed by participants.

Disadvantages—more time consuming for participant than personal interview or Q, bandwagon effects (everyone chimes in with personal anecdote on an issue, making it difficult to assess its representativeness), no anonymity—social bias.

Direct Observation—best data of the bunch, because it's firsthand and does not need interpretation or communication to collector. Can collect data on virtually any aspect of the tasks. Many ergonomists attempt the tasks themselves to help identify problems for beginners.

Disadvantages—access to work area may be restricted, extremely time-intensive, work may be affected by observer's presence or interactions, difficult to collect all relevant data real-time (may have to resort to videotaping), difficult to anticipate all data that must be collected and create easy-to-use forms, may have to infer difficulty unless worker is primed to point out.

Types of Direct Observation:

Activity Sampling—at prescribed time intervals record activity in task. Yields % time doing various activities within task, but not sequence information, difficulty, location, or hazards.

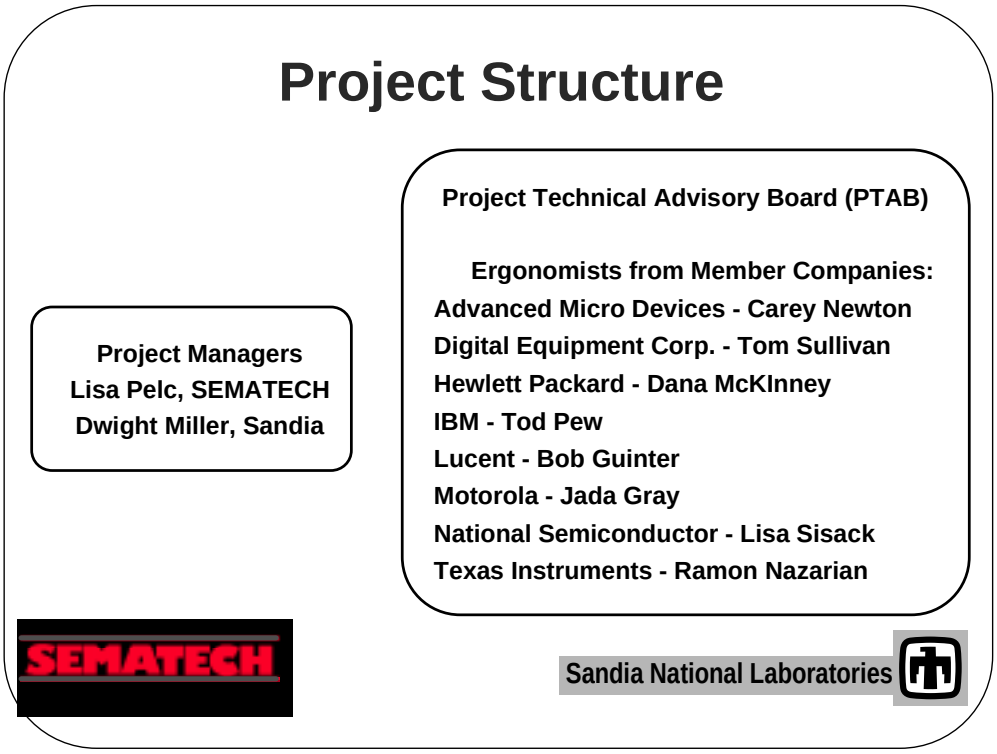
Function Analysis—general term for several analyses, process analysis, flow charts of the sequential process of a task, including product operations, movements, storage, quality inspections, etc. Flow diagrams, operational sequence diagrams, timeline analysis w/Gantt charts.

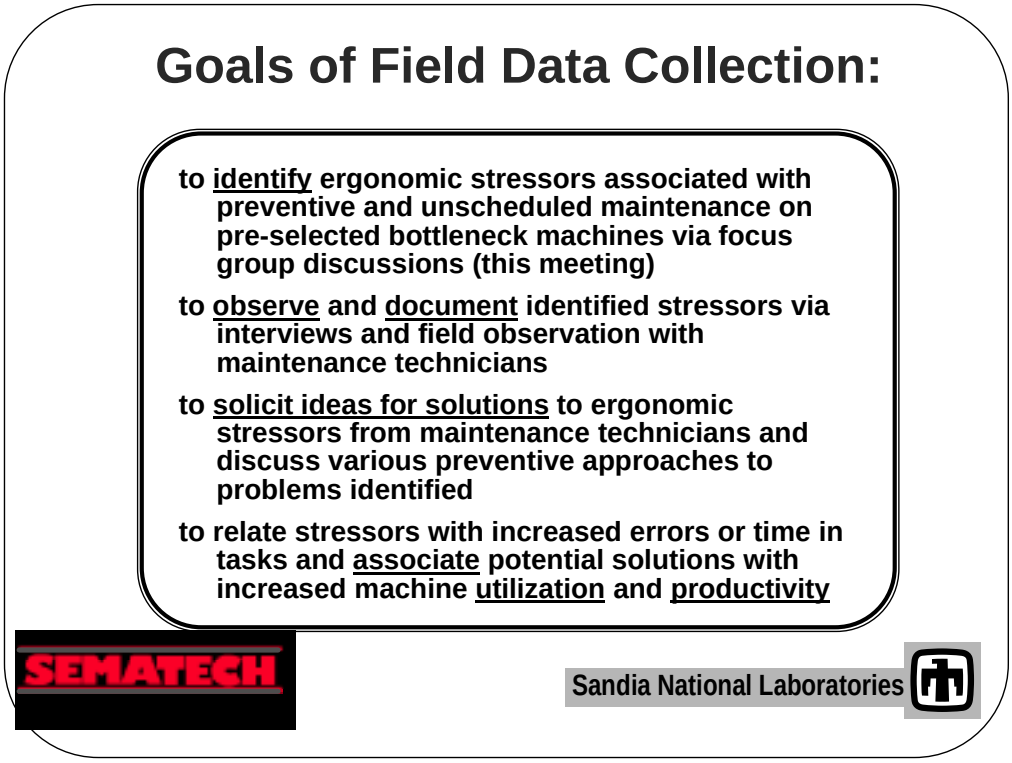
Network Analysis—indicates relationships of system entities by time, distance, frequency, or importance. Includes critical path method, PERT, SAINT, link analysis - showing relative frequencies of movement or interaction.

Task Analysis—typically applied to one worker, TA breaks down a job or large task into smaller components and identifies skills and tools required, behavioral components, and in cases of reliability analyses, probabilities of human error.

Work Load Measurement & Analysis—probably not relevant to discussion, but it involves measuring expenditures, stresses, and strains on human physiology during work and designing tasks so as not to exceed prescribed fractions of total work capacities.

APPENDIX C
Field Slides for Maintenance Staff Focus-Group Session





Ergonomic Stressors that Might Affect Productivity

Physical - heavy lifting, strenuous torquing, long reaches, prolonged awkward postures, pushing/pulling, stooping, pinch grips, overhead reaches, extremity or whole-body vibration, excessive repetitions or keyboard work, accessability to components,

Mental - poorly written procedures, hard to read displays, controls that are counter-compatible, tricky alignment, setting, or balancing tasks, difficult fault diagnosis, hard to remember task steps, things that are confusing, hard-to-use auxillary equipment

SEMATECH

Sandia National Laboratories

We're Not Really Interested In:

Environmental Factors - noise, ambient lighting, air quality, chemical exposure, plant bulk supply hook-ups, gray area housekeeping, etc.

Safety Issues - warning labels, guards and shields, pinch points, robot arm dangers, heat/cold, radiation, lubricants, solvents, etc.

Clothing Issues - particle shields, booties, breathing apparatus, gloves, etc.

Organizational Factors - shift rotations, assignments, teamwork, training, communication with operators, time to arrive at machine, etc.

SEMATECH

Sandia National Laboratories

Think of Tasks That Have Any of These Characteristics:

*****Tedious,,,,,,

Difficult to Perform

^~! Stressful !@#

POORLY DESIGNED

LABORIOUS

?Konfuzing?

T.i.m.e.....-.....C.o.n.s.u.m.i.n.g.....

SEMATECH

Sandia National Laboratories

Focus Group Exercise

Think about both PM and Unscheduled Maintenance tasks with the Applied Materials 5500 Deposition Tool.

Given the criteria we talked about, which tasks are the best candidates for observation ?

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

_____ o PM o UM

SEMATECH

Sandia National Laboratories

Prioritized List of Tasks

Using the list of tasks just developed, vote on the worst 3 tasks. The number of votes will determine the ranking of the tasks. The ranked list of maintenance operations on the Applied Materials 5500 Deposition tool are:

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____

SEMATECH

Sandia National Laboratories

Task Observations

Thank you for your valuable inputs to our project. We will schedule field interviews/obervations with your management.

The field work will involve us going with you on chosen maintenance tasks, asking you questions about the tasks, and recording task information of checklists. Remember, we are intersted in what design features in the equipment and the operations make life difficult for you. We are not interested in assessing your performance.

Please be as frank and honest as you can about task difficulties. The data we collect will probably be fed back to the designers and manufacturers of the equipment so that they can learn from their mistakes and design future equipment that is more maintainable.

We thank you in advance for your cooperation.

SEMATECH

Sandia National Laboratories

APPENDIX D
Sandia Ergonomic Maintenance Checklist

Questions for Maintenance Technician prior to field observations:

Task Information and Timing

How often is this task performed on each machine? ____Times per_____

What is the typical duration of the entire task? ___ hrs.____min.

What segment of the task will I be observing?_____

How long does this segment typically take to perform? ___ hrs.____min.

Will you be under any time pressure to complete the task?

None 1--------2 Some--------3 Moderate--------4 Considerable--------5 Severe

Experience

How much training did you get on this task?_____

Who performed the training?_____

How many times (total) have you performed this task?_____

When was the last time you performed this task?_____

Do you have any ideas on how to improve the task?_____

_____

_____

_____

Session Information:

Observer_____ Machine_____

Task Performed_____ ❑ PM ❑ UM

Auxil. Equipment needed_____

Performed by: ❑ in-house tech.(s) ❑ contractor(s) ❑ factory rep.(s)

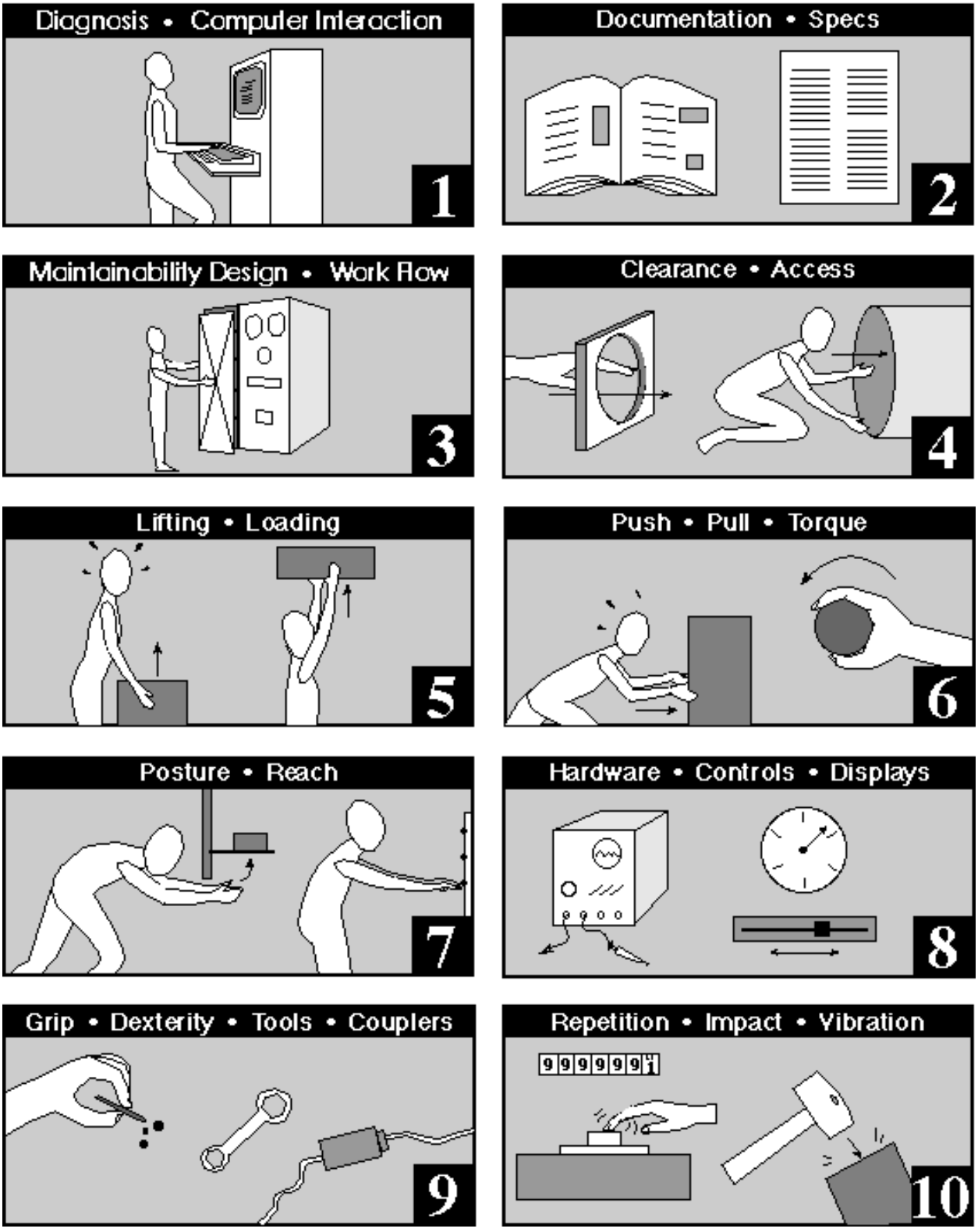
❑ other _____

Current shift hours:_____ to _____ Today's date:_____

Session start time:_____ Session end time:_____

Checklist data covers portion of task, or steps:_____

STRESSOR ROADMAP



1a DIAGNOSIS HUMAN-COMPUTER INTERACTION 1a

Diagnosis

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Must integrate info from displays	☐☐☐				☐☐☐
Incomplete info	☐☐☐				☐☐☐
Have to look up codes	☐☐☐				☐☐☐
Must search for info	☐☐☐				☐☐☐
Automated diagnosis is wrong	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

Must use documents to diagnose	☐☐☐				☐☐☐
Must diagnose without aids	☐☐☐				☐☐☐
Must perform tests to diagnose faults	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

Input Devices

Keyboard

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Used as pointer	☐☐☐				☐☐☐
Bad location	☐☐☐				☐☐☐
Standing ht <33" or >40"	☐☐☐				☐☐☐
Seated ht <26" or >30"	☐☐☐				☐☐☐
Keys worn out	☐☐☐				☐☐☐
Inappropriate for task	☐☐☐				☐☐☐
Force too sensitive	☐☐☐				☐☐☐
Force too stiff	☐☐☐				☐☐☐
Too much typing	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

Pointing Device

Too sensitive	☐☐☐				☐☐☐
Too coarse	☐☐☐				☐☐☐
Discontinuous control	☐☐☐				☐☐☐
Confusing buttons	☐☐☐				☐☐☐
CTD Issue	☐☐☐				☐☐☐

Touch Screen

Poor alignment	☐☐☐				☐☐☐
Multiple touches needed	☐☐☐				☐☐☐
Lightpen difficult to use	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

— Use reverse side for notes —

1b DIAGNOSIS HUMAN-COMPUTER INTERACTION 1b

Computer Interaction

Monitor — DIFFICULTY | DESCRIPTION/LOCATION | + | ERROR POSSIBLE | CONSEQUENCE

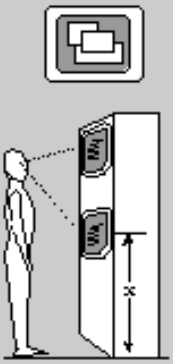
- Mostly text
- _____

Possible Solution

Feedback — DIFFICULTY | DESCRIPTION/LOCATION | + | ERROR POSSIBLE | CONSEQUENCE

- Delayed feedback
- Inappropriate feedback
- Status info for long tasks not shown
- _____

Possible Solution



Screen Navigation — SEVERITY | LOCATION/STEP | + | ERROR POSSIBLE | P(ERROR)

- No home key
- Number of menus/ steps > 3 to do task
- Machine status not displayed
- Machine status not displayed adequately
- Standing — monitor lower than 52" or higher than 58"
- Sitting — lower than 37" or higher than 47" elbows higher than 65" incline < 15°
- _____

Possible Solution

Color — DIFFICULTY | DESCRIPTION/LOCATION | + | ERROR POSSIBLE | CONSEQUENCE

- Violates green-yellow-red coding
- Screens use bright multiple colors
- Color contrast insufficient for reading
- Monochrome — could use one color
- _____

Possible Solution

— Use reverse side for notes —

2 DOCUMENTATION · SPECS 2

Documentation

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Not needed	☐☐				☐☐
Hard to find data	☐☐				☐☐
Reading level too high	☐☐				☐☐
Illogical organization	☐☐				☐☐
Steps missing	☐☐				☐☐
Repeated steps	☐☐				☐☐
Not enough illustrations	☐☐				☐☐
Print too small	☐☐				☐☐
Checklists not used	☐☐				☐☐
Multiple sources needed to do job	☐☐				☐☐
Too big	☐☐				☐☐
Too heavy	☐☐				☐☐
Specification/ tolerance not correct	☐☐				☐☐
Ranges not correct	☐☐				☐☐
Schematics too large	☐☐				☐☐
Busy schematics	☐☐				☐☐
Can't access document while doing task	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

Software-based Documentation

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Hard to navigate	☐☐				☐☐
Slow to respond	☐☐				☐☐
Too much scrolling required	☐☐				☐☐
Hard to read	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

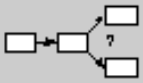
— Use reverse side for notes —

3 MAINTAINABILITY DESIGN • WORK FLOW 3

Tool Not Designed For Maintainability

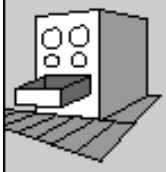
DIFFICULTY | DESCRIPTION/LOCATION | + | ERROR POSSIBLE | CONSEQUENCE

No individual access; have to move objects to gain access ☐☐☐ _____ _____ _____ ☐☐☐



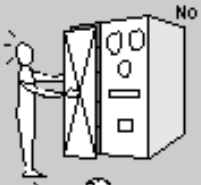
Steps illogical — inefficient workflow ☐☐☐ _____ _____ _____ ☐☐☐

No modular replacement ☐☐☐ _____ _____ _____ ☐☐☐



No roll out drawers ☐☐☐ _____ _____ _____ ☐☐☐

Drawers extend into aisles ☐☐☐ _____ _____ _____ ☐☐☐



No quick-disconnects used ☐☐☐ _____ _____ _____ ☐☐☐

Difficult enclosure panel removal ☐☐☐ _____ _____ _____ ☐☐☐

Work segment(s) done under time pressure ☐☐☐ _____ _____ _____ ☐☐☐

No documents used when needed (voluntary) ☐☐☐ _____ _____ _____ ☐☐☐

Paper not allowed in lab ☐☐☐ _____ _____ _____ ☐☐☐

Rest break(s) needed ☐☐☐ _____ _____ _____ ☐☐☐

Poor access to test points ☐☐☐ _____ _____ _____ ☐☐☐

_____ ☐☐☐ _____ _____ _____ ☐☐☐

Possible Solution

— Use reverse side for notes —

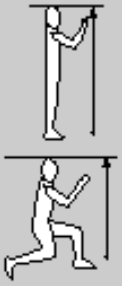
4a CLEARANCE • ACCESS 4a

Whole Body

Hatch

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Vertical hatch < 24"	☐☐				☐☐
Horizontal hatch < 24" high	☐☐				☐☐
	☐☐				☐☐

Possible Solution

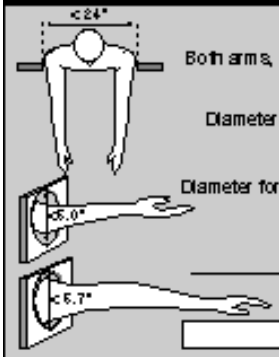


Standing

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Vertical height < 80"	☐☐				☐☐
Kneeling height < 48"	☐☐				☐☐
	☐☐				☐☐

Possible Solution

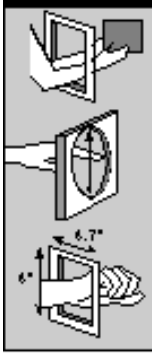
Arms



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Both arms, 1 opening < 24"	☐☐				☐☐
Diameter for elbow < 5.0"	☐☐				☐☐
Diameter for shoulder < 5.7"	☐☐				☐☐
	☐☐				☐☐

Possible Solution

Hands



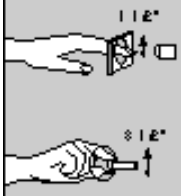
	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Too tight for 2 hands	☐☐				☐☐
Opening for open hand < 2" x 4"	☐☐				☐☐
Opening for fist < 6" x 6.7"	☐☐				☐☐
	☐☐				☐☐

Possible Solution

— Use reverse side for notes —

4b CLEARANCE • ACCESS 4b

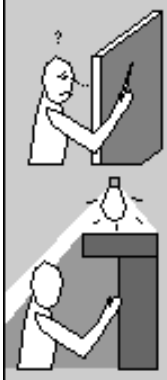
Fingers



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
< 1 1/2" diameter push button	□□□				□□□
2 finger twist < 3 1/2" diameter	□□□				□□□
	□□□				□□□

Possible Solution

Vision



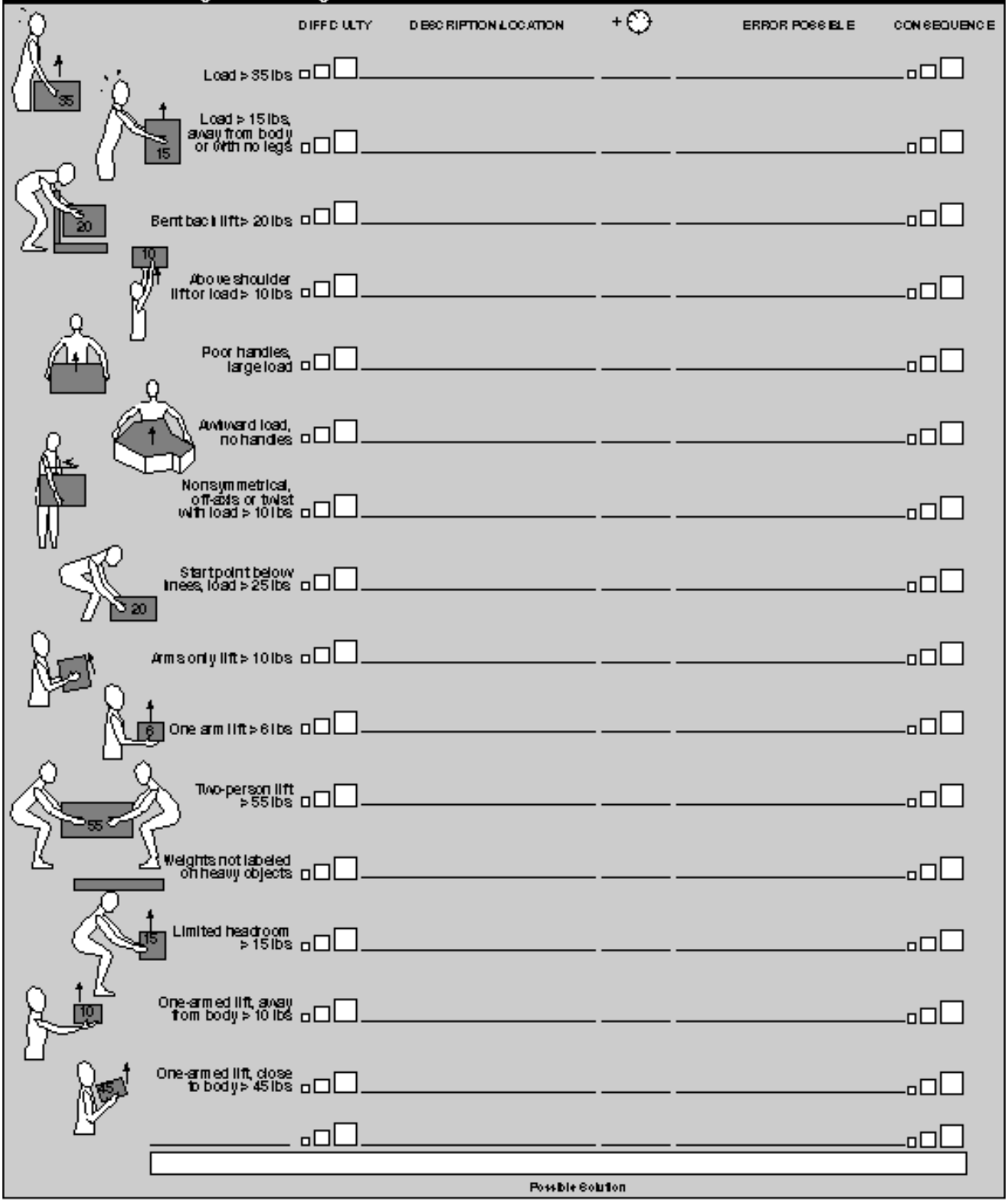
	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Inadequate visual access	□□□				□□□
Inadequate lighting for task	□□□				□□□
	□□□				□□□

Possible Solution

— Use reverse side for notes —

5 LIFTING • LOADING 5

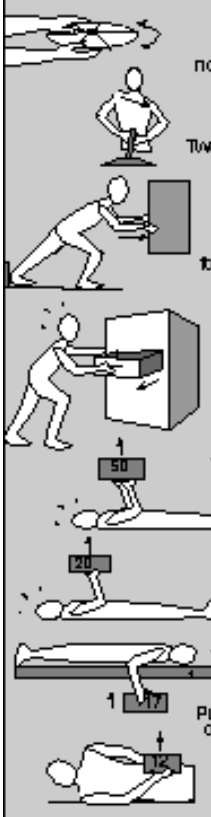
Lifting • Loading



— Use reverse side for notes —

6 PUSH • PULL • TORQUE 6

Push • Pull



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Two hands, no shoulders > 9 lbs	☐☐☐				☐☐☐
Two hands, shoulder, back > 50 lbs	☐☐☐				☐☐☐
Whole body with footbrace > 100 lbs	☐☐☐				☐☐☐
One hand push or pull > 20 lbs	☐☐☐				☐☐☐
Push, lying down two arms, > 50 lbs	☐☐☐				☐☐☐
Push, lying down one arm, > 20 lbs	☐☐☐				☐☐☐
Pull, lying face down, one arm, > 17 lbs	☐☐☐				☐☐☐
Pull, lying sideways one arm, > 12 lbs or > 17 lbs if using two arms	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

Torque

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
One hand > 15 ft lbs	☐☐☐				☐☐☐
Arm > 15 ft lbs	☐☐☐				☐☐☐
Body > 40 ft lbs	☐☐☐				☐☐☐
_____	☐☐☐				☐☐☐

Possible Solution

— Use reverse side for notes —

7a POSTURE • SITTING • REACH • WRIST 7a

Posture

	AMOUNT/DURATION	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Neck flexion > 20°	☐☐				☐☐
Any Neck extension	☐☐				☐☐
Neck side bending > 20°	☐☐				☐☐
Neck twist > 45°	☐☐				☐☐
Trunk flexion > 20°	☐☐				☐☐
Trunk side bending > 20°	☐☐				☐☐
Static standing posture > 45 min.					
Trunk twist > 20°	☐☐				☐☐
Feet/legs uneven surface	☐☐				☐☐
Feet/legs bent supporting body knee > 1 min.	☐☐				☐☐
Feet/legs kneel, crouch	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

Sitting

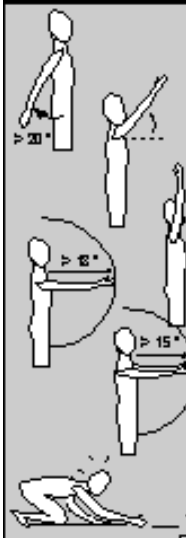
	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Too low	☐☐				☐☐
No backrest	☐☐				☐☐
Static sitting > 1 hr.	☐☐				☐☐
No cushion	☐☐				☐☐
Stool with no footring	☐☐				☐☐
Sitting on floor	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

— Use reverse side for notes —

7b POSTURE • SITTING • REACH • WRIST 7b

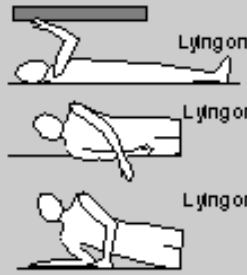
Reach



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Arms > 20° extension	☐☐				☐☐
Reach over shoulder	☐☐				☐☐
Reach overhead	☐☐				☐☐
Reach/grasp male, 1 arm > 15°	☐☐				☐☐
Reach 2 arms > 15°	☐☐				☐☐
Reach below sub flooring	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

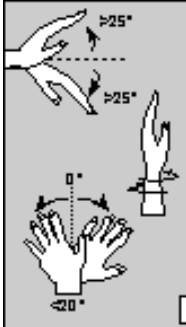
Lying



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Lying on floor (back)	☐☐				☐☐
Lying on floor (side) on shoulder	☐☐				☐☐
Lying on floor (side) on elbow	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

Wrist

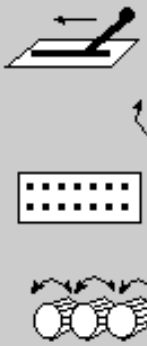


	SEVERITY	LOCATION/STEP	+	ERROR POSSIBLE	P(ERROR)
Prolonged extension	☐☐				☐☐
Prolonged flexion	☐☐				☐☐
Prolonged supination	☐☐				☐☐
Prolonged pronation	☐☐				☐☐
Prolonged ulnar/ radial deviation	☐☐				☐☐
_____	☐☐				☐☐

— Use reverse side for notes —

8 HARDWARE • CONTROLS • DISPLAYS 8

Controls



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
High resistance	☐ ☐				☐ ☐
Too small	☐ ☐				☐ ☐
Poor labeling	☐ ☐				☐ ☐
Poorly located	☐ ☐				☐ ☐
Missing warnings	☐ ☐				☐ ☐
Too coarse	☐ ☐				☐ ☐
Unstable set point	☐ ☐				☐ ☐
Little clearance between	☐ ☐				☐ ☐
_____	☐ ☐				☐ ☐

Possible Solution

Displays

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Normal operation range/caution/danger not shown	☐ ☐				☐ ☐
Green/yellow/red color coding violated	☐ ☐				☐ ☐
Digital, but need analog	☐ ☐				☐ ☐
Analog, but need digital	☐ ☐				☐ ☐
Can't read because of: Glare	☐ ☐				☐ ☐
Shadows	☐ ☐				☐ ☐
Small numbers/letters	☐ ☐				☐ ☐
Bad angle	☐ ☐				☐ ☐
_____	☐ ☐				☐ ☐
Auditory Displays					
Not distinguishable from others	☐ ☐				☐ ☐
Alarm defeatable with no reminder	☐ ☐				☐ ☐
Not used as warning nuisance	☐ ☐				☐ ☐
Too soft	☐ ☐				☐ ☐
Too loud	☐ ☐				☐ ☐
_____	☐ ☐				☐ ☐

Possible Solution

Push Buttons

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Too small for finger	☐ ☐				☐ ☐
Resistance too great	☐ ☐				☐ ☐
Emergency OFF too small	☐ ☐				☐ ☐
Emergency OFF low resistance	☐ ☐				☐ ☐
Poor location	☐ ☐				☐ ☐
_____	☐ ☐				☐ ☐

Possible Solution

9a GRIP • DEXTERITY • TOOLS COUPLERS 9a

Grip

Pencil, Test Leads, Fasteners, Paper

Twist Small Knob With Fingers

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Object < 1", frequent or high force	☐☐				☐☐
_____	☐☐				☐☐
Frequently	☐☐				☐☐
High torque	☐☐				☐☐
Poor coupling/ smooth surface	☐☐				☐☐
_____	☐☐				☐☐

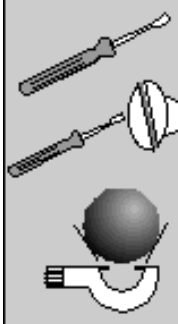
Possible Solution

Dexterity

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Picking up small objects	☐☐				☐☐
Manipulating small objects	☐☐				☐☐
Fitting small objects	☐☐				☐☐
Tiny tools needed	☐☐				☐☐
Frequently used fasteners are not captive	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

Tools



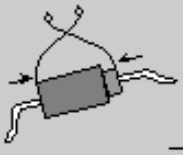
	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Handles too narrow for torque	☐☐				☐☐
Tips wrong size or shape	☐☐				☐☐
Inappropriate tool for measuring	☐☐				☐☐
Special tools required	☐☐				☐☐
Design does not minimize number tools needed	☐☐				☐☐
_____	☐☐				☐☐

Possible Solution

— Use reverse side for notes —

9b GRIP • DEXTERITY • TOOLS COUPLERS 9b

Couplers



	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Difficulty pulling apart	☐☐☐				☐☐☐
Difficulty joining manually	☐☐☐				☐☐☐
Coupler can be inverted	☐☐☐				☐☐☐
Tool needed to join coupler	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

Possible Solution

Handles

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
3/4" to 1 1/2" in diameter	☐☐☐				☐☐☐
Length < 5.0"	☐☐☐				☐☐☐
Clearance < 2"	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

Possible Solution

— Use reverse side for notes —

10 a REPETITION • IMPACT • VIBRATION 10 a

Finger Only

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Low force ≥ 35 reps/min.	☐☐☐				☐☐☐
Medium force ≥ 20 reps/min.	☐☐☐				☐☐☐
High force ≥ 10 reps/min.	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

Possible Solution

Hand/Wrist Torque

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Low force ≥ 35 reps/min.	☐☐☐				☐☐☐
Medium force ≥ 20 reps/min.	☐☐☐				☐☐☐
High force ≥ 10 reps/min.	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

Possible Solution

Arm Repetition

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Low force ≥ 20 reps/min.	☐☐☐				☐☐☐
Medium force ≥ 10 reps/min.	☐☐☐				☐☐☐
High force ≥ 5 reps/min.	☐☐☐				☐☐☐
Frequency is > 15/min.	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

Possible Solution

Shoulder Repetition

	DIFFICULTY	DESCRIPTION/LOCATION	+	ERROR POSSIBLE	CONSEQUENCE
Low force ≥ 15 reps/min.	☐☐☐				☐☐☐
Medium force ≥ 7 reps/min.	☐☐☐				☐☐☐
High force ≥ 3 reps/min.	☐☐☐				☐☐☐
	☐☐☐				☐☐☐

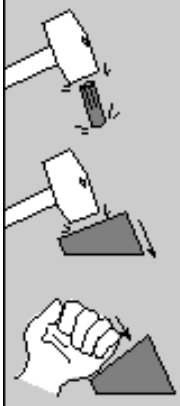
Possible Solution

— Use reverse side for notes —

10 b REPETITION • IMPACT • VIBRATION 10 b

Arm/Hand Vibration

Hammer



DIFFICULTY | DESCRIPTION/LOCATION | + ⏱ | ERROR POSSIBLE | CONSEQUENCE

Small Hammer & Fasteners

Frequent use ☐☐☐ _____ _____ _____ ☐☐☐

Large Hammer – Impact Tools

Frequent use ☐☐☐ _____ _____ _____ ☐☐☐

Large hammer to Move Heavy Object

Frequent use ☐☐☐ _____ _____ _____ ☐☐☐

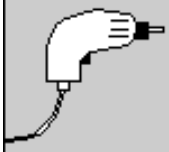
Hand used as hammer ☐☐☐ _____ _____ _____ ☐☐☐

_____ ☐☐☐ _____ _____ _____ ☐☐☐

Possible Solution

Vibration

Power Tools



DIFFICULTY | DESCRIPTION/LOCATION | + ⏱ | ERROR POSSIBLE | CONSEQUENCE

Used < 5 min. ☐☐☐ _____ _____ _____ ☐☐☐

Used < 15 min. ☐☐☐ _____ _____ _____ ☐☐☐

Used > 15 min. ☐☐☐ _____ _____ _____ ☐☐☐

_____ ☐☐☐ _____ _____ _____ ☐☐☐

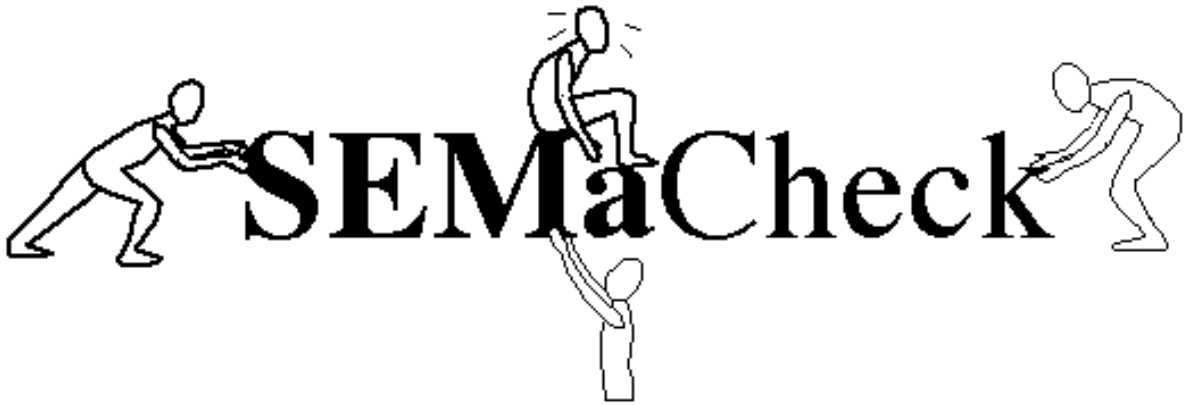
Possible Solution

— Use reverse side for notes —

APPENDIX E
PTAB Suggestions For Checklist Revision

Problem	Suggested Solution	Implementation
1. Too long for field use	Write as one or two pages to eliminate flipping through numerous pages, keep detailed stressor lists, but as more a reference section	First two pages only have fill-in forms, only one page turn is necessary
2. Consequence and difficulty need to be defined	Include damage and injury within consequence, break out cognitive and physical difficulty, include small timelines for each	Instructions are included, on the data pages are response fields with all fill-in items defined
3. Cognitive and hardware stressors were not used	Keep in checklist as memory joggers	Those sections were retained for future use
4. Make more user-friendly	Add a method to quantify the data—prioritize time, injury potential, etc.	Cost score formula is explained in instructions
5. Users unsure about how to develop solutions	Add a place to check where in process stressor occurred	Data field in checklist was relabeled
6. Field and design requirements are different	Make two checklists—one for field with 1–2 pages, and one for detailed analysis like original	Fill-in forms are followed by reference section w/detailed stressors and ID codes
7. Checklist is not readily available	Make available to all member companies, provide computerized version for use in paperless fabs	Will be made available on WWW, no funding exists for computerized version at this time

APPENDIX F
Revised SEMaCheck



Sandia Ergonomic Maintenance Checklist

Developed for SEMATECH by

Sandia National Laboratories

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SEMaCheck Instructions

1. Copy pages 3, 4, and 5 as necessary for collecting data on different tasks, one set for each maintenance task or sub-task.

2. Study the reference section, pages 6-15, to become familiar with the types of stressors to be recorded during the observation period. Add any you think are missing. If you do not understand any of the stressors, consult a specialist with human factors or ergonomics training.

3. Fill out page 3 with information obtained from the maintenance technician prior to starting the task.

4. Fill out pages 4 and 5 as work progresses. Record only significant physical or cognitive stressors, encountered by the technician that negatively impact the efficiency of performing the task--increase the time taken, increase chances for mistakes, increase risks to equipment or for injury.

5. Follow the instructions under the first data line on pages 4 and 5, which are elaborated on below:

Category — Match the stressor observed with the appropriate category numbers shown in the “road map” at the tops of the pages 4 and 5, and record in the box at the far left of the response line

Stressor — Write a brief description of the stressor--what it is as opposed to where it takes place

Difficulty Level — Check the small box for low, middle box for medium, and large box for severe stressor, in terms of negative impact on worker productivity

Sub-task — Identify or describe the part of the task with which the stressor is associated

Clock — Enter the estimated additional time taken due to the stressor in minutes--be sure not to repeat the minutes if combining several stressors

Potential Error — Describe a possible error that could be committed due to the presence of the stressor, but only if the error would have some negative consequences–not if the error would be immediately corrected

Consequence Level — Check the small box for low, middle box for medium, and large box for high consequences of an error made

Stressor Code — Look up the stressor code in the reference section and fill in the blank. If code does not exist, critically evaluate if the stressor is severe enough to report. If so, put an “X” in the blank and write a description of the stressor in the reference section. If the stressor is relatively mild, or would take prolonged exposure to cause productivity deficits, drop the stressor from further analysis.

Possible Solution — This blank space is for writing in any ideas concerning what would alleviate the stressor, either through machine redesign, protective measures, different tools, etc.

SEMaCheck

Sandia Ergonomic Maintenance Checklist

Questions for Maintenance Technician prior to field observations:

Task Information and Timing

How often is this task performed on each machine?_____Times per_____

What is the typical duration of the entire task? _____hrs. _____min.

What segment of the task will I be observing?_____

How long does this segment typically take to perform? _____hrs. _____min.

Will you be under any time pressure to complete the task? **1 None** · **2 Some** · **3 Moderate** · **4 Considerable** · **5 Severe**

Experience

How much training did you get on this task? _____

Who performed the training? _____

How many times (total) have you performed this task? _____

When was the last time you performed this task? _____

Do you have any ideas on how to improve the task?_____

_____

_____

Session Information:

Observer_____ Machine_____

Task Performed_____ ☐PM ☐UM

Auxil. Equipment needed_____

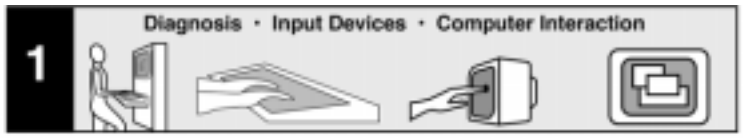
Performed by: ☐in-house tech.(s) ☐contractor(s) ☐factory rep.(s)

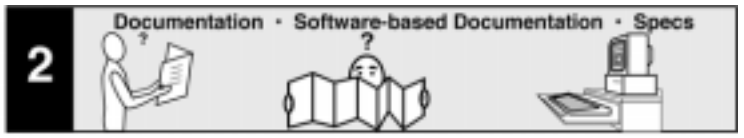
☐other _____

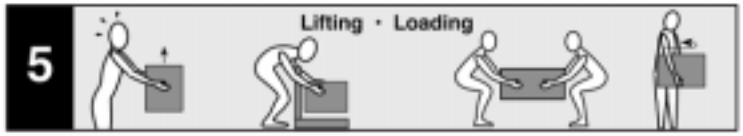
Current shift hours:_____ to _____ Today's date: _____

Session start time:_____ Session end time: _____

Checklist data covers portion of task, or steps:_____







Category	Stressor	Difficulty Level	Sub-Task	+ (minutes)	Potential Error	Consequence Level	Stressor Code
Category # from above	*Describe stressor*	*How difficult or severe*	*Describe sub-task being performed*	*Extra time task takes due to stressor*	*Error possibility with negative consequences*	*Impact of the error*	*Detailed code from back*
POSSIBLE SOLUTION							
POSSIBLE SOLUTION							

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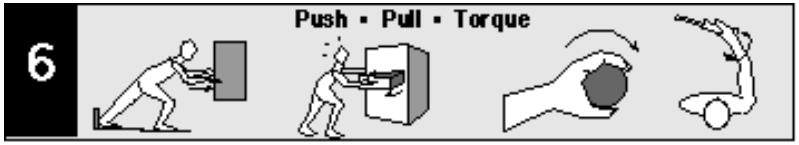

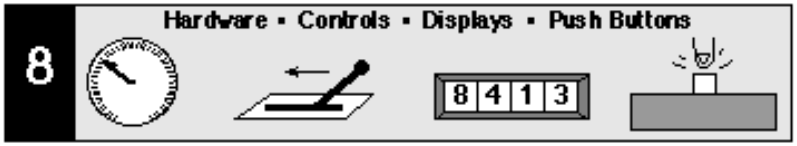

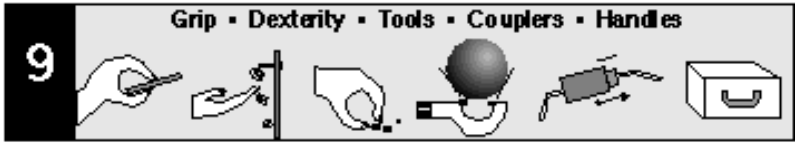

Category	Stressor	Difficulty Level	Sub-Task	+ (minutes)	Potential Error	Consequence Level	Stressor Code
Category # from above	*Describe stressor*	*How difficult or severe*	*Describe sub-task being performed*	*Extra time task takes due to stressor*	*Error possibility with negative consequences*	*Impact of the error*	*Detailed code from back*
POSSIBLE SOLUTION							
POSSIBLE SOLUTION							

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1 FAULT DIAGNOSIS • HUMAN-COMPUTER INTERACTION 1

A. Fault Diagnosis

1-A-1 Must integrate related info from several displays

1-A-2 Incomplete info

1-A-3 Have to look up fault codes

Must search for info to diagnose 1-A-4

Automated diagnosis is wrong 1-A-5

Must use documents to diagnose 1-A-6

Must diagnose without aids, but they are needed 1-A-7

Must perform tests to diagnose faults 1-A-8

Machine status not displayed 1-A-9

Machine status not displayed adequately 1-A-10

B. Input Devices

1-B-1 Keys used as pointers

1-B-2 Bad location, or inconvenient to use

1-B-3 Standing ht. <38" or >42"

1-B-4 Seated ht. <25" or >30"

Keys worn out; some do not work 1-B-5

Inappropriate for task 1-B-6

Key force too sensitive 1-B-7

Key force too stiff 1-B-8

Too much typing required 1-B-9

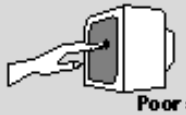
Too sensitive 1-B-10

Too coarse 1-B-11

Discontinuous control 1-B-12

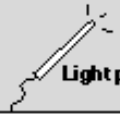
Confusing buttons 1-B-13

Demands joint postures that could lead to CTD 1-B-14 (see 7-E)



Multiple touches needed 1-B-15

Poor alignment 1-B-16



Light pen difficult to use 1-B-17

C. Computer Interaction

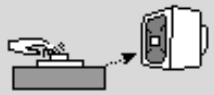
Mostly text 1-C-1

No home key 1-C-2

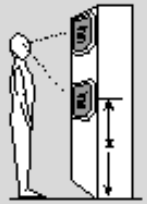
Number of menus/steps > 3 to do task 1-C-3

Delayed feedback 1-C-4

Inappropriate feedback 1-C-5



Status info for long tasks not shown 1-C-6



Standing—
monitor lower than 52"
or higher than 58" 1-C-7

Sitting—
lower than 37"
or higher than 47"
stacked higher than 55"
incline < 15° 1-C-8

Violates green-yellow-red coding 1-C-9

Screens use bright multiple colors 1-C-10

Color contrast insufficient for reading 1-C-11

Monochrome—
could use colors 1-C-12

Other: 1-C-13

1-C-14

1-C-15

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2

DOCUMENTATION • SPECS

2

A. Documentation

2-A-1 Hard to find data

Illogical organization 2-A-3

2-A-2 Reading level too high

Steps missing 2-A-4

Repeated steps 2-A-5

2-A-6 Not enough illustrations

2-A-7 Print too small

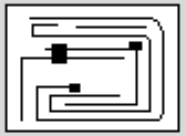
Checklists not available 2-A-8

Multiple sources needed to do job 2-A-9

Paper too big 2-A-10

Documents too heavy 2-A-11

2-A-12 Schematics too large



Busy schematics 2-A-15

Specifications/tolerances not correct 2-A-14

Can't access document while doing task 2-A-16

Documents not used when needed 2-A-17

Paper not allowed in fab 2-A-18

Documentation not available when needed 2-A-19

Other: 2-A-20

2-A-21

2-A-22

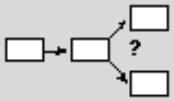
3

MAINTAINABILITY DESIGN • WORK FLOW

3

A. Tool Not Designed For Maintainability

No individual access; have to move objects to gain access to component 3-A-1

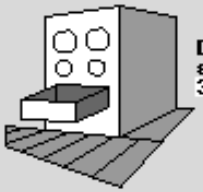


Steps illogical—inefficient workflow 3-A-2

No modular replacement of major parts 3-A-3

Captive fasteners not used 3-A-4

No roll out chassis drawers 3-A-5



Drawers extend into aisles—safety issue 3-A-6

No alignment pins—have to support component while attaching fasteners 3-A-7

Difficult enclosure panel removal 3-A-8

No quick-disconnects used 3-A-9

Work segment(s) done under heavy time pressure 3-A-10

Rest break(s) needed 3-A-11

Poor access to test points 3-A-12

Two maintenance techs needed 3-A-13

Other: 3-A-14

3-A-15

3-A-16

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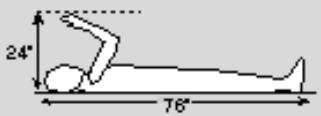
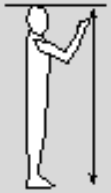
4 CLEARANCE • ACCESS 4

A. Whole Body

Access opening hatch < 24" 4-A-1



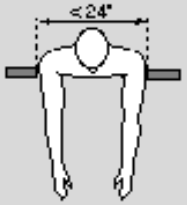
Horizontal hatch < 24" high 4-A-2



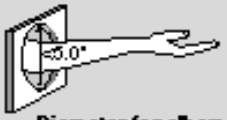
Vertical height < 75" 4-A-3

Kneeling height < 48" 4-A-4

B. Arms



Both arms, 1 opening < 24" 4B-1



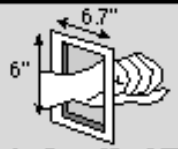
Diameter for elbow < 5.0" 4B-2

Diameter for shoulder < 5.7" 4B-3

C. Hands

Too tight for 2 hands 4-C-1

Opening for open hand < 2" x 4" 4-C-2



Opening for fist < 6" x 6.7" 4-C-3

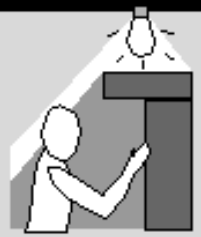
D. Fingers

< 1 1/2" diameter push button 4-D-1

2 finger twist < 3 1/2" diameter 4-D-2

E. Vision

Inadequate visual access to work 4-E-1



Inadequate lighting for task 4-E-2

Other: 4-E-3

4-E-4

4-E-5

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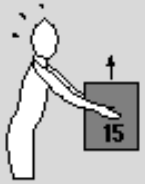
5

LIFTING • LOADING

5

A. Lifting • Loading

Load > 35 lbs 5-A-1



Load > 15 lbs, away from body or with no legs 5-A-2

Bent back lift > 20 lbs 5-A-3

Above shoulder lift or load > 10 lbs 5-A-4

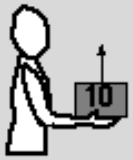
Poor handles, large load 5-A-5

Awkward load, no handles 5-A-6

Nonsymmetrical, off-axis or twist with load > 10 lbs 5-A-7

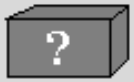
Start point below knees, load > 25 lbs 5-A-8

Arms only lift > 20 lbs 5-A-9

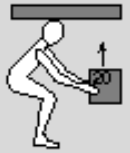


One arm lift > 10 lbs 5-A-10

Two-person lift > 55 lbs 5-A-11



Weights not labeled on heavy objects 5-A-12



Limited headroom > 20 lbs 5-A-13

Other: 5-A-14

5-A-15

5-A-16

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6 PUSH • PULL • TORQUE 6

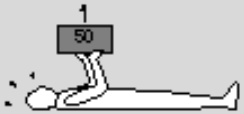
A. Push • Pull

Two hands, no shoulders > 9 lbs 6-A-1

Two hands, shoulder, back > 50 lbs 6-A-2

Whole body with foot brace > 100 lbs 6-A-3

One hand push or pull > 20 lbs 6-A-4



Push, lying down two arms, > 50 lbs 6-A-5

Push, lying down one arm, > 20 lbs 6-A-6

Pull, lying face down, one arm, > 17 lbs 6-A-7

Pull, lying sideways one arm, >12 lbs or > 17 lbs if using two arms 6-A-8

B. Torque

One hand > 15 ft lbs 6-B-1

Arm > 15 ft lbs 6-B-2

Body > 40 ft lbs 6-B-3

Other: 6-B-4

6-B-5

6-B-6

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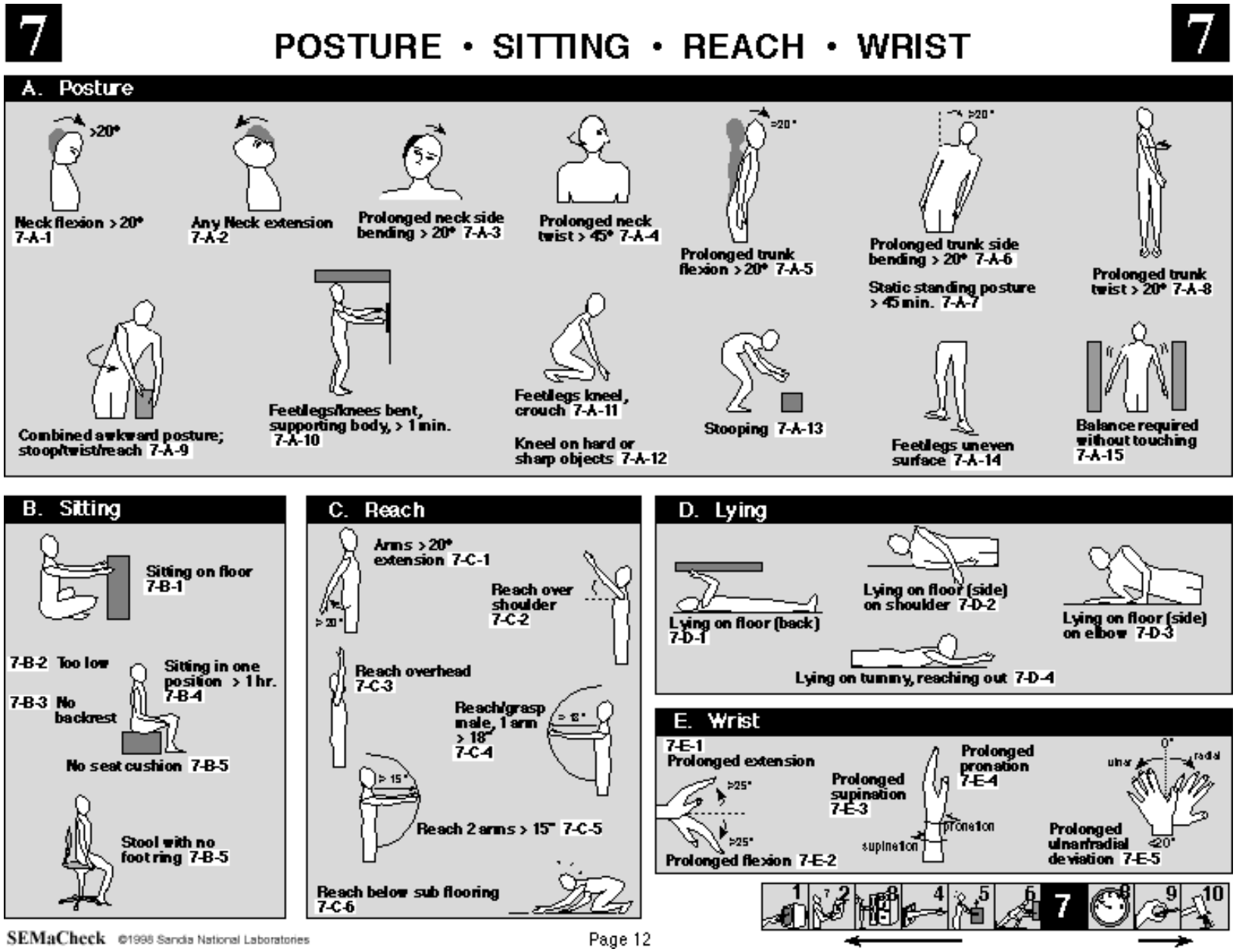
7
POSTURE • SITTING • REACH • WRIST
7
A. Posture
>20°
Neck flexion > 20° 7-A-1
Any Neck extension 7-A-2
Prolonged neck side bending > 20° 7-A-3
Prolonged neck twist > 45° 7-A-4
>20°
Prolonged trunk flexion > 20° 7-A-5
>20°
Prolonged trunk side bending > 20° 7-A-6
Static standing posture > 45 min. 7-A-7
Prolonged trunk twist > 20° 7-A-8
Combined awkward posture; stoop/twist/reach 7-A-9
Feet/legs/knees bent, supporting body, > 1 min. 7-A-10
Feet/legs kneel, crouch 7-A-11
Kneel on hard or sharp objects 7-A-12
Stooping 7-A-13
Feet/legs uneven surface 7-A-14
Balance required without touching 7-A-15
B. Sitting
Sitting on floor 7-B-1
7-B-2 Too low
7-B-3 No backrest
Sitting in one position > 1 hr. 7-B-4
No seat cushion 7-B-5
Stool with no foot ring 7-B-5
C. Reach
Arms > 20° extension 7-C-1
> 20°
Reach over shoulder 7-C-2
Reach overhead 7-C-3
Reach/grasp male, 1 arm > 18" 7-C-4
> 15°
Reach 2 arms > 15" 7-C-5
Reach below sub flooring 7-C-6
D. Lying
Lying on floor (back) 7-D-1
Lying on floor (side) on shoulder 7-D-2
Lying on floor (side) on elbow 7-D-3
Lying on tummy, reaching out 7-D-4
E. Wrist
7-E-1 Prolonged extension
>25°
>25°
Prolonged flexion 7-E-2
Prolonged supination 7-E-3
supination
pronation
Prolonged pronation 7-E-4
0°
ulnar
radial
20°
Prolonged ulnar/radial deviation 7-E-5
1 2 3 4 5 6 7 8 9 10
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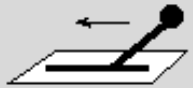
Page 12

8 HARDWARE • CONTROLS • DISPLAYS 8

A. Controls



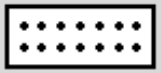
High resistance 8-A-1

Too small 8-A-2

Too coarse 8-A-3

Unstable set point 8-A-4

Poor labeling 8-A-5



Poorly located 8-A-6

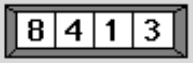
Missing warnings 8-A-7

Little clearance between 8-A-8

B. Displays

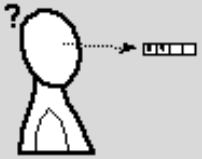
Normal operation range/caution/danger not shown 8-B-1

Green/yellow/red color coding violated 8-B-2



Digital, but need analog 8-B-3

Analog, but need digital 8-B-4



Can't read because of:

Glare 8-B-5

Shadows 8-B-6

Small numbers/letters 8-B-7

Bad angle 8-B-8

Auditory Displays

Not distinguishable from others 8-B-9

Alarm defeatable with no reminder 8-B-10

Not used as warning – nuisance 8-B-11

Too soft/can't hear 8-B-12

Too loud/obnoxious 8-B-13

C. Push Buttons

Too small for finger 8-C-1

Resistance too great 8-C-2

Emergency OFF too small 8-C-3

Emergency OFF low resistance 8-C-4

Emergency OFF poor location 8-C-5

Other: 8-C-6

8-C-7

8-C-8

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9 GRIP • DEXTERITY • TOOLS • COUPLERS 9

A. Grip

Pencil, Test Leads, Fasteners, Paper

Object < 1", frequent or high force 9-A-1

Twist Small Knob with Fingers

Frequently 9-A-2

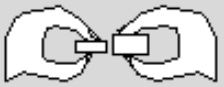
High torque 9-A-3

Poor coupling/ smooth surface 9-A-4

B. Dexterity

Picking up small objects 9-B-1

Fitting small objects 9-B-3



9-B-5 Frequently used fasteners are not captive

Manipulating small objects 9-B-2

Tiny tools needed 9-B-4

C. Tools

Handles too narrow for torque 9-C-1

Inappropriate tool for measuring 9-C-3

Tips wrong size or shape 9-C-2

Special tools required 9-C-4

Have to leave area to get tools 9-C-5

Design does not mininize number tools needed 9-C-6

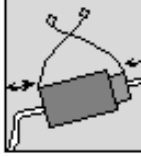
Tool box over 25 lbs. 9-C-7

D. Couplers

Difficulty pulling apart 9-D-1

Difficulty joining manually 9-D-2

Coupler can be inverted 9-D-3



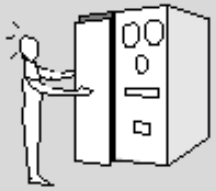
Tool needed to join or disengage coupler 9-D-4

E. Handles

Not 3/4" to 1 1/2" in diameter 9-E-1

Length < 5.0" 9-E-2

Clearance < 2" 9-E-3



Handles at inappropriate locations 9-E-4

No handles on enclosure panels or access doors 9-E-5

Other: 9-E-6

9-E-7

9-E-8

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10

REPETITION • IMPACT • VIBRATION

10

A. Finger Only

10-A-1 Low force ≥ 35 reps/min.

Medium force ≥ 20 reps/min. 10-A-2

High force ≥ 10 reps/min. 10-A-3

B. Hand/Wrist Torque

10-B-1 Low force ≥ 35 reps/min.

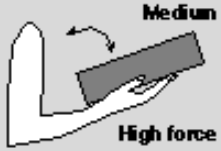
Medium force ≥ 20 reps/min. 10-B-2

High force ≥ 10 reps/min. 10-B-3

C. Arm Repetition

Low force ≥ 20 reps/min. 10-C-1

Medium force ≥ 10 reps/min. 10-C-2



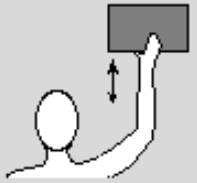
High force ≥ 5 reps/min. 10-C-3

Frequency is > 15/min. 10-C-4

Scrubbing tool with cleaner 10-C-5

D. Shoulder Repetition

10-D-1 Low force ≥ 15 reps/min.



Medium force ≥ 7 reps/min. 10-D-2

High force ≥ 3 reps/min. 10-D-3

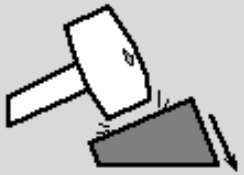
E. Arm/Hand Vibration

Small Hammer

Frequent use 10-E-1

Large Hammer—Impact Tools

Frequent use 10-E-2

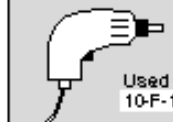


Large Hammer to Move Heavy Object

Frequent use 10-E-3

Hand used as hammer 10-E-4

F. Vibration



Used > 15 min. 10-F-1

Other: 10-F-2

10-F-3

10-F-4

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APPENDIX G COMPLETE DATA SET

	Mtype	Machine	MBrand	Task	Freq.	Nom.T...	Act...	Pres...
1	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
2	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
3	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
4	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
5	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
6	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
7	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
8	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
9	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
10	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
11	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
12	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
13	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Beam Stop	.5	30	•	2
14	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
15	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
16	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
17	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
18	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
19	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
20	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
21	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
22	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
23	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
24	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
25	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
26	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
27	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
28	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
29	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
30	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
31	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
32	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
33	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
34	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
35	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
36	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
37	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
38	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
39	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
40	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
41	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
42	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
43	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
44	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
45	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
46	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
47	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
48	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
49	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
50	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
51	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
52	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
53	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
54	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3

	Mtype	Machine	MBrand	Task	Freq.	Nom.T..	Act...	Pres...
55	IMPL	I-AMAT 9500, IMP 10	9500	Remove/Replace Source	24.0	120	•	3
56	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
57	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
58	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
59	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
60	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
61	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
62	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
63	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
64	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
65	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
66	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
67	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
68	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
69	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
70	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
71	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
72	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
73	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
74	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
75	IMPL	I-AMAT 9500, IMP 10	9500	Scrub MRS & Source Cham...	24.0	60	60	3
76	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
77	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
78	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
79	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
80	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
81	DEP	CVD-AMAT 5000	CVD	Beam Line PM (remove/repl...	12.0	60	•	3
82	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
83	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
84	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
85	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
86	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
87	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
88	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
89	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
90	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
91	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
92	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
93	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
94	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
95	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
96	DEP	CVD-AMAT 5000	CVD	Clean Siline Chamber	24.0	60	105	1
97	DEP	CVD-AMAT 5000	CVD	Remove Extraction Electrod...	12.0	60	•	3
98	DEP	CVD-AMAT 5000	CVD	Remove Extraction Electrod...	12.0	60	•	3
99	DEP	CVD-AMAT 5000	CVD	Remove Extraction Electrod...	12.0	60	•	3
100	IMPL	Imp-EATON GSD	EAT	Ebara pump	2.0	120	120	3
101	IMPL	Imp-EATON GSD	EAT	Post Excell Electrode	2.0	30	•	3
102	IMPL	Imp-EATON GSD	EAT	Post Excell Electrode	2.0	30	•	3
103	IMPL	Imp-EATON GSD	EAT	Post Excell Electrode	2.0	30	•	3
104	IMPL	Imp-EATON GSD	EAT	Post Excell Electrode	2.0	30	•	3
105	IMPL	Imp-EATON GSD	EAT	Post Excell Electrode	2.0	30	•	3
106	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
107	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
108	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2

	Mtype	Machine	MBrand	Task	Freq.	Nom.T...	Act...	Pres...
109	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
110	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
111	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
112	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
113	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
114	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
115	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
116	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
117	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
118	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
119	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
120	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
121	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
122	IMPL	Imp-EATON GSD	EAT	Semiannual PM	2.0	120	120	2
123	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
124	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
125	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
126	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
127	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
128	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
129	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
130	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
131	IMPL	Imp-EATON GSD	EAT	Source Housing PM	24.0	120	60	2
132	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
133	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
134	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
135	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
136	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
137	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
138	IMPL	Imp-EATON GSD	EAT	Source, Extractor Exchange	24.0	120	120	3
139	STEP	S-SVG Micrascan Step...	MICR	14-Day PM	30.0	30	•	•
140	STEP	S-SVG Micrascan Step...	MICR	14-Day PM	30.0	30	•	•
141	STEP	S-SVG Micrascan Step...	MICR	14-Day PM	30.0	30	•	•
142	STEP	S-SVG Micrascan Step...	MICR	Focus	104	20	12	3
143	STEP	S-SVG Micrascan Step...	MICR	Focus	104	20	12	3
144	STEP	S-SVG Micrascan Step...	MICR	Focus	104	20	12	3
145	STEP	S-SVG Micrascan Step...	MICR	Lamp Changeout	2.0	60	•	•
146	STEP	S-SVG Micrascan Step...	MICR	Lamp Changeout	2.0	60	•	•
147	STEP	S-SVG Micrascan Step...	MICR	Lamp Changeout	2.0	60	•	•
148	STEP	S-SVG Micrascan Step...	MICR	Lift Arm on Longstroke & R...	12.0	300	•	•
149	STEP	S-SVG Micrascan Step...	MICR	Lift Arm on Longstroke & R...	12.0	300	•	•
150	STEP	S-SVG Micrascan Step...	MICR	Lift Arm on Longstroke & R...	12.0	300	•	•
151	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
152	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
153	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
154	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
155	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
156	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
157	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
158	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
159	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
160	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
161	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
162	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2

	Mtype	Machine	MBrand	Task	Freq.	Nom.T...	Act...	Pres...
163	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
164	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
165	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
166	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
167	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
168	STEP	S-Nikon Steprs Body 7	NIK	Cleaning & Lubricating Lea...	26.0	60	20	2
169	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
170	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
171	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
172	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
173	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
174	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
175	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
176	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
177	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
178	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
179	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
180	STEP	S-Nikon Stepr Body 11	NIK	Particle on chuck	170	10	20	4
181	DEP	S-Novellus Concept One	NOV	Gate Assembly (Valve) Clean	4.0	38	8	1
182	DEP	S-Novellus Concept One	NOV	Gate Assembly (Valve) Clean	4.0	38	8	1
183	DEP	S-Novellus Concept One	NOV	Gate Assembly (Valve) Clean	4.0	38	8	1
184	DEP	S-Novellus Concept One	NOV	Gate Assembly (Valve) Clean	4.0	38	8	1
185	DEP	S-Novellus Concept One	NOV	Gate Assembly (Valve) Clean	4.0	38	8	1
186	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
187	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
188	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
189	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
190	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
191	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
192	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
193	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
194	DEP	S-Novellus Concept One	NOV	Heater Block Scrup	24.0	120	•	1
195	DEP	S-Novellus Concept One	NOV	Spindle Rebuild	4.0	38	•	1
196	DEP	S-Novellus Concept One	NOV	Spindle Rebuild	4.0	38	•	1
197	DEP	S-Novellus Concept One	NOV	Spindle Rebuild	4.0	38	•	1
198	DEP	S-Novellus Concept One	NOV	Spindle Rebuild	4.0	38	•	1
199	DEP	S-Novellus Concept One	NOV	Spindle Rebuild	4.0	38	•	1
200	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
201	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
202	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
203	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
204	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
205	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
206	IMPL	Imp-Varian Implanter	VAR	Air Bearing Replacement	1.0	720	•	4
207	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
208	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
209	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
210	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
211	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
212	IMPL	Imp-Varian Implanter	VAR	Beam Dumpliner/Scan Defl...	2.0	180	210	3
213	IMPL	Imp-Varian Implanter	VAR	Cylanoid Failure	2.0	60	•	4
214	IMPL	Imp-Varian Implanter	VAR	Cylanoid Failure	2.0	60	•	4
215	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
216	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2

	Mtype	Machine	MBrand	Task	Freq.	Nom.T...	Act...	Pres...
217	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
218	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
219	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
220	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
221	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
222	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
223	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
224	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
225	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
226	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
227	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
228	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
229	IMPL	Imp-Varian E1000 Imp.	VAR	Manipulator Changeout	12.0	50	•	2
230	IMPL	Imp-Varian Implanter	VAR	Post Acell Plate Change	.5	180	210	4
231	IMPL	Imp-Varian Implanter	VAR	Post Acell Plate Change	.5	180	210	4
232	IMPL	Imp-Varian Implanter	VAR	Post Acell Plate Change	.5	180	210	4
233	IMPL	Imp-Varian Implanter	VAR	Post Acell Plate Change	.5	180	210	4
234	IMPL	Imp-Varian Implanter	VAR	Post Acell Plate Change	.5	180	210	4
235	IMPL	Imp-Varian	VAR	Remove Source Bushing PM	12.0	60	•	3
236	IMPL	Imp-Varian	VAR	Remove Source Bushing PM	12.0	60	•	3
237	IMPL	Imp-Varian	VAR	Remove Source Bushing PM	12.0	60	•	3
238	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
239	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
240	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
241	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
242	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
243	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
244	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
245	IMPL	Imp-Varian E1000 Imp.	VAR	Remove/Replace Mass Slit ...	12.0	60	•	2
246	IMPL	Imp-Varian E1000 Imp.	VAR	Source Change	24.0	38	•	3
247	IMPL	Imp-Varian E1000 Imp.	VAR	Source Change	24.0	38	•	3
248	IMPL	Imp-Varian E1000 Imp.	VAR	Source Change	24.0	38	•	3
249	IMPL	Imp-Varian E1000 Imp.	VAR	Source Change	24.0	38	•	3
250	IMPL	Imp-Varian E1000 Imp.	VAR	Source Change	24.0	38	•	3

	Who	Tim...	Group	Block	Item #	Add...	Diffi...	Suggestion	Write-In	Erro...	Cons...	Inclu.Sc...
1	In House	9	4	3	1	2	1				0	292
2	In House	9	4	3	2	2	1				0	292
3	In House	9	5	1	11	0	3				0	292
4	In House	9	5	1	1	0	3				0	292
5	In House	9	3	1	1	0	3				0	292
6	In House	9	5	1	5	0	3				0	292
7	In House	9	9	5	4	0	3		None; n...		0	292
8	In House	9	6	1	3	0	1				0	292
9	In House	9	5	1	12	0	1				0	292
10	In House	9	10	2	1	0	1				0	292
11	In House	9	9	2	2	0	1				0	292
12	In House	9	1	1	8	0	1				0	292
13	In House	9	4	4	2	0	1				0	292
14	In House	5	1	2	17	2	2				0	292
15	In House	5	3	1	1	0	3				0	292
16	In House	5	7	1	6	0	3				0	292
17	In House	5	5	1	13	0	3				0	292
18	In House	5	5	1	8	0	3				0	292
19	In House	5	5	1	16	0	3		No Han...		0	292
20	In House	5	7	1	10	0	3				0	292
21	In House	5	5	1	6	0	3				0	292
22	In House	5	5	1	1	0	3				0	292
23	In House	5	5	1	3	0	3				0	292
24	In House	5	9	2	5	5	1				0	292
25	In House	5	5	1	2	0	3				0	292
26	In House	5	5	1	7	0	3				0	292
27	In House	5	4	4	2	2	1				1	292
28	In House	5	4	5	1	2	1				1	292
29	In House	5	9	3	4	5	2				2	292
30	In House	5	7	3	6	0	3			Dr...	2	292
31	In House	5	7	1	5	5	3				0	292
32	In House	5	6	1	7	5	3				3	292
33	In House	5	7	3	5	0	3			Dr...	2	292
34	In House	5	4	1	5	5	3				2	292
35	In House	5	7	5	1	0	3			Dr...	2	292
36	In House	5	4	1	4	0	3			Ba...	2	292
37	In House	5	3	1	7	5	3				3	292
38	In House	5	3	1	10	0	2				1	292
39	In House	5	3	1	8	0	2				1	292
40	In House	5	1	3	4	0	2				1	292
41	In House	5	1	3	1	0	2				1	292
42	In House	5	2	2	5	0	2		Not Co...		2	292
43	In House	5	2	1	17	0	2				2	292
44	In House	5	1	2	10	3	1		No Key...		2	292
45	In House	5	7	1	9	0	2				0	292
46	In House	5	5	1	9	0	2				0	292
47	In House	5	7	1	1	0	2				0	292
48	In House	5	5	1	5	0	2				0	292
49	In House	5	10	1	1	0	1				0	292
50	In House	5	9	2	2	0	2				0	292
51	In House	5	1	3	8	0	1				1	292
52	In House	5	9	2	1	0	1				0	292
53	In House	5	5	1	12	0	2				0	292
54	In House	5	6	1	9	0	2		Back Cl...		0	292

	Who	Tim...	Group	Block	Item #	Add...	Diffi...	Suggestion	Write-In	Erro...	Cons...	Inclu.Sc...
55	In House	5	7	1	8	0	2				0	292
56	In House	7	7	1	1	0	2				0	292
57	In House	7	4	1	5	0	3			Ine...	0	292
58	In House	7	10	3	2	0	1				0	292
59	In House	7	7	1	3	0	2				0	292
60	In House	7	7	1	11	0	2				0	292
61	In House	7	7	1	7	0	2				0	292
62	In House	7	4	1	4	5	3			Ine...	0	292
63	In House	7	4	3	1	5	2				0	292
64	In House	7	7	4	2	5	2			Ine...	0	292
65	In House	7	10	1	1	0	1				0	292
66	In House	7	10	2	1	0	1				0	292
67	In House	7	7	5	5	0	2				0	292
68	In House	7	7	3	6	5	2			Ine...	0	292
69	In House	7	7	1	5	0	2				0	292
70	In House	7	7	5	2	0	2				0	292
71	In House	7	7	5	1	0	2				0	292
72	In House	7	4	5	1	0	2			No...	2	292
73	In House	7	4	5	2	0	1			No...	2	292
74	In House	7	9	3	6	0	2	Better scr...	Pinch Grip		0	292
75	In House	7	7	1	10	0	2				0	292
76	In House	8	6	1	7	0	2				0	1960
77	In House	8	5	1	2	0	2	Install me...			0	1960
78	In House	8	4	1	3	0	3				0	1960
79	In House	8	5	1	12	0	3				0	1960
80	In House	8	3	1	7	30	3				0	1960
81	In House	8	5	1	12	0	3				0	1960
82	In House	9	3	1	9	0	3				0	1960
83	In House	9	9	2	1	10	2				0	1960
84	In House	9	2	2	1	0	2				0	1960
85	In House	9	7	3	7	0	3				0	1960
86	In House	9	9	4	5	20	2				0	1960
87	In House	9	1	3	5	0	2				0	1960
88	In House	9	3	1	1	5	2				0	1960
89	In House	9	5	1	15	0	3				0	1960
90	In House	9	4	5	1	0	3				0	1960
91	In House	9	1	1	3	5	2				0	1960
92	In House	9	7	1	3	0	3				0	1960
93	In House	9	4	5	3	0	3				0	1960
94	In House	9	1	1	4	0	2				0	1960
95	In House	9	7	3	2	10	3				0	1960
96	In House	9	1	3	2	0	3				0	1960
97	In House	8	5	1	12	0	3				0	1960
98	In House	8	5	1	2	0	3				0	1960
99	In House	8	5	1	16	0	3		Limited ...		0	1960
100	In House	8	3	1	4	60	3			Da...	3	432
101	In House	10	5	1	14	10	3			dr...	3	432
102	In House	10	7	1	9	10	2			dr...	3	432
103	In House	10	4	5	1	10	3			dr...	1	432
104	In House	10	4	3	2	10	3			dr...	1	432
105	In House	10	4	1	5	0	2				0	432
106	In House	8	4	2	4	0	2				0	432
107	In House	8	9	1	1	0	2				0	432
108	In House	8	4	1	3	30	3				0	432

	Who	Tim...	Group	Block	Item #	Add...	Diffi...	Suggestion	Write-In	Erro...	Cons...	Inclu.Sc...
109	In House	8	7	5	2	0	2				0	432
110	In House	8	4	5	2	0	2				0	432
111	In House	8	9	2	2	0	2				0	432
112	In House	8	7	1	9	0	3				0	432
113	In House	8	5	1	9	0	3				0	432
114	In House	8	7	1	10	0	3				0	432
115	In House	8	5	1	1	0	3				0	432
116	In House	8	4	5	1	15	2				0	432
117	In House	8	7	3	2	0	2				0	432
118	In House	8	9	2	5	0	2				0	432
119	In House	8	9	6	1	0	1		No han...		0	432
120	In House	8	7	5	1	0	2				0	432
121	In House	8	6	1	9	0	2		Kneelin...		0	432
122	In House	8	9	2	1	0	2				0	432
123	Factory	15	9	5	4	0	3				0	432
124	Factory	15	7	1	10	0	3				0	432
125	Factory	15	7	1	9	0	3				0	432
126	Factory	15	6	1	9	0	3				0	432
127	Factory	15	7	1	1	0	2				0	432
128	Factory	15	7	1	5	0	2				0	432
129	Factory	15	5	1	9	0	3				0	432
130	Factory	15	5	1	1	0	3				0	432
131	Factory	15	9	6	1	10	1				0	432
132	In House	10	5	1	10	10	3			da...	3	432
133	In House	10	7	1	9	15	2			da...	3	432
134	In House	10	3	1	6	15	3				0	432
135	In House	10	4	4	2	10	3			da...	3	432
136	In House	10	9	3	6	15	3			da...	3	432
137	In House	10	4	5	1	0	3				0	432
138	In House	10	5	1	10	15	3			inc...	2	432
139	In House	•	7	1	5	0	1				0	600
140	In House	•	7	1	6	0	1				0	600
141	In House	•	7	3	5	0	1				0	600
142	In House	7	4	1	5	2	2				0	600
143	In House	7	4	4	2	1	1				0	600
144	In House	7	7	3	3	1	1				0	600
145	Factory	•	3	1	6	0	3				0	600
146	Factory	•	7	3	3	0	3				0	600
147	Factory	•	4	5	1	0	3				0	600
148	Factory	•	7	1	9	0	3				0	600
149	Factory	•	7	1	8	0	3				0	600
150	Factory	•	5	1	11	0	3				0	600
151	In House	8	4	1	2	0	3				0	936
152	In House	8	7	1	10	0	3				0	936
153	In House	8	7	1	2	0	3				0	936
154	In House	8	4	5	1	5	3				0	936
155	In House	8	3	1	7	5	2				0	936
156	In House	8	4	2	4	20	3		Must re...		0	936
157	In House	8	4	5	2	5	3				0	936
158	In House	8	9	1	1	0	2				0	936
159	In House	8	7	1	3	0	2				0	936
160	In House	8	9	1	6	0	2		Must us...		0	936
161	In House	8	9	5	1	0	1		No han...		0	936
162	In House	8	7	5	2	0	2				0	936

	Who	Tim...	Group	Block	Item #	Add...	Diffi...	Suggestion	Write-In	Erro...	Cons...	Inclu.Sc...
163	In House	8	7	1	7	0	2				0	936
164	In House	8	3	1	5	0	3				0	936
165	In House	8	7	1	5	0	3				0	936
166	In House	8	7	1	9	0	3				0	936
167	In House	8	7	3	4	0	3				0	936
168	In House	8	7	1	4	0	3				0	936
169	In House	11	4	1	5	0	3				0	936
170	In House	11	7	1	10	0	3				0	936
171	In House	11	7	1	5	0	2				0	936
172	In House	11	4	5	2	0	2				0	936
173	In House	11	4	5	1	0	2				0	936
174	In House	11	7	1	7	0	2				0	936
175	In House	11	7	3	4	0	3				0	936
176	In House	11	7	1	9	0	3				0	936
177	In House	11	7	1	4	0	2				0	936
178	In House	11	3	1	8	0	2				0	936
179	In House	11	3	1	7	2	3				0	936
180	In House	11	7	5	1	0	1				0	936
181	In House	7	7	1	5	2	2				0	1344
182	In House	7	7	3	3	1	2				0	1344
183	In House	7	9	6	1	1	2		Force &...		0	1344
184	In House	7	4	3	1	1	1				0	1344
185	In House	7	9	2	5	1	1				0	1344
186	In House	7	7	3	4	0	2				0	1344
187	In House	7	7	1	8	10	2			Injury	0	1344
188	In House	7	7	1	5	10	2			Injury	0	1344
189	In House	7	5	1	6	1	2			Injury	0	1344
190	In House	7	7	1	6	5	2			Injury	0	1344
191	In House	7	7	5	1	10	2				0	1344
192	In House	7	5	1	1	0	2				0	1344
193	In House	7	10	3	4	10	3			Injury	2	1344
194	In House	7	10	4	4	5	2		Scrub f...	Injury	2	1344
195	In House	7	7	1	10	0	2				0	1344
196	In House	7	9	2	6	2	2		Fingers ...	ali...	1	1344
197	In House	7	9	2	3	0	2				0	1344
198	In House	7	4	5	1	3	2			To...	3	1344
199	In House	7	9	1	1	0	2				0	1344
200	In House	8	4	1	2	0	2			injury	1	976
201	In House	8	5	1	7	0	3				0	976
202	In House	8	3	1	1	120	3			ite...	3	976
203	In House	8	4	5	1	0	2				0	976
204	In House	8	5	1	4	0	3				0	976
205	In House	8	4	1	1	0	2			injury	1	976
206	In House	8	7	1	7	0	3				0	976
207	In House	8	3	1	6	30	3				0	976
208	In House	8	7	3	4	10	1			da...	3	976
209	In House	8	7	1	7	10	2			da...	3	976
210	In House	8	3	1	7	0	3				0	976
211	In House	8	7	3	5	0	1				0	976
212	In House	8	3	1	1	10	1			da...	3	976
213	In House	8	7	4	3	15	3				0	976
214	In House	8	7	3	7	15	3		Reach i...		0	976
215	In House	7	3	1	1	15	2				0	976
216	In House	7	7	3	5	5	3			Mi...	1	976

	Who	Tim...	Group	Block	Item #	Add...	Diffi...	Suggestion	Write-In	Erro...	Cons...	Inclu.Sc...
217	In House	7	10	1	1	0	2				0	976
218	In House	7	9	1	1	0	2	Use pins i...			0	976
219	In House	7	4	5	1	0	1				0	976
220	In House	7	10	2	1	5	2	Use pins i...			0	976
221	In House	7	5	1	2	1	3	Pullout dr...		Mi...	1	976
222	In House	7	7	5	2	1	2				0	976
223	In House	7	4	1	4	3	2				0	976
224	In House	7	7	1	5	0	3	Pullout dr...			0	976
225	In House	7	9	3	1	2	1				0	976
226	In House	7	7	1	8	3	3				0	976
227	In House	7	3	1	4	2	2				0	976
228	In House	7	10	2	2	2	1	Use pins i...			0	976
229	In House	7	5	1	13	1	3	Pullout dr...		Mi...	1	976
230	In House	8	4	1	1	15	2			da...	3	976
231	In House	8	5	1	7	0	3			da...	3	976
232	In House	8	5	1	11	15	3			da...	3	976
233	In House	8	7	1	7	0	2			da...	3	976
234	In House	8	7	3	2	0	2				0	976
235	In House	8	5	1	5	0	3				0	976
236	In House	8	5	1	2	0	3				0	976
237	In House	8	5	1	12	0	3				0	976
238	In House	7	9	2	1	1	1				0	976
239	In House	7	5	1	13	2	3	Pullout dr...			0	976
240	In House	7	7	1	8	0	3				0	976
241	In House	7	9	1	1	6	2	Pins inste...			0	976
242	In House	7	4	5	1	2	2	Pullout dr...			0	976
243	In House	7	7	1	5	0	2	Pullout dr...		Be...	0	976
244	In House	7	7	3	5	0	2				0	976
245	In House	7	5	1	2	2	3	Pullout dr...		Hit ...	1	976
246	In House	7	5	1	2	0	2			wri...	3	976
247	In House	7	9	1	1	1	1				0	976
248	In House	7	7	3	2	1	1	Hoist may...			0	976
249	In House	7	6	1	4	1	1				0	976
250	In House	7	9	2	1	0	1				0	976

APPENDIX H
Technicians' and Observers' Solutions

Machine	Task/Task Segment	Suggested Solution
Applied 5000	Chamber clean Cleaning Silane chamber	Improve access; package service tools with cleaning supplies in PM tool kit
Applied 9500	Beam Line PM Remove/Replace MRS	Install a mechanical hoist to assist lifting of device
	R/R Beam Stop UM R/R Beam Stop Plate	handles on shielding and plate; lighter weight; mechanical hoist
	R/R Source, MRS, etc. PM R/R Source	more head room above MRS; handles on shields; hinged shields; install keyboard
	Scrub MRS & Source Chmbrs Scrub implanter chambers PM	use different scrubber (better scrub pad); use chemical to clean residue; more head room
Nikon Stepper Body 7	Clean & Lube Lead Screws PM same as task	improve access to the lead screws
Nikon Stepper Body 11	Particle on Chuck UM Access and Clean	improve access to chuck; improve door removal latches
	Reticle Change same	better software, decrease process steps
Varian	Source Change PM Remove Source & Replace	hoist or support for the source as it is pulled out (better design than previous hoist which did not adequately catch the source and caused sheering)
Varian	Manipulator Change-out PM Remove/Replace Manipulator	pins for pullout drawers instead of bolts and screws
Varian	6-month PM Beam Dump Lines, Scan Deflector, Dipole Lines	relocate or redesign door to allow better access; relocate smoke detector to allow removal of scanner
Varian	Solenoid Failure UM same	improve access and removal of vacuum pump
Varian	Post Excell Plate Change UM same	improve access; a device to assist lifting
Varian	Air Bearing Replacement UM same	redesign so that vacuum pump removal is not necessary (very time consuming)
Novellus Concept One	Heater Block Scrub PM same	self-cleaning block; 2-person lift for barrel removal
Eaton GSD-160	Source Housing PM	quick disconnects on modular parts (couplers)
Eaton	Source/Extractor PM Source Change & Extractor	guide or support to help bear weight and align bolts
Eaton	Post Excell Electrode PM same	improve access to bolts and unit; a guide help align bolts, support weight
Eaton	Ebara Pump Maintenance PM same	install pump package on pullout drawer for easier access and maintenance

APPENDIX I.
Solutions for Top Ten Stressors

The top ten stressors and total cost scores are listed in the first column. Potential solutions for the stressors were suggested by technicians, SNL engineers, and PTAB members. Each solution was rated by three SNL engineers as to relative benefit and cost. The assumptions were: design changes are made during a regular (not a rework) design cycle or process, benefits are considered in terms of productivity, costs are considered in terms of supplier's costs in design and implementation. The three were negotiated to arrive at consensus scores. The ratings were used together with the combined cost scores (in parentheses at left) to develop optimized sets of solutions for different spending levels (see Appendix J).

Stressor	Solutions	Relative Benefit (1-10)	Cost (1-10)
1. Difficult Panel Removal (1474)	Eliminate fasteners, use snap fit or hanging panels	6	3
	Use captive fasteners or quick disconnects in convenient locations	5	2
	Use lighter panels and add handles in appropriate locations for lifting	6	3
	Use telescoping or sliding panels to eliminate panel removal	7	5
	User provides storage space for removed panels somewhere near the equipment	4	4
2. Kneeling, standing with legs bent (1182)	Locate most frequently accessed components between waist and eye levels	9	9
	Use fatigue mats or pad the flooring inside enclosures	3	1
	Provide knee pads to maintenance personnel	1	1
	Provide folding stools or sit-stand supports	3	1
3. Arm lifting (1028)	Improve body access so that lifts are closer to torso	7	7
	Use guide-locating devices such as pins to help locate and support components while fastening	8	4
	Significantly reduce the weights of removable components	6	7
	Provide supports or hoists for parts over 50 lb.	9	5
4. Long reaches (977)	Provide light extension handles for tools	3	2
5. Poor component access (813)	Use roll-out drawers and hinged subassemblies to fold out electronic chassis, etc. either for immediate access external to enclosure or to provide access to other components deeper in the enclosure	10	10
	Route gas and electrical lines together to increase access space between groups of lines	4	5
6. Awkward postures (727)	Mount frequently accessed components at upper torso heights	9	9
	Enlarge footprint conservatively and strategically to increase body access space within enclosure	9	4
	Provide built-in steps for reaching higher parts	4	3

Stressor	Solutions	Relative Benefit (1-10)	Cost (1-10)
7. Poor visual access (714)	Increase local illumination to 100 ft.-c	6	1
	Increase access openings in bulkheads	6	3
	Provide swing-away subassemblies	9	9
	Relocate fasteners on parts for visibility	4	5
	Provide tactile cues for blind work	5	4
	Use captive fasteners	4	2
8. Poor arm, hand, or finger access (613)	Enlarge access ports in panels and bulkheads	8	5
	Locate serviceable parts on exterior of enclosure	10	9
	Provide special tools to reach into tight quarters	8	4
9. Heavy lifting (279)	Label any removable parts exceeding 30 lb.,	3	1
	Provide adequate handles for two-person lifts	6	2
	Provide supports or hoists for parts exceeding 50 lb.,	9	5
	Provide closer torso access, room to stand erect, and good footing for heavy lifts	7	6
10. Pinch grip, small objects (236)	Use captive fasteners	7	2
	Provide magnetized tools	4	1
	Use larger fasteners than required by strength of materials requirements	3	2
	Provide tools with larger diameter handles	5	1
	Redesign fine adjustments to be less frequent	7	6
	Total Cost		153

APPENDIX J
Solution Strategies

Using the relative cost and benefit scores shown in Appendix I, the following sets of solutions were selected via an optimization algorithm. The algorithm looks for the highest benefit/cost ratios while observing the logical constraints shown in the solutions column. The assumed total cost is 153, based on the sum of the relative cost scores from Appendix I. Optimal solution sets are shown in the columns under the spending limit or "budget" column headings. A budget of 20 out of 153 is considered minimal spending, while a budget of 40 is about 25% of the total, and 70 is about half of the total.

Solutions **Budget =**	**20**	**30**	**40**	**50**	**60**	**70**
Eliminate fasteners, use snap fit or hanging panels		•	•	•	•	•
OR						
Use captive fasteners or quick disconnects in convenient locations on enclosure panels	•					
Use lighter panels and add handles in appropriate locations for lifting	•	•	•	•	•	•
OR						
Use telescoping or sliding panels to eliminate panel removal						
OR						
User provides storage space for removed panels somewhere near the equipment		•	•	•	•	•
Locate most frequently accessed components between waist and eye levels, (OR REST IN GROUP)						
Use fatigue mats inside enclosures	•	•	•	•	•	•
OR						
Provide knee pads to maintenance personnel						
Provide folding stools or sit-stand supports		•	•	•	•	•
Improve body access so that lifts are closer to torso			•	•	•	•
Use guide-locating devices such as pins to help locate and support components while fastening	•	•	•	•	•	•
Significantly reduce the weights of removable components						
OR						
Provide supports or hoists for parts over 50 #	•	•	•	•	•	•
Provide light extension handles for tools		•	•	•	•	•
Use roll-out drawers and hinged subassemblies to fold out electronic chassis, etc. either for immediate access external to enclosure or to provide access to other components deeper in the enclosure						•
Route gas and electrical lines together to increase access space between groups of lines						
Mount frequently accessed components at upper torso heights						
Enlarge footprint conservatively and strategically to increase body access space within enclosure	•	•	•	•	•	•

Solutions Budget =	20	30	40	50	60	70
Provide built-in steps for reaching higher parts					•	•
Increase local illumination to 100 ft.-c.	•	•	•	•	•	•
Increase access openings in bulkheads OR Provide swing-away subassemblies OR Relocate fasteners on parts for visibility			•	•	•	•
Provide tactile cues for blind work					•	•
Use captive fasteners on parts difficult to see		•		•	•	•
Enlarge access ports in panels and bulkheads OR Locate serviceable parts on exterior of enclosure OR Provide special tools to reach into tight quarters				•	•	•
Label any removable parts exceeding 30 # Provide handles for two-person lifts OR Provide supports or hoists for parts exceeding 50 lb. (see above) Provide closer torso access, room to stand erect, and good footing for heavy lifts					•	•
Use captive fasteners to eliminate small parts OR Provide magnetized tools to captivate nuts OR Use larger fasteners than required by strength of materials requirements					•	•
Provide tools with larger diameter handles Redesign fine adjustments to be less frequent				•	•	•

APPENDIX K
Individual Tool Problems/Solutions

The following descriptions address the highest scoring stressors observed during data collection on the seven machines. Tasks, findings, cost scores, and solutions are listed. This is not an exhaustive list. More complete data were sent to the machine manufacturers as feedback, with the intention of alerting the suppliers of problems and kindling the problem-solving process.

Applied 5000 CVD

Task: Chamber Clean

Findings:
1. Fasteners unhooked too easily when disassembling the chamber, which added about 20 minutes to the normal task time. During the entire cleaning of the chamber, the tech had to lean against wires and couplers, which somtimes causes them to disconnect. Cost score = 379.

2. The tech had to reach above his shoulder to disassemble plates, which added about 10 minutes. Cost score = 310

3. The tech removed screws while wearing gloves, which added about 10 minutes. Cost score = 207.

4. Many menus hamper computer interaction, added about 5 minutes. Cost score = 121.

5. The tech had to remove doors to gain access and clean, which added about 5 minutes. Cost score = 121.

6. The tech had to carry a heavy tool chest (over 50 lbs.) upstairs. The techs had arranged for one to leave his tool chest upstairs for PMs, but not everyone was allowed to use this tool chest. Cost score = 113.

Solutions:
1. A cover that prevents the tech's body from pressing against couplers.

2. Improve access.

3. Package tools with cleaning supplies (PM tool kit).

Applied 9500 Implanter

Task: Beam Line PM (MRS, Flight Tube and Isolation Valve)

Finding: The technician had difficulty removing the enclosure panels which must be removed to access the flight tube, MRS and isolation valve. The time added to the normal task completion time was 5 to 30 minutes. The cost score is 52.

Solution: Handles on shields or hinged shields.

Task:	Removal of the MRS Shield and MRS
Finding:	1. Had difficulty removing MRS shield, estimated to weigh over 35 pounds. The additional time was about 5 minutes. Cost score = 52.
	2. Trunk flexion greater than 20 deg. was necessary.
Solution:	Handles on the shields

Task:	Remove/Replace Source
Findings:	1. The technician did not have sufficient head room (kneeling, ceiling too low). The additional time was about 5 minutes. Cost score = 48.
	2. Insufficient standing room (corona bar too low).
	Cost score = 45.
	3. The technician had to reach down to perform tasks; could have dropped the MRS. Cost score = 36.
	4. A special tool was required to remove parts, also, tools were missing, e.g., crank wrench. Additional time about 5 min.
	Cost score = 27.
	5. The technician's wrist was in extension with a load when removing the MRS from the chamber. Cost score = 23.
	6. The tech had a poor view of some screws and bolts; added about 2 minutes. Cost score = 18.
Solutions:	More head room above MRS, handles on shields, hinged shields, install a keyboard.

Task:	Scrubbing the Implanter Chambers
Findings:	1. Standing room was not adequate causing inefficient cleaning. Added about 5 min. Cost score = 45.
	2. The technician had to kneel or lie down to reach below the platform which could result in inefficient cleaning. Added about 5 min. Cost score = 36.
	3. Prolonged wrist extension was necessary. Cost score = 23.
	4. Trunk flexion greater than 20 deg. was necessary.
	Cost score = 22.
	5. The chambers were too small to allow use of both hands. Added about 5 min. Cost score = 21.
	6. The technician had difficulty seeing into some areas requiring cleaning, therefore, could not determine if clean enough. Cost score = 18.
Solutions:	

Nikon Stepper

Task:	Cleaning and Lubricating Lead Screws
Findings:	1. The technician had to find a place to put the panels after removing them, which added about 5 minutes to the normal task time. The cost score is 807.
	2. The technician had to reach around other components to reach the lead screws. Added about 20 min. Cost score = 284.
	3. Due to poor visual access, the tech had to perform the task partly by feel which could result in inadequate greasing. Cost score = 161.
	4. Poor view of lead screws due to inadequate lighting; added about 5 minutes. Cost score = 161.
	5. The tech had to stand in a bent knee position for up to one hour with short breaks to change position. Cost score = 132.
	6. The tech had to reach (static arm reach over 24 inches). Cost score = 132.
Solutions:	Improve access to the lead screws. Provide tools with longer extensions. Improve lighting at task.

Task:	Cleaning Procedure (Particle on Chuck)
Findings:	1. The tech had difficulty removing a panel due to the latches, which added about 2 minutes. Cost score = 807
	2. The tech could not get close enough to see the chuck clearly. Cost score = 161.
	3. Lighting for the task was inadequate. Cost score = 161.
	4. The tech had to perform tasks on knees for over 10 min. Cost score = 132.
	5. Arm reach greater than 18 inches was necessary to access chuck. Cost score = 132.
Solutions:	1. Improve door removal latches.
	2. Improve access to the chuck.

Eaton Implanter

Task:	Post Excell Electrode PM
Findings:	1. The technician must work in a bent leg or stooped position which makes part dropping or injury more likely and adds about 5 minutes to the task completion time. Cost score = 251.
	2. The tech must support PE electrode while securing it, which makes part dropping or injury more likely and adds about 10 minutes to the task completion time. Cost score = 246.
	3. A one-arm lift of the PE electrode (over 30 pounds) away from the tech's body was necessary. Cost score 188.

	4. The tech had a poor view of the bolts. Added about 10 min. Cost score 134.
Solution:	Improve access to bolts and unit; provide a guide to help line up the bolts and support some of the weight.

Task:	Source/Extractor PM
Findings:	1. The tech had to crouch while working in the extractor area, which made part damage more likely and added about 5 min. Cost score = 251.
	2. Twice, the tech had to support part weight with one arm. The source, which weighed about 25 pounds, was less likely to be seated properly and added about 15 minutes. The extractor weighed about 35 pounds and was more likely to be damaged. Cost score = 246.
	3. A narrow space restricted access to the part, which makes part damage or dropped screws more likely. Cost score = 162.
	4. The tech had a poor view when removing/inserting screws. Cost score = 134.
Solution:	A guide or support to help bear weight and align bolts.

Task:	Semi-annual PM
Findings:	1. Static kneel position was necessary. Cost score = 251.
	2. Some fasteners were difficult to see, which added about 15 minutes to the task time. Cost score = 134.
Solution:	

Task:	Ebara Pump Maintenance
Finding:	The tech had to remove the pump with a lift in order to service it. Added about 1 hour. Cost score = 273.
Solution:	Install pump package on a pullout drawer for easy access and maintenance.
Task:	Source Housing PM
Findings:	1. Tech had to support component while attaching fasteners. Cost score = 274.
	2. Tech performed disconnecting and removal tasks in bent-knee position. Cost score = 251.
Solution:	

Varian Implanter

Task:	Manipulator Change-out
Findings:	1. The technician had to remove the source housing to access the manipulator, which added about 15 minutes to the normal task completion time. Cost score = 381.

	2. The tech had to lift the manipulator in a manner that made injury and part damage more likely (arm lift away from the body). Added about 1 minute. Cost score = 183.
	3. The tech had to reach to grasp the manipulator, then lift and remove it. Added about 5 min. Cost score = 142.
Solution:	Pullout drawers.

Task:	6-Month PM
Findings:	1. The tech had to move a door and fire detector to remove the scanner, which added about 10 minutes. Cost score = 381.
	2. 1- and 2-arm reaches were necessary, which made part damage more likely and added about 10 min. Cost score = 142.
	3. A tech had to twist and reach to assist in removal of the scanner. Added about 10 min. Cost score = 105.
Solutions:	1. Relocate or redesign door to allow better access.
	2. Relocate the smoke detector to allow removal of the scanner.

Task:	Air Bearing Replacement (UM)
Findings:	1. The tech had to move the vacuum pump to gain access, which increased the task time by about 2 hours. Many operations require removal of the vacuum pump, which can add 2 hours to any job in this area. Cost score = 381.
	2. The tech had to twist his trunk while working in the area with the pump in place. Cost score = 105.
	3. Access was difficult without removal of the vacuum pump. Cost score = 98.
Solution:	

Task:	Removal/Replacement of Mass Slit Assembly
Findings:	1. The tech had to perform an arm lift away from the body, which made damage to the mass slit assembly and injury more likely. Added 1 to 2 min. Cost score = 183.
	2. The tech had to reach to access the mass slit assembly. Cost score = 142.
Solution:	Use pullout drawers.

Task:	Post Excell Plate Change
Findings:	1. A 2-person lift was necessary that made part damage more likely and added about 15 minutes. Cost score = 126.
	2. The tech had to twist and lift. Cost score = 105.
	3. The tech had to twist and lift due to limited access, which added about 15 minutes. Cost score = 98.

Task:	UM due to Solenoid Failure
Findings:	1. The tech had to reach with his arms to work in the solenoid area, which added about 15 minutes to the task time. Cost score = 110.
	2. The tech had to lie on his side in the end station area while working on the solenoid. Cost score = 110.
Solution:	Improve access.

Task:	Remove Source Bushing PM
Finding:	Difficult lift of large box (about 40 lbs.) away from body; also, one tech holds while another romoves bolts. Cost score = 183.
Solution:	

Task:	Source Change PM
Finding:	Load (Source) held away from tech's body while pulling out.Cost score = 183.
Solution:	Hoist or support for the source as it is pulled out.

Novellus Concept One

Task:	Heater Block Scrub
Findings:	1. The technician had to scrub at about chest height, which added about 10 minutes to the normal task time. Cost score = 290.
	2. The tech scrubbed with his shoulder flexed about 90 deg., which added about 5 minutes. Cost score = 124.
	3. The tech scrubbed with his trunk flexed more than 20 degrees, which added about 10 minutes. Cost score = 116.
Solution:	Self-cleaning block. Provide step stool.

Task:	Removal/Replacement of Spindle
Finding:	The tech had poor visual access when aligning the spindle, which increased the normal task time by about 3 minutes. Cost score = 130.
Solution:	

Task:	Gate Assembly Clean PM
Finding:	The tech removed bolts and performed cleaning while sitting on the floor with trunk flexed greater than 20 deg. The tech was about 5 ft. 6 in. tall; a larger person would have had more difficulty. Cost score = 116.
Solution:	

SVG Micrascan

Task:	Focus (removal of screws)

Finding:	1. The technician had to kneel due to limited head clearance, which added about 2 minutes to the normal task time. Cost score = 119.
	2. Turning screws to reinsert was hindered by limited space; added about 1 minute. Cost score = 37.
	3. The tech had to reach overhead when readjusting the focus; added about 1 minute. Cost score = 23.
Solution:	Better access.

Task:	Changing the lamp
Finding:	Tech had to reach overhead to remove bolts and open panel. Cost score = 23.
Solution:	Provide step stool of built-in, flip down supports for technician to stand on.

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