PERFORMANCE ASSESSMENT

OVERVIEW: The Performance Assessment module measures how well a product or process performs to meet the functional requirements of the use cluster. Performance data are collected for both the baseline and the substitute processes and used as a basis for a comparative evaluation. The amount of effort required to perform a useful performance assessment may vary depending on the thoroughness of the study and the specific nature of the process under consideration. The performance assessment can involve an actual operating trial of the baseline and substitutes during a performance demonstration project or, if both the baseline and substitutes are well known and documented, the compiling of performance information from literature sources. This module provides assistance in developing methodologies for collecting comparative performance data and conducting a performance assessment. The focus of this module is on the design of an actual operating trial rather than compiling performance information from literature sources.

GOALS:

- Design accurate and reliable performance measures.
- Select and use protocols for measuring performance to achieve reproducible testing results, and to remove bias from the interpretation of results.
- Develop a supplier data sheet to facilitate collection of required data from vendors and suppliers.
- Develop an observer data sheet to ensure that consistent and complete data are collected during performance testing.
- Evaluate relative performance of substitutes.

PEOPLE SKILLS: The following lists the types of skills or knowledge that are needed to complete this module.

- Familiarity with the required characteristics of the baseline and substitutes and the factors affecting performance.
- Knowledge of measuring techniques and quality control testing procedures.
- Familiarity with the details of the operation of the baseline and substitutes under review.
- Ability to analyze variability of results using qualitative or statistical techniques.

Within a business or DfE project team, the people who might supply these skills include a process engineer, process operator, industrial engineer, or statistician. Vendors of equipment or chemicals used in the process may also be a good resource.

DEFINITION OF TERMS:

American Society for Testing and Materials (ASTM): An independent group that sets standard testing procedures for a variety of materials (e.g., environmental effects on galvanized metal surfaces, light bulb life testing).

Bias: Testing error caused by systematically favoring some outcomes over others.

Blind Testing: An experimental method in which the material or process under study is not known to an operator to avoid influence on performance/results testing.

Generic Formulation: A generic classification into which a group of similar chemicals or chemical formulations can be grouped, in order to be evaluated, protecting the proprietary nature of a formulation.

Objective Characteristics: Characteristics which when measured are independent of the measurer's influence (e.g., weight, size).

Reproducibility: The ability of a test to give consistent results.

Subjective Characteristics: Characteristics which when measured and assigned a value are influenced by the perceptions of the measurer (e.g., color, sound, taste).

Test Vehicle: A standardized unit that can be used as a basis for testing different processes (e.g., a standard circuit board design that can be used to test the ability of several different processes to plate a conductive material into the holes on the board).

Underwriters Laboratory (U.L.): An independent group that tests and certifies the safety of electrical appliances (e.g., toasters, electric hand drills, lamps).

Variability: The measured difference in certain characteristics of similar items (e.g., paint thickness, color consistency, part cleanliness).

APPROACH/METHODOLOGY: The following presents a summary of the technical approach or methodology for designing and conducting a performance demonstration. Further methodological details for Steps 4, 5, 6, 9, 12, and 13 are included in the Methodology Details section. In the procedure described below, the example of the use of a liquid cleaning agent applied to the surface of an ink-coated printing screen is used. Examples of an observer data sheet, and the testing methodology protocol for the screen printing industry are included in Appendix E.

Performance Protocol

Step 1: Obtain chemical properties data relevant to performance from the Chemical Properties module. Relevant properties for the example of a liquid cleaning agent to remove ink from a printing screen include vapor pressure (reflects tendency for evaporation), boiling point (indicates usable temperature range), and flashpoint (indicates fire ignition temperature level).

Step 2: Review the functional requirements of the use cluster listed in the Chemistry of Use & Process Description module. For the cited example, a minimal amount of residual ink on the screen after cleaning may be a specified requirement. A performance criteria may be that the screen must be cleaned until no visible ink residue remains on the screen surface.

Step 3: Identify relevant performance characteristics that could be qualitatively or quantitatively evaluated during the performance demonstration. These might include the ease of use (e.g., the physical effort required to clean the screens), the time required to accomplish the desired function (e.g., cleaning), the effectiveness of the substitute in achieving the function, or the effect of the substitute on the quality of the finished product (e.g., will use of the cleaner reduce the life of the screen).

Step 4: Identify variables which could significantly influence the results of the performance demonstration if not properly controlled. These might include process variables outside of the use cluster such as upstream process chemistry that must be adjusted to be compatible with the substitutes.

Step 5: Define methods of measuring each of the performance characteristics identified in Step 3. These methods, which may include laboratory testing as well as on-site analysis during the demonstration, should minimize the effect on results of the variables identified in Step 4. If applicable, the design and use of a test vehicle can help accomplish the above objectives.

Step 6: Define the parameters or conditions under which the demonstration of the baseline and substitutes will be performed. These parameters include when and where the demonstration will take place, along with who will observe the demonstration. Performance demonstration conditions should simulate real operating conditions as much as possible.

Step 7: Establish a procedure to quantitatively or qualitatively analyze each of the performance measures identified in Step 5. Analysis may be required on-site during the performance demonstration (e.g., how many cycles a screen will process before failure, testing to what extent a part is dried, etc.) or after the demonstration at a special test facility (e.g., the amount of light transmitted through a cleaned screen). Suppliers of chemicals and equipment should be consulted to ensure that the analysis methods are unbiased and do not favor a particular product or technology.

Step 8: Establish a performance scale for each of the performance measures to facilitate a comparative evaluation of the substitutes. The scale should consider both subjective and objective characteristics. (For example, visual inspection could be used to assign a high, medium or low level of cleanliness. A quantitative test, such as light transmission through cleaned screens, could be used to quantitatively measure the amount of residual ink left on a screen after cleaning.) Some objective characteristics can be evaluated using standard product specifications, such as military specifications.

Step 9: Develop a performance demonstration protocol based on the information developed in Steps 3 through 8.

Step 10: Review the Energy Impacts, Resource Conservation, and Cost Analysis modules to determine what data are required from the performance demonstration to complete those modules. Include in the protocol methods for collecting energy use, resources consumption and cost data, if required. The following data are typically gathered by the performance assessment:

- Energy Impact data: Collect data on energy consumed by motors, pumps, air fans, and other energy consuming process equipment. Data may include power rating, average duty, and average load.
- Resource Conservation data: Collect data on quantities of resources used in the process. Use direct measurement or examine historical records to determine rates of resources consumption (e.g., the amount of spent cleaner generated in the cleaning of screens).
- Cost Analysis data: Collect information on costs, such as operating and maintenance costs, process equipment costs, raw materials, utilities, as well as applicable indirect costs (e.g., waste management expenditures).

Step 11: If time and resources allow, perform test runs to evaluate the performance demonstration protocol for factors such as reproducibility. Performing trial runs will ensure that all important variables have been identified and controlled, and will highlight significant errors or impracticalities in the protocol.

Supplier and Observer Data Sheets

Step 12: Develop a supplier data sheet to collect consistent data from suppliers and vendors of the use cluster chemicals or technologies. One important purpose of the supplier data sheet is to collect information regarding the proprietary formulations of chemical products, which is necessary for the risk characterization component of a CTSA. The same data sheet should be disseminated to each of the vendors or suppliers of the chemicals or technologies being employed in the demonstration.

Step 13: Develop an observer data sheet to facilitate the collection and recording of consistent data at the time of the performance demonstrations. Because similar types of data must be collected, it may be helpful to use the questionnaire developed in the Workplace Practices & Source Release Assessment module as a basis for developing the observer data sheet. The data sheet should be completed by the observer for each test run at each performance demonstration site. In order to ensure an efficient on-site performance demonstration, it may be useful to distribute portions of the observer data sheet to participating test facilities prior to the demonstration. To minimize the variation in data recording, it is preferable to have the same observer complete the on-site portion of each data sheet.

Performance Results

Step 14: Conduct performance demonstrations for each of the alternatives using the performance protocol developed in Step 9. The demonstrations should be carried out in the presence of a neutral observer who can record the process conditions and complete the observer data sheet.

Step 15: If the test vehicle is to be shipped to an off-site laboratory for analysis, the observer should record the identification code of the test vehicle, package it according to a standard protocol and ship it to this laboratory. Only reporting the identification code to the off-site laboratory, and not the type of substitute demonstrated on the test vehicle, ensures blind testing by the off-site laboratory.

Step 16: Compare the performance results with the previously-defined performance characteristics to evaluate the comparative efficacy of the substitutes (e.g., substitute 1 failed to clean the screen effectively and was time-consuming, but substitute 2 cleaned the surface effectively and quickly). It is important to note that results from the performance demonstration may not be easily comparable, particularly if all key variables are not identified or able to be controlled.

Step 17: Transfer energy use, resource consumption and cost data to the appropriate modules. Transfer chemical formulation data to the Exposure Assessment module. Transfer performance assessment results from Step 14 to the Risk, Competitiveness & Conservation Data Summary module.

METHODOLOGY DETAILS: This section presents methodology details for completing Steps 4, 5, 6, 9, 12, and 13. If necessary, additional information on these and other steps can be found in the published guidance.

Details: Step 4, Identifying Variables

Given the screen cleaning example, the types of variables that could significantly influence the results of the performance demonstration, if not properly controlled, include the following:

- Environmental:
  - Ambient light levels needed for operator to judge screen cleanliness after cleaning operations.
  - Ambient air temperature can affect cleaning agent efficiency.
- Human Operator:
  - Different operators may handle and clean screens with different speeds and thoroughness.
- Process System:
  - Ink type and viscosity may affect cleaner action.
  - Design of screens may affect ease of cleaning along edges and in corners.

Details: Step 5, Measurement Methods and Test Vehicle Design

To reduce the potential for variation in the test results and thus improve the reproducibility of the test protocol, the performance demonstration should be designed to:

- Minimize the influence of secondary parameters (e.g., room temperature variation) to isolate the effect of the chemical/process on the performance results.
- Consider the different application methods or operational characteristics that may be required with one or more of the substitutes (e.g., spray application in lieu of hand wipe-on of screen cleaning agent).
- Use blind testing to minimize operator influence on the test outcome (e.g., different screen cleaning agents being evaluated could be provided to a worker in containers labeled with a number of different codes, several of which could be for the same cleaning agent).
- Minimize the potential for compounded effects caused by lack of control over several process variables. In this regard, it is important to identify all key variables so that all but a single performance measure can be controlled to the extent possible or practical.

A test vehicle can be developed and used to standardize the conditions and minimize the variables that can occur when testing several different processes. The use of a test vehicle is not always possible and should only be used when it is applicable and makes sense (e.g., a test vehicle may not be needed to test the efficacy of different chemical agents removing ink from a silkscreen). A test vehicle should not be used unless it can be designed to test all of the alternatives being considered. The design of the test vehicle should be done using input from manufacturers, DfE project team members, and suppliers of chemicals or technologies to ensure that the test vehicle performs its function without favoring a particular process being tested. The test vehicle should be designed to:

- Facilitate the testing of the performance characteristics listed in Step 3 for all of the alternatives being evaluated.
- Minimize the effect on results of the variables identified in Step 4 (e.g., use a screen with a consistent amount of stencil coverage and intricacy).

- Be broadly applicable to the range of products being evaluated (e.g., the variation of hole sizes on a circuit board test vehicle should be representative of the range of hole sizes used for a circuit board).

In addition, to minimize variation, test vehicles used at different demonstration sites should be manufactured under identical conditions at a single facility prior to shipment to the demonstration sites. This will minimize the variation in the test vehicles themselves.

Test vehicles that will be shipped to an off-site laboratory following processing at the demonstration site should be labeled with an identification code. The laboratory should use the same test methods to analyze all of the test vehicles, regardless of whether the test methods are qualitative or quantitative.

Standard ASTM or U.L. methods and military or other product specifications are available for some manufacturing processes and products and may be useful in designing the performance demonstration. Trade associations may have developed standard testing procedures for other processes or products. However, unique tests may need to be developed for many processes or products.

Details: Step 6, Selecting the Demonstration Sites

The performance demonstration may be carried out at any of the following facility types:
- Current operating facility.
- Operating facility that acts as a supplier test site.
- Supplier or trade association test site or demonstration facility.

Details: Step 9, Developing the Performance Demonstration Protocol

The performance demonstration protocol may include:
- A description of the test vehicle, if applicable, including specifications for manufacturing the test vehicle.
- The performance characteristics to be reported from the performance demonstrations.
- The processing or testing methodology (a step-by-step description of how the on-site performance demonstrations will be conducted, including any processing or testing requirements).
- The processing or testing parameters (the conditions under which the demonstration should be performed).
- The analysis procedures that will measure the performance characteristics.
- The performance scale that will be used to compare the results of the performance assessment.
- The number of times each test or analysis should be run.

Details: Step 12, Preparing a Supplier Data Sheet

The supplier data sheet can be used to collect the following types of data:

- Process operating parameters (e.g., compatibility with other process steps, product life, limitations, etc.).
- Material safety data sheets.
- Product formulation data.
- Equipment operating and maintenance procedures.
- Waste disposal requirements.
- Energy, cost, or resource data listed in Step 10 that are best supplied by vendors or suppliers (e.g., equipment power rating, equipment costs, maintenance costs, etc.).
- Any other data that are best supplied by the vendors or suppliers.

When proprietary chemical products are being used, the use of generic formulations may be necessary to obtain proprietary chemical formulation data from the supplier. A generic formulation allows the chemical formulation data to be evaluated in the process while protecting the proprietary nature of the chemical product. The generic formula is typically developed through the combined efforts of the suppliers and vendors of the chemical products along with members of the DfE project team, especially persons involved in the Exposure Assessment and Risk Characterization components of a CTSA (see Chapter 2: Preparing for a CTSA). An example method for preparing a generic formula is shown below.

(1) Group similar chemicals into categories. The categories can either be by chemical name or by similar chemical compound (e.g., alcohols).

(2) Provide a range of concentrations for the actual quantity of a chemical within the product formulation (e.g., 50-60 percent toluene).

(3) Exclude quantities of specific chemicals that are under a concentration agreed upon by the project team (e.g., one percent), such as surfactants or salts. Do not exclude potentially hazardous materials or chemicals that are regulated.

This method can be used to group formulations with specific chemicals in a range of concentrations (e.g., Product A: 20-40 percent methyl ethyl ketone, 15-25 percent butyl acetate, 10-20 percent methanol, 20-40 percent toluene), or to specify the actual concentrations of a chemical group (e.g., 40 percent propylene glycol series ethers, which can represent a number of different, but structurally similar, chemicals).

Details: Step 13, Developing an Observer Data Sheet

The observer data sheet should collect the following types of data:

- Personnel (e.g., facility contact, individuals performing demonstration, etc.).
- Demonstration conditions (e.g., ambient air temperature, air ventilation rate, humidity, etc.).

- Process description (e.g., equipment used, process steps, chemical product compositions, etc.).
- Type and identification code of test vehicle, if applicable.
- Observed operating procedures (e.g., time a panel is immersed in a chemical bath, process cycle time, amount of chemical used to clean a screen, etc.).
- Exposure data (e.g., chemical handling procedures, worker activities, personal protective equipment worn by workers, etc.).
- Process variables (e.g., temperature of chemical baths, worker operation inconsistencies).
- Energy, cost, and raw materials data listed in Step 10 (e.g., average energy load and duty, utility costs, water consumption rates, etc.).
- Any other data that are best collected by a neutral observer at the time of the performance demonstration.

In order to ensure an efficient on-site performance demonstration, it may be useful to distribute portions of the observer data sheet to participating demonstration sites prior to the demonstration. The partial observer data sheet should include:

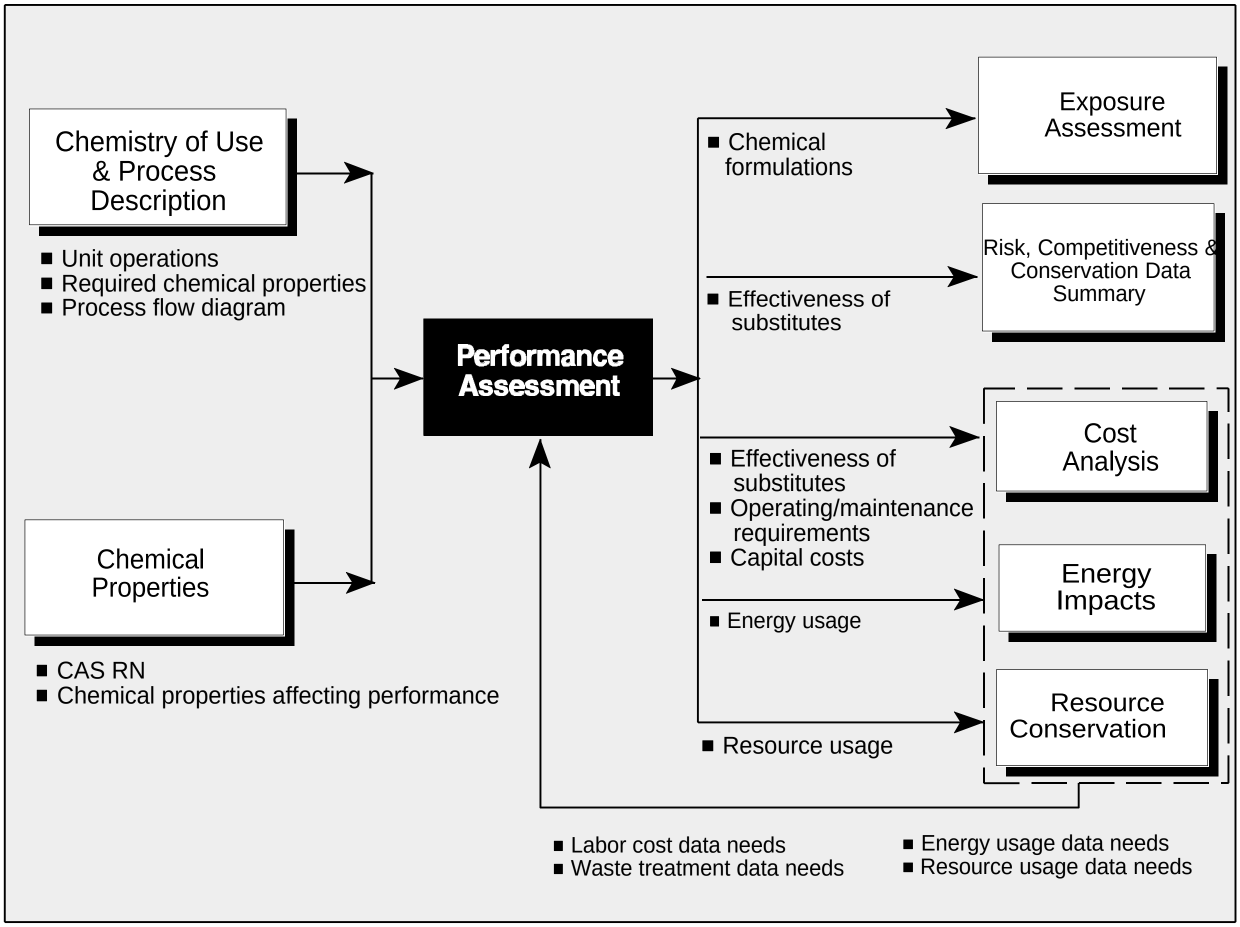
- A description of the process as it is performed at the specific test facility.
- Data that are difficult or time consuming to obtain (e.g., annual sludge volumes, data from company purchase records, equipment reliability data).
- Process history data (e.g., recent changes in equipment or operating practices that could effect the validity of data collected).
- Employee data (e.g., number of employees per shift, hours per shift).
- Any other data that can be collected by the facility that will help prepare observers for the demonstration or that are not readily available on-site.

By collecting and reviewing the facility completed portion of the observer data sheet prior to the facility test, the performance demonstration will be facilitated by allowing:

- Observers to become familiar with important process information prior to the performance demonstration.
- Data to be collected that are difficult or time consuming to obtain during a short on-site visit (e.g., annual chemical consumption, utility costs).
- The demonstration site to obtain the particular chemical products or technologies that are to be tested.

FLOW OF INFORMATION: The Performance Assessment module receives data requirements from the Energy Impacts, Resource Conservation, and Cost Analysis modules. It receives chemical and process information from the Chemistry of Use & Process Description and Chemical Properties modules. Performance data are transferred to the Exposure Assessment, Risk, Competitiveness & Conservation Data Summary, Cost Analysis, Energy Impacts, and Resource Conservation modules. Example information flows are shown in Figure 7-2.

-FIGURE 7-2: PERFORMANCE ASSESSMENT MODULE: EXAMPLE INFORMATION FLOWS



ANALYTICAL MODELS: None cited.

PUBLISHED GUIDANCE: Table 7-2 presents references for published guidance relevant to the design of a performance demonstration project.

TABLE 7-2: PUBLISHED GUIDANCE ON PERFORMANCE ASSESSMENT

Reference	Type of Guidance
Kume, Hitoshi. 1987. *Statistical Methods for Quality Improvement.*	Methods for using statistics to measure performance, specifically quality, for the baseline and alternative chemicals or processes.
Montgomery, Douglas C. 1991. *Design and Analysis of Experiments*.	Information on designing non-biased experiments and statistical analysis of the results.

TABLE 7-2: PUBLISHED GUIDANCE ON PERFORMANCE ASSESSMENT	
Reference	**Type of Guidance**
Ray, Martyn S. 1988. *Engineering Experimentation: Ideas, Techniques, and Presentation*.	In-depth coverage of experimental techniques and equipment for measuring performance.

Note: References are listed in shortened format, with complete references given in the reference list following Chapter 10.

DATA SOURCES: None cited.