How to Measure Performance

A Handbook of Techniques and Tools

U.S. Department of Energy

Defense Programs

Special Projects Group (DP-31)

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Office of Operating Experience, Analysis and Feedback (EH-33)

TRADE®

Performance Based Management

PBM SIG

Special Interest Group

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How to Measure Performance
A Handbook of Techniques and Tools

Prepared by the
Training Resources and Data Exchange (TRADE)
Performance-Based Management Special Interest Group

for the
Special Project Group
Assistant Secretary for Defense Programs

and the
Office of Operating Experience, Analysis and Feedback
Assistant Secretary for Environment, Safety and Health
U.S. Department of Energy

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PREFACE

Introduction

The Training Resources and Data Exchange (TRADE) Performance-Based Management Special Interest Group (PBM SIG) was chartered to foster continuous improvement and facilitate the use of performance-based management techniques within the U.S. Department of Energy (DOE) community. This handbook has been compiled by the PBM SIG to provide reference material to assist in the development, utilization, evaluation, and interpretation of performance measurement techniques and tools to support the efficient and effective management of operations.

Contributors

The following members of the TRADE PBM SIG served as the project team for the compilation of this handbook:

- Joel Anderson, Los Alamos National Laboratory
- Will Artley, Oak Ridge Institute for Science and Education
- Amanda Denton, Lockheed Martin Energy Systems, Inc.
- Cynthia Eubanks, Lockheed Martin Energy Systems, Inc.
- Jean George, Lawrence Livermore National Laboratory
- Tammra Horning, Lockheed Martin Energy Systems, Inc.
- Bob Lyon, Lockheed Idaho Technologies Company
- Jeff Murphy, Lawrence Livermore National Laboratory
- Barbara Strack, Westinghouse Savannah River Corporation
- Kim Wilson, West Valley Nuclear Services

Other subject matter experts in performance-based management programs who provided information or participated in the preparation or review of this handbook include Anne Roe, Westinghouse Savannah River Corporation; Stan Love, retired, Sandia National Laboratories-Albuquerque; Buck Koonce, University of California; Mary Ayles, Jack Ewing, and R. S. (Bud) Leete, Lockheed Martin Energy Systems, Inc.; Megan Lohmann, DOE Nevada; TRADE PBM SIG Advisors Paul Krumpe and Richard Day, DOE Headquarters.

OVERVIEW

"How to measure performance?" How often do you ask yourself this question? Once a week? Once a month? Never? If you're a successful manager in a successful organization, you probably ask yourself this question every single day. However, measuring performance often isn't easy.

In the performance measurement arena, you don't always (or even often) get the results that you expect, want, or predict. After expending a great deal of energy collecting information, just when the results look promising, you find that you're measuring the wrong things.

It doesn't have to be this way. Two key words, although they won't completely solve your performance measurement problems, can put you on the path to success: disciplined approach. All too often performance measurement programs, created with the best intentions, fail because they were short sighted, ill conceived, and unfocused. Most of these ailments can be traced to one source: the lack of a viable approach to performance measurement from the start.

This handbook offers three such disciplined, systematic approaches.

- The first approach, the Performance Measurement Process, was developed by the DOE Nevada Family Quality Forum. This approach is quite detailed and outlines an 11-step process for measuring performance.
- The second approach, Developing Performance Indicators . . . A Systematic Approach, was used at Sandia National Laboratories. It is less detail-oriented than the first, and uses a fictitious company, the Hackenstack Firewood Company, for anecdotal purposes.
- The third approach, Developing Performance Metrics-the University of California Approach, was developed by the University of California. This method is broadest in scope.

Different organizations have different needs. Providing multiple approaches allows an organization to pick and choose which approach, or combination of approaches, is right for it.

It is important to remember that the approaches previously outlined were developed independently; they may use different terminology. For instance, what the first approach refers to as a performance measure may be referred to as a performance indicator in the second approach, or a performance metric in the third. All three approaches are referring to the same concept; however, each uses a different nomenclature (in fact, each approach has its own glossary). Fortunately, this causes problems only when comparing one approach to another, so be careful when you reach this stage.

A sound approach to performance measurement is a necessary ingredient for ensured success, but it alone is not sufficient. You will also need to know what to do with performance measurement data once it has been collected. The last few sections of this handbook provide some helpful hints on proven methods of data analysis and management.

Section 1

Development Processes

1.0 Overview

The use of performance measures in business is hardly new. Companies have been measuring costs, quality, quantity, cycle time, efficiency, productivity, etc., of products, services, and processes as long as ways to measure those things have existed. What is new to some extent is having those who do the work determine some of what should be measured in order that they might better control, understand, and improve what they do.

This section contains information that can help an organization determine what kind of measures it needs, provide some guidance on what should be measured, and show how to set up a measuring system. Approaches used by three different sources are included. The basic fundamentals are the same in each case; however, the specific methods are slightly different. These three approaches address those who actually do the work in determining the appropriate performance measures.

The concepts introduced here apply anywhere in an organization, from the highest levels of a company down to the area where a specific task is accomplished. The elements of continuous improvement are built into the methodologies.

SECTION 1: DEVELOPMENT PROCESSES

1.0 OVERVIEW

1.1 Performance Measurement Process

Introduction

Performance measures are recognized as an important element of all Total Quality Management programs. Managers and supervisors directing the efforts of an organization or a group have a responsibility to know how, when, and where to institute a wide range of changes. These changes cannot be sensibly implemented without knowledge of the appropriate information upon which they are based. In addition, among many organizations within the Department of Energy (DOE) complex, there is currently no standardized approach to developing and implementing performance measurement systems. As a result, performance measures have not been fully adopted to gauge the success of the various quality management programs practiced by members of the Department of Energy Nevada Operations Office (DOE/NV) Family Quality Forum.

To address these issues, the steering committee members commissioned a work group to study the development, implementation, and operation of performance measurement systems. This guidance document, the product of the work group, provides a comprehensive, step-by-step explanation of how to develop performance measurements at any level within an organization and how to evaluate their effectiveness.

Appendix A contains a glossary of terms that may be used in this guidance document. The accompanying Case Study (Appendix B) illustrates a practical example of how to put the concepts of the guidance document to use. Appendix C contains examples of performance measurements that can be considered.

The implementation of performance measurements for a specific process should involve as many cognizant employees as possible to stimulate ideas and reinforce the notion that this is a team effort requiring buy-in from all involved in order to succeed. Substantial benefits are realized by organizations implementing performance measurement programs. These benefits are realized almost immediately through an improved understanding of processes by all employees. Furthermore, individuals get an opportunity to receive a broadened perspective of the organization's functions, rather than the more limited perspective of their own immediate span of control.

As a process, performance measurement is not simply concerned with collecting data associated with a predefined performance goal or standard. Performance measurement is better thought of as an overall management system involving prevention and detection aimed at achieving conformance of the work product or service to your customer's requirements. Additionally, it is concerned with process optimization through increased efficiency and effectiveness of the process or product. These actions occur in a continuous cycle, allowing options for expansion and improvement of the work process or product as better techniques are discovered and implemented.

SECTION 1: DEVELOPMENT PROCESSES

1.1 PERFORMANCE MEASUREMENT PROCESS

Performance measurement is primarily managing outcome, and one of its main purposes is to reduce or eliminate overall variation in the work product or process. The goal is to arrive at sound decisions about actions affecting the product or process and its output.

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What Are Performance Measures?

Performance measures quantitatively tell us something important about our products, services, and the processes that produce them. They are a tool to help us understand, manage, and improve what our organizations do. Performance measures let us know:

- how well we are doing
- if we are meeting our goals
- if our customers are satisfied
- if our processes are in statistical control
- if and where improvements are necessary.

They provide us with the information necessary to make intelligent decisions about what we do.

A performance measure is composed of a number and a unit of measure. The number gives us a magnitude (how much) and the unit gives the number a meaning (what). Performance measures are always tied to a goal or an objective (the target). Performance measures can be represented by single dimensional units like hours, meters, nanoseconds, dollars, number of reports, number of errors, number of CPR-certified employees, length of time to design hardware, etc. They can show the variation in a process or deviation from design specifications. Single-dimensional units of measure usually represent very basic and fundamental measures of some process or product.

More often, multidimensional units of measure are used. These are performance measures expressed as ratios of two or more fundamental units. These may be units like miles per gallon (a performance measure of fuel economy), number of accidents per million hours worked (a performance measure of the companies safety program), or number of on-time vendor deliveries per total number of vendor deliveries. Performance measures expressed this way almost always convey more information than the single-dimensional or single-unit performance measures. Ideally, performance measures should be expressed in units of measure that are the most meaningful to those who must use or make decisions based on those measures.

SECTION 1: DEVELOPMENT PROCESSES

1.1 PERFORMANCE MEASUREMENT PROCESS

Most performance measures can be grouped into one of the following six general categories. However, certain organizations may develop their own categories as appropriate depending on the organization's mission:

1. Effectiveness: A process characteristic indicating the degree to which the process output (work product) conforms to requirements.(Are we doing the right things?)
2. Efficiency: A process characteristic indicating the degree to which the process produces the required output at minimum resource cost. (Are we doing things right?)
3. Quality: The degree to which a product or service meets customer requirements and expectations.
4. Timeliness: Measures whether a unit of work was done correctly and on time. Criteria must be established to define what constitutes timeliness for a given unit of work. The criterion is usually based on customer requirements.
5. Productivity: The value added by the process divided by the value of the labor and capital consumed.
6. Safety: Measures the overall health of the organization and the working environment of its employees.

The following reflect the attributes of an ideal unit of measure:

- Reflects the customer's needs as well as our own
- Provides an agreed upon basis for decision making
- Is understandable
- Applies broadly
- May be interpreted uniformly
- Is compatible with existing sensors (a way to measure it exists)
- Is precise in interpreting the results
- Is economical to apply

Performance data must support the mission assignment(s) from the highest organizational level downward to the performance level. Therefore, the measurements that are used must reflect the assigned work at that level.

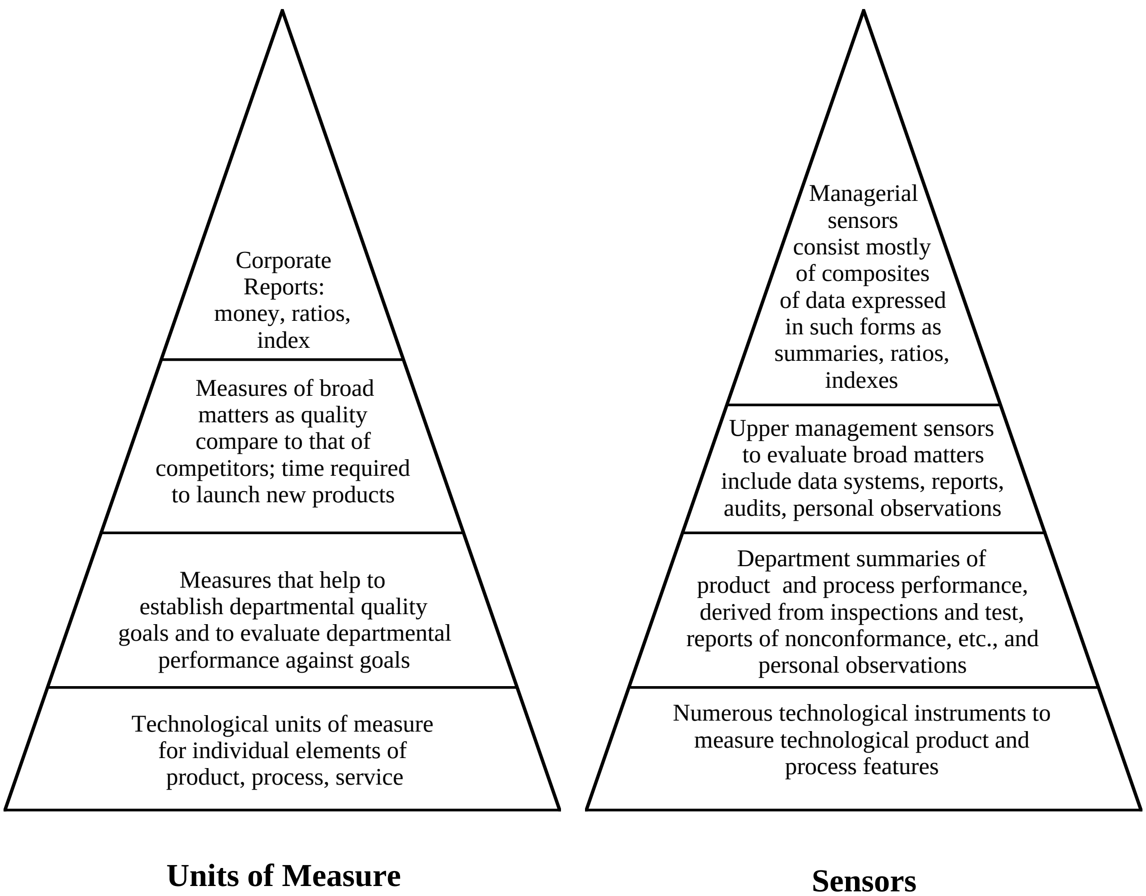
Within a system, units of measure should interconnect to form a pyramid (Figure 1.1). Technological units start at the base. These are measures of individual units of products and of individual elements of service.

The next level of units serve to summarize the basic data (e.g., percent defective for specific processes, documents, product components, service cycles, and persons.)

Next are units of measure that serve to express quality for entire departments, product lines, and classes of service. In large organizations, there may be multiple layers of this category.

At the top are the financial and upper management units (measures, indexes, ratios, etc.), which serve the needs of the highest levels in the organization: corporate, divisional, and functional.

Figure 1.1
Pyramid Used at All Levels of the Company



What Are the Benefits of Measurements?

Listed below are seven important benefits of measurements:

1. To identify whether we are meeting customer requirements. How do we know that we are providing the services/products that our customers require?
2. To help us understand our processes. To confirm what we know or reveal what we don't know. Do we know where the problems are?
3. To ensure decisions are based on fact, not on emotion. Are our decisions based upon well-documented facts and figures or on intuition and gut feelings?
4. To show where improvements need to be made. Where can we do better? How can we improve?
5. To show if improvements actually happened. Do we have a clear picture?
6. To reveal problems that bias, emotion, and longevity cover up. If we have been doing our job for a long time without measurements, we might assume incorrectly that things are going well. (They may or may not be, but without measurements there is no way to tell.)
7. To identify whether suppliers are meeting our requirements. Do our suppliers know if our requirements are being met?

Why Do We Need to Measure?

If you cannot measure an activity, you cannot control it. If you cannot control it, you cannot manage it. Without dependable measurements, intelligent decisions cannot be made. Measurements, therefore, can be used for:

1. Control: Measurements help to reduce variation. For example, a typical control for DOE contractor accountability measurement is the Work Authorization Directive System (WADS) and Performance Evaluation Plan (PEP). Their purpose is to reduce expense overruns so that agreed-to objectives can be achieved.
2. Self-Assessment: Measurements can be used to assess how well a process is doing, including improvements that have been made.
3. Continuous Improvement: Measurements can be used to identify defect sources, process trends, and defect prevention, and to determine process efficiency and effectiveness, as well as opportunities for improvement.
4. Management Assessment: Without measurements there is no way to be certain we are meeting value-added objectives or that we are being effective and efficient. The basic concept of performance measurement involves (a) planning and meeting established operating goals/standards; (b) detecting deviations from planned levels of performance; and (c) restoring performance to the planned levels or achieving new levels of performance.

What Is the Foundation for a Performance Measurement System?

Successful performance measurement systems adhere to the following principles:

1. Measure only what is important. Do not measure too much; measure things that impact customer satisfaction.
2. Focus on customer needs. Ask our customers if they think this is what we should measure.
3. Involve employees (workers) in the design and implementation of the measurement system. Give them a sense of ownership, which leads to improvements in the quality of the measurement system.

The basic feedback loop shown in Figure 1.2 presents a systematic series of steps for maintaining conformance to goals/standards by communicating performance data back to the responsible worker and/or decision maker to take appropriate action(s).

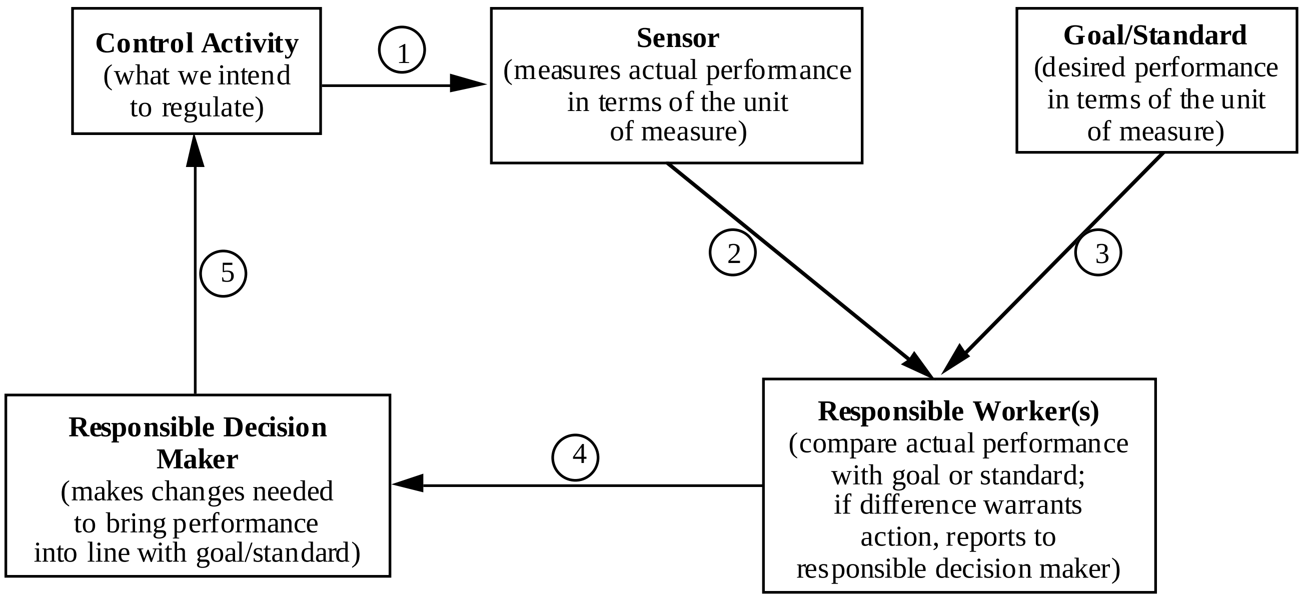
Without the basic feedback loop, no performance measurement system will ever ensure an effective and efficient operation, and, as a result, conformance to customers' requirements.

The message of the feedback loop is that to achieve the goal or standard, those responsible for managing the critical activity(ies) must always be in a position to know (a) what is to be done; (b) what is being done; (c) when to take corrective action; and (d) when to change the goal or standard.

The basic elements of the feedback loop and their interrelations are:

1. The Sensor evaluates actual performance.
2. The Sensor reports this performance to a Responsible Worker.
3. The Responsible Worker also receives information on what the goal or standard is.
4. The Responsible Worker compares actual performance to the goal. If the difference warrants action, the worker reports to a Responsible Decision Maker. (This could signal a need for corrective action.)
5. The Responsible Decision Maker verifies variance, determines if corrective action is necessary, and, if so, makes the changes needed to bring performance back in line with the goals.

Figure 1.2
Basic Feedback Loop



Process Overview

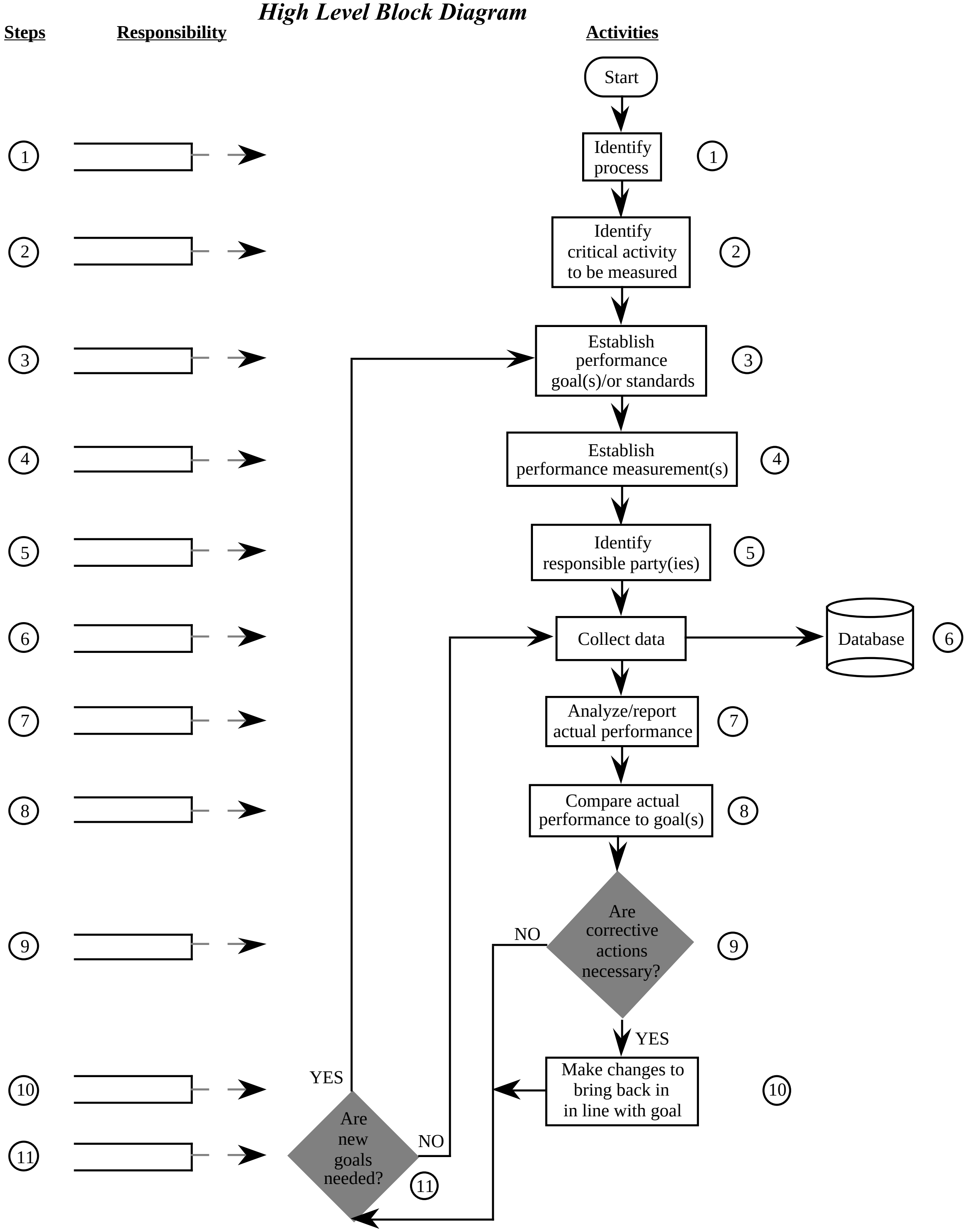
Figure 1.3 shows a high level block diagram of the performance measurement process. It has been separated into 11 discrete steps. This is a guideline, intended to show the process generically. Different organizations who best know their own internal processes should feel free to adapt the guidelines where necessary to best fit within their operations. Subcomponents within the steps may need to be exchanged, or it may be necessary to revisit completed steps of the process based on new information arising from latter steps.

A brief description of each of the process steps follows:

1. Identify the process flow. This is the first and perhaps most important step. If your employees cannot agree on their process(es), how can they effectively measure them or utilize the output of what they have measured?
2. Identify the critical activity to be measured. The critical activity is that culminating activity where it makes the most sense to locate a sensor and define an individual performance measure within a process.

3. Establish performance goal(s) or standards. All performance measures should be tied to a predefined goal or standard, even if the goal is at first somewhat subjective. Having goals and standards is the only way to meaningfully interpret the results of your measurements and gauge the success of your management systems.
4. Establish performance measurement(s). In this step, you continue to build the performance measurement system by identifying individual measures.
5. Identify responsible party(s). A specific entity (as in a team or an individual) needs to be assigned the responsibilities for each of the steps in the performance measurement process.
6. Collect data. In addition to writing down the numbers, the data need to be pre-analyzed in a timely fashion to observe any early trends and confirm the adequacy of your data collection system.
7. Analyze/report actual performance. In this step, the raw data are formally converted into performance measures, displayed in an understandable form, and disseminated in the form of a report.
8. Compare actual performance to goal(s). In this step, compare performance, as presented in the report, to predetermined goals or standards and determine the variation (if any).
9. Are corrective actions necessary? Depending on the magnitude of the variation between measurements and goals, some form of corrective action may be required.
10. Make changes to bring back in line with goal. This step only occurs if corrective action is expected to be necessary. The actual determination of the corrective action is part of the quality improvement process, not the performance measurement process. This step is primarily concerned with improvement of your management system.
11. Are new goals needed? Even in successful systems, changes may need to be revised in order to establish ones that challenge an organization’s resources, but do not overtax them. Goals and standards need periodic evaluation to keep up with the latest organizational processes.

Figure 1.3
Performance Measurement Process
High Level Block Diagram



1.1 PERFORMANCE MEASUREMENT PROCESS

Step 1: Identify Process

In identifying the process, an understanding of what you want to measure is of critical importance. Usually there are many processes and functions, each potentially needing performance measures. If there are multiple processes, consider the business impacts, and select those processes that are most important to the customer (both internal and external) to satisfy their requirements and/or those processes with problem areas identified by management. These then become the key (or important) processes.

A process needs to be manageable in size. A lot of effort can be wasted if you do not start with a well-defined process. You should ask the following:

A. What product or service do we produce?

B. Who are our customer(s)?

C. What comprises our process?

- What do we do?
- How do we do it?
- What starts our process?
- What ends our process?

Before you try to control a process, you must understand it. A flow diagram is an invaluable tool and the best way to understand a process. Flowcharting the entire process, down to the task level, sets the stage for developing performance measures.

All parties who are involved in the process should participate in creating the flowcharts. In a team environment, individuals will receive a new understanding of their processes. As participants, you can count on their later support to make the performance measurement system work.

OUTPUT: A LIST OF PROCESSES, KEY PROCESSES, AND FLOW DIAGRAMS FOR THESE KEY PROCESSES.

Step 2: Identify Critical Activity(ies) to be Measured

It is important to choose only the critical activity(ies) to be measured. We measure these activities to control them. Controlling, or keeping things on course, is not something we do in the abstract. Control is applied to a specific critical activity. When making your selection, focus on key areas and processes rather than people.

Examine each activity in the process and identify those that are critical. Critical activities are those that significantly impact total process efficiency, effectiveness, quality, timeliness, productivity, or safety. At the management level, critical activities impact management priorities, organizational goals, and external customer goals.

Ask the following: Does it relate, directly or indirectly, to the ultimate goal of customer satisfaction? Every critical activity should. For example, on-time delivery is directly related to customer satisfaction. Use quality tools such as the Pareto principle, brainstorming, or examining data to help prioritize the critical activities.

Confirm that the activity is critical. Do all concerned agree that this activity needs to be watched closely and acted on if its performance is less than desirable? Is it something that should be continuously improved? Does the benefit exceed the cost of taking the measurement? If the answer is "no" to any of these questions, you should reevaluate why you consider it critical.

Each critical activity becomes the hub around which a feedback loop is constructed. (Figure 1.2)

It is at this step you begin to think about what you want to know or understand about the critical activity and/or process. Perhaps the most fundamental step in establishing any measurement system is answering the question, “What do I want to know.” The key issue then becomes, "How do we generate useful information?" Learning to ask the right questions is a key skill in effective data collection. Accurate, precise data collected through an elaborately designed statistical sampling plan is useless if it does not clearly address a question that someone cares about. It is crucial to be able to state precisely what it is you want to know about the activity you are going to measure. Without this knowledge, there is no basis for making measurements.

To generate useful information, planning for good data collection proceeds along the following lines:

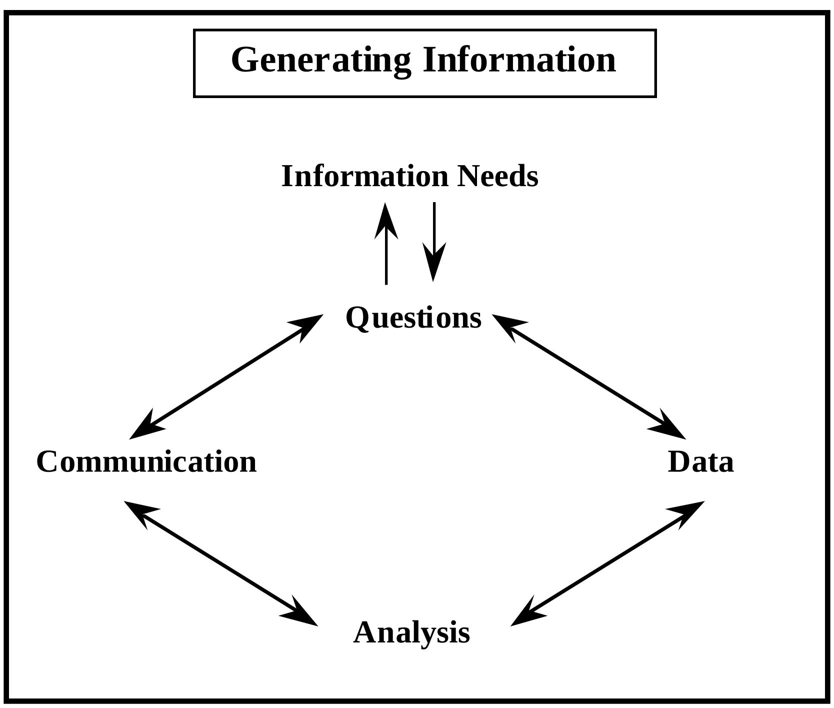
- What question do we need to answer?
- How will we recognize and communicate the answers to the question?
- What data-analysis tools (Pareto diagram, histogram, bar graph, control charts, etc.) do we envision using? How will we communicate the results?
- What type of data do the data analysis tools require?

- Where in the process can we get these data?
- Who in the process can give us these data?
- How can we collect these data from people with minimum effort and chance of error?
- What additional information do we need to capture for future analysis, reference, and tractability?

Notice how this planning process (Figure 1.4) essentially works backward through the model for generating useful information. We start by defining the question. Then, rather than diving into the details of data collection, we consider how we might communicate the answer to the question and what types of analysis we will need to perform. This helps us define our data needs and clarifies what characteristics are most important in the data. With this understanding as a foundation, we can deal more coherently with the where, who, how, and what else issue of data collection.

OUTPUT: A LIST OF THE CRITICAL ACTIVITY AREAS FOR THE KEY PROCESS.

Figure 1.4
Model for Generating Useful Information



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Information generation begins and ends with questions. To generate information, we need to:

- Formulate precisely the question we are trying to answer.
- Collect the data and facts relating to that question.
- Analyze the data to determine the factual answer to the question.
- Present the data in a way that clearly communicates the answer to the question.

Step 3: Establish Performance Goal(s) or Standard(s)

Goals and standards are necessary; otherwise there is no logical basis for choosing what to measure, what decisions to make, or what action to take. Goals can be a management directive or can be set in response to customer needs or complaints. Know your customers and their expectations. For each critical activity selected for measurement, it is necessary to establish a performance goal or standard. This is an "aimed-at" target, an achievement toward which effort is expended. Standards often are mandated by external sources (e.g., Occupational Safety and Health Administration [OSHA], government regulations, etc.). Knowledge of performance is not enough; you must have a basis for comparison before you can decide or act.

The concept of establishing performance goals/standards is not limited to numbered quantities, i.e., budget, deliveries. Neither is it limited to "things." The concept of standards extends to business practices, routines, methods, and procedures as well.

Performance goals can be established for (1) the overall process output, and/or, (2) the critical activities that produce the output. In any case, if this is the first set of goals or standards to be established, and no basis for setting goals or standards exists, a baseline period of observation is appropriate prior to establishing the goal or standard.

Good performance goals or standards are:

- Attainable: Should be met with reasonable effort under the conditions that are expected to prevail.
- Economic: Cost of setting and administering should be low in relation to the activity covered.
- Applicable: Should fit the conditions under which they are to be used. If conditions vary, should contain built-in flexibility to meet these variables.
- Consistent: Should help to unify communication and operations throughout all functions of the company.

- All-inclusive: Should cover all interrelated activities. Failing this, standards will be met at the expense of those activities for which standards have not been set.
- Understandable: Should be expressed in simple, clear terms, so as to avoid misinterpretation or vagueness. Instructions for use should be specific and complete.
- Measurable**:** Should be able to communicate with precision.
- Stable**:** Should have a long enough life to provide predictability and to amortize the effort of preparing them.
- Adaptable**:** Should be designed so that elements can be added, changed, and brought up to date without redoing the entire structure.
- Legitimate**:** Should be officially approved.
- Equitable**:** Should be accepted as a fair basis for comparison by the people who have the job of meeting the goal or standard.
- Customer Focus**:** Should address areas important to the customer (internal/external) such as cycle time, quality, cost schedule performance, and customer satisfaction.

OUTPUT: A LIST OF GOALS FOR EACH CRITICAL ACTIVITY WITHIN THE PROCESS

Step 4: Establish Performance Measurement(s)

This step involves performing several activities that will continue to build the performance measurement system. Each performance measurement consists of a defined unit of measure (the performance measure itself), a sensor to measure or record the raw data, and a frequency with which the measurements are made. To develop a measure, the team performs the following activities:

- translates “what do I want to know” into a performance measure
- identifies the raw data that will generate the performance measure
- determines where to locate the raw data
- identifies the sensor or measurement instrument that will collect the data for the performance measures
- determines how often to make the measurements

At this point, your team has agreed upon which process to measure (Step 1), identified the critical activities of your process with emphasis on those that impact quality, efficiency, timeliness, customer satisfaction, etc. (Step 2), looked at goals for these activities, products, and services (where they exist), and has quantified these goals where possible (Step 3). Your team should use the knowledge gained from these previous steps to help state precisely what you want to know about the critical activities or the process as a whole. Think of this step as one that will allow you to generate useful information rather than just generating data. The purpose of this information is to provide everyone involved with an agreed-upon basis for making sensible decisions about your processes, products, and services. Don't move on until the team agrees on what information you are trying to extract from the measurements.

Translate into Performance Measures

Having identified precisely what you want to know or understand about your process, you must now assemble this knowledge into a performance measure. Performance measures, and the data necessary to generate them, should be chosen to answer the questions you have just posed above. At this point, your team must decide how you will "say it in numbers."

Performance measures are generally easiest to determine for activities or processes that have established and quantified goals. In such cases, the performance measures are usually stated in the same units as or similar units to the goals.

When no goals exist for an activity (or the process as a whole), the team should revisit the fundamental question of what it is they wish to know. The performance measures should provide quantitative answers to their questions in units that relate to those questions. The team may wish to reread **What Are Performance Measures?** on Page 1 - 4 to reinforce the concept of a unit of measure and what it should convey.

The following example of a vendor selection process should prove useful in illustrating how to turn a question posed into one of a possible performance measure:

> You are part of a work team within the procurement department of your company. Over the years the number of vendors from which you make purchases has grown astronomically and you need some basis upon which to help decide which vendors perform the best. You have concluded that one of the more fundamental questions you would like to answer is "how well do our vendors meet the contract delivery dates?" Your team needs to choose a performance measure that will help answer this question. After putting several possible performance measures on a flip chart and examining what information each could convey, the team decided to use:
>
> % on-time deliveries per month

To ensure the team understood what this measure will provide them, they rewrote this measure in terms of the units that are actually used to calculate it. The performance measure then looks like this:

$$\frac{\text{number of on-time deliveries per month}}{\text{total number of deliveries per month}} \times 100\%$$

Both versions of the performance measure are essentially the same, but the second actually conveys more information to the reader and provides an indication of what data goes into the measurement. This performance measure should help the team answer the question of how well vendors are meeting contract delivery dates. By writing their performance measure in more fundamental units, the team will be better prepared to move to the next activity, which is identifying the raw data needed.

A good way to "test" a team's understanding of the performance measures they have chosen is to have them describe how they would display their results graphically. Have the team explain what type of graph they would use for each performance measure and how they would interpret the results. Quite often, seeing a performance measure displayed graphically will help determine if it will actually provide the information needed. Doing this simple step now will help ensure the team that it has chosen the right performance measure.

In reality, many work teams may find that some of their performance measures do not really tell them what they want to know. Don't panic, even performance measures that don't quite work may help refocus the team on the real issues they hope to address. Introduce a new set of measures and try again.

Identify the Raw Data

The purpose of this activity is to identify the raw data you will need to generate the performance measures. It is difficult to perform a measurement if the needed data and data source have not been identified. For very simple processes with straightforward performance measures, this step may seem simple. However, very complex or high-level performance measures may require many raw data from numerous sources. In general, performance measures are seldom generated directly in a single measurement or from a single source. They usually (but not always) consist of some combination of other raw data elements as in the example above. To illustrate the difference, consider the following examples:

1. Your workgroup enters data from customer order forms into an electronic database. Your group decided that the number of errors per day was a useful performance measure for that process. The raw data for your measurement consist of counting the errors in the database each day. In this case, the collection of raw data needed <u>is</u> the performance measure and it has been measured directly.

2. You are in the procurement department and your team has decided to use the percent of on-time deliveries per month of key vendors as a performance measure. The raw data you need consist of four sets. First, you need the delivery date on the contract that was awarded to your vendors. Second, you need the date the delivery was made. Third, you must compute if the delivery was on time and count how many deliveries there were for each vendor. Fourth, the team will need the total number of deliveries made within the month for that vendor. Unlike example 1, several elements of raw data are required to reconstruct the performance measure.
3. Your management team considers the company's overhead burden rate to be an excellent high-level performance measure. This measure is very complex and is frequently performed by the company's accountants and budget analysts. Such measures require many raw data elements that consist of facilities costs, human resource benefits, training costs, rework costs, sales income, and so on. This performance measure requires that many lower level measures are taken and "rolled up" into the higher level measure. Many data elements must be collected along the way.

When the team completes this activity, it should have a list of the raw data elements needed to generate the performance measures. In addition, the team should consider what, if any, computations or calculations must be performed with or on the data.

Locate the Raw Data

The purpose of this activity is to determine if and where the data exist. Stated differently, it's a matter of locating at what step in a process to make a measurement, at what point in time, or at what physical or geographical location. Quite often, this activity is performed concurrently with the previous one.

In the simplest case you may find that your work group already has the raw data collected and you need only retrieve in order to generate the associated performance measure. In other cases, the data you need may have been collected by another department. For instance, in Example 2 above, the delivery date was probably collected by the Shipping and Receiving Department. Examine the data you need and determine if your own work group, department, or an external group is already collecting it.

If the data do not presently exist, the team will have to determine where to find it. The process of locating it is generally quite straightforward. This is particularly true if the team is measuring its own process. The measurement point is <u>usually</u> located at or near each critical activity that was identified in Step 2. This is generally the case if your performance measure is measuring an activity within the process rather than the overall process itself. For performance measures that assess some overall aspect of a process, the collection point usually occurs at the culmination of a process.

More global performance measures generally require data from many sources as in Example 3 above. Before proceeding, the team must determine where the data are located, or where in the process, at what point in time, and at what physical location the data will be collected.

Continuing with the procurement example, we would probably find something like the following take place:

> The team has determined what raw data they will need to construct their performance measure and now they must locate the data. In this example the process is rather simple. The contract delivery date is recorded within the procurement department itself on several documents and within a database so that retrieval will be trivial. The second data element is recorded by the Shipping and Receiving department and is likewise simple to extract. All that remains to reconstruct the performance measure are the computations with the data.

Identify the Sensor

By this point, the team has determined what raw data they require, where it is located, and where it will be collected. To proceed, they must determine how they will actually measure or collect what they need. A sensor is required to accomplish the measurement.

A sensor is a device or person that is able to detect (sense) the presence or absence of some phenomena and (generally) provide a reading of the intensity (how much) of that phenomena in a quantifiable form with the appropriate units of measure. The sensor is what or who will do the measuring or data collection for your measurement system.

Sensors take many forms depending on what they are designed to measure. For technical and manufacturing processes, there are sensors that can accurately measure length (micrometer), temperature (thermocouple), voltage (digital voltmeter or digitizer), and so on. For less technical processes there are databases, log books, time cards, and checksheets. In some cases, the sensor makes a measurement and a person records the results. In other cases, only a human is capable of "sensing" some phenomena and some other device is used to record the result. Many inspection activities can only be performed by humans. There are also automated data collection systems or sensors that require no human intervention other than calibration or maintenance. Many manufacturing processes employ such sensors to detect, measure, and record the presence of nonstandard products.

Choosing a sensor usually involves asking simple questions about the measurement you hope to make:

1. What am I trying to measure; what kind of data are they?
2. Where will I make the measurement; where are the data?
3. Am I simply trying to measure the presence or absence of some feature? (Was the order placed, was the report delivered? Did the computer help desk solve the problem?)
4. Do I need to sense the degree or magnitude of some feature or count how many?
5. How accurate and precise must my measurements be?
6. Do the measurements occur at a particular point in time or space?

In most cases, the sensor will be rather obvious, but the team should be prepared to give some thought to how they will measure and collect their data. For instance, the need for accuracy and/or precision may rule out certain sensors. If you rely on a human as a sensor, you must consider all the possible biases that are inherent in human sensors. Step 6 discusses biases and their potential solutions. Replacing human sensors with technological instruments may be the best solution if a particularly critical measurement requires unusual accuracy or precision.

When the team completes this step, it should have a sensor identified for each raw data element and should have determined where the sensor will be deployed.

> The procurement team determined that the sensor for their first data element (contract delivery date) would be the "buyer's diary," an electronic database maintained by each buyer in company-supported software. The second sensor was determined to be the "receiving log," which was maintained at the receiving dock by a receiving clerk. This sensor provided the actual delivery date for each order. Having identified the sensors, the team could now acquire the necessary data.

Determine How Often to Make Measurements

In this last activity, the team will determine how often measurements should be made. In a sense, there are two distinct types of measures taken when a performance measurement system is adopted. One type of measure is the performance measure itself. This measure is generally taken (calculated) and reported over some regular or repeating time interval. In the procurement example, the performance measure is calculated and presumably reported at a frequency of once per month. Some performance measures are used to observe real-time trends in a process and may be measured and plotted daily. In general, the frequency of measurement for the performance measure is usually determined when the performance measure itself is determined. Often the unit of measure chosen as the performance measure contains or alludes to the frequency of measurement.

The other measure that should be addressed is that of the raw data itself. The frequency with which raw data are collected or measured may have a significant impact upon the interpretation of the performance measure. For some performance measures, this amounts to asking how many data are needed to make the measure valid or statistically significant. Each team or manager will have to determine how often measurements must be made (data taken) to ensure statistical significance and believable results.

Again, using the procurement example, the raw data for this measure are each time a buyer enters contract data into the database and each time the receiving clerk logs in a delivery. It could be said then that the frequency of measurement or data collection is continuous; that is data are rewarded each time a transaction or delivery occurs.

Processes that are repeated numerous times per hour or may only require a sample measure of every tenth event or so. Other events, like the procurement example, are measured or recorded each time they happen. Teams should use their best judgment in choosing the frequency of data collection and should consult the company's statistician or quality consultant if there is some question.

OUTPUT: THE PERFORMANCE MEASURE AND ITS COMPONENTS

Step 5: Identify Responsible Party(ies)

Steps 1 through 4 are primarily team activities. To continue the performance measurement process, the responsible worker(s) and the responsible decision maker must be defined. (In some instances, one person may be responsible for the entire system.) It is now appropriate to determine who should:

- Collect the data
- Analyze/report actual performance
- Compare actual performance to goal/standard
- Determine if corrective action is necessary
- Make changes

Ideally, responsibility should be assigned to individuals commensurate with authority. This means that each responsible party should:

1. Know what the goals are
2. Know what the actual performance is
3. Have the authority to implement changes if performance does not conform to goals and standards

To hold someone responsible in the absence of authority prevents them from performing their job and creates the risk of unwarranted blame.

OUTPUT: A LIST OF PEOPLE AND THEIR AREAS OF RESPONSIBILITY.

Step 6: Collect Data

The determination of conformance depends on meaningful and valid data. Before you start out to collect a lot of new data, it is always wise to look at the data you already have to make certain you have extracted all the information you can from it. In addition, you may wish to refer back to Step 2 and review planning for good data collection.

Information, as a term, comprises the answers to your questions. Data are a set of facts presented in quantitative or descriptive form. Obviously, data must be specific enough to provide you with relevant information. There are two basic kinds of data:

- Measured or variables data: Data that may take on any value within some range. This type of data provides a more detailed history of your business process. This involves collecting numeric values that quantify a measurement and therefore require small samples. If the data set is potentially large, consider recording a representative sample for this type of data.

  Examples:

  ◊ Cost of overnight mail

  ◊ Dollar value of stock

  ◊ Number of days it takes to solve a problem

  ◊ Diameter of a shaft

- ◊ Number of hours to process an engineering change request
- ◊ Number of errors on a letter

- Counted or attribute data: Data that may take on only discrete values. Attribute data need not be numeric. These kinds of data are counted, not measured, and generally require large sample sizes to be useful. Counting methods include defective/nondefective; yes/no; accept/reject.

  Examples

  - ◊ Was the letter typed with no errors?
  - ◊ Did the meeting start on time?
  - ◊ Was the phone answered by the second ring?
  - ◊ Was the report turned in on schedule?

A system owner needs to supervise the data collection process to determine if the data is being collected properly; if people are doing their assignments. Some form of preliminary analysis is necessary during the data collection process. Is your measurement system functioning as designed? Check the frequency of data collection. Is it often enough? Is it too often? Make adjustments as necessary and provide feedback to the data collectors.

Data Collection Forms

There are two types of forms commonly used to aid in data collection. Often combinations of these are used:

- Checksheet: A form specially designed so that the results can be readily interpreted from the form itself. This form of data collection is ideal for capturing special (worker controlled) cause of process variation since the worker can interpret the results and take corrective actions immediately.
- Data Sheet: A form designed to collect data in a simple tabular or column format (often related to time-dependent data). Specific bits of data–numbers, words, or marks–are entered in spaces on the sheet. As a result, additional processing is typically required after the data are collected in order to construct the tool needed for analysis. This form of data collection is usually used for capturing common (manager controlled) causes of process variations.

Data Collection System

This system ensures that all of our measurements are collected and stored. The type of data and frequency of measurement will help you determine how to collect it. Some data fit well into checksheets or data sheets that collect information in simple tabular or columnar format.

Other measurements lend themselves to easy entry into a computer database. Whatever system is chosen should provide easy access and be understandable by those who are tasked with reviewing the data. Those tasked with performing the data collection should understand the data collection system, have the necessary forms at hand, be trained in the data collection, and have access to instructions pertaining to the system.

The data collected needs to be accurate. Inaccurate data may give the wrong answer to our information questions. One of the most troublesome sources of error is called bias. It is important to understand bias and to allow for this during the development and implementation of any data collection system. Design of data collection forms and processes can reduce bias.
Some types of biases that may occur:

- Exclusion–some part of the process or the data has been left out of the data collection process
- Interaction–the data collection itself interferes with the process it is measuring
- Perception–the data collector biases (distorts) the data
- Operational–the data collection procedures were not followed or were specified incorrectly or ambiguously
- Nonresponse–some of the data are missing or not obtained
- Estimation–statistical biases
- Collection time period–the time period or frequency selected for data collection distorts the data, typically by missing significant events or cyclic occurrences.

OUTPUT: A GROWING LIST OF DATA. DATA SHOULD BE MONITORED AS THEY ARE BEING COLLECTED.

Step 7: Analyze/Report Actual Performance

Before drawing conclusions from the data, you should verify that the data collection process has met the following requirements:

- Review the information questions that were originally asked. Do the data collected still appear to answer those questions?
- Is there any evidence of bias in the collecting process?
- Is the number of observations collected the number specified? If not, why?
- Do you have enough data to draw meaningful conclusions?

Once the raw data are collected and verified, it is time for analysis. In most instances, your recorded data are not necessarily the actual performance measurement. Performance measurements are usually formulated based on one or more raw data inputs. Therefore, you need to assemble the raw data into a performance measurement.

The next step in analyzing data is deciding how you are going to present or display the data. You usually group the data in a form that makes it easier to draw conclusions. This grouping or summarizing may take several forms: tabulation, graphs, or statistical comparisons. Sometimes, single data grouping will suffice for the purposes of decision making. In more complex cases, and especially where larger amounts of data must be dealt with, multiple groupings are essential for creating a clear base for analysis.

After summarizing your data, you develop your report. A number of tools are available to assist you. Below are some of the more widely used tools and concepts to help you in your reporting.

- Use spread sheets and databases as appropriate to organize and categorize the data and to graphically show the trends. This will greatly improve the ease and quality of interpretation. Some of the more common graphic presentations are histograms, bar charts, pie charts, scatter diagrams, and control charts.
- Make the report comparative to the goals.
- Make use of summaries. The common purpose is to present a single important total rather than many subtotals. Through this summary, the reader is able to understand enough to judge whether to go into detail or to skip on to the next summary.
- Be aware of pitfalls in your data presentation. Averaging your data on a monthly basis might shorten the amount of information presented, but could hide variations within the monthly period. Choices of scales on graphs and plots could skew interpretation.

- Standardize the calendar so that the month begins and ends uniformly for all reports. Failing this, the relation of cause to effect is influenced by the fact that events tend to congest at the end of the reporting period.
- Adopt a standard format. Use the same size of sheets or charts. As far as possible, use the same scales and headings.

Reports may take many forms. However, at this stage, the report is intended to be a status transfer of information to the responsible decision maker for the process. Therefore, the report will likely consist of sets of tables or charts that track the performance measures, supplemented with basic conclusions.

OUTPUT: A PRESENTATION OF THE DATA IN THE FORM OF A REPORT.

Step 8: Compare Actual Performance to Goal/Standard

Within their span of control, responsible workers compare actual performance with the goal or standard. If variance warrants action, a report is made to the responsible decision maker.

Once the comparison against the goal or standard is initially established, you have several alternatives available for possible actions. You can decide to:

- Forget it. Variance is not significant.
- Fix it. (Step 9 and 10)
- Challenge the goal or standard. (Step 11)

If there is no significant variance, then continue the data collection cycle. If there is a variance between the goal and the performance measure, look at the magnitude. If it is significant, report to the decision maker. If a decision to implement a corrective action is warranted, go to Step 9.

OUTPUT: DECISION BASED ON PERFORMANCE VARIANCE.

Step 9: Determine if Corrective Action(s) is Necessary

Step 9 is a decision step. You can either change the process or change the goal. If the variance is large, you may have a problem with your process and will need to make corrections to bring the performance back into line with the desired goal or standard. To address these potential problems, you can form a quality improvement team or do a root cause analysis to evaluate. Consider, too, that the goal may have been unrealistic.

If the variance is small, your process is probably in good shape. But, you should consider reevaluating your goals to make them more challenging. In addition, if you do make changes to the process, you will need to reevaluate goals to make sure they are still viable.
The key objectives of correction are:

1. To remove defects; in many cases this is worker-controllable.
2. To remove the cause of defects. Dependent upon the defect cause, this may be worker or management controllable.
3. To attain a new state of process performance, one that will prevent defects from happening.
4. To maintain or enhance the efficiency and effectiveness of the process. This is an essential condition for continuing process improvement and ultimately increasing the competitiveness and profitability of the business itself.

OUTPUT: ACTION PLAN TO IMPLEMENT CHANGES OR REEVALUATE GOALS (STEP 11).

Step 10: Make Changes to Bring Process Back in Line with Goal or Standard

This is the final step in closing the feedback loop: Making changes to bring the process back in line with the goal or standard. Changes comprise a number of actions that are carried out to achieve one or more of the correction objectives listed in Step 9.

The prime result of these corrective actions should be removal of all identified causes of defects resulting in an improved or a new process.

OUTPUT: A SUCCESSFULLY IMPLEMENTED PLAN.

Step 11: Determine if New Goals or Measures are Needed

The decision to create new performance measures or goals will depend on three major factors:

1. The degree of success in achieving previous objectives.
2. The extent of any change to the scope of the work processes.
3. The adequacy of current measures to communicate improvement status relative to critical work processes.

Goals need to be challenging, but also realistically achievable. If previously set objectives were attained with great difficulty, or not reached at all, then it may be reasonable to re-adjust expectations. This also applies to the objectives that were too easily met. Extensive scope changes to the work processes will also necessitate establishing new performance measures and goals. Changes in performance measures and goals should be considered annually and integrated into planning and budgeting activities.

OUTPUT: NEW GOALS, MEASURES, OR NO CHANGE.

GLOSSARY: These definitions apply to terminologies used in Section 1.0 Development Processes:

Accuracy: The closeness of a measurement to the accepted true value. The smaller the difference between the measurement and the true value, the more accurate the measurement.

Attribute Data: Data that may take on only discrete values; they need not be numeric. These kinds of data are counted, not measured, and generally require large sample sizes to be useful.

Bias (of measurement): A tendency or inclination of outlook that is a troublesome source of error in human sensing.

Checksheet: A form specially designed so that results can be readily interpreted from the form itself.

Continuous Improvement: The ongoing improvement of products, services, and processes through incremental and measurable enhancements.

Control: The set of activities employed to detect and correct variation in order to maintain or restore a desired state of conformance with quality goals.

Corrective Action: Measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition.

Critical Activity: Activity(ies) that significantly impact total process efficiency, effectiveness, quality, timeliness, productivity, or safety. At the management level, they impact management priorities, organizational goals, and external customer goals.

Customer: An entity that receives products, services, or deliverables. Customers may be either internal or external.

Data: Information or a set of facts presented in descriptive form. There are two basic kinds of data: measured (also known as variables data) and counted (also known as attribute data).

Data Collection System: A broadly defined term indicating that set of equipment, log books, data sheets, and personnel used to record and store the information required to generate the performance measurements of a process.

Data Sheet: A form designed to collect data in a simple tabular or column format. Specific bits of data–numbers, words, or marks–are entered in spaces on the sheet. Additional processing is typically required after the data are collected in order to construct the tool needed for analysis.

Defect: A nonconformance to the product quality goals; it leads to customer dissatisfaction.

DOE/NV Family: DOE/NV, DOE/NV Contractors, and users of DOE/NV facilities.

Effectiveness: A process characteristic indicating the degree to which the process output (work product) conforms to requirements.

Efficiency: A process characteristic indicating the degree to which the process produces the required output at minimum cost.

Feedback: Communication of quality performance to sources that can take appropriate action.

Feedback Loop: A systematic series of steps for maintaining conformance to quality goals by feeding back performance data for evaluation and corrective action. This is the basic mechanism for quality control.

Frequency: One of the components of a performance measurement that indicates how often the measurement is made.

Goal: A statement of attainment/achievement that is proposed to be accomplished or attained with an implication of sustained effort and energy.

Management Assessment: The determination of the appropriateness, thoroughness, and effectiveness of management processes.

Optimum: A planned result that meets the needs of customer and supplier alike, meets competition, and minimizes the customer’s and supplier’s combined costs.

Organization: Any program, facility, operation, or division.

Performance Measure: A generic term encompassing the quantitative basis by which objectives are established and performance is assessed and gauged. Performance measures include performance objectives and criteria (POCs), performance indicators, and any other means that evaluate the success in achieving a specified goal.

Performance Measurement Category: An organizationally dependent grouping of related performance measures that convey a characteristic of a process, such as cycle time.

Performance Measurement System: The organized means of defining, collecting, analyzing, reporting, and making decisions regarding all performance measures within a process.

Precision: The closeness of a group of repeated measurements, to their mean value. The smaller the difference between the group of repeat measurements and the mean value, the more precise the instrument. Precision is an indicator of the repeatability, or consistency, of the measurement.

Process: Any activity or group of activities that takes an input, adds value to it, and provides an output to a customer. The logical organization of people, materials, energy, equipment, and procedures into work activities designed to produce a specified end result (work product).

Productivity: The value added by the process divided by the value of the labor and capital consumed.

Quality: The degree to which a product or service meets customer requirements and expectations.

Raw Data: Data not processed or interpreted.

Safety: Measures the overall health of the organization and the working environment of its employees.

Self Assessment: The continuous process of comparing performance with desired objectives to identify opportunities for improvement. Assessments conducted by individuals, groups, or organizations relating to their own work.

Sensor: A specialized detecting device designed to recognize the presence and intensity of certain phenomena and to convert this sensed knowledge into information.

Timeliness: Measures whether a unit of work was done correctly and on time. Criteria must be established to define what constitutes timeliness for a given unit of work. The criterion is usually based on customer requirements.

Unit of Measure: A defined amount of some quality feature that permits evaluation of that feature in numbers.

Validation: A determination that an improvement action is functioning as designed and has eliminated the specific issue for which it was designed.

Variable Data: Data that may take on any value within some range. It provides a more detailed history of a business process. This involves collecting numeric values that quantify a measurement and therefore requires small samples.

Variance: In quality management terminology, any nonconformance to specification.

Verification: The determination that an improvement action has been implemented as designed.

Worker Controllable: A state in which the worker possesses: (1) the means of knowing what is the quality goal; (2) the means of knowing what is the actual quality performance; and (3) the means of changing performance in the event of nonconformance.

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1.2 Developing Performance Measures–A Systematic Approach

Overview

Change might be inevitable, but all too often it occurs like an unguided missile seeking an elusive target at unpredictable speeds. For most activities, it is far better to manage change with a plan–one that includes clear goals and useful indications of progress toward a desired objective. Participants in an activity need to know what outcome is expected, where their work contributes to the overall goal, how well things are progressing, and what to do if results are not occurring as they should. This approach places performance measures right where they should be: integrated with the activity.

Such integration makes it possible for performance measures to be effective agents for change. If the measures quantify results of an activity, one only needs to compare the measured data with desired goals to know if actions are needed. In other words, the measures should carry the message.

Inappropriate measures are often the results of random selection methods. For example, brainstorming exercises can get people thinking about what is possible and provide long lists of what *could* be measured. Unfortunately, such efforts by themselves do not provide reliable lists of what *should* be measured. Unless the measures are firmly connected to results from a defined process, it is difficult to know what corrective actions to take and to predict with confidence what effects those changes will have.

If you want to be able to identify effective corrective actions to improve products and services, results of all key processes must be measured. In this way, one can identify specific processes that need to change if progress is not satisfactory.

For example, suppose sales are not meeting goals. What actions could be taken? The answer should depend on what is causing the problem. If poor technical service is causing customers to shy away, it will do no good to change or add sales personnel. Also, replacing technicians won't help if the poor service is caused by a lack of replacement parts. Suppose the replacement parts are on hand, but, unknown to the service personnel, the parts are defective? If proper measures are instituted for each key process (purchasing, inventory control, service, etc.), the cause for substandard results can be found quickly and corrected.

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Structure and Terminology

A structured approach provides a rational defensible basis for selecting measures and, should it become necessary, for making changes to the work processes. The viewpoint here is that achieving *goals* depends on the performance of interrelated sets of *activities* and *processes* that form a *system* to be managed. It follows that you can improve the selection of *performance measures* if they are based on the desired outcomes of the system and the results expected of each process in the system. In turn, this suggests a systematic approach to develop performance measures. This methodology will be described in the following sections.

Before the procedure is described, some key words should be discussed. Some of the terms used throughout this document could be interpreted differently by different readers; therefore, we are providing a short glossary of terms as they are used in this section. These are meant to be useful interpretations, not standard definitions.

A **system** is an interconnected set of **processes**, and a process is a set of **activities** that produce **products** or **services (results)**. Products and services are treated alike; that is the output of a process might be a product (like computer boards) or a service (like training). **Performance measures** are quantitative evaluations of the products or services of a process or system. **Metrics** are standards of measurement (such as length, area, frequency, mass, and so on).

In addition, there are terms such as **Performance Indicators** and **Indexes**. Dealing with these gets complicated because people use them in very different ways, and there is no one standard to which we can appeal. Some use *indicator* and *measure* interchangeably, while others see *indicators* as subsets of *measures*. Others see *indicators* as sets of related measures. Still others prefer *indexes*, often thought of as sets of related measures (sometimes individually weighted) that track changes compared to a reference. For example, the Consumer Price Index measures inflation by combining the prices of selected goods and comparing the results over time. Other examples include an Index of Indicators (*Business Week*) that report various areas of the economy (production, construction, etc.).

These more sophisticated concepts are important, but they are beyond the scope of this document. What is relevant here is that the more data that are combined, the broader the actions that must be taken to change the situation. The closer the measures are to the activity (i.e., less complex data), the more focused the actions that can be taken. Regardless of the complexity of the system, however, the development procedure to be described will apply.

The Process

Developing performance measures has a definite relationship with Total Quality Management. Consider a quality process at AT&T:

AT&T Management & Improvement Steps

A. Establish process management responsibilities.
B. Define process and identify customer requirements.
C. Define and establish measures.
D. Assess conformance to customer requirements.
E. Investigate the process for improvement opportunities.
F. Rank improvement opportunities and set objectives.
G. Improve process quality.

In this process, Tasks B, C, and D are the core of performance measure development. In fact, the systematic method to be described amounts to an elaboration of these three tasks. These three have been extended to the following six steps:

1. Decide the outcomes wanted.
2. Describe the major work processes involved.
3. Identify the key results needed.
4. Establish performance goals for the results.
5. Define measures for the goals.
6. Select appropriate metrics.

Each of these six steps will be discussed in the following sections. We will create a very small company, **Hackenstack Firewood**, that we can use to help us get a working knowledge of this systematic method for developing performance measures.

Step 1: Describe the Outcomes Wanted

First Law of Performance: If you try to be the best at everything, you'll be the best at nothing.

Why are we doing this work? The answer is to achieve some outcome or objective (the words are used interchangeably in this process). As used here, objectives might not seem very definitive. However, they are very important because they set the direction for all processes in the system. Essentially, objectives (or outcomes) are statements of the wants, needs, and expectations of customers and other stakeholders. Objectives are the warm and somewhat fuzzy expressions that should form the mindset for all who are involved in the system. Examples are:

- Supply good pizza with superior delivery service.
- Be the safest airline and offer the lowest fares.
- Produce user-friendly VCRs.

Realize that the desired outcome sets the strategic direction of an enterprise. Consequently, tactical decisions about what the business does, how it is done, and what gets measured must relate to this strategic statement. The outcome or objective statement is a driving force for the selection of performance measures. In the end, what is done and measured somehow must connect with the desired outcome. For instance, to achieve its objective, that airline will have to spend resources for equipment and maintenance, not for in-flight meals and reserved seating. And, the measures should relate to safety and costs that drive ticket prices.

The choices of outcomes should be limited and selected carefully. A major consideration is focus; avoid the desire to be the best of everything. If you can pick something you are sure you would succeed at, that choice probably should be your number one objective. In the case of Hackenstack Firewood, the employees decided that the result of their effort should be to: *"Deliver firewood profitably at competitive prices."*

Step 2: Describe the Major Work Processes Involved

Second Law of Performance: People are more important than the process, but a good process is important to people.

What are we doing, and how are we (or should we be) doing it? Processes and their activities are the means to achieve the outcomes–the end results–identified in Step 1. To improve the chances of meeting objectives, be sure to understand the system, that is, the operational structure that underlies the effort. This task is not so obvious. The work we all do usually is part of a larger assignment that is, in turn, part of a larger job, and so on. Quite often, the work contributes to more than one assignment or, as is the case with Environment, Safety, & Health (ES&H) initiatives, it is not always clear which work responds to ES&H requirements and which tasks are unique to building the widget. Further, the interconnections between functions are not clearly defined or understood. Such complexities make it even more important to describe carefully the system you want to measure.

Often, the system already is in place, and with luck, it is documented (more or less). In any case, it is helpful to start with a simplified chart similar to the one in Figure 1.5. A system starts and ends with customers. In between are identifiable processes that transform inputs (like money or raw materials) into progressively more useful items (such as thread, then cloth, then clothing). Some interim products might be enablers, such as operating permits and instructions.

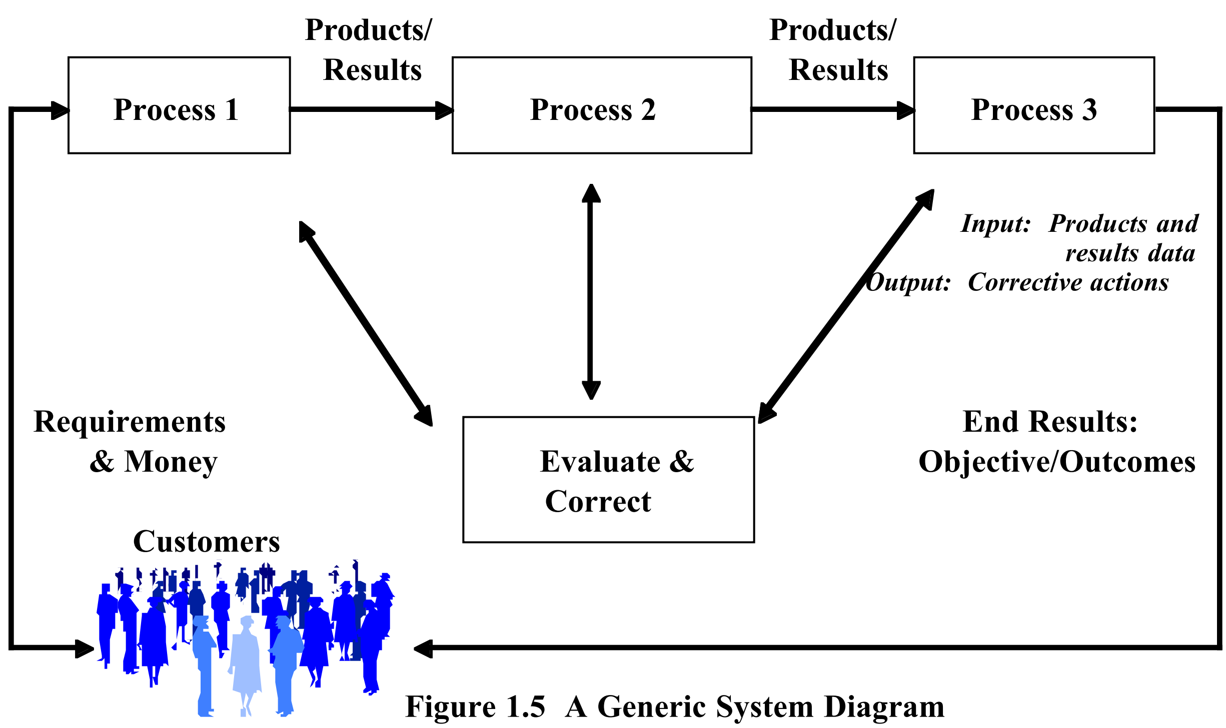


Figure 1.5 A Generic System Diagram

Notice in Figure 1.6 the two-headed arrows between the Customers and Managers, and next to the "Evaluate & Correct" process. These indicate important give-and-take interactions, implying that the inputs and outputs involved are dynamic and subject to negotiations. For example, the price that customers are willing to pay is variable, as are the requirements for customer satisfaction. These factors will influence the measures to be selected later.

This part of the procedure is similar to benchmarking and should include interviews with the people doing the work. People often achieve desired results in spite of, not because of, the process that exists. Thus, examining work processes usually leads to discovery of some that can and should be improved. After examining their operations, the employees at Hackenstack Firewood decided that all of their activities could be placed in the four process blocks shown in Figure 1.6.

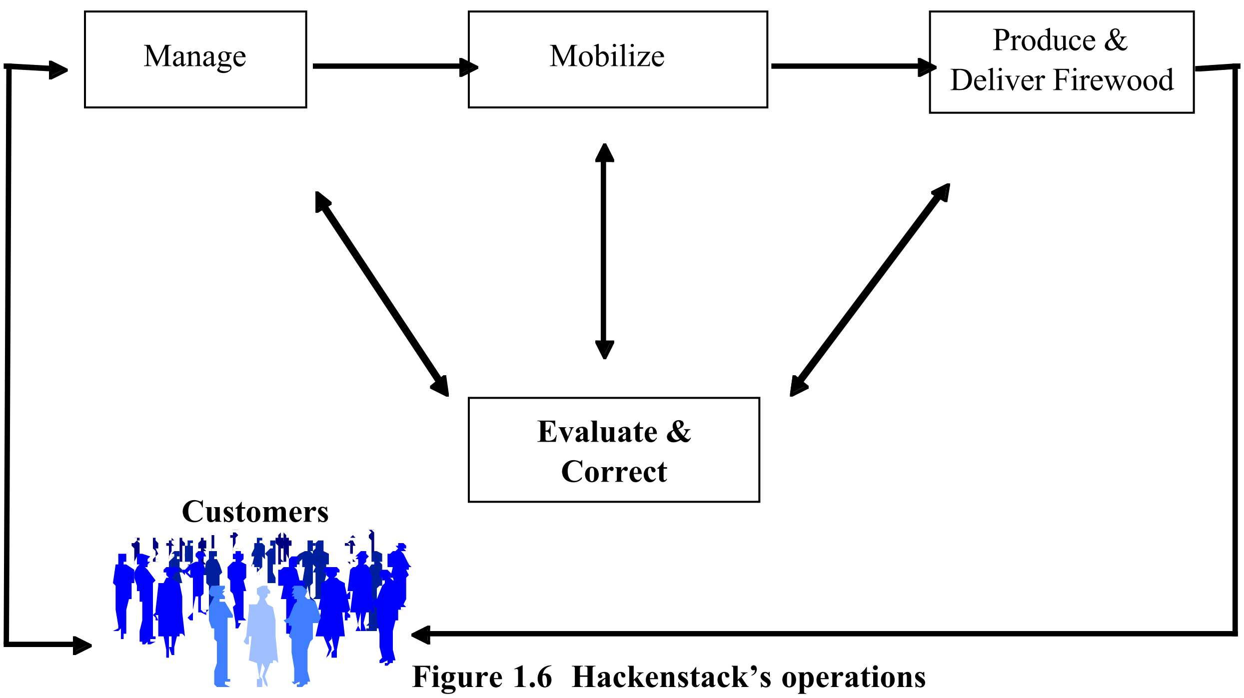


Figure 1.6 Hackenstack's operations

Next, the products (results) of the individual processes have to be identified so that measures can be developed. Note that after the six-step procedure is completed for the system, it is repeated for each process (Manage, Mobilize, Produce, and Deliver Firewood).

Step 3: Identify the Key Results Needed

Third Law of Performance: If you can't describe it, you can't improve it.

What is produced? The "products" are the outputs or results of each process in the system. That is, the purpose of the activities in each process is to produce some result (a product or service) that is needed by other processes. Products of any given process are inputs to other connected processes in the system. Ultimately, the final products of the system are those that meet the strategic results–the objective–desired by the company.

For example, in the Hackenstack system, customers provide their requirements (such as amount and type of firewood) and money to Hackenstack management. These are identified as the most important products, or results, from customers, and so they will be included in the list of what is to be measured. In turn, the function of the "Manage" process is to provide the necessary paperwork and funding that is needed by the mobilization crew. Thus, the products of the first process are Funding, Permits, and Orders. They will be added to the list of items to be measured.

Next the mobilization crew prepares the field equipment (trucks, saws, etc.) and operating paperwork (maps, orders, permits, etc.) for the Field Crew who actually cut, stack, and deliver the firewood. Figure 1.7 shows the completed diagram, and Table 1.1 summarizes the processes and associated products.

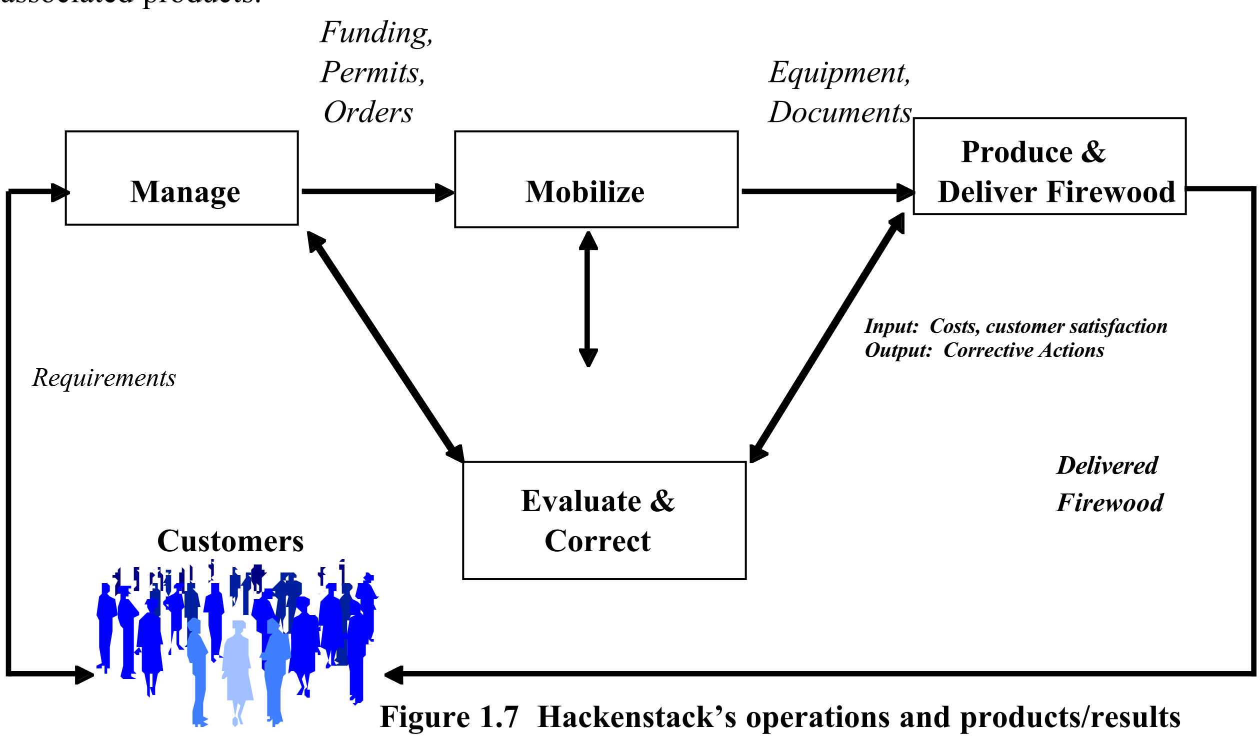


Figure 1.7 Hackenstack's operations and products/results

Element/Process	Products/Results
Customers	Income, Requirements
Manage	Funding, Permits, Orders
Mobilize	Equipment, Documentation
Produce & Deliver Firewood	Delivered firewood
Evaluate & Correct	Costs, Customer Satisfaction

Table 1.1. Hackenstack Firewood's Products/Results

Notice the "Evaluate & Correct" process. This function needs to be included in all systems if they are to be effective and efficient. This is the process that evaluates the performance data and prescribes changes that might be needed to meet the goals and objectives of the enterprise. This process is unique because, in addition to the products already mentioned, this process will examine customer satisfaction as well as costs throughout the system. While this is shown as a separate block, remember that the activities might very well be performed by the managers, mobilizers, and field crews. It is just the process, not the performer, that is identified here.

This discussion alludes to other issues, such as the politics and personal interactions that must accompany any such effort. For purposes of this document, however, suffice it to say that at every step, it is critical to obtain active endorsement and approval from all the involved and affected personnel. Otherwise, when goals aren't being met, the time-honored practice of finger pointing will commence, and the problems won't get resolved.

Step 4: Establish Performance Goals for the Results

Fourth Law of Performance: If you don't have a goal, you can't score.

How will I know when I get there? And an acid test: What will be done if progress isn't satisfactory? There are many questions to ask about this step. Setting goals is very important because you can spend a lot of resources trying to meet them. You're familiar with "no pain, no gain"? The **PAIN** is worth it if the goals are:

- **P**rofitable *(Is it worthwhile to improve this? Favorable Benefit/Cost?)*
- **A**chievable *(Can it be improved? How? Who will do it?)*
- **I**mportant *(Does it matter to anyone?)*
- **N**umerical *(Without a number, you won't know when you get there.)*

The **GAIN** is in reaching the goals, because: **G**oals **A**re **I**mprovement **N**umbers.

There are various ways to determine goals. One of the best methods is to ask the customer for each of the product(s) you listed in the previous step. In the system diagram, the "customer" is the group or individual receiving the product. Determine the Customer's Satisfaction Factors (or Critical Success Factors, CSFs) that relate to each product. CSFs are the few key things that must be right for the process to be successful in the customer's view. Section 2.1.2.7 includes a form that can be helpful when interviewing stakeholders to negotiate goals.

The goals should be stated in simple terms using numbers, such as "Deliver 500 completed manuals with fewer than three errors by the end of the month," or "Improve the average student grade to a minimum of 93 within six months."

Be sure to differentiate among lofty goals, stretch goals, and realistic goals. It is best to establish realistic goals–those you have a decent chance to reach–and after reaching them, establish new ones.

Here are some other considerations that might help to set goals:

- People involved in the process should be able to evaluate their contributions
- Is there an intrinsic limit?
- Is there a safety limit?
- Is there a required level?
- Watch out for diminishing returns; at some point, the return will no longer be worth the investment.
- Try benchmarking. Find out how well others are doing with similar processes.

Hackenstack's Committee of the Whole developed the goals listed in Table 1.2. For example, after researching available wood supplies and performing a market survey, they decided that it would be reasonable for them to capture one fourth of the regional market, and that if the price is right, customers would purchase twice the amount of Hackenstack firewood in the coming year. To achieve these goals and meet their prime objective, they also found they would have to sell an average of 50 cords of wood each day at $90 a cord. This, they believe, would keep customers and themselves happy. The remaining goals are the corresponding improvements needed in the products of the enabling processes to help meet the primary goals.

Process	Products	Goals
Customers (Output)	Income Requirements	25% of the regional market Twice last year's volume
Manage	Funding Permits Orders	+10% - 0% of budget request 100% timely availability 98% error free
Mobilize	Equipment Documentation	97% uptime 99% error free
Produce & Deliver Firewood	Delivered Firewood	Customer cost £ $ 90 cord 50 cords per day
Evaluate & Correct	Corrective Actions Surveys Costs Customer Satisfaction	100% on-time completion Positive perception ≥ 80% +0%, -10% of budget See Customer output goals

Table 1.2 Hackenstack Firewood's Annual Goals

Step 5: Define Measures for the Goals

Fifth Law of Performance: **Measuring the activity usually improves the activity, but not the result.**

What can you use to track progress? Measures are descriptions of the items to be monitored. At this stage, measures should be described with relative terms like "percentage of the market" and "average prices."

While there is no specific formula for selecting performance measures, there are some characteristics that are typical of the good ones. They:

- **reflect results, not the activities used to produce results**
- **relate directly to a performance goal**
- **are based on measurable data**

- **contain normalized metrics for benchmarking**
- **are practical and easily understood by all**
- **provide a continual self assessment**
- **provide a benefit that exceeds the cost**
- **are accepted and have owners**

The first criterion is important because it is very tempting to select measures that are easy, while the right measures can be difficult. For example, the effects of training can be very hard to assess. It can be time consuming to interview employees and managers to find out if the training has improved worker abilities on the job. Rather than spend the time to do the interviews, people often change the measure to something like “the number of class hours completed” (essentially a useless measure unless it is accompanied by some measure of acquired skills).

Find appropriate measures by examining all the goals listed in the previous step. For example, Hackenstack’s goal to keep the selling price of firewood at or below $90 a cord clearly implies that a measure of customer prices must be included. This simplicity will always be the case if the goals are chosen well and stated numerically. Difficulties occur when goals are poorly or incompletely stated, such as “satisfy the customer.” This would be difficult to measure because this goal doesn’t make it clear what will satisfy the customer! On the other hand, as the Hackenstack team observed, they must be satisfying the customer if sales and income are progressing toward or beyond the goal. There are other measures for customer satisfaction, of course. But to be useful, they must relate to some numerical goal.

While selecting measures, it is wise to remember that the idea is to be able to track progress and to be able to change processes (or activities, or the system) as needed to improve results. So, it will help to ask if the system measures you choose will be adequate to identify which process needs fixing. Also, consider what practical actions could be taken if any of the products are not progressing toward the goal fast enough. This thought experiment will help you select the right measures you need to help you make decisions later.

Finally, there must be a balance to the number of measures; after all, you can’t and shouldn’t measure more than you have time to evaluate.

Appendix C contains an extensive list of performance measures for various processes that may be helpful in determining measures for your situation.

Table 1.3 shows the measures selected by the Hackenstack Firewood team.

Process	Products	Goals	Measures
Customers	Income	25% of the regional market	Income compared with regional markets
	Requirements	Twice last year's volume	Volume delivered compared with last year
Manage	Funding	+10% - 0% of budget request	Available funds compared with budget request
	Permits	100% timely availability	Permits available when needed
	Orders	98% error free	Proportion of error free orders
Mobilize	Equipment	97% uptime	Proportion of available equipment time
	Documentation	99% error free	Proportion of error free documents
Produce & Deliver Firewood	Delivered Firewood	Selling price £ $90 cord	Average selling price
		50 cords per day	Average daily volume produced
Evaluate & Correct	Corrective Actions	100% on-time completion	Proportion of corrective actions completed on time
	Surveys	Positive perception ≥ 80%	Perception scores
	Costs	+0%, -10% of budget (90% to 100% of budget)	Spending

Table 1.3 Hackenstack Firewood Team's Measures

Step 6: Identify the Required Metrics

Sixth Law of Performance: **If you know the score, you should be able to predict the outcome.**

What specific things do I measure? Metrics–the actual measurements to make–should be fairly obvious from the descriptions of the measures composed in the previous step. Examine the measures statements and the goals to identify the units required for each term.

For example, to support Hackenstack Firewood's goal to capture 25% of the regional market, the measure is the Company's income compared with the total dollars spent by customers in the region. This translates into dollars received by Hackenstack divided by the total dollars received by all firewood companies in the region during the same time period (perhaps monthly or weekly if possible). Notice that this fraction is dimensionless, expressing a percentage. The comparison, or ratio of two meaningful dollar figures creates a normalized measure that can be used for tracking and comparing with other similar businesses. Another way to normalize is to use a ration of actual versus planned results. Metrics for a measure of yield quality might be the number of acceptable units produced divided by the total number of units produced.

Of course there are more issues that might need attention. Can Hackenstack find out the total income of their competitors? If not, what other measure can they consider? Perhaps the data only are available annually; that will not help because by the time they get the data, it will be too late to take any action. In this case, estimates based on projections from last year's regional income could be useful.

The complete summary of the Hackenstack Firewood system is tabulated in Table 1.4.

Process	Products	Goals	Measures	Metrics *
Customers	Income	25% of the regional market	Income compared with regional markets	$ income / $ regional
	Requirements	Twice last year's volume	Volume delivered compared with last year	# cords this year / # cords last year
Manage	Funding	+10% - 0% of budget request	Available funds compared with budget request	$ funding / $ requested
	Permits	100% timely availability	Permits available when needed	# permits available / # permits needed
	Orders	98% error free	Proportion of error-free orders	# error-free orders / # orders issued
Mobilize	Equipment	97% uptime	Proportion of available equipment time	Equipment hrs. avail. / Equipment hrs. needed
	Documentation	99% error free	Proportion of error-free documents	# error-free documents / # documents issued
Produce & Deliver Firewood	Delivered Firewood	Selling price £ $ 90 cord	Average selling price	$ income / # cords sold
		50 cords per day	Average daily volume produced	# cords stocked / days
Evaluate & Correct	Corrective Actions	100% on-time completion	Proportion of corrective actions completed on time	# completed on time / # scheduled
	Surveys	Positive perception ≥ 80%	Perception scores	Total actual score / Total possible score
	Costs	+0%, -10% of budget	Spending	$ spent / $ budgeted

*** The time intervals for each metric will be the same but may differ between measures.**

Table 1.4 Hackenstack Firewood Company System Summary

Supporting Information

This section contains additional forms, worksheets, and a glossary that will help you use the process described above.

Glossary

Activities: Actions that change resources from one form to another.

Goal: A specific, numerical result that is to be achieved by the process or system.

Indexes: Sets of related measures or indicators (sometimes individually weighted) that track changes compared to a reference.

Metrics: Standards of measure (such as length, area, frequency, etc.).

Normalize: Adjust metrics to allow comparisons with a reference or standard (usually done by using rates or percentages).

Objective: A statement of the general condition to be achieved (e.g., “work safely”).

Performance Indicator: Pointers comprising of related performance measures that reveal changes compared to a reference; that is, an indicator is composed of one or more measures

Performance Measure: Quantitative descriptions of the quality of products or services of a process or system.

Process: A set of activities that produce products or services.

Product: A tangible result of a process or system.

Service: Work done for others; also a result of a process or system.

System: A logical, interconnected set of processes.

System Verification & Performance Goals

Interview Questions to Validate the System Definition

1. Verify the accuracy of each process block with the owners/representatives:

Question: Are these correct?

Input	Yes	No
Process	Yes	No
Products	Yes	No
Results desired	Yes	No

If any changes are suggested, specify them:

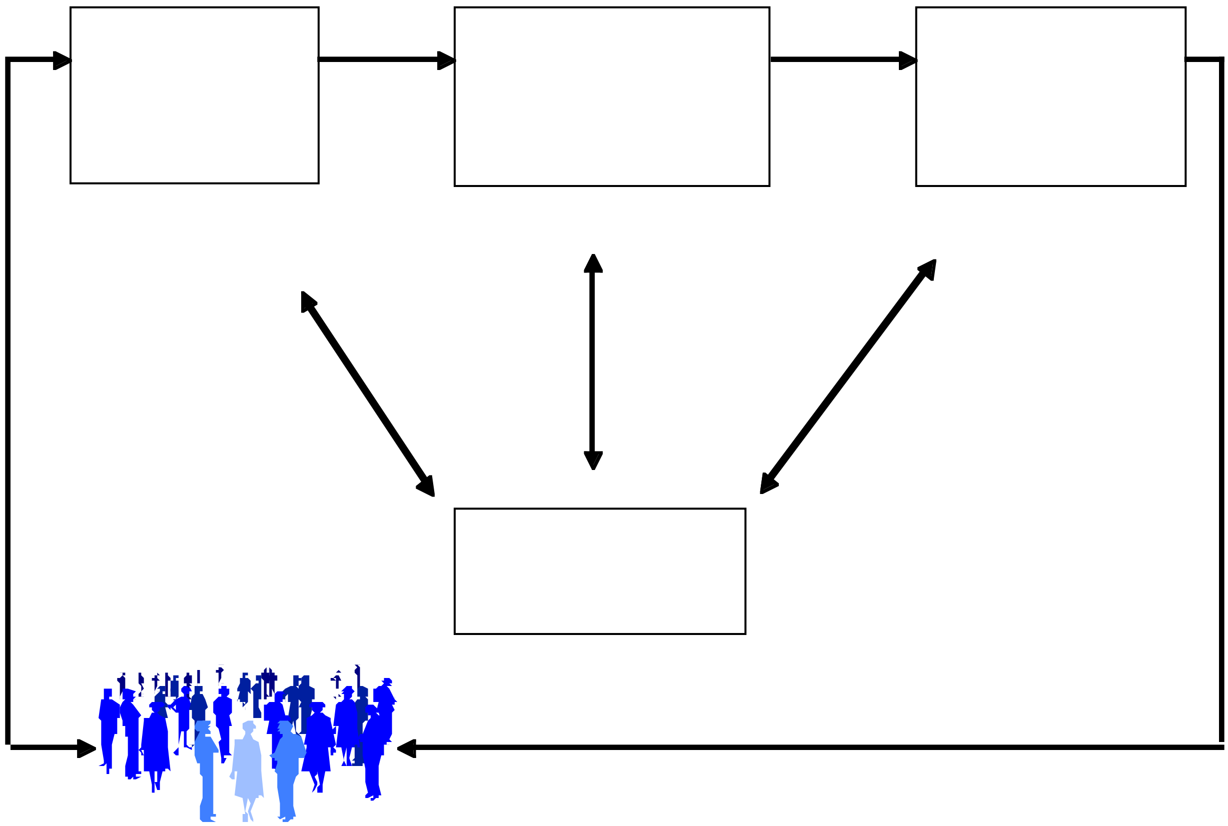
2. Identify the product goals:

Question: What are the most important expectations of the products; that is, what do you want to have happen as a result of these outputs?

3. Determine if there are existing performance measures of value:

Question: Have you identified any specific, quantitative feedback that you want or require?

System Flowchart



System Summary Table

PROCESS	PRODUCT	GOAL	MEASURE	METRIC

1.3 Developing Performance Metrics – University of California Approach

Introduction

Performance metrics should be constructed to encourage performance improvement, effectiveness, efficiency, and appropriate levels of internal controls. They should incorporate "best practices" related to the performance being measured and cost/risk/benefit analysis, where appropriate. Performance measurement is an important cornerstone of the contracts between the University of California and the Department of Energy for the operation of the laboratories. This section discusses the principles and concepts used in developing effective performance metrics for these contracts.

The Department of Energy has promulgated a set of Total Quality Management guidelines that indicate that performance metrics should lead to a quantitative assessment of gains in:

- Customer satisfaction
- Organizational performance
- Workforce excellence

The key elements of the performance metrics to meet these guidelines should address the following key elements:

- Alignment with organizational mission
- Quality of product
- Timely delivery
- Cost reduction and/or avoidance
- Cycle time reduction
- Customer satisfaction
- Meeting DOE requirements
- Meeting commitments

The Process

The first step in developing performance metrics is to involve the people who are responsible for the work to be measured because they are the most knowledgeable about the work. Once these people are identified and involved, it is necessary to:

- Identify critical work processes and customer requirements.
- Identify critical results desired and align them to customer requirements.
- Develop measurements for the critical work processes or critical results.
- Establish performance goals, standards, or benchmarks.

The establishment of performance goals can best be specified when they are defined within three primary levels:

- **Objectives**: Broad, general areas of review. These generally reflect the end goals based on the mission of a function.
- **Criteria**: Specific areas of accomplishment that satisfy major divisions of responsibility within a function.
- **Measures**: Metrics designed to drive improvement and characterize progress made under each criteria. These are specific quantifiable goals based on individual expected work outputs.

The SMART test is frequently used to provide a quick reference to determine the quality of a particular performance metric:

- **S = Specific**: clear and focused to avoid misinterpretation. Should include measure assumptions and definitions and be easily interpreted.
- **M = Measurable**: can be quantified and compared to other data. It should allow for meaningful statistical analysis. Avoid "yes/no" measures except in limited cases, such as start-up or systems-in-place situations.
- **A = Attainable**: achievable, reasonable, and credible under conditions expected.
- **R = Realistic**: fits into the organization's constraints and is cost-effective.
- **T= Timely**: doable within the time frame given.

Types of Metrics

Quality performance metrics allow for the collection of meaningful data for trending and analysis of rate-of-change over time. Examples are:

- Trending against known standards: the standards may come from either internal or external sources and may include benchmarks.
- Trending with standards to be established: usually this type of metric is used in conjunction with establishing a baseline.
- Milestones achieved.

"Yes/no" metrics are used in certain situations, usually involving establishing trends, baselines, or targets, or in start-up cases. Because there is no valid calibration of the level of performance for this type of measure, they should be used sparingly. Examples are:

- Establish/implement a system.
- System is in place (without regard to effectiveness).
- Analysis performed (without criteria).
- Reporting achieved (without analyses).
- Threshold achieved (arbitrary standards).

Classification of Performance Metrics

Measure of...	Measures...	Expressed as ratio of...
Efficiency	Ability of an organization to perform a task	Actual input/ planned input
Effectiveness	Ability of an organization to plan for output from its processes	Actual output/ planned output
Quality	Whether a unit of work was done correctly. Criteria to define "correctness" are established by the customer(s).	Number of units produced correctly/total number of units produced.
Timeliness	Whether a unit of work was done on time. Criteria to define "on-time" are established by the customer(s).	Number of units produced on time/total number of units produced.
Productivity	The amount of a resource used to produce a unit of work	Outputs/inputs

The following questions serve as a checklist to determine the quality of the performance metrics that have been defined:

- Is the metric objectively measurable?
- Does the metric include a clear statement of the end results expected?
- Does the metric support customer requirements, including compliance issues where appropriate? (Keep in mind that in some areas compliance is performance; e.g., ES&H.)
- Does the metric focus on the effectiveness and/or efficiency of the system being measured?
- Does the metric allow for meaningful trend or statistical analysis?
- Have appropriate industry or other external standards been applied?
- Does the metric include milestones and or indicators to express qualitative criteria?
- Are the metrics challenging but at the same time attainable?
- Are assumptions and definitions specified for what constitutes satisfactory performance?
- Have those who are responsible for the performance being measured been fully involved in the development of this metric?
- Has the metric been mutually agreed upon by you and your customers?

Common Terms with Performance Metrics

Commonly used terms concerning performance metrics are:

Baselining: The process of establishing a reference set of data that reflect the current state of a process, system, or product.

Benchmark: A standard or point of reference for measurement. By providing ranges or averages, benchmarks enable an organization to compare performance in certain key areas with other organizations.

Benchmarking: A method of measuring a process, system, or outcome within an organization against those of a recognized leader. The purpose of benchmarking is to provide a target for improved performance.

Best in class: Leader or top performer in relation to a particular performance goal as identified through a benchmark.

Effectiveness: The ability to accomplish a desired result or to fulfill a purpose or intent.

Efficiency: The quality or degree of effective operations as measured against cost, resources, and time.

Goal: A target level of performance expressed as a tangible, measurable objective against which actual achievement can be compared.

Lower control limit: The lower line on a control chart below which variation is not expected. This is mathematically represented by the average minus three standard deviations.

1-10-100 Rule: The rule that states that if a problem is not fixed in a timely manner when first discovered, it will be more costly to fix later (in terms of both time and money). The rule recognizes that it makes a difference when a problem is discovered and resolved.

Quality Grid: A quality improvement concept that divides quality work into *what is* done (doing the right things) and *how* its done (doing things the right way)-

How You Do It

Right Things Wrong	**Right Things Right**	*What you do*
Wrong Things Wrong	**Wrong Things Right**	

Re-engineering: A process of rethinking and redesigning work processes to achieve noticeable improvements in service delivery responsive to customer needs and/or achieve significant reductions in cost.

Standards: A prescribed set of rules, conditions, or requirements used to measure or define the quality or quantity of particular performance elements.

Value-added: Process or steps that enhance an outcome.

Upper control limit: The upper line on a control chart above which variation is not expected. This is mathematically represented by the average plus three standard deviations.

References

Three basic references useful in the development of performance metrics are "Total Quality Management Guidelines," U.S. Department of Energy, December 1993, and the annual "Malcom Baldrige National Quality Award Criteria" and its companion volume, "The Handbook for the Board of Examiners." The latter two documents are published by the National Institute of Standards and Technology, an agency of the U.S. Department of Commerce.

1.4 Performance Indexes

Often it is necessary to present information from several related areas simultaneously. This is done to provide a statistical measure of how performance changes over time. The performance index is a management tool that allows multiple sets of information to be compiled into an overall measure. This section provides examples on different approaches that can be taken to develop a performance index.

Overview

Up until this point you've learned about developing and working with single performance measures. Now it is time to branch out into the world of performance indicators and indexes. For the purpose of this section, a performance indicator (PI) is defined as the result of the comparative analysis of a performance measurement outcome to a corresponding performance goal. These measurements give an indication of performance. However, when you have too many indications to consider, performance indexing becomes a useful performance management tool. The philosophy behind using performance indexes is simple: they condense a great deal of information into one number. We know that when dealing with a small number of indicators, PI-related information is easy to assimilate. But what happens when you're not dealing with just one or two PIs? What happens if you have 10, or 15, or 20 separate but related indicators to review. With some increasing, and others decreasing, while still others remain the same, how do you determine what is happening *overall*? The answer is to use an index.

Consider this: if I handed you a newspaper and asked, "How's the stock market doing?" would you examine the trend associated with each of the 5000+ stocks listed on the financial pages before giving me your answer? Hopefully, not. A quicker, simpler, and more efficient method would be to turn to the financial pages, and look at one of many business *indexes* that appear there, say the Standard and Poors 500 Index (S&P 500). The advantage of the S&P 500 Index is that it gives you a general indication of trends in the stock market at a glance. The downside of the index is that it will not give you specific information on any one particular stock.

So, what exactly is an index? Simply put, an index is a statistical measure of how a variable, or set of variables, changes over time. The purpose of an index is to give a quick, overall picture of performance.

The power of using indexes as management tools clearly resides in their ability to capture the information contained in a large number of variables in one number. For instance, economists can use one number, the Consumer Price Index (CPI), to capture pricing information on several hundred different consumer products. Now, instead of having to track over 400 different prices, they only need to track one number–the CPI. Economists place a lot of trust in this index; annual cost-of-living adjustments and retirement benefits for over *50 million* civil servants are directly linked to fluctuations in the CPI.

How do you create an index? This is not an easy question to answer because there is no one set formula or algorithm for generating indexes. However, there are certain concepts that apply to all indexes, the most important being that all indexes are designed for a particular purpose, and that the design process involves choosing the correct (related) indicators and then combining them in a manner that supports the intended purpose of the index.

Now, simply because there is no patent method for producing an index does not mean that creating one has to be a complicated matter. In fact, it can be as simple as computing the ratio between two numbers.

It is not the intent of this handbook to address each and every method that can be used to develop index numbers, nor will it make you an expert in the statistics behind developing indexes (for those interested in a more in-depth study of indexing methods, a list of references has been included). What it will do, hopefully, is give you an appreciation of the power of using performance indexes as a management tool, and provide you with a few examples of methods that are currently being used throughout the DOE complex and private industry to create performance indexes. These methods range from fairly simple to fairly complicated. They include:

- the DOE Occupational Injury/Illness Cost Index
- the Westinghouse Hanford Company Conduct of Operations Event Index
- the Eastman Kodak Company Safety Performance Index
- the Defense Programs Average of Performance Relatives

Each of these methods will be discussed in detail in the following section.

Examples

Example 1: The DOE Occupational Injury/Illness Cost Index

This index is the simplest of the three methods presented above. Essentially, the cost index is a linear combination of weighted parameters:

$$\text{Index} = (W_1 \times P_1) + (W_2 \times P_2) + \ldots + (W_n \times P_n)$$

where Ws are constant weighting factors, and Ps are individual measurable items. When determining the weighting factors, the following could be taken into account:

- Dollar Cost Analysis
- Probability Risk Assessment

- Cost/Benefit Analysis
- Expert Opinion

A strength of weighted linear combinations is that they can assist in determining how to allocate limited resources. That is, if $W_1 = 3$ and $W_2 = 1$, then, given limited resources, addressing P_1 provides more benefit than addressing P_2 and resources could be applied accordingly. Essentially, this is a "tradeoff" where one unit of improvement in P_1 is worth losing up to 3 units of P_2.

Caution! People will make these tradeoffs! If you mix safety and production indicators together, you may, unwittingly, be sending the signal that degradation in safety performance can be offset by increased production.

The DOE Occupational Injury/Illness Cost Index combines the following indicators:

- Number of fatalities (**D**)
- Number of transfers or terminations due to injury or illness (**T**)
- Number of lost workday cases (**LWC**)
- Number of days away from work (**WDL**)
- Number of restricted workdays (**WDLR**)
- Number of non-fatal cases without days away from work or restricted workdays (**NFC**)

The weighting factors were determined using dollar cost analysis.

- Index = 100[(1,000,000)(**D**) + (500,000)(**T**) + (2,000)(**LWC**) + (1,000)(**WDL**) + (400)(**WDLR**) + (2,000)(**NFC**)]/Total hours worked

Example 2: Westinghouse Hanford Conduct of Operations Event Index

Let's look at another example of an index based on linear combinations: the Conduct of Operations Event Index developed at the Westinghouse Hanford Company. This index is different from the previous example in that it does not utilize weighting factors for the components. Basically, this index measures the number of certain types of occurrence reports per 200,000 hours worked by an organization. This index uses information that can be obtained from the Occurrence Reporting and Processing System (ORPS). The following parameters are combined:

A. Skin and clothing contaminations: Number of Occurrence Reports with nature of Occurrence of 4B (Personnel Contamination).

B. Violations of Procedures: Number of Occurrence Reports with a Root Cause of 3C (Violations of Requirement or Procedure).

C. Procedure Problem: Number of Occurrence Reports with Root Cause of 2A or 2B.

2A - Defective or inadequate procedure

2B - Lack of procedure

D. Training Deficiency: Number of Occurrence Reports with Root Causes 5A through 5E

5A - No training provided

5B - Insufficient practice or hands-on experience

5C - Inadequate content

5D - Insufficient refresher training

5E - Inadequate presentation or materials

E. Management Problem: Number of Occurrence Reports with Root Causes 6A through 6F.

6A - Inadequate administrative control

6B - Work organization/planning deficiency

6C - Inadequate supervision

6D - Improper resource allocation

6E - Policy not adequately defined, disseminated, or enforced

6F - Other management problem

F. Lockout/tagout errors: Number of Occurrence Reports judged to be lockout/tagout related.

G. Work control errors: Number of Occurrence Reports judged to be work control related.

Note that some of the Occurrence Reports could fall into multiple categories and will be counted more than once.

H. Person-hours worked: Each facility determines which employees should be included in the person-hours calculation.

The index calculation is based on the number of occurrences that happened during the time period (as per the above criteria) divided by the opportunities for occurrences to happen (i.e., person-hours worked):

Index Calculation:

$$\text{Index} = \frac{(A + B + C + D + E + F + G)}{(H/200{,}000)}$$

The use of person-hours assumes that the larger the operating force of a facility, the more opportunity there is for Conduct of Operations type events. Dividing by person-hours worked is an attempt to express the conduct of operations as a rate identical to the method used for Lost Work Day Case Rate.

Example 3: Eastman Kodak Safety Performance Index

The Eastman Kodak company uses an interesting and effective methodology for creating performance indexes. Basically, the method used by Kodak involves mapping the range of performance for several metrics onto a fixed scale, applying a multiplier to the value extracted from the scale, and adding the results together. An example of how this index is computed follows (this example has been adopted from Kodak' handbook for Safety Performance Indexing and modified slightly for the purposes of this example).

Developing a Performance Matrix

The first step in the Kodak process involves developing a ***performance matrix*** that shows goals and ranges of performance for several metrics. Figure 1.8 is an example of a performance matrix.

At Kodak, developing this matrix is a 10-step process:

Step 1: Select indicators that are related to and that measure progress in the area for which you intend to develop an index. Kodak developed a Safety Performance Index. In this example, we will use the Kodak method to develop a Conduct of Operations Index. Remember to ensure that the performance indicators that are chosen are clearly defined. Once the appropriate performance indicators are chosen, list them down the left column of the matrix (see Figure 1.8).

	Performance Level										Calculations			
Performance Indicator (PI)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Value	Level	Wt.	Score
Unplanned Safety Function Actuations														
Violations of Operating Procedures														
Unplanned Shutdowns														
Number of Unusual Occurrences														

Figure 1.8
Example Performance Matrix

Step 2: For each of the component performance indicators, determine its relative importance and the impact that it should have on the index. The total of the weight for the constituent performance indicators must add up to 100%. Write the value of the weights in the "Wt." column. (See Figure 1.9).

	Performance Level										Calculations			
Performance Indicator (PI)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Value	Level	Wt.	Score
Unplanned Safety Function Actuations													***20***	
Violations of Operating Procedures													***30***	
Unplanned Shutdowns													***30***	
Number of Unusual Occurrences													***20***	

Figure 1.9
Example Performance Matrix with Weights

Step 3: Establish the baseline value for each performance indicator. In the matrix, *level 7* represents the baseline. A good baseline might be a four-quarter average.

Step 4: Determine a goal for each measure. In the matrix, performance *level 3* represents the goal.

Step 5: Determine a "stretch goal" for each performance indicator. This goal should be attainable, but only if your facility performs superbly. In Figure 1.10, the stretch goal is represented by *level 1* in the matrix.

	Performance Level										Calculations			
Performance Indicator (PI)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Value	Level	Wt.	Score
Unplanned Safety Function Actuations	***15***		***30***				***50***						20	
Violations of Operating Procedures	***8***		***25***				***45***						30	
Unplanned Shutdowns	***10***		***20***				***30***						30	
Number of Unusual Occurrences	***20***		***35***				***60***						20	

Figure 1.10
Example Performance Matrix with Baselines and Goals

Step 6: Establish intermediate goals for levels 4, 5, and 6 in the matrix. These may be specific milestones determined by line management, or they may be simple numeric increments between the baseline and the goal.

Step 7: Determine values for levels 8, 9, and 10. It is possible that performance can be worse than the baseline. To account for this, set appropriate values for levels 8, 9, and 10.

Step 8: Assign a value to Level 2 PIs. You should now have all performance levels filled in as shown in the example in Figure 1.11.

	Performance Level										Calculations			
Performance Indicator (PI)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Value	Level	Wt.	Score
Unplanned Safety Function Actuations	***15***	20	***30***	35	40	45	***50***	60	70	80			20	
Violations of Operating Procedures	***8***	15	***25***	30	35	40	***45***	50	55	60			30	
Unplanned Shutdowns	***10***	15	***20***	23	25	27	***30***	34	38	42			30	
Number of Unusual Occurrences	***20***	25	***35***	45	50	55	***60***	65	70	75			20	

Figure 1.11
Example Performance Matrix with Completed Performance Levels

Step 9: Debug the matrix. Use stakeholder feedback to evaluate the initial selection of performance indicators, the performance levels, assigned weights, and so on. Make necessary changes.

Step 10: Develop a system for scoring and displaying results. It is important to assign the responsibility for collecting, calculating, plotting, and disseminating performance index information. It is equally important to set up a mechanism for the periodic review and updating of each performance matrix.

Remember, for each of the PIs chosen in this example, an increase in value represents a *decrease* in performance. This may not always be the case. For this reason, it is important to understand how increases and decreases in each indicator relate to performance, and to determine the baseline values, goals, and stretch goals accordingly.

Calculating the Performance Index

The first step in calculating the index is to measure the current value for each performance indicator. Then, using the matrix, determine the corresponding performance levels. In situations where the value for a performance indicator falls between performance levels, choose the next higher level. For instance, say that during the last measuring period there were 53 unusual occurrence reports (UORs). Since there is no performance level that corresponds exactly to 53 UORs, you would choose the next higher level, or 55, which corresponds to *performance level 6*.

For illustrative purposes, assume that measuring the performance indicators that make up our hypothetical Conduct of Operations Index yields the following results:

- Unplanned Safety Function Actuations — 38 events
- Violations of Operating Procedures — 50 events
- Unplanned Shutdowns — 23 events
- Number of UORs — 53 events

Based on the above values, the completed performance matrix would appear as it does in Figure 1.12.

	Performance Level										**Calculations**			
Performance Indicator (PI)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Value	Level	Wt.	Score
Unplanned Safety Function Actuations	***15***	20	***30***	35	40	45	***50***	60	70	80	38	5	20	100
Violations of Operating Procedures	***8***	15	***25***	30	35	40	***45***	50	55	60	50	8	30	240
Unplanned Shutdowns	***10***	15	***20***	23	25	27	***30***	34	38	42	23	4	30	120
Number of Unusual Occurrences	***20***	25	***35***	45	50	55	***60***	65	70	75	53	6	20	120

Figure 1.12
Example Completed Performance Matrix

The score for each performance indicator is determined by multiplying the *level* times the *weight*. Once this is done, the scores are added together to determine the composite results. In this case, it yields a value of (100 + 240 + 120 + 120) = 580 for the index. This could be compared to a baseline value for the index of 700 (performance *level 7* for all indicators), and a goal of 300 (performance *level 3* for all indicators). Ideally, values for this index would be calculated every month, quarter, or whatever time period is chosen, and tracked over time.

Example 4: Defense Programs Average of Performance Relatives

This method is based on determining incremental changes in a number of indicators, relative to a baseline period in time, and then averaging these changes or ratios. It is similar to methods used to compute certain economic indexes. The incremental changes are referred to as "performance relatives" (i.e., performance during a given period *relative* to performance during a set baseline period). Remember that this index it is not an absolute indicator. It is only meaningful when tracked over time and compared to past performance.

Performance Relative

A performance relative is a number that compares the value for a certain measure in a given period to the value for the same measure at some fixed period in the past. The best way to demonstrate this idea is by example. This example refers to price relatives rather than performance relatives; however, the two are conceptually identical.

• Example 1: Say you have three commodities, rice , barley, and oats, whose prices in 1970 were $1.00/bushel, $1.25/bushel, and $1.50/bushel, respectively.

In 1980 the prices for these same three commodities were: rice, $1.25/bushel, barley, $1.10/bushel, and oats, $1.75/bushel.

Using 1970 as the baseline year, the price relatives (PR) for these three items would be:

$PR_{rice} = Price_{1980}/Price_{1970} = \$1.25/\$1.00 = 1.25$

$PR_{barley} = Price_{1980}/Price_{1970} = \$1.10/\$1.25 = .88$

$PR_{oats} = Price_{1980}/Price_{1970} = \$1.75/\$1.50 = 1.17$

The price relatives computed in Example 1 give a good indication of how the prices for these commodities fluctuated from 1970 to 1980 — the prices for rice and oats increased, while the price for barley decreased. This is a good indicator of what happened individually, but what about what happened overall?

Average of Performance Relatives

The next step is to compute an average of performance. Many sources agree that the most balanced method for doing this is to use a geometric mean. The reason behind using the geometric mean is beyond the scope of this handbook. However, those who would like to gain a better understanding of the statistics behind this method may consult the **Suggested Reading** on Page 71.

- Geometric mean of performance relatives:

$$I = \frac{\text{antilog}\left(\sum \log P_i/P_o\right)}{n}$$

P_i = series performance indicator
P_o = baseline value
n = number of performance indicators in the series

The formula above may seem a bit imposing at first; it isn't. It is simply one way to compute an average. Instead of adding ($PR_{rice} + PR_{barley} + PR_{oats}$) and dividing by 3, which would give you a simple arithmetic mean, you are multiplying (PR_{rice}) x (PR_{barley}) x (PR_{oats}) and taking the nth root, or cube root, which gives you a simple geometric mean.

- Example 1 (continued): Using the above formula, the index value for the three commodities in 1970 would be 100 — this is our baseline value. The value for 1980 would then be:

$$\text{Index} = [(1.25 \times 1.17 \times .88)^{1/3}] \times 100 = 109 \text{ points}$$

The index value in 1980, 109, is meaningless in absolute terms. It only takes on meaning when compared to the baseline value for the index, or 100, and, as you can see, the value of the index increased by 9 points from 1970 to 1980.

Next, let's assume that twice as much rice is consumed as either barley or oats. It follows that rice should contribute more heavily to the index, say twice as much. Here's how this weighting factor could be handled:

$$\text{Index} = [(1.25 \times 1.25 \times 1.17 \times .88)^{1/4}] \times 100 = 113 \text{ points}$$

The increased emphasis on rice (PR 1.25) increased the value of the index by 4 points.

Suggested Reading

1. Clark, Charles T., and Schkade Lawrence W., *Statistical Analysis for Administrative Decisions,* South-Western Publishing Co., 1979.

2. Fisher, Irving, *The Making of Index Numbers,* Houghton Mifflin Company, 1927.

3. Persons, Warren Milton, *The Construction of Index Numbers*, Houghton Mifflin Company, 1928.

4. *Safety Performance Indexing: Metrics for Safety Performance Improvement Projects*, Eastman Kodak Company, 1994.

Section 2

Data Tools

2.0 Overview

Performance Measuring

Introduction

Performance measures are an important topic. People are pursuing excellence and are eager for results to show their efforts are working. Having data is fundamental, and the old saying, "without data, you're just another person with an opinion," has its wisdom. Still, the use of performance measures is not as easy as it appears, and poor use can do more harm than good.

The following introduction is taken from "Grassroots Approach to Statistical Methods" and is reprinted with the permission of R. S. (Bud) Leete, Lockheed Martin Energy Systems.

Why Do We Measure?

Measuring is the act of assigning numbers to properties or characteristics. We measure to quantify a situation, to regulate, or to understand what affects things we see. Sometimes we measure with gauges and instruments; sometimes, we simply count things. Performance measures can help you understand and improve performance. It is exciting to measure, to benchmark, and to stretch to do better.

Some Measures are More Direct than Others

A first step in deciding what to measure is to decide what you want to improve. Sometimes there is a direct measure. For example, runners or swimmers who want to improve their performance in a 100-yard race can measure their times directly as a performance measure. In golf, measuring performance by the score shot may seem appropriate. However, it is important to note that the golfer's score is not as direct a performance measure as the swimmer's time, because factors like course difficulty and playing conditions vary considerably. In tennis or figure skating, it is even harder to arrive at a performance measure.

Similar difficulties arise at work. Suppose we want to improve morale. Surveys are a possibility. We could ask people, "how is your morale?" and administer a survey periodically. The answer is subjective, and people may tire of being asked this question periodically, especially if morale does not improve. Eventually, we might devise a measure that is indirect, but easier to obtain, like attendance. "If morale is high, people will come to work," will be our logic. A performance indicator is born. Of course, other factors influence attendance, such as sickness, family situations, births, deaths, and the weather.

It is important, therefore, that performance measures be as direct as possible. To improve attendance, measure attendance. To improve cycle times, measure cycle times. If you want to improve morale, you may be better off deciding how to improve morale and measuring your efforts.

Rule 1: The more directly you can measure, the better.

Operational Definitions

Once you decide what to measure, carefully and thoughtfully determine how to take your measurement. Likewise, if you are counting you need to know exactly what you should and should not count. This is the process of setting operational definitions.

As an example, suppose you want to measure the level of beryllium in a work area as an industrial safety performance measure. You'll be taking smear samples. Should you check places at random? Should you instruct the technicians to look for the "worst" places or at "typical" places? Should you select a set of specific places and check those same places each measuring period? Should you average the values? What measuring method should be used in the laboratory? Should the lab perform duplicate analyses and average them?

Questions like these are important to the long-range success of the indicator. Efforts to standardize and communicate instructions are needed. Operational definitions are instructions and turn general terms, such as "contamination" or "scrap," into specific actions, procedures, and computations. Without them, we leave ourselves vulnerable to variations people will introduce in interpreting incomplete instructions.

Rule 2: Define exactly how to collect the data for the indicator and how to make the computation. Then, make sure everyone understands.

How Defined is the Underlying Process?

There are two types of studies: "enumerative" and "analytical" studies. Enumerative studies are those that show how things are but have no value in predicting. Taking a census is an enumerative study. Measuring corn yield is an enumerative process. The farming conditions of 1984 or 1987 or whenever are gone forever. They will never be repeated. In this sense, there is no consistent underlying process. Analytical studies are used to study a process and show what that process is capable of doing in the future unless something changes that process.

Dr. Walter Shewhart, a pioneer in statistical process control, said a process consists of equipment, methods, materials, and people being blended to produce output in some environment. For example, in farming, the environment is at times so dominant that the measure of yield may reveal little of the farmer's processing methods, the quality of the soil, or seeds.

2.0 OVERVIEW

In developing a performance measure, flowchart the process that produces the result you will measure. If you can, you'll be able to use the performance measure as a tool for improving. If you can't, the road to improving will be winding, at best.

Rule 3: If you can't flowchart the process you want to improve, a performance measure will offer little insight into what you should do to improve.

Interpreting What You See

Variation is a fact of life. What we want to do with performance measures is to understand the variation. We want to learn how to influence performance with elements of the process that we can control. To interpret what we see, we need to know about variation and how observations vary. We need to understand statistical methods.

Rule 4: Use the numbers to help people improve, not to judge people.

Statistical Models of a Process

Mathematicians have studied physical phenomena for years to understand and model how things work. Consequently, statistical methods have been developed that everyone working with performance measures should understand. Two main aspects of statistical methods deal with statistical distributions and statistical control.

It is important for leaders, whether they be leaders of a company or key members of a team, to understand statistical concepts on variation, including statistical distributions and statistical control. They should also understand special causes, common causes, and control charting. In addition, they should clearly understand the concept of "tampering" with a process.

Rule 5: Learn to understand variation. You'll be more effective.

Types of Variation

One way of visualizing variation is through a demonstration. Dr. W. Edwards Deming, often called the father of modern statistics, wrote of a funnel experiment that helps explain variation. This experiment requires a funnel, a marble, a stand to hold the funnel steady, a flat place to work, and paper and pencil. On a level space, we arrange the funnel and its stand. We mark a spot on our paper as the "target" and position the stand so we can drop the marble through the funnel and land it on the target. The "process" consists of taking the marble, dropping it in a swirling motion into the funnel, and letting it land on the paper. We use the pencil to mark where the marble comes to rest. Marking lets us see the pattern of variation.

When the pattern of variation is observed after 30 or so drops one can see how the pencil marks on the paper tend to form a natural pattern. This is the pattern of variation. The funnel, all set up for the workers to use, is the "system." Workers perform the operations in the system. They are given the funnel, the marble, and the procedures to follow. Managers are responsible for the system. If a change is required in funnel height, or composition, in the marble composition or diameter, or in the flatness of the table, the change can only be made by managers. The local workers are those who work inside the system but don't have the authority to change it. Managers are the workers who have the authority to make changes to the system.

This natural pattern of variation shows what the process is capable of doing. When the marble process continues to run, the pattern becomes predictable. We don't know where the next marble will fall, but we can expect the pattern to be preserved. If it is not preserved, we look for a special cause.

A key concept is that we must study the pattern of variation. If it is controlled, meaning observations fall seemingly at random within some overall natural pattern, then the process is performing at its natural capability. It is a management responsibility to improve a controlled process. If it is uncontrolled or unstable, meaning the observations fall in patterns that seem to defy the laws of probability, then special causes of variation are present. The local workers ought to be able to identify these special causes because of their closeness to the process.

Rule 6: Only management can improve a controlled process.

Tampering

When people don't understand variation, many things can happen: (1) trends are identified when there are no trends, (2) trends are not identified when there are trends, (3) employees blame or credit others for things over which others have no control, (4) past performance can't be understood, and (5) future plans can't be made.

Any time you see common cause variation and make a process adjustment to correct for this variation, you increase the variation in your process. You make it worse. Adjusting a process when you should not is called "tampering." Consider a process operator who works at a control station, monitoring the moisture content of a powder being processed. Every 15 minutes, he samples the powder. If it is below 5.4 percent, he turns a knob to raise the moisture content. If it is above 5.4 percent, he lowers the moisture content. He sounds like a conscientious worker. In truth, he is unnecessarily adding variation to the process. Likewise, for a manager or supervisor to react to normal process variation and expect explanations or corrective actions is wasteful. "Last month there were six instances of machine breakdowns. This month there were eight. Why are breakdowns up 25 percent?"

Rule 7: Ignorance of variation is not bliss. It increases variation.

2.0 OVERVIEW

The Use of Goals

Goals encourage us and challenge us to act. Worthwhile goals are to stay in business, to provide jobs, to reduce costs, to communicate more with customers, to better understand our processes, and to promote teamwork. In our excitement to meet our goals, we must remember tampering.

Suppose someone sets a goal that "we will not have more than 20 off-quality pieces in any month." Typical actions that might come from this are: (1) soliciting reasons why some months have more than 20 off-quality reasons, (2) comparing data on months with more than 20 off-quality pieces to the data on the "good" months, (3) having celebrations for months where the goal is met, and (4) taking disciplinary action on workers who produce off-quality work or on supervisors when goals are missed. While the intention of producing less off-quality work is good, any of these actions can be harmful. They can lead to fear, cover-up of off-quality work, and breakdown of teamwork. Those who understand variation could show that this process is a controlled process, operating at a level that is obviously unsatisfactory to those wishing it were better. Rule 6 tells us that management must improve the underlying system.

Rule 8: We insist on driver's education for those who want to drive; we should insist on statistical education for those who want to set goals for others.

Statistical Methods of Looking at Performance Measures

What are the signals to look for in process data? How do we spot unusual variation in a performance measure? There are several tests to use. Using statistical methods, control charts can be developed. When control limits are computed and charted the probabilities of a value exceeding the control limits are remote. Thus, values that fall outside the control limits are considered signals of special causes and must be investigated.

Good performance measures are also assessed using statistical methods for run charts. When the results are plotted, values are observed in relation to the center (median) line. Eight consecutive points above or eight consecutive points below the center line signal the presence of a special cause causing a shift in level. Six consecutive points, each of which larger (or each of which is smaller) than its preceding point, are the statistical signal of a trend.

When signals of special causes are identified, the local workers need to be involved. When no signals of special causes exist, the process is operating at its best. Dr. Deming wrote that workers are not trained until they produce output in statistical control. Once the output is in statistical control, the process is performing to its natural limits and can be improved only by system improvements, which is a management function.

Rule 9: We learn when a curious person sees an unusual event and acts.

A Performance Measure Illustration

Figure 2.1 shows a performance measure that Baldrige Award Examiners use as a model. While they are not prescriptive to suggest that we should be measuring the percent of shipments on time, the style is one to copy because it: (1) has significance to the organization; (2) shows trend data for a significant period of time; and (3) shows benchmark results from other organizations.

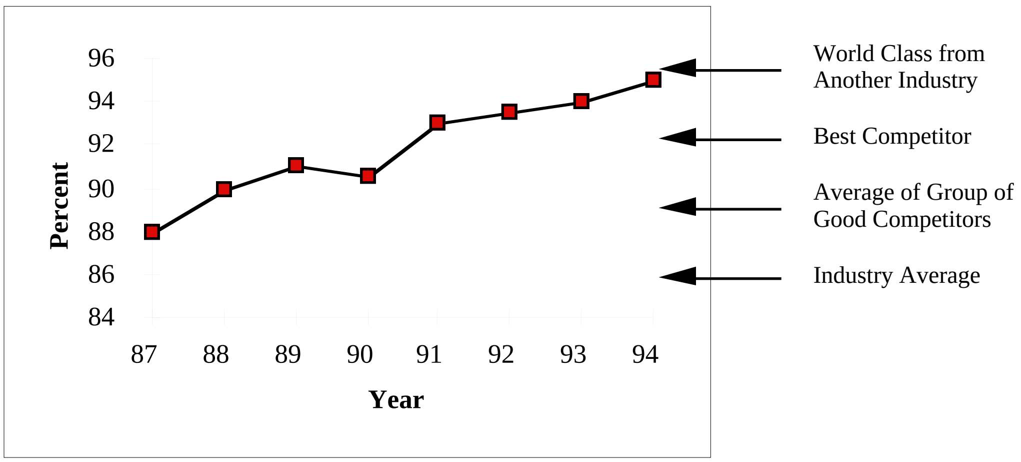


Figure 2.1
Percent of Shipments on Time for Product Line A

Note also that while the summary is given on a year-by-year basis as an organizational measure, there are supporting monthly results that can be assessed and studied for special causes.

Summary

Performance measures focus attention on data. There have been successes where merely the calling of attention to expected results produced improvement. However, some methods of using data to bring about improvement are more successful than others. Teamwork, cooperation, and openness are assets to an organization working to improve. As Ralph Stayer of Johnsonville Sausage said, “Everyone wants to excel. Everyone wants to be part of a winning team.” Too much zeal for results and accountability can lead to tampering and exactly the opposite effect we wish to produce.

Few situations in the business world are entirely black and white. Education is required. Organizations need to decide what measures they need to be competitive and work to establish processes and systems that produce the desired results. The use of statistical methods is important. So is the knowledge of how to work with and learn from others.

2.1 Data Collection Techniques

At times, you may want to use information collected in one system or database in other formats. This may be done to share data between locations, utilize another software package for specialized data manipulation, or export data for use in reports or other documents.

Generally, to the extent possible, the creation of duplicate databases is discouraged. If the source data are changing, the destination data will need to be updated periodically to ensure that current data are being accessed. However, on other occasions, it is useful to take a "snapshot" of the data by copying the desired records and fields into a separate file. This allows the user to manipulate the data to obtain counts and trends without the data changing between operations.

The following sections will discuss items that should be considered in sharing data between systems or software packages. The first section will discuss general considerations in downloading data. The second section deals specifically with downloading data from the DOE Performance Indicator Data System (PIDS).

Guide for Downloading Data

There are two different approaches to transferring data between systems. The first consists of transferring formatted files, e.g., a .DBF file, while the second consists of transferring a formatted ASCII text file that can be imported into the destination system. The preferred method depends on the capability of the host and destination databases and the desired information to be transferred.

Many database and spreadsheet software packages will work with a number of different file formats. In some cases, the file formats are directly compatible between software packages. For example, FoxPro will directly load or accept a .DBF file created with dBASE. In other cases, a conversion utility is required. For example, the Lotus 123 translate utility will convert a number of different database and spreadsheet formats into a file that can be loaded directly into Lotus 123. In many cases, these translation utilities are not directly available from the main application menu but must be run from a higher level menu or directly from the DOS prompt. The most common formats that are directly compatible with multiple software packages are the WKS format for spreadsheet programs and the DBF format for databases.

If a format is not available that can be moved directly between software packages, or translated to work with another package, most software packages will export and import a formatted ASCII data file. The two most commonly used types of formatted ASCII data files used in transferring data between applications are the standard data format (SDF) and the character delimited format (CDF).

In the SDF format, each row contains one record and each field is a predefined size. No punctuation is used in the records and each record ends with a carriage return and line feed. This format is particularly useful for working with columnar data. An example of a file in SDF format is shown below.

Smith	Tom	25	234-43-5547
Jones	John	41	442-78-4531

The CDF format is widely used in spreadsheets and databases. In this format, each row again contains one record. However, fields are separated by a character, usually a comma, and character data are enclosed by punctuation marks, usually a double quote. Leading or trailing blanks in the data are trimmed off (i.e., fields may be varying lengths). Again, each record ends with a carriage return and line feed.

The above file in CDF format, with comma separators and double quote delimiters, would be captured as:

"Smith", "Tom", 25, "234-43-5547"

"Jones", "John", 41, "442-78-4531"

Although commas are most commonly used as separators and double quotes as delimiters, many software packages allow the user to specify the characters that are used. In some cases, use of an alternate character may be preferable. For example, FoxPro will output a tab delimited file that is particularly useful for outputting data that will be imported into a word processor.

It should be noted that, in some software packages, the file extension is important when creating a text file for importing into a software package. For example, dBASE requires a .TXT extension for files that are being imported.

Some general hints on downloading data from one system:

1. Make a backup copy of the downloaded file and the file it will be imported into BEFORE you do anything else.
2. Many database systems include some type of a unique identifying field for each record, e.g., an index number. If this field is accessible, including it in the download may be useful to facilitate later downloads to update information or include additional fields from the host database.

3. When data are moved between software packages using formatted ASCII files, each field will be imported into a different column in a spreadsheet or into a different field in a database. If you are importing data into an existing database or spreadsheet, the order of the fields in the downloaded file needs to match the order of the fields in the existing database. The field sizes in the existing database must be at least as large as the corresponding fields in the downloaded data.
4. "Layered" spreadsheets (e.g., multidimensional .WK3 worksheets) do not import well into other programs. Frequently the layers are lost. It is better to save the spreadsheet in a different format and then try to import it.
5. Print a sample of the downloaded file (use a small font). Even though you can view the file on screen, some problems in data continuity are more apparent on the printed page.
6. If the file to be imported contains a large number of fields or extensive narrative data, keep in mind that each line in the file will be treated as a separate record. Depending on the system or the software package being used, there may be a limit to the line length. If this is the case, the data for a single record may wrap to more than one line, and subsequent lines need to be associated with the main record line during the import process.

Downloading Data from PIDs

The current design of DOE's Performance Indicator Data System (PIDS) provides the capability of downloading data in a formatted ASCII data file (CDF format). This data file is compatible with most spreadsheet and database programs.

The delimited ASCII file download option from the PIDS report option automatically creates a file in the same format as the upload file that is used for submitting data to PIDS. Each line is a separate record. Fields are separated by commas, and all data are delimited with double quotes. All data in PIDS are treated as character data. The format for a performance indicator (PI) data record in PIDS is as follows:

"year-quarter", "facility or contractor", "PI", "PI value", "change flag", "PI narrative"

The characteristics of the fields are as follows:

Year-Quarter	Character (4)
Facility	Character (20)
PI number	Character (8)
PI value	Character (14)
Change flag	Character (2)
Narrative	Character (Unlimited)

PI numbers or identifiers are stored without decimal points, e.g., PI 1.2 is stored as 12.

All PI values are stored in PIDS as character data. In some cases, data may not be available. In the records where values are not available, the value is replaced by a code as follows:

-1 Currently unavailable (CU)
-2 Not available - security concerns (NAS)
-3 Not applicable (NA)

The format for a PIDS root cause (RC) data record is as follows:

"year-quarter", "facility or contractor", "RPI", "root cause", "RC value", "change flat", "PI narrative".

The characteristics of the fields are as follows:

Year-Quarter	Character (4)
Facility	Character (20)
RPI number	Character (8)
Root cause	Character (4)
RC value	Character (14)
Change flag	Character (2)
Narrative	Character (Unlimited)

The RPI number is the PI number or identifier, preceded by the letter "R", e.g. R12.
When an error is detected after the data submission deadline, an errata form must be approved and submitted in order for data to be changed in PIDS. The format for an errata record is as follows:

"year-quarter", "facility or contractor", "PI", "old PI value", "new PI value", "change flag", "PI narrative", "errata basis".

The characteristics of the fields are as follows:

Year-Quarter	Character (4)
Facility	Character (20)
PI number	Character (8)
Old PI Value	Character (14)
New PI value	Character (14)
Change flag	Character (2)
Narrative	Character (Unlimited)
Errata basis	Character (Unlimited)

2.1 DATA COLLECTION TECHNIQUES

Use of the Internet

The use of the Internet has also become a valuable tool to collect, capture, and share information from different sources. Internet provides many capabilities, including the capability to transfer data files electronically. Large amounts of data can be transferred from one location to another in a matter of seconds. This capability can improve the timeliness of obtaining information necessary to support organizational performance measurement analyses. Many books and manuals are available that provide information on use of Internet.

2.1 DATA COLLECTION TECHNIQUES

2.2 Charts, Graphs and Diagrams

Control Charts

Statistical process control was developed as a feedback system that aids in preventing defects rather than allowing defects to occur. One element of a process control system is control charts. Dr. Walter Shewhart defined the concept of common and special cause variation during the 1920s at Bell Laboratories. He developed a tool that he called the control chart, which could graphically depict variation. This control chart, could also distinguish the two types of variation from each other, thus allowing for the elimination of special causes and the reduction of common cause variation.

There are several types of variables data and attributes data control charts. This section will discuss the different types of control charts, the applications of each control chart, and the interpretation of the data.

Types of Control Charts

Variables data are quantitative data that can be measured. Some examples are the diameter of a bearing or the thickness of a newly minted coin. Variables data are usually represented as X-bar and R-charts and X-bar and s-charts.

Attributes data are qualitative data that can be counted. Some examples are a count of scratches per item or a count of acceptability for a go/no-go gauge. Attributes data are usually represented as nonconforming units and are analyzed by using p, np, c, or u control charts.

First, determine what variable you will measure. Then gather data and chart the data accordingly (Figure 2.2).

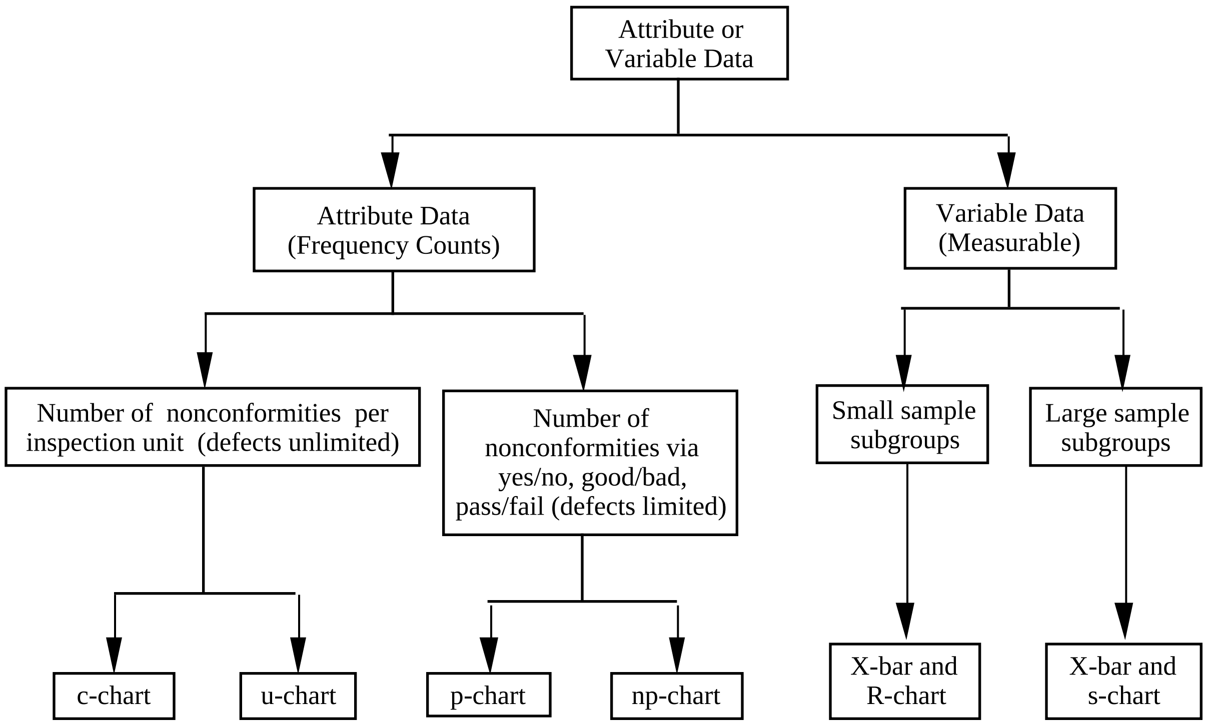


Figure 2.2
Sample Control Chart

X-bar and R-charts

The principal types of control charts used to analyze variables data are X-bar and R-charts. X-bar and R-charts are used in conjunction with each other. The measurements describe a process characteristic and are reported in small subgroups of constant sizes (usually two to five measurements per subgroup). Construction and use of these types of charts typically involve the following steps:

- Select the size, frequency, and number of subgroups.
- Assemble the data for the periods of interest.
- Calculate the average (X-bar) and the range R of each subgroup.
- Plot the averages and ranges on the control charts.
- Calculate the central line control limits; plot them on the control chart.
- Study the charts for stability and/or trends.

X-bar and s-charts

X-bar and s-charts (sample standard deviation) are also used in conjunction with each other and are measured from process characteristics. The sample standard deviation is a more efficient indicator of process variability, especially with larger sample sizes. However, it is more difficult to calculate and is less sensitive in detecting special causes of variation that cause only a single value in a subgroup to be unusual. Construction and use of these types of charts typically involve the following steps:

- Select the size, frequency, and number of subgroups.
- Assemble the data for the periods of interest.
- Calculate s, s-bar (average), and the control limits for both the X-bar and s chart, and the X-double bar chart.
- Plot the data on the control charts.
- Calculate the central line control limits; plot them on the control chart.
- Study the charts for stability and/or trends.

X-charts

Unlike X-bar and R-charts, which collect and evaluate subgroups of data, X-charts (sometimes referred to as individuals charts) involve the analysis of individual measured quantities for indications of process control or unusual variation. The standard deviation for X-charts is calculated using a moving range.

The following process should be used in developing and analyzing X-charts:

- Assemble data for the periods of interest.
- Calculate the average of the individual values.
- Calculate the individual moving ranges (all ranges will be positive numbers).
- Average the ranges.
- Calculate the standard deviation and subsequent control limits for the individual values.
- Plot the average and limit lines for the individual values and analyze for trends.

C-chart

The c-chart is the principal type of control chart used to analyze attributes data. C-charts (sometimes referred to as "count" charts) are used in dealing with counts of a given event over consecutive periods of time. The following process should be used in developing and analyzing c-charts:

- Assemble data for the periods of interest.
- Calculate the data central line.
- Calculate the upper and lower control limits.
- Plot central line, and control limits.
- Study the charts for stability and/or trends.

U-chart

U-charts (sometimes referred to as "rate" charts) deal with event counts when the area of opportunity is not constant during each period. The steps to follow for constructing a u-chart are the same as a c-chart, except that the control limits are computed for each individual quarter because the number of standard units varies.

P-chart

P-charts (sometimes referred to as "proportion" charts) are used to show the fraction nonconforming of a nonstandard sample size over a constant area of opportunity (e.g., each period of interest). The steps to follow for constructing a P-chart are the same as a c-chart, except that the control limits are computed for each time period because the sample size varies.

NP-chart

Like p-charts, np-charts are used to analyze nonconforming items over a constant area of opportunity; however, the np-chart focuses on the number of nonconforming items when the sample size is constant. The steps to follow for constructing an np-chart are the same as for a p-chart.

Use of Control Charts

Control charts serve to direct management attention toward special causes of variation in a system when they appear. Limit lines drawn on the charts provide guides for evaluation of performance. These lines (called control lines) indicate the dispersion of data on a statistical basis and indicate if an abnormal situation (e.g., the process is not in control or special causes are adversely influencing a process in control) has occurred.

In evaluating control charts, managers should look for the following indications:

- Outliers - Data that fall outside the control lines.
- Runs - Series of data points over or below the central line. A "run" of 7 consecutive points or 10 out of 11 points indicates an abnormality. Other approaches exist for identifying runs, such as detecting two of the last three data points beyond two standard deviations (2-sigma) and the more general CUSUM (cumulative sum discussed in Section 3.2.7) procedures, which involve adding up standardized deviations from the calculated mean to detect abnormalities (such as runs or trends) sooner.
- Trends - Continual rise or fall of data points. If seven data points rise or fall continuously, an abnormality is considered to exist.
- Periodicity - Data show the same pattern of change over time. Also known as a cyclical pattern.

In summary, the two main uses for control charts are: (1) to monitor whether the system is stable and under control (to warn of changes), and (2) to substantiate results from changes introduced into the system (to confirm results).

Treatment of "Outliers"

In constructing control charts, individual or groups of data points may appear near or beyond the calculated control limit lines. Since these data appear to indicate that a system is or may not be in control (e.g., stable), additional evaluation may be needed to ascertain if the data in question are the result of common cause or special cause variation. If the data are clearly influenced by a one-time aberration (e.g., special cause), there could be a basis for excluding the number or estimating what the actual value should have been for the purpose of determining actual system control limits.

Treatment of "Rare" Events

For trending PI data using c- and u-charts, the average used to calculate control limits should be equal to or greater than five. Where the limited nature of the data does not support the use of control charts, the use of more sensitive trend tests may provide a better indication of actual trends. An example would be multinomial likelihood ratio tests that involve comparing the likelihood of postulated rates of data change (e.g., constant, increasing, or decreasing) assuming the data are generated by a multinomial distribution.

Scaling of Control Charts

The following general criteria should be applied to the depiction of trend data on control charts: (1) the scale should be set so that the chart can be quickly understood, and (2) the data together with the limit lines should span at least half of the vertical axis.

Histograms

A histogram is a bar chart. It is designed to show:

- a distribution or spread of data
- the numbers of times various measurement values occur
- groups of values so patterns of variation are easily identifiable
- the average as well as variability of a data set

Histograms are most often used to record frequency of events associated with measurements of time or cost. Histograms may be used when the characteristics of one or more sets of data need to be summarized, when checking for possible variations in incoming data, and when absolute values reveal less information than trends and patterns would. The viewer can quickly and easily see the shape of the distribution of a process, which may lead to further analysis of correlation.
Listed below are the elements of a histogram and an explanation of what each element displays:

- Horizontal axis: lists measurement values.
- Vertical axis: shows frequency or amount of values.
- Width of each bar: represents an arbitrary range of values.
- Height of each bar: represents the number of times the values within specified range are observed.
- Pattern created by the bar heights: displays a graphic distribution.

How to Construct a Histogram

To construct a histogram, you should collect as many measurable data points as possible using a frequency table. Spreadsheet software programs (e.g., Excel or Access) are the best way to collect and store frequency tables. As a general statistical rule, at least 100 measurement values are required for an accurate distribution picture and at least 30 data points are required for reliable regression analysis.

1. Determine the number of bars or intervals.
The number of intervals, bars, or columns is based on the total number of measurement values collected. Example:

Number of Measurements	Number of Bars
Under 50	5-7
50-100	6-10
100-249	7-12
Over 249	10-20

2. Determine the range of the bars.
Find the overall range of the data by subtracting the smallest value from the largest value. Then divide the overall range by the number of bars to determine the range of each bar. Round your answers up to a convenient value.

3. Determine the starting point of each interval and the bar limits.
Start with the smallest data point as the starting point of the first interval. Add the interval width that was determined to be the range of each bar. The sum is the starting point for the next interval. These are interval labels for the horizontal axis. It is customary to extend the scale one interval above and below range.

4. Construct a histogram worksheet or document the spreadsheet.
Identify the purpose, date, names of data collector and data source, the sample size, time period, and unit of measure. Record the limits for each bar, the tally of measurement values it represents, and the total frequencies of those values.

5. Construct the histogram.
Label the axes. List the values for the bar limits from left to right on the horizontal axis. Label the vertical axis with a scale large enough to accommodate the frequency of the tallest bar. Each data point can appear in only one interval. To make sure that no measurement values fall on either edge of a bar, add a logical decimal value to each limit.

Draw each bar to the height that corresponds to the frequency of the values it represents. A bar or column is centered around the midpoint of its interval.

6. Interpret the completed histogram.

Look for one of the patterns described below and consider the recommended actions to investigate the causes of non-normal distributions. To make it easier to compare the distribution to a standard or an average value, draw a dashed line for reference on the diagram. Figure 2.3 provides examples of these different distribution types.

- **Normal:** Not caused by any identifiable variable. Desirable distribution, no action required.
- **Saw-toothed:** Range of values for each bar is not the same or certain values were excluded from the range. Review the bar widths on the horizontal axis and/or check the source of the data and the way the data were gathered.
- **Bi-modal:** Variation maybe the result of cyclical factors or two sources of data. If two sources of data are combined, try to separate them. If cycles are expected, no action is required.
- **Skewed:** Sometimes the pattern is expected, especially with measurement of time.

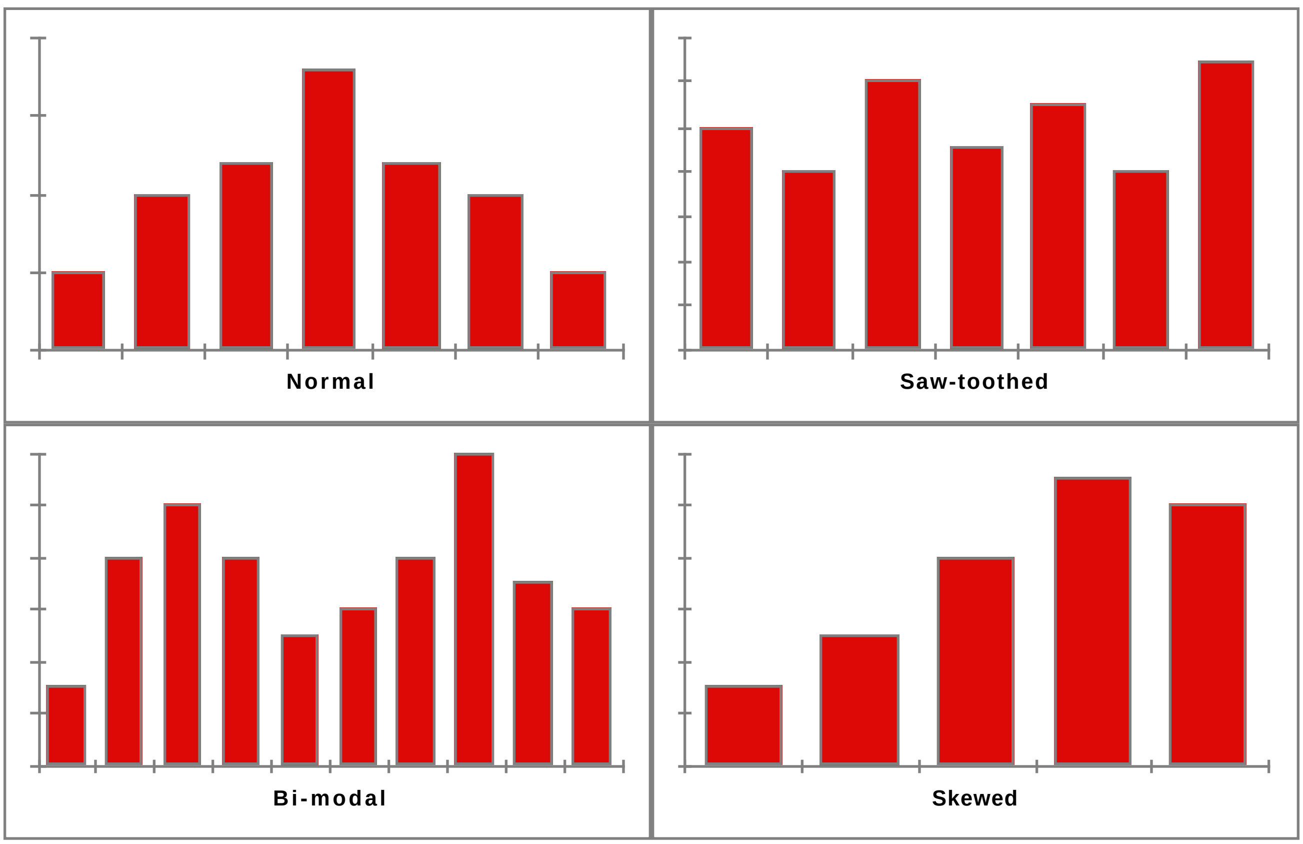


Figure 2.3
Types of Distributions

How to Display a Histogram - Software

Excel and Access are common spreadsheet databases used for data collection and storage. They will automatically graph frequency data into histogram format as desired. Histograms are most effective for visual analysis of population data where correlations may be further investigated. When graphing histograms, always ask if the picture is reasonable and logically correct; there is always the danger that software programs can make graphically pleasing displays from illogical input.

The Pareto Principle

The Pareto Principle derives its name from Vilfredo Federico Domaso Pareto, an Italian-Swiss socio-economist and trained, practicing engineer. As Chair of Economics in the Faculty of Law at Lausanne University in 1892 and forerunner in the field of mathematical approaches to socio-economics problems, Pareto conducted a study of the distribution of personal incomes of an entire economy. This led him to postulate that:

- Personal income will be distributed among the populace along the same lines in all countries.
- The pattern of income distribution cannot be easily changed.
- The number of incomes was more concentrated among the lower income groups.
- The majority of the wealth was in the hand of a few individuals.

Pareto postulated that, in an entire economic population, only a few individuals controlled the majority of wealth. This proved to be valid and become known as Pareto's Law, Pareto's Concept, or Pareto's Principle. Historically, the Pareto Principle has come to be more universally known as the 80/20 rule, i.e., an 80% improvement in quality or performance can reasonably be expected by eliminating 20% of the causes of unacceptable quality or performance.

Dr. Joseph M. Juran, Chairman Emeritus, Juran Institute, and world-renowned authority on quality management, was the first to apply this concept to the industrial environment. He noted that in many situations where a group of factors contribute to a common effect, only a vital few account for the bulk of the effect, and the useful many in the population account for the rest. Many problems associated with quality and performance adhere to this principle to identify and separate the vital few from the useful many.

The Pareto Concept

The simplicity of the Pareto concept makes it prone to be underestimated and overlooked as a key tool for quality improvement. Generally, individuals tend to think they know the important problem areas requiring attention; if we know, why do the problem areas exist? The most benefit derived from a Pareto analysis is to identify and define improvements for quality or performance improvement.

The idea is quite simple, but to gain a working knowledge of the Pareto Principle and its application, it is necessary to understand these basic elements:

- **Pareto Analysis** - creating a pictorial array of representative sample data that ranks the parts to the whole, with the objective to use the facts to find the highest concentration of quality improvement potential in the fewest number of projects or remedies to achieve the highest return for the investment.
- **Pareto Diagram** - the Category Contribution, the causes of whatever is being investigated, are listed and a percentage is assigned for each (Relative Frequency) to total 100%. A vertical bar chart is constructed, from left to right, in order of magnitude, using the percentages for each category.
- **Relative Frequency** = [(Category Contribution) / (Total of all Categories)] x 100 expressed in bar chart form.
- **Cumulative Frequency** = [(Relative Frequency of Category Contribution) + (Previous Cumulative Frequency)] expressed as a line graph with points of the line determined from the right edge of each bar or as a stacked bar chart.
- **Break Point** - the percentage point on the line graph for Cumulative Frequency at which there is a significant decrease in the slope of the plotted line.
- **Vital Few** - Category Contributions that appear to the left of the Break Point account for the bulk of the effect or those that account for the first 60 percent, or so, of the total.
- **Trivial Many** - Category Contributions that appear to the right of the Break Point, which account for the least of the effect.

Pareto Diagram Analysis

Pareto analysis provides the mechanism to control and direct effort by fact, not by emotion. It helps to clearly establish top priorities and to identify both profitable and unprofitable targets. Pareto analysis is useful to:

- Prioritize problems, goals, and objectives
- Identify root causes
- Select and define key quality improvement programs
- Select key customer relations and service programs
- Select key employee relations improvement programs
- Select and define key performance improvement programs
- Address the Vital Few and the Trivial Many causes of nonconformance
- Maximize research and product development time

- Verify operating procedures and manufacturing processes
- Product or services sales and distribution
- Allocate physical, financial and human resources

Pareto analysis may be applicable in the presentation of Performance Indicators data through selection of representative process characteristics that truly determine or directly or indirectly influence or confirm the desired quality or performance result or outcome. Typical observations from Paretodiagram analyses might reveal:

- 80% of all warranty repairs of a product were attributed to 20% of its parts.
- 75% of quality defects result from 15% of operations within a process.
- 10% of the items inventoried represent 70% of the total cost of inventory.

Pareto diagram observations may show the following: (1) that the bars are roughly the same size; (2) that it takes more than half of the categories to determine 60-80 percent; or (3) if the most frequent problem is not the most important. STOP after the first problem is resolved and develop a more discrete set of nonconformance cause parameters to survey, analyze, and diagram.

Process Capability

Process Capability is a determination of whether an existing process is capable of attaining the specified (or desired) performance. Process Capability has a precise, limited definition in a manufacturing context. This determination is based upon observing the history of the process output data. Statistical Process Control is used to determine the expected bounds of the data. These bounds (which are the three standard deviation control limits) are compared to the manufacturing specification for the process. A more general utilization of this concept can be applicable to Department of Energy facilities and processes.

Statistical Control

In order to assess process capability, the process must first be in statistical control. The data that have been charted must be reviewed against their three standard deviation control limits. If no data points are outside of the control limits, and no discernible trends are detected (using the criteria given in the section on Control Charts beginning on Page 2-13), then the process is in control. The original work by Dr. Shewhart emphasized strongly that a process should not be declared in control unless the pattern of random variation has persisted for some time and for a sizable volume of output. He recommended taking at least 25 samples (data points) prior to declaring a process is in control. However, assessments using less data may be made. Using less data for the assessment takes some experience and can become more of an art than a science.

In some cases, a process with a single data point outside of the control limits may still be assessed as in control. To do this requires investigation of the cause(s) for the single data point being unusual. In short, if you can assign a reason for the value of the out-of-control point, and you can reasonably state that such an event will not reoccur, then you should disregard this point, treat it as an outlier, and not include it in the average or control limit calculations.

With the determination that the process is in control, you have also accepted the hypothesis that the process data will continue to behave as the past data have. It will continue to have the same average, and 99.7% of all future data points will fall between the upper and lower (three standard deviation) control limits. All variations that occur in the future data can be assumed to be due to random variation. This has important implications for management of the process, which will be explored later in this section.

Process Capability Analysis

Once the process is in control, the upper and lower control limits may be compared to the specification limits for the process. Generally, specification limits exist in manufacturing processes; for example, the diameter of the bolt shall be 5 cm plus or minus .01 cm. If the upper and lower control limits for bolt size were 5.01 and 4.98 cm, then we would fail the process capability determination (4.98 cm is outside the lower specification limit of 4.99 cm). If we improved our bolt manufacturing such that the new control limits were 4.993 and 5.007 cm, then we would have an acceptable process capability. That is, it would be highly unlikely (less than .3 percent) that we would manufacture a bolt that would fail the specification limits.

Note that even if our process has an acceptable process capability, we should still continue to practice continuous improvement and strive to minimize the variation in bolt sizes to be as close to 5 cm as is economically feasible. Reducing the variation in component sizes does tend to reduce several hidden costs (an undersize bolt paired with an oversize nut) when processes are highly variable. It may be economically worthwhile to consistently provide bolts that are much better than the specification.

If the control chart(s) are in statistical control, then calculate the process capability by comparing the natural tolerance (NT) of the process to the engineering tolerance (ET) of the specifications:

- NT = Upper Control Limit - Lower Control Limit
- ET = Upper Specification Limit - Lower Specification Limit.

If NT £ ET, the process is capable of meeting specifications. If NT > ET, then the process is not capable of meeting specifications.

At this point, if you are studying variables data and your process is in control and capable, you may want to investigate whether the process is in control with respect to the average. Depending on the data, X-bar and R-charts, or X-bar and s-charts must be graphed. Methods to describe this charting are described in detail in the Western Electric Company's *AT&T Statistical Quality Control Handbook*, 1984.

The same statistical rules listed in the section on Control Charts (beginning on Page 2-13) apply to determine if the charts are in control. If the charts are in control, then calculate a Capability Ratio (CR):

$$CR = (UCL - LCL) / (USL - LSL).$$

A good capability ratio should be less than one. Also, a Capability Index (C_{PK}) must be calculated.

$$C_{pk} = (USL - \text{X-bar})/3s \qquad \textbf{or} \qquad C_{pk} = (LSL - \text{X-bar})/3s$$

Select whichever calculation yields the smaller index. A good capability index should be greater than one.

Now, estimate the percent of product that will be produced out of specification by calculating a Z score.

$$Z_{high} = |(USL - \text{X-bar})/s| \qquad \textbf{or} \qquad Z_{low} = |(LSL - \text{X-bar})/s$$

If the absolute value of Z is >=3, then there are essentially zero defects. However, if the absolute value of Z is < 3, there are defects. A comparison of the Z score value on a Z table will provide an estimate of the percent of product that will be out of specification. Z tables can be found in many statistics textbooks, including *Statistical Quality Control*, 1989, by Grant and Leavenworth.

Use of Process Capability at DOE Facilities

Generally, the DOE facilities are not involved in producing bolts that must meet a specified limit. However, being aware of the process control limits is important for management of DOE facilities. A primary goal of Statistical Process Control and Performance Indicators is to communicate the capabilities of the process being analyzed. If the process is not in control, then efforts should be taken to understand why the process is out of control.

If there are a number of outlying data points (outside of the control limits, also known as outliers), the effort should be made to determine the cause(s) that drove the points out of control. These causes should then be used as a basis for management action to bring the process into control. A process that is forever fluctuating in an unknown manner is nearly impossible to manage. Bringing the process "in control" allows for the use of the control limits to predict future behavior of the process.

If there is a discernible trend, then there is an ongoing process change. If this trend is a result of a management action taken to improve the process and the trend is in the improving direction, then promote the trend. Eventually the effect of the change will stabilize, and you can compute new average and control limits once the process is again in control. The new average and control limits may be compared to the previous average and control limits to assess the impact of the management action. If the process data have a discernible trend, but there is no known action that caused it, then the cause(s) of the trend must be investigated.

If a major process change has just been implemented, then one would not expect the process to be in control. After these changes have been implemented, the process should eventually stabilize with a new average and new control limits. If you discover that you are continually making major process changes and the process data are becoming increasingly erratic, you may be experiencing process tampering as previously mentioned in this handbook.

Management Philosophy

Use of Statistical Process Control with Performance Indicator data provides important information for managers. Managers can use the process capability information in order to manage the processes they are responsible for. The control limits provide a reasonable guarantee of the expected extreme values of the process data. If these extreme values (and/or the average) are determined to be unacceptable, then management must embark on process changes in order to improve the outcome of the process.

Many management philosophies focus upon outcomes. There is justification in this, as it can be said that without the bottom line positive outcomes and results, a company will not stay in business. However, it must be realized that outcomes are the result of processes. In order to change existing outcomes for the better, the process that created the outcomes in question must be understood, and management must create changes to these processes.

Dr. Deming has stated:

- Management's job is prediction and there is no prediction without theory.
- There are no data on the future. Data from the past must be used to form a base for prediction.
- 94% of the changes required for improvement will require action by management.

All of these management philosophy statements point to the importance of managers understanding the processes that they control. In order to improve, the existing process capability must be known. Statistical Process Control and Process Capability provide the tools to:

- Measure current performance.
- Describe the state of statistical control.
- Attain statistical control.
- Determine if process changes are needed.
- Determine the effects of process changes once implemented.

Scatter Diagram

The scatter diagram is a useful plot for identifying a potential relationship between two variables. The data are collected in pairs on the two variables, say (x_i, y_i), for I=1,2 . . . n. The y_i is plotted against the corresponding x_i. The shape of the scatter diagram often indicates what type of relationship may be occurring between the two variables.

Scatter diagrams aid in the interpretation of correlation. The correlation coefficient, denoted by r, is a measure of linear association between two variables. The values of r range from -1 to +1, inclusively. A value of r close to zero signifies little, if any, linear association between the variables. Values of r close to either -1 or +1 indicates a high degree of association. Positive values of r indicate that as one variable increases, the other increases. Negative values of r indicate that as one variable increases, the other decreases. A value of +1 (-1) indicates that the data fall on a positive (negative) straight line.

The correlation coefficient is a measure of linear association only. Scatter diagrams will indicate curved relationships if they exist. In addition, the correlation coefficient will be badly distorted by outlying data. The scatter diagram can be used to locate outliers to check for their validity. Scatter diagrams and correlation coefficients are useful for identifying potential relationships. Designed experiments must be used to verify causality.

Several example scatter diagrams and their correlation coefficients are indicated below in Figure 2.4.

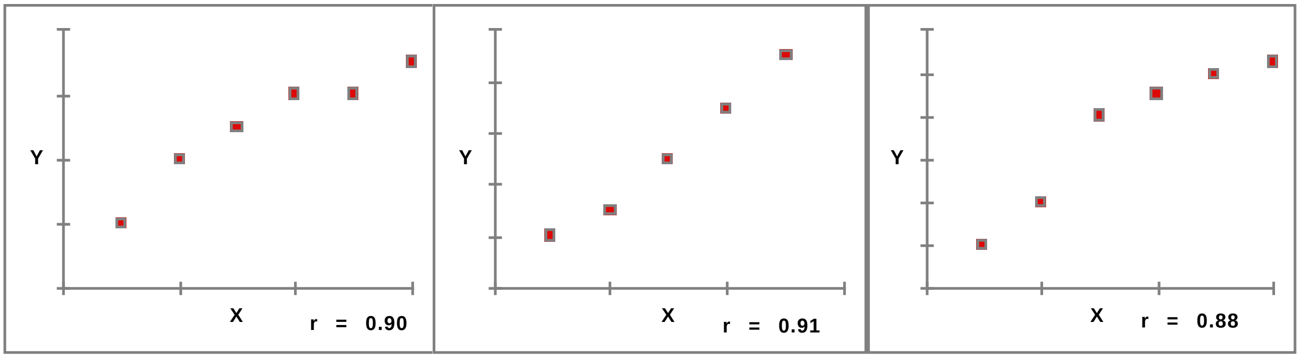


Figure 2.4
Scatter Plots and Correlation Coefficients

Cumulative Sum Trend Analysis Technique

Cumulative sum trend analysis can be applied to a performance measure to detect trends more quickly than standard control charting methods (i.e., Shewhart methods) are able to do. Cumulative sum trend applications are contained in most of the widely used PC-based statistics packages. Cumulative sum analysis is better at detecting small shifts (i.e., one standard deviation) of the process mean than standard control charting and provides an earlier indication of whether improvement efforts are succeeding or not, which is an important part of the evaluation of performance measures used in continuous improvement efforts.

A cumulative sum chart is a plot of the cumulative sequential differences between each data point and the process average over time. A positive slope of the graph indicates an average higher than the process average; a flat slope indicates an average the same as the process average; and a negative slope indicates an average less than the process average. Changes in the process averages are more easily seen plotted as a cumulative sum than in a standard control chart format.

Detection of a shift in the process average can be accomplished graphically with a horizontal V mask overlay on the plot of the cumulative sum data points. The user specifies the desired level of confidence and also the power of the method for detecting a change in the process average; for example, one standard deviation.

Determination of a trend shift is accomplished by centering the mask at a point of interest. The time at which the shift occurred is indicated where previous points cross one of the arms.

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2.3 Presentation Approaches

Presentation and display of data resulting from measuring and monitoring a process or product involves more than just drawing graphs. Effective data presentation includes understanding the type of data to be utilized, who the intended audience is, and how the information will be used. This section provides ideas to consider using when determining the most effective method to present your information.

Effective Data Presentation

Before actually presenting any information, it is beneficial to evaluate and understand a few key areas:

- Who is the audience?
- What is the intended use of the data? Will it be used to support decisions and take actions or is it just to monitor performance?
- What is the basic message you want to communicate (here is where we are and how we are doing)?
- What is the presentation format (report, brochure, oral presentation, etc.)?
- What is the underlying nature of the data and any assumptions?

A key point to keep in mind is that decisions should not be made based on graphs alone. No graph can tell you everything you need to know. The purpose of presenting the data graphically is to provide information to assist in decision making and to monitor activities or progress. Combine graphs with narrative discussions to help the reader understand the data in the proper perspective related to operations. Consider including the following:

- Explain what the values mean for your organization.
- Relate to historical performance.
- Identify influencing factors (nature of operations, seasonal changes, significant management initiatives).
- Relate to management performance goals.
- Explain significant increases or decreases.

Use the data to try to answer the following questions for the reader:

- Is there a trend over time?
- Should I take any action? What kind of action?
- What contributes the most to the total (focus on the vital few)?
- Are we focusing on the highest priority actions?

Figures 2.5 through 2.10 demonstrate how the chart type you choose can influence the message you are trying to convey.

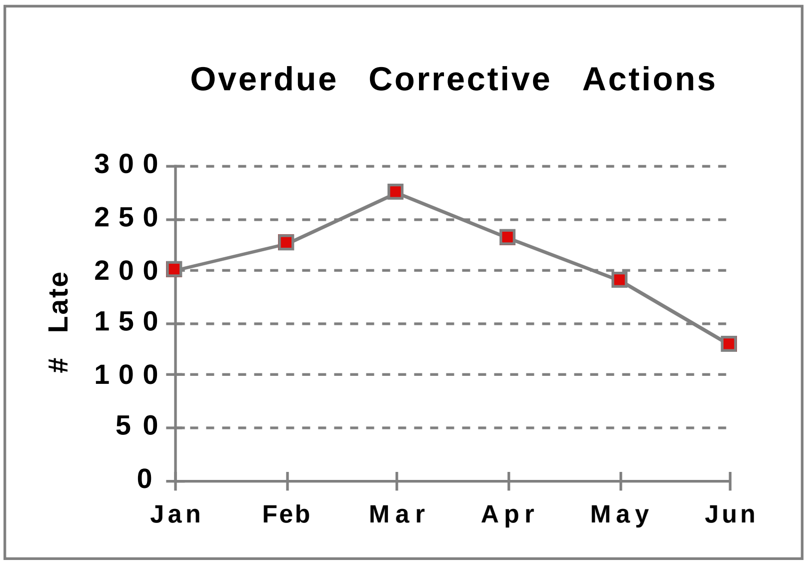


Figure 2.5
Is there a trend over time?
A commonly used approach

We often look at information to determine if there is a trend over time. Figure 2.5 shows an example of a graph commonly used to present data over a period of time. However, looking only at the total late items over time provides limited information. A more meaningful approach might be to look at the overdue rate, which allows you to factor in changes in both the number of open actions and the number that are late. This could be represented by the number of late corrective actions divided by the total number of open corrective actions, such as in Figure 2.6.

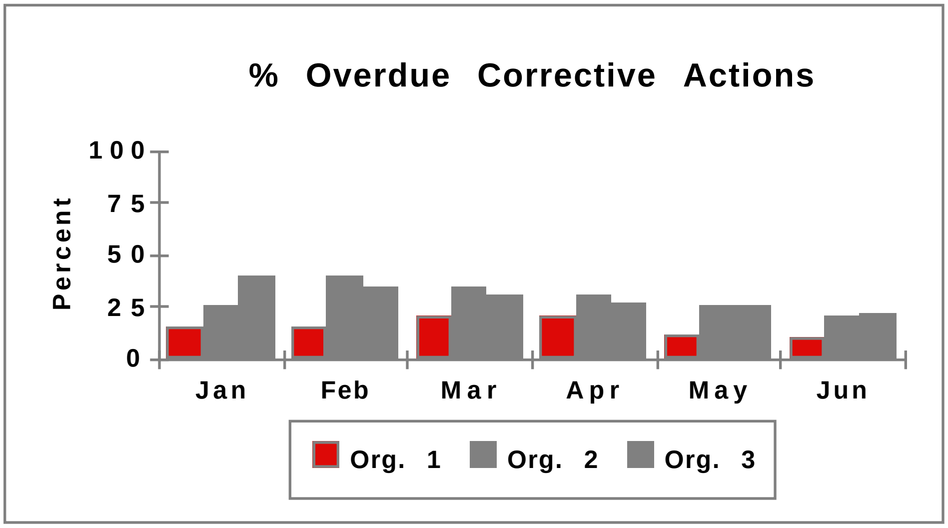


Figure 2.6
Is there a trend over time?
Same data, more information

Figure 2.6 uses the same data as Fig. 2.5, but provides more information by presenting the data differently. The combination graph shows both trends in the overall rate and the individual organizations' rates over time. Apply statistical analysis techniques to determine the presence and significance of any trends. Evaluate individual components of the rate (numerator and denominator) to determine which organization is influencing the overall rate the most.

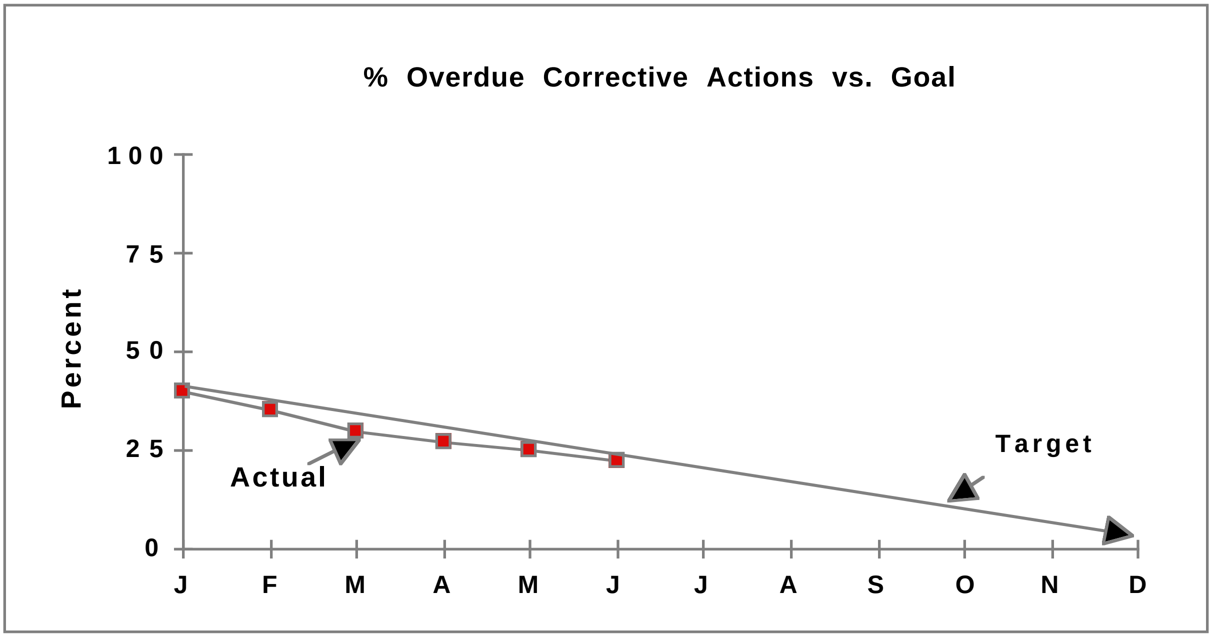


Figure 2.7
Progress toward a defined target

If targets are used, they should be realistic and achievable. The graph shown by itself in Figure 2.7 infers that the target will be met.

A control chart, as shown in Figure 2.8 for example, may lead you to question the assumption that the defined target will be met. Different types of actions are needed to influence the overall totals for systems in control versus systems out of control.

Notice how axis scale selection can significantly influence the impression given. Additionally, horizontal grid lines can make control lines difficult to read.

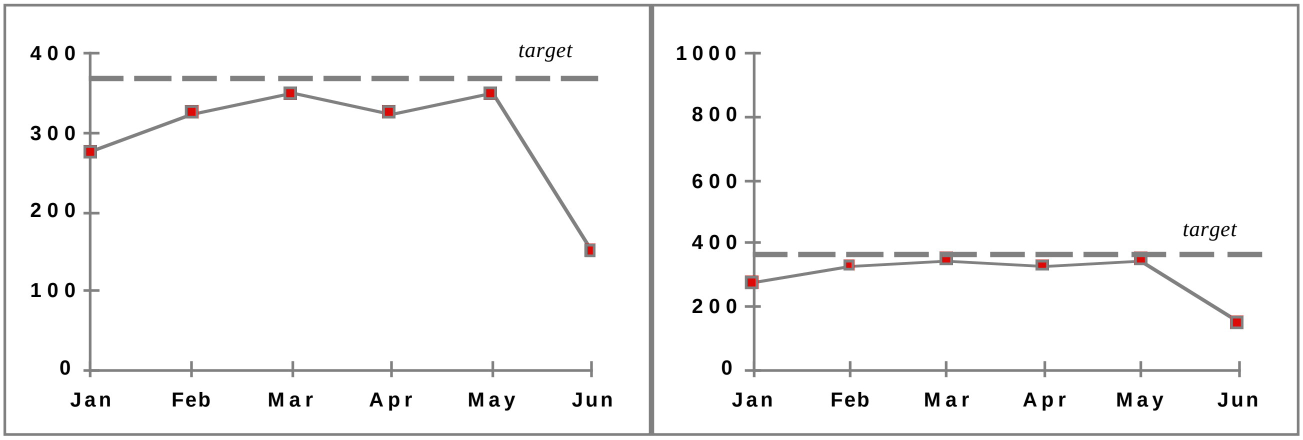


Figure 2.8
Should I take any action??
What kind of action?
System stability must be considered

A chart such as the one shown in Figure 2.9 will help you determine where to focus attention to have the most impact on the overall rate. In this chart, consideration is given to both components of the overall rate to determine what contributes the most to the total.

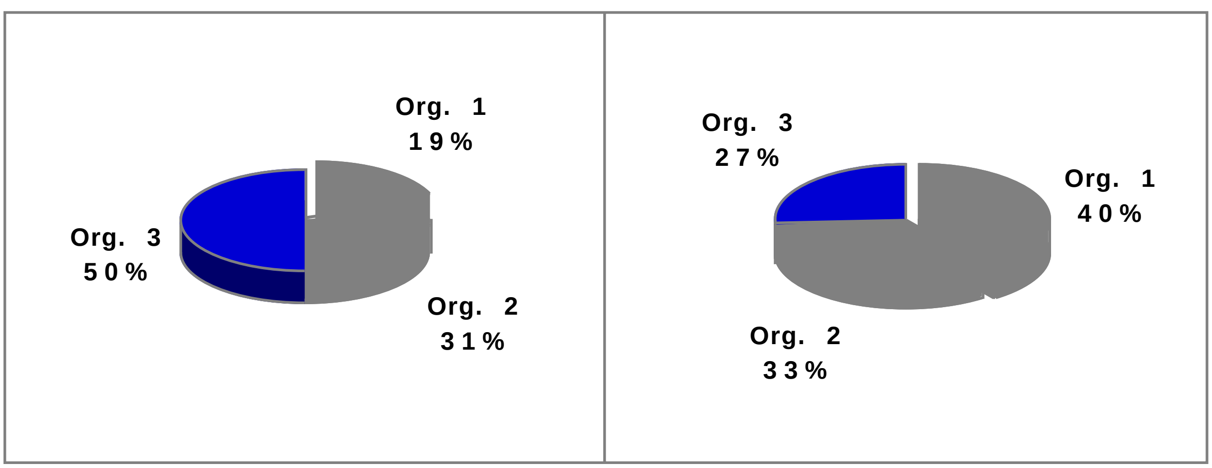


Figure 2.9
What contributes the most to the total?
Focus on the vital few

The graph shown in Figure 2.10 tells you whether high and/or medium priority actions are dominating the overdue items. It also shows historical trends for overdue items for each priority level and for the total overdue. If your presentation is in color, you can choose traditional colors to indicate priority levels (red showing danger for high priority overdue items, yellow showing warning for medium priority, and green indicating low priority).

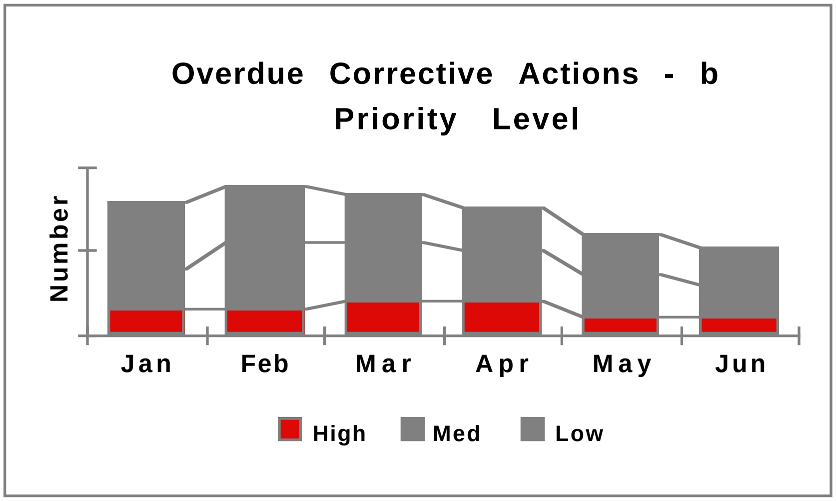


Figure 2.10

Are we focusing on the highest priority actions?

Focus on the critical areas

Choosing the Right Chart Type

There are a few universal rules about which chart type best portrays any given set of data, and in many cases the same data set can be shown many different ways. The hard part is determining which chart type emphasizes the point you are trying to make or puts the right "spin" on the data. The following provides some general comments on different chart types.

Vertical bar chart: Vertical bar charts are used to show how values change over time. They are typically used for a limited time series (i.e., just a few years, quarters, months, or whatever time period you are working with). Vertical bar charts are good for handling multiple series for comparison purposes.

Stacked vertical bar chart: Stacked vertical bar charts convey the same information as ordinary vertical bar charts, but allow you to display subelements which contribute to the overall bar. This may be helpful in understanding changes from one period to another.

Vertical line chart: Vertical line charts are best for showing changes in a group of values over longer periods of time. They are also recommended if you are displaying several groups of data simultaneously. Control limits are often included in vertical line charts to evaluate variability.

Horizontal bar chart: Horizontal bar charts are best for simple comparisons of different individual values at one time. A vertical bar, line, area or 3-D riser chart would be more beneficial if you want to evaluate change over time.

Pie chart: Pie charts are often the best way to portray the contribution of parts to a whole. They are used to show a "snap-shot" at a specific time.

Scatter chart: Scatter charts show the correlation of two sets of numbers by plotting where the variables intersect. Scatter charts are useful when the coordinates on the horizontal scale, often time intervals, are irregular.

Histogram: Histograms show the frequency of the values in a set of data. Data is plotted in increasing or decreasing order based on the frequency count for each data value.

Chart Design: A Few Tips and Hints

The charting area is the focal point of the chart. The graphical, dramatic representation of numbers as bars, risers, lines, pies, and the like is what makes a chart so powerful. So make your charting area as prominent as possible without squeezing other chart elements off the page. If you can still get your point across without footnotes, axis titles, or legends, do so to make the charting area bigger. However, remember that the document needs to communicate enough information to be a stand-alone document. The following is a list of tips to keep in mind when designing your chart.

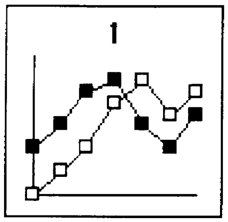
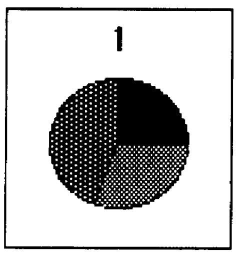
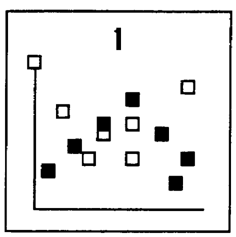
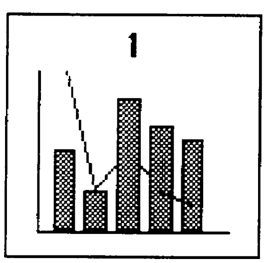
- ***Less is more:*** Do not try to put too many series in a chart. Line charts are especially intolerant of overcrowding. More than three or four lines, particularly if the lines follow much the same direction, is visually confusing. The only exception to this rule is creating a line chart of several series that people would not expect to be similar.
- ***Group bars to show relationships:*** Group bars together tightly if you are trying to suggest that they belong together. If you are showing a group of bars over a series of years, for example, it makes sense to cluster the bars for each year and leave a little extra space between years. If there is no need to do this with your chart data, put more space between your bars and make them a little wider so they are easier to see.
- ***Add definition with black outlines:*** Give the bars in bar charts, the slices in pie charts, and the risers in 3-D charts a little definition by making their outlines black, or a dark, brilliant color. If you are making your chart into a slide, the people at the back of the room will appreciate being able to distinguish the elements.

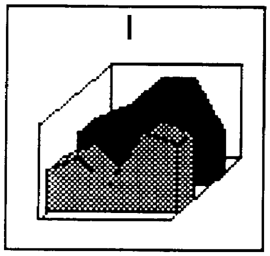
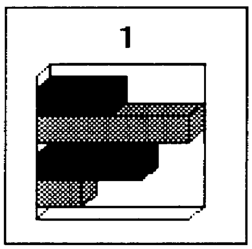
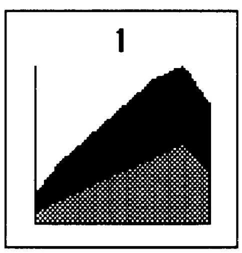
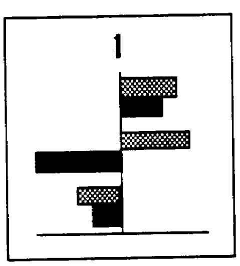
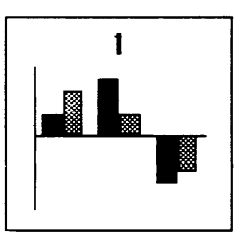
- ***Use grids in moderation:*** When using grid lines in your charting area, use only as many as are needed to get an approximate idea of the value of any given data point in the chart. Too many grid lines create visual clutter. Balance horizontal and vertical grid lines so that the rectangles they create are not too long and narrow or tall and narrow. Use soft colors, such as gray, for grid lines. Once you have defined the color and weight of the grid lines, make sure the chart frame (the frame around the charting area) is black or a dark, brilliant color and heavier than the grid lines.
- ***Choose colors carefully:*** When choosing colors, use your company's corporate colors where possible and appropriate. Failing that, you can use software-supplied templates or color wheels. Also consider where your chart will appear. If it is going to be part of a computer screen show or a slide presentation in a large room, use strong, coordinating colors that attract attention and help the people at the back of the room distinguish the individual series. However, if it is going in a publication where it will be examined at close range, keep the colors softer so you do not overwhelm the reader.
- ***Limit use of typefaces:*** Use one typeface, or at most two, on each chart, and use the same size and weight for similar elements such as the axes and legend text. A recommended setting for these is in 12 to 18 points and bold. If you use the bold and italic fonts in a typeface, as well as different sizes, you can generate enough typographic variety without going outside that type family.
- ***Choose legible typefaces:*** Pick a typeface that looks clear in smaller sizes and in bold, especially if your chart is to be printed in a small size in a publication, or if it will be viewed by a large audience in a big room. If your title is big enough, you can use just about any typeface for it, and it will be legible. However, for legend text, axes, footnotes and the like, take more care. Use faces that are neither too light nor too heavy.
- ***Set type against an appropriate background:*** Be careful about the background behind your type. Some color combinations, such as pink or violet type and a medium or dark blue background, could make your audience feel a little dizzy. If you are using a dark background color, your type must be bright enough to be readable; it should not look as if the background is trying to "swallow it up." If you are using light type on a dark background, use a bold weight, especially with smaller type sizes. Complex fill patterns in the background can also make type hard to read, particularly smaller items like legend text and axis scales.
- ***Use pattern fills with moderation:*** Many charting software packages can create just about any kind of color combination or fill pattern you can imagine. But do not become carried away with color and patterns without thinking about your output device. Sophisticated fill patterns take up more disk space and take longer to print on color printers.

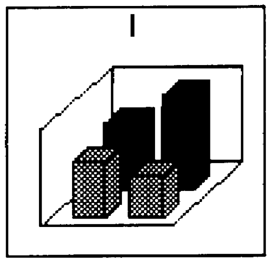
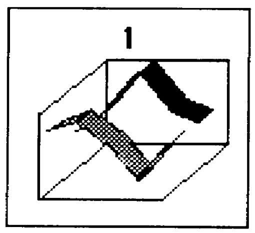
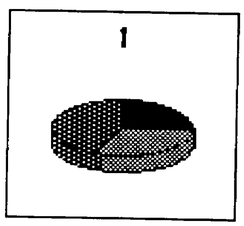
Sample Charts

Table 2.1 provides sample charts that may be helpful when choosing the appropriate chart type for your presentation.

Table 2.1 Sample Charts

	**LINE** Shows trends or changes in data over a period of time; similar to an area chart, but emphasizes time flow and rate of change, rather than amount of change.
	**PIE** Shows the relationship or proportions of parts to a whole (always contains just one data series); good for highlighting a significant element.
	**XY (Scatter)** Shows the relationship or degree of relationship between the numeric values in different groups of data; useful for finding patterns or trends and for determining whether variables are dependent upon or affect one another.
	**COMBINATION** Shows related data that are measured in different units (up to four axes can be used in a combination chart); combines different data to show comparisons and relationships that might not otherwise be recognized.

	**3-D AREA** Shows a 3-D view of an area chart, emphasizes the sum of plotted values, and separates data series into distinct rows to show differences between the series.
	**3-D BAR** Shows a 3-D view of a bar chart; similar to a column chart, but categories are organized vertically instead of horizontally.
	**AREA** Shows the relative importance of values over a period of time; similar to a line chart, but emphasizes the amount of change (magnitude of values) rather than the rate of change.
	**BAR** Shows individual figures at a specific time or draws comparisons between items, but not to a whole; similar to a column chart, but categories are organized vertically instead of horizontally, placing less emphasis on time flow.
	**COLUMN** Shows variation over a period of time or draws comparison between items, but not to a whole; horizontal orientation suggests time flow more than a bar chart.

	**3-D COLUMN** Shows a 3-D view of a column chart; emphasizes comparison of data points along two axes - a category axis and a data series axis - so that you can compare data within a data series more easily and still view data by category.
	**3-D LINE** Shows lines in a line chart as 3-D ribbons; makes individual lines easier to view, particularly when they cross, while still showing all data series in one chart for comparison.
	**3-D PIE** Shows a pie chart with height to the slices; places additional emphasis on data values that are in front.

Simplified Graph/Report Generation

Spreadsheet and database software can be used to generate pareto charts, bar charts, pie charts, and scatter diagrams. The choice of which software to use is often based on personal preference or company policy.

However, software for more complex analyses and presentation beyond that performed by common spreadsheet and database software packages can be difficult to find. A comprehensive list of software used for data acquisition, data presentation, statistical analysis, and other subjects related to quality assurance and quality control is provided in the annual Quality Progress Software Directory produced by the American Society for Quality Control (ASQC). The 1995 report, published in March 1995, listed over 500 software packages. There are two parts to the annual Quality Progress Software Directory:

- A two-dimensional matrix lists each software package and indicates its applicability across 19 categories, such as calibration, data acquisition, and management.

- An index of each of the software packages (alphabetical by company) that includes a brief description of the software, hardware requirements, and price. Included in the description are company telephone and fax numbers and addresses, so the company can be contacted directly for more information.

The annual ASQC Quality Progress Software Directory can be obtained by writing to: ASQC Quality Press, P.O. Box 3005, Milwaukee, WI 53201-9488; or by telephoning 1-800-248-1946.

Appendix A

Glossary of Terms

Glossary of Terms

Note: The following glossary was compiled from various documents used within the Department of Energy. Where shown, the number in parentheses indicates the associated reference document (see page A-15).

A

Acceptance

The decision that an item, process, or service conforms to specified characteristics defined in codes, standards, or other requirement documents. (3)

Accountability

Responsibility for an activity, accompanied by rewards and recognition for good performance, and adverse consequences for performance that is unreasonably poor. (2)

Activity

Actions taken by a program or an organization to achieve its objectives. (2)

Assessment

An all-inclusive term used to denote the act of determining, through a review of objective evidence and witnessing the performance of activities, whether items, processes, or services meet specified requirements. Assessments are conducted through implementation of the following actions: audits, performance evaluations, management system reviews, peer reviews, or surveillances, which are planned and documented by trained and qualified personnel. (5)

Assessment/Verification

The act of reviewing, inspecting, testing, checking, conducting surveillances, auditing, or otherwise determining and documenting whether items, processes, or services meet specified requirements. DOE Order 5700.6C uses the terms assessment and verification synonymously. This order defines these terms by who is performing the work; assessments are performed by or for senior management, and verifications are performed by the line organization. (9)

A

Audit

A planned and documented activity performed to determine by investigation, examination, or evaluation of objective evidence the adequacy of and compliance with established procedures, instructions, drawings, and other applicable documents and the effectiveness of implementation. Audit should not be confused with surveillances or inspection activities performed for the sole purpose of process control or product acceptance. (3)

Also, a systematic check to determine the quality of operation of some function or activity. Audits may be of two basic types: (1) performance audits in which quantitative data are independently obtained for comparison with routinely obtained data in a measurement system, or (2) system audits of a qualitative nature that consist of an on-site review of a laboratory's quality system and physical facilities for sampling, calibration, and measurement. (5)

B

Baseline

The current level of performance at which an organization, process, or function is operating. (2)

Benchmarking

To measure an organization's products or services against the best existing products or services of the same type; the benchmark defines the 100 percent mark on the measurement scale. (2)

Also, the process of comparing and measuring an organization's own performance on a particular process against the performance of organizations judged to be the best of a comparable industry. (3)

Bottom Up

Starting with input from the people who actually do the work and consolidating that input through successively higher levels of management. (2)

C

C-Chart

Also referred to as "count" charts, these are used in dealing with counts of a given event over consecutive periods of time. Many of the initial DOE performance indicators involve counts of events for consecutive calendar year quarters, making c-chart analysis of these indicators appropriate. (1)

Cascaded Down

Starting with a top level of management, communicated to successively lower levels of management and employees.

Characteristics

Any property or attribute of an item, process, or service that is distinct, describable, and measurable.

Common Causes of Variation

Indicated by statistical techniques, but the causes themselves need more detailed analysis to be fully identified. Common causes of variation are usually the responsibility of management to correct, although other people directly connected with the process sometimes are in a better position to identify the causes and pass them on to management for correction. (1)

Continuous Improvement

The undying betterment of a process based on constant measurement and analysis of results produced by the process and use of that analysis to modify the process. (2)

Also, where performance gains achieved are maintained and early identification of deteriorating environmental, safety, and health conditions is accomplished. (1)

Control Charts

The two main uses for these charts are to monitor whether the system is stable and under control (to warn of changes), and to substantiate results from changes introduced into the system (to confirm positive results). (1)

C

Control Lines/Limits

The “limit lines” drawn on charts to provide guides for evaluation of performance indicate the dispersion of data on a statistical basis and indicate if an abnormal situation (e.g., the process is not in control or special causes are adversely influencing a process in control) has occurred. (1)

Also, two control limits are the statistical mean (average) plus three times the standard deviation and the statistical mean minus three times the standard deviation. (5)

Corrective Action

Measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition. (5)

Criteria

The rules or tests against which the quality of performance can be measured. They are most effective when expressed quantitatively. Fundamental criteria are contained in policies and objectives, as well as codes, standards, regulations, and recognized professional practices that DOE and DOE contractors are required to observe. (3)

D

Data

Factual information, regardless of media and format, used as a basis for reasoning, discussion, or calculation. (5)

Data Reduction

Any and all processes that change either the form of expression or quantity of data values or numbers of data items. (5)

D

Data Validation

The systematic effort to review data in order to ensure acceptable data quality. A systematic process for reviewing a body of data against a set of criteria to provide assurance that the data are adequate for their intended use. A systematic review process conducted to confirm the degree of truth in an analytical measurement. The process includes the review of all pertinent sample analysis and quality assurance/quality control (QA/QC) data compared to recognized standards or criteria. Data validation consists of data editing, screening, checking, auditing, verification, certification, and review. The "screening" process may be done by manual and/or computer methods, and it may use any consistent techniques, such as sample limits, to screen out impossible values or complicated acceptable relationships of the data with other data. (5)

Distribution Charts

Data are divided into categories of interest (e.g., root causes or reporting elements). It is then graphed as a stacked bar chart to compare the relative contribution of each category to the total. (1)

Distribution Diagram

A block diagram showing data in order of contribution to the total. The horizontal axis of the Distribution Diagram lists the most frequent item in the performance indicator population on the left and progresses in descending order to the least frequent item on the extreme right. The cumulative total of the items is reflected above the block at each interval. By structuring the data in this form, the Distribution Diagram provides a focus on the largest contributing items in each performance indicator. (1)

G

Goal

The result that a program or organization aims to accomplish. (2)

Also, a statement of attainment/achievement, which is proposed to be accomplished or attained with an implication of sustained effort and energy. (3)

G

Guideline

A suggested practice that is not mandatory in programs intended to comply with a standard. The word "should" or "may" denotes a guideline; the word "shall" or "must" denotes a requirement. (3)

I

Item

An all-inclusive term used in place of the following; appurtenance, sample, assembly, component, equipment, material, module, part, structure, subassembly, subsystem, unit, documented concepts, or data. (7,8)

L

Lessons Learned

A summary intended for the beneficial use of the receiver, of conditions detected at any facility that may include techniques and actions employed to correct the condition. DOE Order 5000.3B suggests that facilities use the Occurrence Reporting and Processing System (ORPS) to identify good practices and lessons learned. (8)

A "good work practice" or innovative approach that is captured and shared to promote repeat application. A lesson learned may also be an adverse work practice or experience that is captured and shared to avoid recurrence. (11)

Limit Lines

Lines drawn on charts to provide guides for evaluation of performance. (1)

Line Manager

Includes all managers in the chain of command from the first-line supervisors to the top manager. (5)

M

Management

All individuals directly responsible and accountable for planning, implementing, and assessing work activities. (5)

Mean

The arithmetic average of a set of numbers. (5)

Measurement

The quantitative parameter used to ascertain the degree of performance. (2)

Metric

Used synonymously with measurement. (2)

O

Objective

A statement of the desired result to be achieved within a specified time. (3)

Occurrence

An unusual or unplanned event having programmatic significance such that it adversely affects or potentially affects the performance, reliability, or safety of a facility. (3)

Outliers

Data that fall outside the control lines. (1)

P

Parameter

A quantity that describes a statistical population or any of a set of physical properties whose values determine the characteristics or behavior of something. (13)

Pareto Analysis

A type of analysis (also known as "distribution diagram") that focuses attention on areas that have the most influence on the total, facilitating the assignment of resources in order to prioritize improvement efforts. (1)

Performance Based

Being associated with the outcome rather than the process. (2)

Performance Goal

The target level of outcomes expressed as a tangible, measurable objective against which actual achievement can be compared. (2)

Performance Indicator(s)

A parameter useful for determining the degree to which an organization has achieved its goals. (2)

Also, a quantifiable expression used to observe and track the status of a process. (3)

Also, the operational information that is indicative of the performance or condition of a facility, group of facilities, or site. (6)

Performance Measure(s)

Encompassing the quantitative basis by which objectives are established and performance is assessed and gauged. Includes performance objectives and criteria (POCs), performance indicators, and any other means that evaluate the success in achieving a specified goal. (3)

Also, the quantitative results used to gauge the degree to which an organization has achieved its goals. (2)

P

Performance Objectives and Criteria (POC)

The quantifiable goals and the basis by which the degree of success in achieving these goals is established. (3)

Periodicity

Data that show the same pattern of change over time, frequently seen in cyclical data. (1)

Q

Quality

A degree to which a product or service meets customer requirements and expectations. (9)

Quality

Actions that provide confidence that quality is achieved. (9)

Quality Management

The management of a process to maximize customer satisfaction at the lowest cost. (2)

R

Root Cause

The basic reasons for conditions adverse to quality that, if corrected, will prevent occurrence or recurrence. (3)

Root Cause Analysis

An analysis performed to determine the cause of part, system, and component failures. (10)

R

Runs

Series of data points above or below the central line. A “run” of seven consecutive points or 10 out of 11 points indicates an abnormality. (1)

S

Self-Assessment

A systematic evaluation of an organization's performance, with the objectives of finding opportunities for improvement and exceptional practices; normally performed by the people involved in the activity, but may also be performed by others within the organization with an arms-length relationship to the work processes. (2)

Senior Management

The manager or managers responsible for mission accomplishment and overall operations. For DOE, DOE Cognizant Secretarial Office, and Field/Operations Office Managers are responsible for mission accomplishment and overall operations. For DOE management and operating (M&O) contractors, the General Manager, or similar top position is responsible for mission accomplishment and overall performance in accordance with the requirements of their contracts or other agreements. (9)

A continuous process of comparing performance with desired objectives to identify opportunities for improvement. Assessments are conducted by individuals, groups, or organizations relating to their own work. (3)

Site

The area comprising or within a DOE laboratory or complex with one or more DOE facilities.

Situation Analysis

The assessment of trends, strengths, weaknesses, opportunities, and threats, giving a picture of the organization's internal and external environment to determine the opportunities or obstacles to achieving organizational goals; performed in preparation for strategic planning efforts. (2)

S

Special Cause of Variation

Also known as assignable causes of variation. A cause that is specific to a group of workers, a particular worker, a specific machine, or a specific local condition. Examples are water in a gasoline tank or poor spark plugs. (12)

Stakeholder

Any group or individual who is affected by or who can affect the future of an organization-customers, employees, suppliers, owners, other agencies, Congress, and critics. (2)

Standard Deviation

A statistic used as a measure of the dispersion in a distribution, the square root of the arithmetic average of the squares of the deviations from the mean. (5)

Strategic Planning

A process for helping an organization envision what it hopes to accomplish in the future, identify and understand obstacles and opportunities that affect the organization's ability to achieve that vision, and set forth the plan of activities and resource use that will best enable the achievement of the goals and objectives. (2)

Surveillance

An act of monitoring or observing a process or activity to verify conformance to specified requirements.

T

Task

A well-defined unit of work having an identifiable beginning and end that is a measurable component of the duties and responsibilities of a specific job.

Top Down

To start with the highest level of management in an organization and propagating through successively lower levels of the organization. (2)

Total Quality Management (TQM)

A management philosophy that involves everyone in an organization in controlling and continuously improving how work is done in order to meet customer expectations of quality. (2)

Also, the management practice of continuous improvement in quality that relies on active participation of both management and employees using analytical tools and teamwork. (4)

Trend Analysis

A statistical methodology used to detect net changes or trends in levels over time. (5)

An analysis of parts, systems, component surveillances, performance, and operating histories to determine such things as failure causes, operational effectiveness, cost-effectiveness, and other attributes. (10)

Continual rise or fall of data points. If seven data points rise or fall continuously, an abnormality is considered to exist. (1)

U

U-Chart

Also referred to as “rate” charts, deal with event counts when the area of opportunity is not constant during each period. The steps to follow for constructing a u-chart are the same as a c-chart, except that the control limits are computed for each individual time period since the number of standards varies. (1)

Unit of Measure

A defined amount of some quality feature that permits evaluation of that feature in numbers. (4)

V

Validation

A determination that an improvement action is functioning as designed and has eliminated the specific issue for which it was designed. (4)

Also, to determine or test the truth or accuracy by comparison or reference. (5)

Verification

A determination that an improvement action has been implemented as designed. (4)

Also, the process of evaluating hardware, software, data, or information to ensure compliance with stated requirements. The act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services, or documents conform to specified requirements. (5)

Vertical Axis Scaling

The following general criteria should be applied to the depiction of trend data on control charts: (1) scale should be set so that the chart can be quickly understood, and (2) data together with the limit lines should span at least half of the vertical axis. (1)

W

Work

A process of performing a defined task or activity; e.g., research and development, operations, maintenance and repair, administration, software development and use. (5)

Also, the process of performing a defined task or activity, for example, research and development, operations, maintenance and repair, administration, software development and use, inspection, safeguards and security, data collection, and analysis. (9)

X

X-Chart

Involve the analysis of individual measured quantities for indications of process control or unusual variation. The standard deviation for x-charts (also referred to as individual charts) is calculated using a moving range. (1)

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Appendix B

Performance Measurement Process Case Study

Cominman Company

Company Background

The Communications & Information Management (Cominman) Company has been in business for 20 years, providing, on a national scale, communications and information management services. The company's warehouse, part of the Property Management Division, provides storage and excess services for company property in the custody of 25 divisions. The warehouse department has a staff of ten personnel: a warehouse supervisor, four property specialists, one property clerk, three drivers, and one data entry clerk. The warehouse makes approximately 50 pickups per week at company locations that include remote areas.

Process Description

To request services from the warehouse, a division customer telephones the warehouse property clerk requesting a pick-up of property for storage or excess. The customer provides the clerk with the property identification number or serial number for each piece of property to be picked up and brought to the warehouse. There are typically one to twenty pieces of property per pick-up. If a pick-up date is not requested by the customer, a date will be provided to the customer by the property clerk. The property clerk completes a property transfer form, which reflects the date of the call, customer's name, division, location, property identification number and date scheduled for pick-up. A goal of the warehouse is not to exceed three days from the date of the call to the time of the pick-up, unless a special date has been requested by the customer. The warehouse receives approximately ten calls per week for pick-ups on special dates. On the scheduled pick-up day, the assigned driver takes the transfer form to the designated location. The driver is responsible for ensuring each piece of property matches the property identification numbers or serial numbers listed on the transfer form. After the truck is loaded, the driver obtains the customer's signature on the transfer form. The driver also signs the form and provides the customer with a copy acknowledging receipt.

The driver returns to the warehouse, where a property specialist annotates the date on the transfer form, unloads the truck, and provides the data entry clerk with the signed copies of the form. The data entry clerk enters the information from the transfer form into the automated accountable property system and the transfer forms are then filed. The data entered are intended to transfer accountability from the division customer to the warehouse.

At the end of the month, division customers receive a computer-generated property list indicating the accountable property in their location for which they are responsible. The customer reviews this report for accuracy. If the customer records do not agree with this listing, the customer calls the warehouse supervisor who logs the complaint with the following information: date of the call, division name, property location, date of the property list, and discrepancies. The supervisor assigns a property specialist to resolve these discrepancies.

Issue

The warehouse supervisor had recently attended a Quality Leadership Seminar during which time a workshop was conducted on Performance Measurements. During a review of the telephone complaint logbook, a supervisor realized that customer complaints were beginning to increase. The supervisor felt that developing Performance Measurements for the warehouse process would be beneficial. Why?

- To ensure that customer requirements are being met. How do we know that we are providing the service that our customers require?
- To ensure an understanding of the process by all warehouse employees.
- To ensure we are meeting value-added objectives or that we are being effective and efficient.
- To ensure decisions are based on fact, not on emotion.
- To show where improvements need to be made. Where can we do better? How can we improve?

The Quality Leadership Seminar stressed the value of a team-based approach when solving problems or establishing performance measures. The supervisor, therefore, decided to involve her entire staff in developing performance measurements for their process. The supervisor was the team leader; a trained facilitator was requested to assist them; and the team elected the property clerk as the secretary. They were ready to start.

> *The group is responsible for many processes, such as delivering property, conducting inventory, etc. For purposes of simplicity, this case study only addresses the process of picking up property or storage.*

Step 1: Identify Process

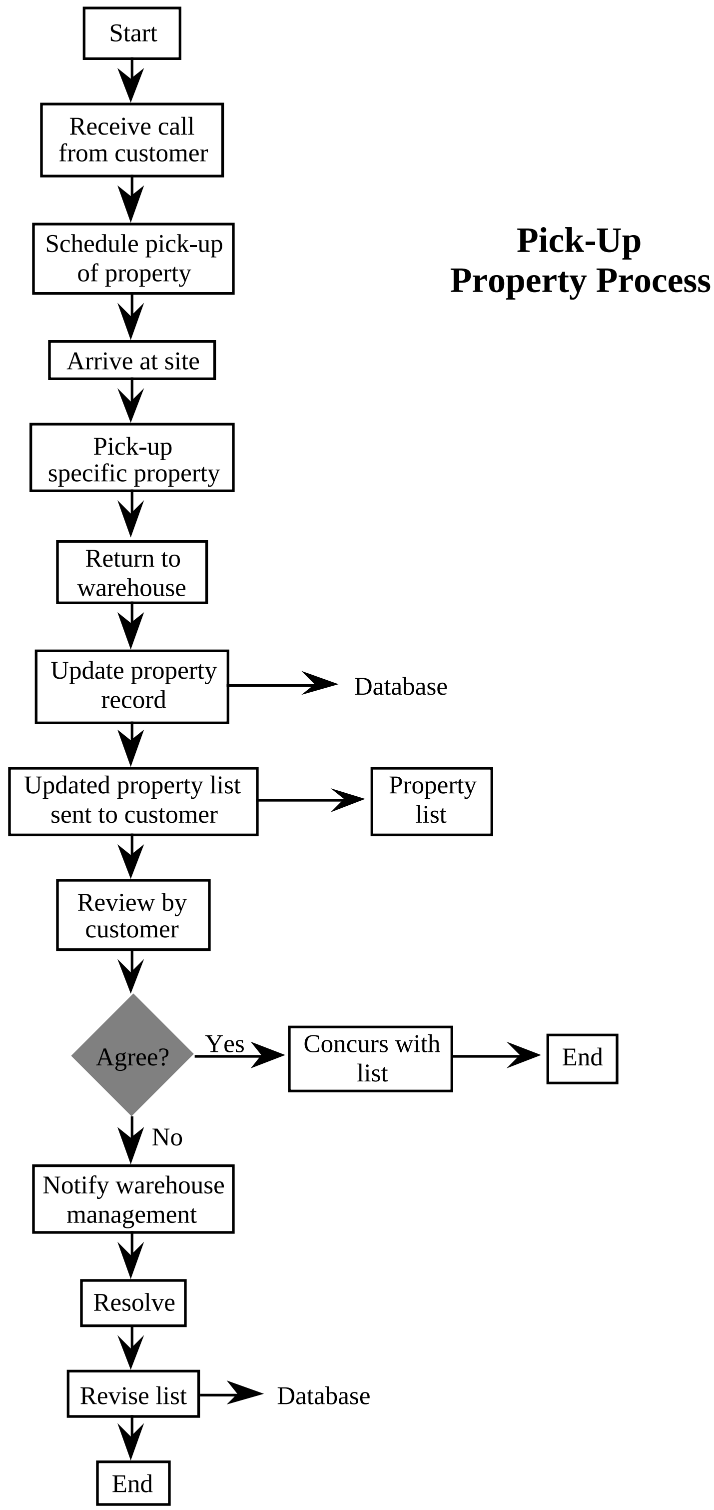
The supervisor thought, "Where do we begin? What is the very first thing we have to do?"

Well first, she thought, we need to define our current process so all my team members can share a common understanding of what we do. The tools? Brainstorming and Flow Diagramming.

- Brainstorming is a group technique for generating new, useful ideas. It uses a few simple rules for discussion that increase the chances for originality and innovation.
- Flow diagramming is a method of graphically describing the activities and sequence that we perform to produce some output in a process. Before you try to control a process, you must understand it. Flow diagramming is basic to understanding our work and the way we function as a whole.

So the supervisor gathered the department together, and they began to document all the steps in their work process. Post-it sheets were all over the wall! What started their work? A telephone call from a customer. What ended their process? An accurate property list. They wrote down all the related activities between these two boundaries (input/output) in the order in which they occurred. The department realized that the flow diagramming session was certainly a time of "discovery." Contrary to what they thought, they did not proceed quickly and they did not proceed methodically through their process from beginning to end, capturing every detail the first time through. A lot of discussion took place. Finally, the department reviewed the completed diagram to see if they had missed any activities or decision points and verified the accuracy of the flow diagram. Is this the actual process? Yes, they all agreed. A lot of time was spent on this effort. However, the supervisor was very pleased. "We have an invaluable tool; a map of our process," she stated (Figure B-1). "Now we can start thinking about performance measurements."

Figure B-1
Step 1: Identify Process
Department's process for picking up property

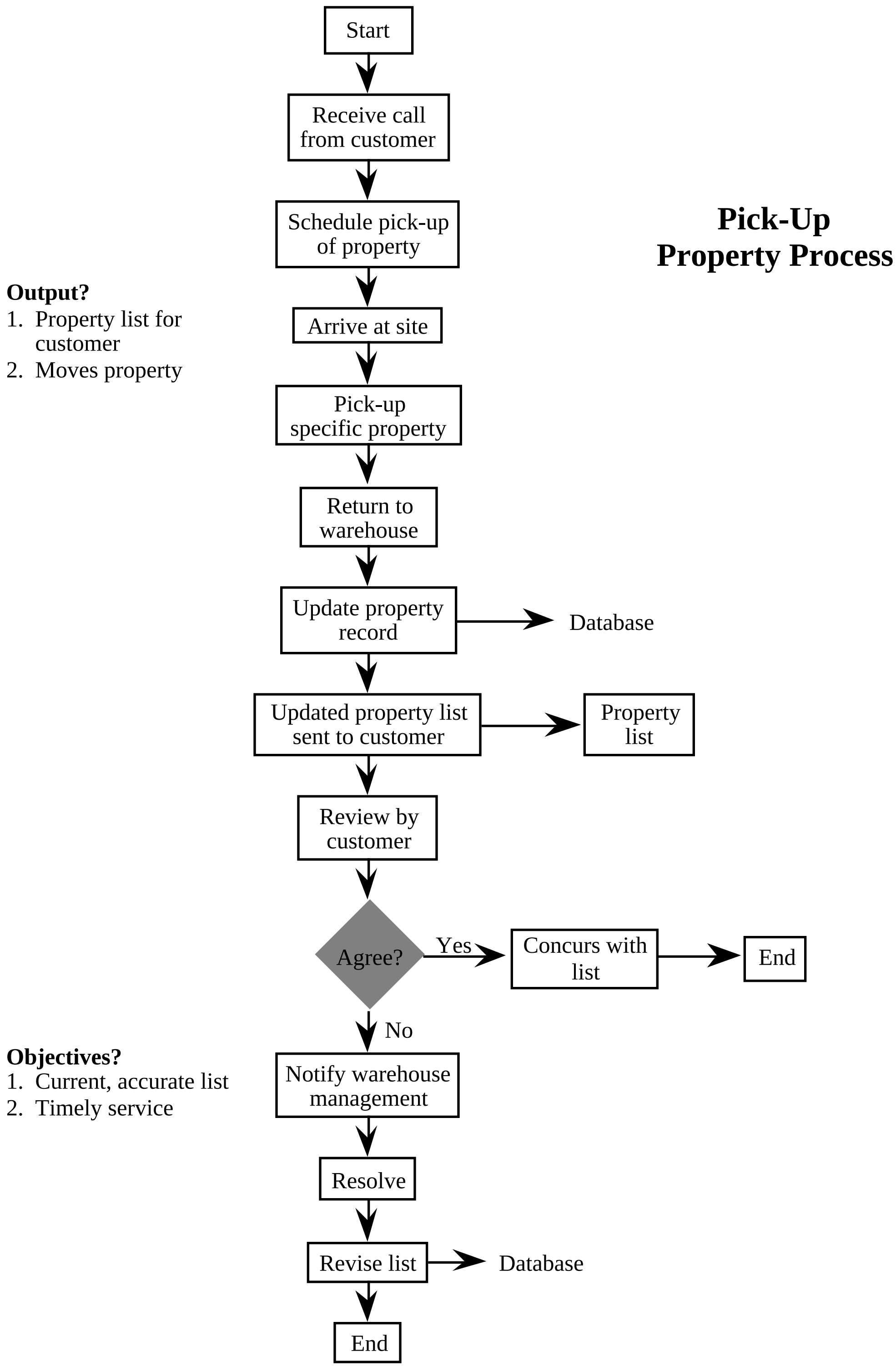


Or can we? The supervisor thought for a moment. She learned in her workshop that performance measurement is better thought of as an overall management system, involving prevention and detection aimed at achieving conformance of the work product or service to our customer's requirements. Performance measurement is primarily managing outcome, and one of its main purposes is to reduce or eliminate overall variation in the work product or process. The goal is to arrive at sound decisions about actions affecting the product or process and its output.

So she asked her department, "What is our product? What is our output?" The department came up with two outputs: (1) a property list for their customer, and (2) removal and storage of company property.

She then told her department that measurements should focus on their customer's needs. They should measure only what is important: Things that impact customer satisfaction, goals given by management, and their own internal objectives. Keeping the customer in mind, she asked her department, "What is the objective of our two outputs?" They responded immediately. Their objectives were (1) a current, accurate property list for our customers; and (2) timely pick up and removal of property. (Refer to flow diagram Figure B-2).

Figure B-2
Step 1: Identify Process - Continued
Department's process for picking up property



Step 2: Identify Critical Activity to be Measured

The next step is determining how objectives will be met.

One of the topics discussed in the Performance Measurement workshop was involving employees in the design and implementation of the measurement system. This gives them a sense of ownership and improves the quality of the measurement system.

The supervisor called her department together again. "We are now ready to identify specific critical activities to set up our control points. Controlling, or keeping things on course, is not something we do in the abstract. Control is applied to a specific critical activity."

She continued to instruct her department that they should examine each activity in the process and identify those that significantly impact total process efficiency and effectiveness. Then they should establish measurements for these critical activities."

> Ask the following: Does it relate, directly or indirectly, to the ultimate goal of customer satisfaction? Every critical activity should.

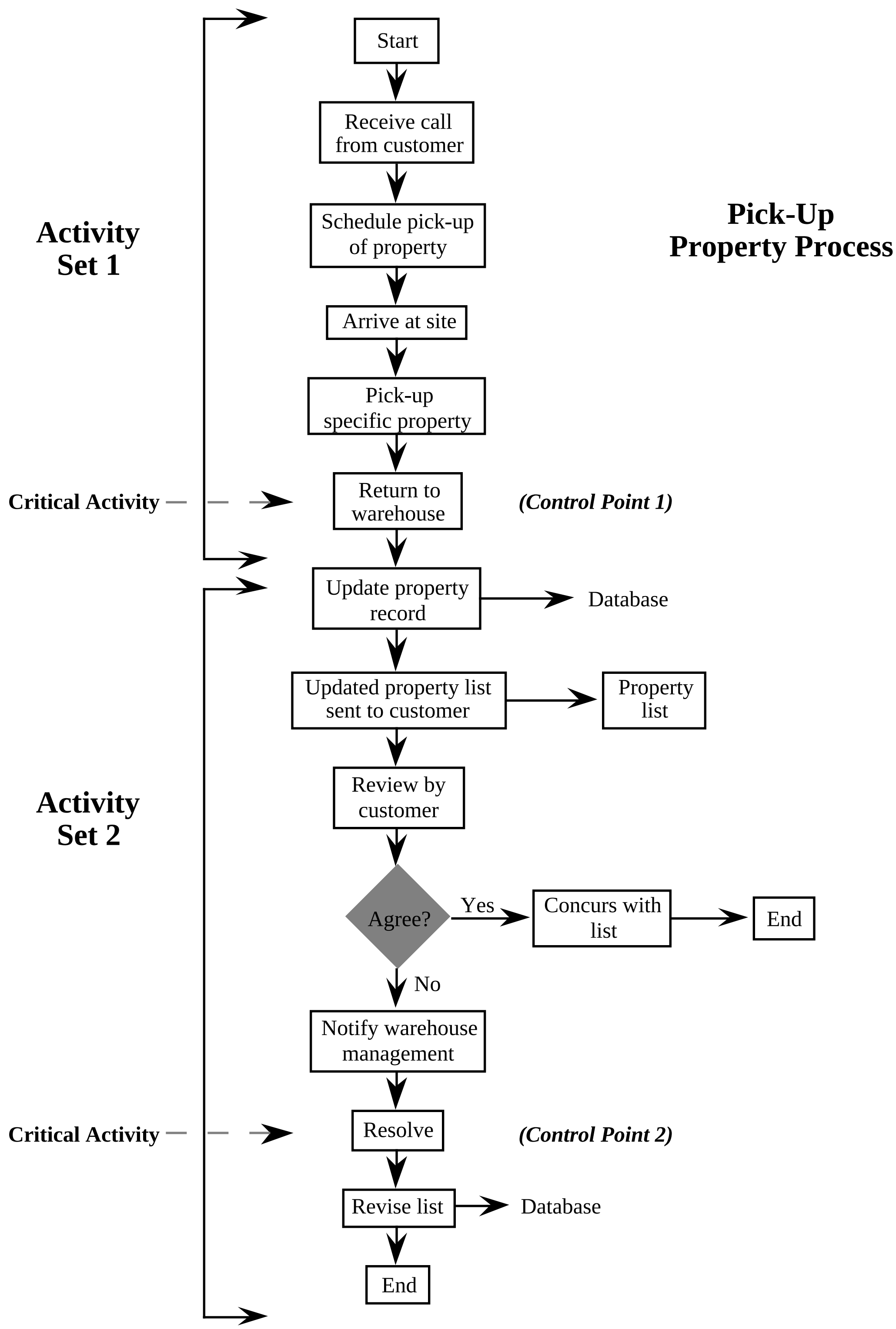
The department began to brainstorm. "Keep focused," the supervisor reminded. "Keep looking at our objectives. How can we accomplish these?" The supervisor stated that as they approached the data collecting step, the key issue was not "how do we collect data?" Rather, the key issue is "How do we generate useful information?" You must learn to ask the right question(s), the supervisor cautioned. "It is crucial to be able to state precisely what it is you want to know about the activity you are going to measure. Without this knowledge, there is no basis for making measurements.

The department thought about this and after some more discussion felt they needed the answers to two questions:

1. How do we know that we are providing the service that our customers require?
2. Where can we do better or improve?

All parties finally agreed upon two sets of critical activities that needed to be watched closely and acted on if performance is less than the desired goal. The reason these were considered critical is they are the sets of activities that produce our outputs (refer back to Figure B-2). Control point 1 is when the driver returns to the warehouse after pick-up. Control point 2 is when a discrepancy on the property report is resolved (Refer to Figure B-3).

Figure B-3
Step 2 - Identify Critical Activity to be Measured



Step 3: Establish Performance Goals or Standards

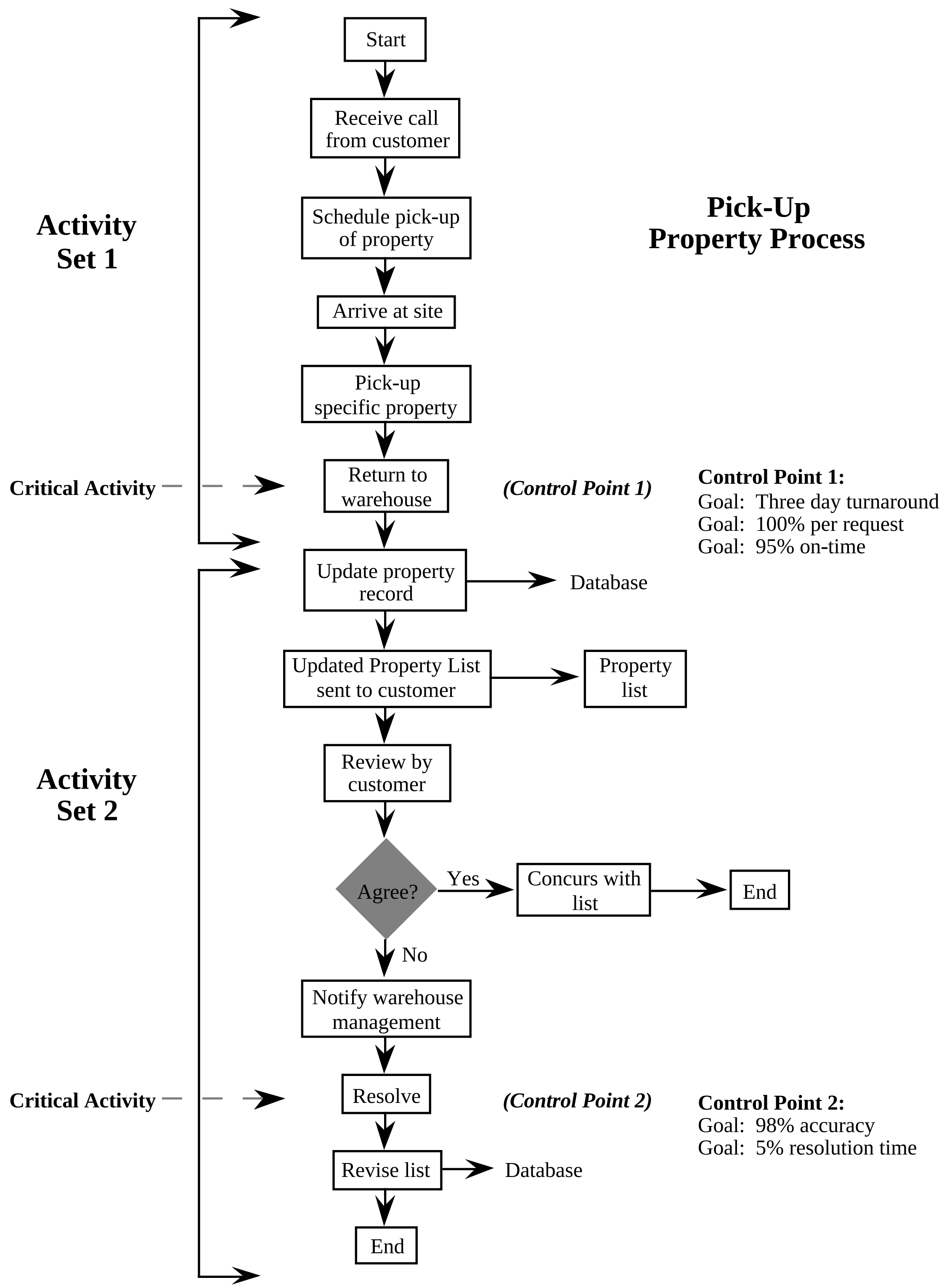
The supervisor was very pleased. "We are moving along quite nicely. Now we are ready to establish a performance goal or standard," she stated. She continued and said that for each control point selected for measurement, it would be necessary to establish a performance goal or standard. She again referred back to her workshop notes. A goal or standard is:

> an "aimed-at" target; an achievement toward which effort is expended. Without a goal or standard, there is no logical basis for making a decision or taking action. Knowledge of performance is not enough; you must have a basis for comparison before you can decide or act.

Because this is the first time the department has ever considered formalizing measurements, they would need to establish some sort of baseline to set goals. The basis for the initial goals chosen were the informal observations made by the department. The department planned to reevaluate the goals in six months.

The department looked at Critical Activity 1, Return to Warehouse. They reviewed their objectives and came up with three goals: (1) three-day turnaround; (2) scheduling pick-up per customer request; and (3) 95% on time pick-ups. For Critical Activity 2, Resolve Discrepancies, they did the same thing and came up with two goals: (1) 98% property list accuracy and (2) no more than 5% of their time-resolving discrepancies. The department was satisfied that these performance goals would produce the output and their corresponding objectives (Refer to Figure B-4). They were now ready to move on to the next major activity.

Figure B-4
Step 3: Establish Performance Goal(s) or Standards



Step 4: Establish Performance Measurement(s)

Again, the supervisor was satisfied with their progress. Now they needed to identify specific performance measures for the two critical activities they identified. The department decided to do some brainstorming to generate potential performance measures. This step took a considerable amount of time, and the team was clearly frustrated.

The supervisor reminded her department that good performance measures exist to aid in understanding how well a process or activity is working or how well a product or service is produced and delivered. “Remember,” she said, “what we measure should help us control and manage our work.” She also reminded them that in addition to identifying performance measures, they must also determine what raw data they will need to collect, find its location, determine what sensors will measure or record the raw data, and decide how often the data will be collected.

The team felt somewhat overwhelmed by what seemed like a difficult task. The supervisor quickly pointed out that for the first time, they would have measurable data that they could track to determine how well they were doing and identify areas for improvement.

The team frequently found themselves asking, “what is it that we really want to know about what we do.” Their supervisor reminded them that since they already had quantifiable goals, they could use these to help determine their performance measures.

Critical Activity 1:

Performance Measure A

One of the goals of the department had always been to perform all property pick-ups in three days or less. The team decided that measuring the number of days elapsed from call to pick-up for all routine requests would be a useful performance measure that could be compared directly to their goal. The raw data needed to construct their performance measure was simply the date of each call for pick-up services and the actual date of pick-up. The data could be retrieved from the Property Transfer form and collected weekly. If 50 regular pick-ups are performed in a week, the team would have 50 measures to plot. The team decided to plot this measure in the form of a histogram, which could be used to display the results of one week’s worth of data. In this way they could display how many deliveries took one day, two days, three days, and so on.

Performance Measure B

The department had already determined that it was very important to make all specially scheduled pick-ups on time. They had already chosen a goal of 100% on-time pick-up for specially scheduled jobs, so they needed a performance measure that would track their results. The team reasoned that a simple performance measure would be the percent of on-time special pick-ups. Since a percent results from the ratio of two numbers, this measure can be shown more clearly as follows:

$$\frac{\text{Number on-time special pick-ups}}{\text{Number scheduled special pick-ups}} \quad \text{X } 100$$

Expressing this performance measure as a ratio gives an indication of what data are needed to actually construct it. In this case, the team would need the number of special pick-ups scheduled for each week and the number performed on time. The Property Transfer form records the scheduled pick-up date and the actual pick-up date.

Performance Measure C

Since the department had a goal that 95% of all pick-ups (without regard to type) would be performed on time, they needed a performance measure to make a comparison. This was rather straightforward, and the team settled on Percent On-Time Pick-Ups. As in the previous performance measure, this measure is the result of a ratio and can be written as:

$$\frac{\text{Number on-time pick-ups}}{\text{Total number of pick-ups}} \quad \text{X } 100$$

In order to make this calculation, the team had to determine what raw data were needed. To calculate the total number of pick-ups, the team noted that they needed to only count the total number of property transfer forms completed each week as this would tell them how many pick-ups were completed. For this performance measure, the number of on-time pick-ups includes both the regular and specially scheduled pick-ups that are performed each week. The teams would have to calculate how many regular pick-ups were on time and how many specially scheduled pick-ups were on time. Again, the property transfer forms record the type of transaction and all dates needed.

Critical Activity 2

Performance Measure A

Another product of the department is the monthly property list, which consists of line items that specify property type, owner, and location. The team had already decided that this list should be at least 98% accurate, and now they needed a performance measure to go assess their work. In this case, the performance measure is the percent of accuracy of the monthly property list. Since this measure results from a ration, it makes sense to write it out the way the calculation is actually performed. Percent accuracy is the percent done correctly error-free and is written as:

$$\frac{\text{Number of error-free line items}}{\text{Total number of line items}} \quad \text{X } 100$$

Written this way, it was obvious to the team what raw data they needed to make this calculation. First, they needed the total number of line items or entries from all of the property lists that they generate each month. This was available in the database and was easily extractable each month. Second, they needed the number of error-free entries for each month. To determine this number, they needed to check the complaint log to find the number of discrepancies that were their fault. The total number of entries minus the discrepancies are the number of error-free line items. Discrepancies that are due to customer error (such as misplacing their own property) do not count against the department.

Performance Measure B

For their final performance measure, the team had already set a goal that they would not spend more than 5% of their time resolving problems resulting from the monthly property list. For their performance measure they chose percent time spent resolving property list problems (time spent by the four property specialists). Again, as a ratio it would be written as:

$$\frac{\text{Total hours spent on resolutions}}{\text{Total hours worked per month}} \quad \text{X } 100$$

The raw data are already spelled out in the numerator and denominator of the performance measure. They consist of the total number of hours the four property specialists spend on problem resolution and the total number of hours they work each month. The sensor to record this did not exist, so the supervisor had the payroll department provide them with a special job number to add to their time card to track time spent resolving property list problems.

The team was pleased with their results (Figure B-5) and was ready to move to the next step.

Step 4: Establish Performance Measurement(s) Summary

Critical Activity 1:

Performance Measure A: Number of days from call to pick-up

Raw Data: Date of call for pick-up services, actual pick-up date

Sensor: Property Transfer Form

Frequency: Weekly

Performance Measure B: % on-time special pick-ups

$$\frac{\text{Number on-time special pick-ups}}{\text{Number scheduled special pick-ups}} \times 100$$

Raw Data: Number of special pick-ups scheduled each week, number on time

Sensor: Property Transfer Form

Frequency: Compiled weekly

Performance Measure C: % on-time pick-ups (for all pick-ups)

$$\frac{\text{Number on-time pick-ups}}{\text{Total number of pick-ups}} \times 100$$

Raw Data: Total number of pick-ups completed, total number on time

Sensor: Property Transfer Form

Frequency: Compiled weekly

Critical Activity 2:

Performance Measure A: % accuracy of monthly report

$$\frac{\text{Number of error-free line items}}{\text{Total number of line items}} \times 100$$

Raw Data: Total number of line items entries generated each month on property list, number of errors detected (used to calculate number error-free)

Sensor: Property List Database, Complaint Log

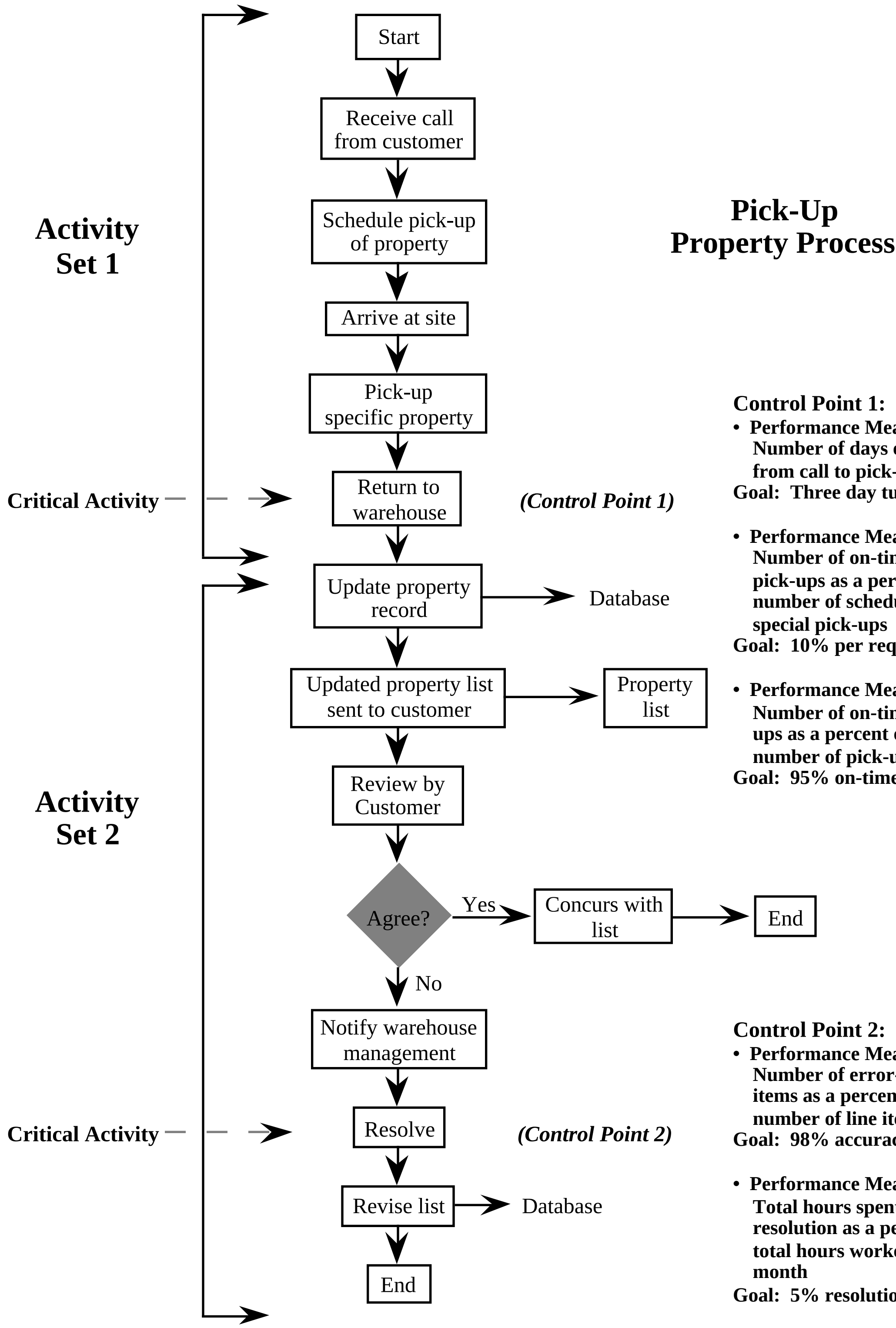
Frequency: Compiled monthly

Performance Measure B: % time spent resolving property list problems

$$\frac{\text{Total hours spent on resolution}}{\text{Total hours worked per month}} \times 100$$

Raw Data:	Total number of hours that the four property specialists spend on problem resolution each month, total hours worked by the property specialists each month
Sensor:	Time card with special job number to track problem resolution time
Frequency:	Compiled monthly

Figure B-5
Step 4 - Establish Performance Measurement(s)



Control Point 1:
- **Performance Measure A:** **Number of days elapsed from call to pick-up**

Goal: Three day turnaround

- **Performance Measure B:** **Number of on-time special pick-ups as a percent of number of scheduled special pick-ups**

Goal: 10% per request

- **Performance Measure C:** **Number of on-time pick-ups as a percent of total number of pick-ups**

Goal: 95% on-time

Control Point 2:
- **Performance Measure A:** **Number of error-free line items as a percent of total number of line items**

Goal: 98% accuracy

- **Performance Measure B:** **Total hours spent on resolution as a percent of total hours worked per month**

Goal: 5% resolution time

Step 5: Identify Responsible Party(ies)

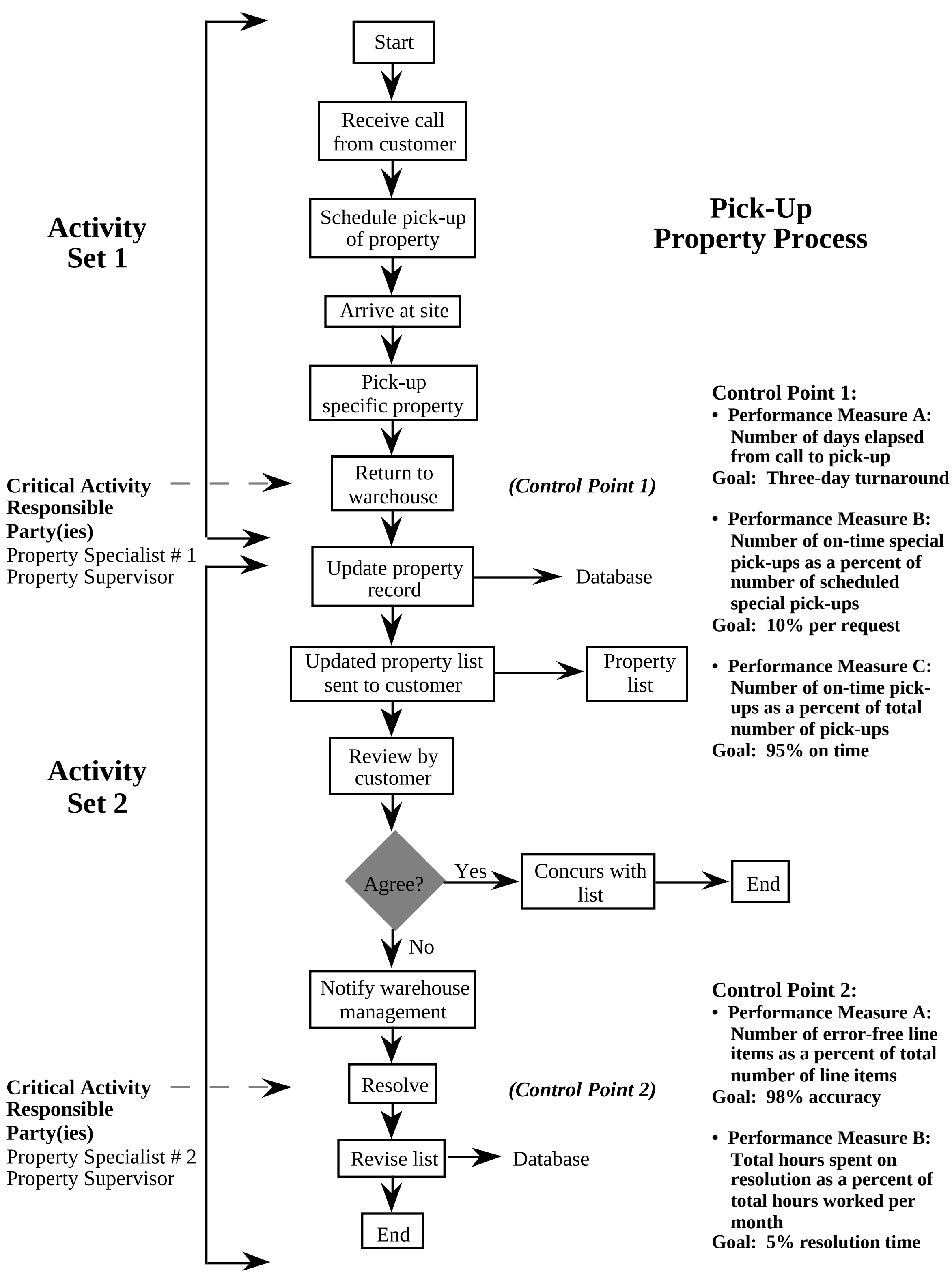
The team was glad they had completed identifying the performance measurements. The next step was a fairly easy one for the team members. They needed to identify responsible parties for collecting the data, analyzing/reporting actual performance, comparing actual performance to goal/standard, determining if corrective actions are necessary, and making changes.

For Critical Activity 1, a property specialist #1 will be responsible for collecting, interpreting, and providing feedback on the data. The warehouse supervisor will be responsible for making decisions and taking action. (Refer to Figure B-6.)

Obviously, many people could be involved in collecting data; however, someone needs to be responsible for compiling the data and comparing actual performance with the department goal. If a difference warrants, they need to notify the decision maker.

For Critical Activity 2, a similar argument was used. The group selected another property specialist #2. However, the same supervisor will be the responsible decision maker. (Refer to Figure B-6.)

Figure B-6
Step 5 - Identify Responsible Party(ies)



Step 6: Collect Data

At this step, the supervisor reviewed her notes again. She remembered from her seminar that even the best of measurement systems have failed because of poor data collection.

As the system owner, she needed to be the one with the overall responsibility for supervising the data collection process. Each employee was of course responsible for the quality of his/her own work, but she needed to be sure the data were being collected properly and that people were doing their assignments.

Data collection was much more than simply writing things down and then analyzing everything after a period of time. She resolved to conduct several preliminary analyses to determine if the measurement system was functioning as designed, that the frequency of data collection was appropriate, and to provide feedback to the data collectors with respect to any adjustments in the system.

In process step 2, schedule pick-up of equipment, the team identified two control points. The first control point covers flow process activity numbers 2, 4, and 5. The second control point covers activity numbers 11 and 12. (See Figure B-7).

For the first control point, the use of an existing property transfer form, already in use for recording the data, was determined to be the most efficient means for collecting the necessary information:

Activity 2: Schedule pick up of equipment

The date the customer placed the request. The scheduled date for the pick-up.

Activities 4 and 5: Pick-up specific property and return to warehouse

The date the property was actually picked up and delivered to the warehouse.

Because of the variety of the raw data comprising the performance measures, the data gathering approach at the second control point was somewhat more complex. A complaint logbook is used to record a description of the problem, its resolution, and related dates. Time charging records of the problem solving personnel could also be reviewed. The required information was:

Activity 11: Notify warehouse management

A description of the problem and the date the division notified the warehouse (complaint logbook).

Activity 12: Resolve

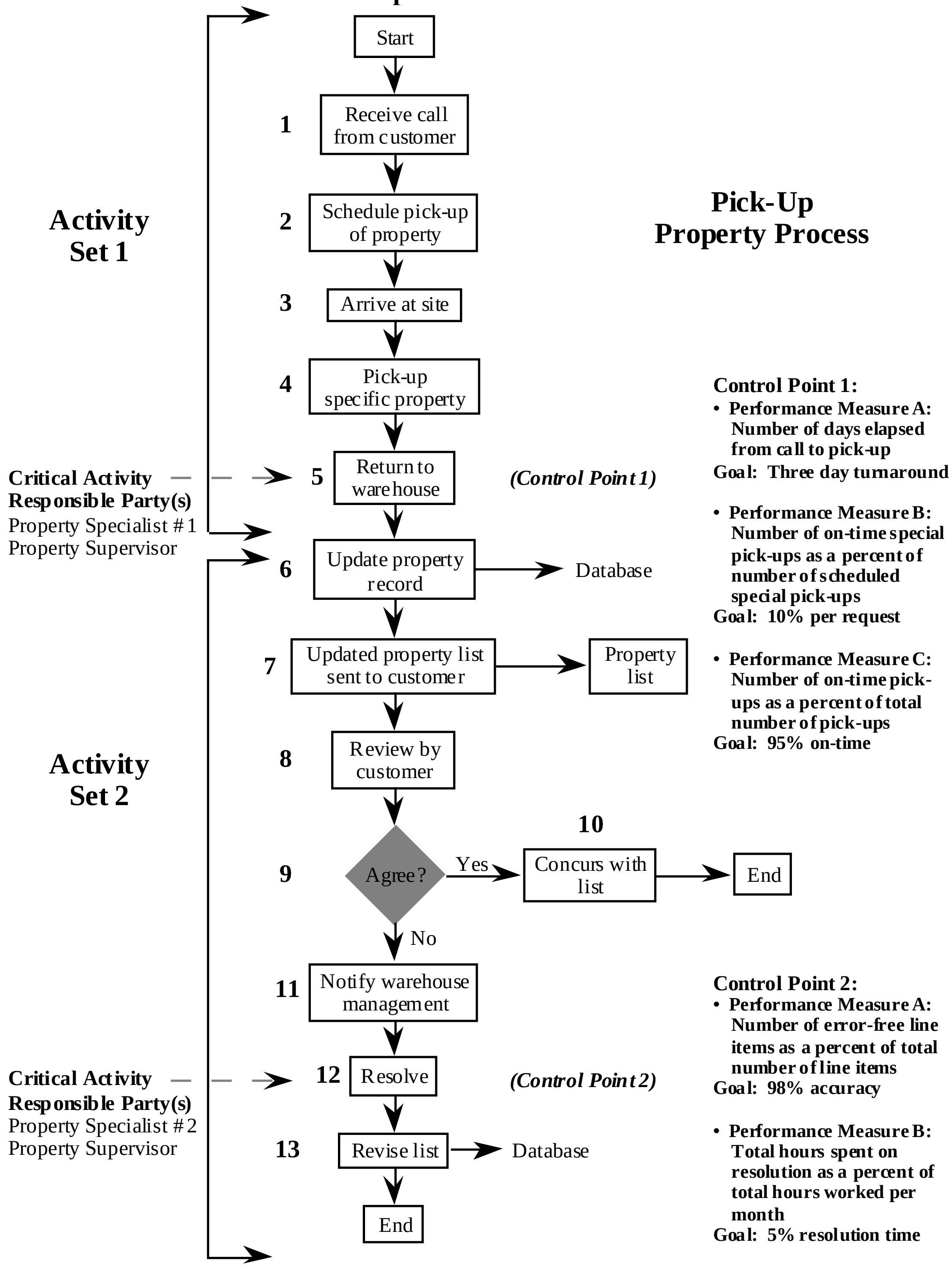
A description of what was done to resolve the issue and the date action was taken (complaint logbook).

The time spent by a property specialist in resolving the specific issue versus the total time spent on all work activities during the issue resolution period (time card records).

The total number of reports distributed during the measurement interval (property reports).

The team gathered data for a five-month period. During the first month, the supervisor had a preliminary look at the data they were collecting on a weekly basis. She continued her spot checks each month until the full collection period was completed. Ultimately, there were no significant changes to the measurement system or collection frequency. The supervisor felt the team had done an excellent job in understanding their process and designing their system. They were now ready to begin Step 7, which involved analyzing the data.

Figure B-7
Step 6 - Collect Data



Step 7: Analyze/Report Actual Performance

After five months, the supervisor felt they had a good baseline on which to start their analysis. Just what do these data mean? The team was reminded of the issue of customer complaints that started them thinking about performance measures. The supervisor asked them, "What were the questions, identified in Step 2, that we felt needed to be answered?" The team responded:

1. How do we know that we are providing the service that our customer requires?
2. Where can we do better or improve?

In this step, we will explore some of the possible ways to analyze and to display the results of these performance measures to clearly communicate the answer to their questions.

They started with Control Point 1. Performance Measure A was: number of days elapsed from call to pick-up. Their goal was pick-up within three days or less from date of call. They had collected the following data:

1. The time a call to pick-up was received
2. The day it was picked up

The forms the team used recorded a lot of information. They revealed how many pick-ups actually took longer than three days and were late, and how early or late each pick-up was. One way to look at the data is to use a bar chart to plot the number of late pick-ups each week (the number of on-time pick-ups could also be plotted). This will show the progress each week, and after several weeks or months, some trends may appear.

Figure B-8 shows a simple bar chart reflecting the number of late pick-ups each week. It shows that in week one, there were five late pick-ups out of 51, with 13 during week two, and so on. The next step would be to investigate what happened during week two and analyze the process to see what can be done to meet the goal.

The same set of data can be used to view the process from a different perspective. A frequency chart, as in Figure B-9, can be created to show the variation in the process. This shows the results of the second week in January (week two in Figure B-8); of the 13 late pick-ups, for eight of them it took four days and for five of them it took five days. The goal is three days or less, and it was seen that it usually takes three days. However, the data also showed that ten times it took one day and nine times it took two days. This type of chart shows how capable the process actually is.

Figure B-8

 # Late Pick-Ups Each Week

With total normal pick-ups shown

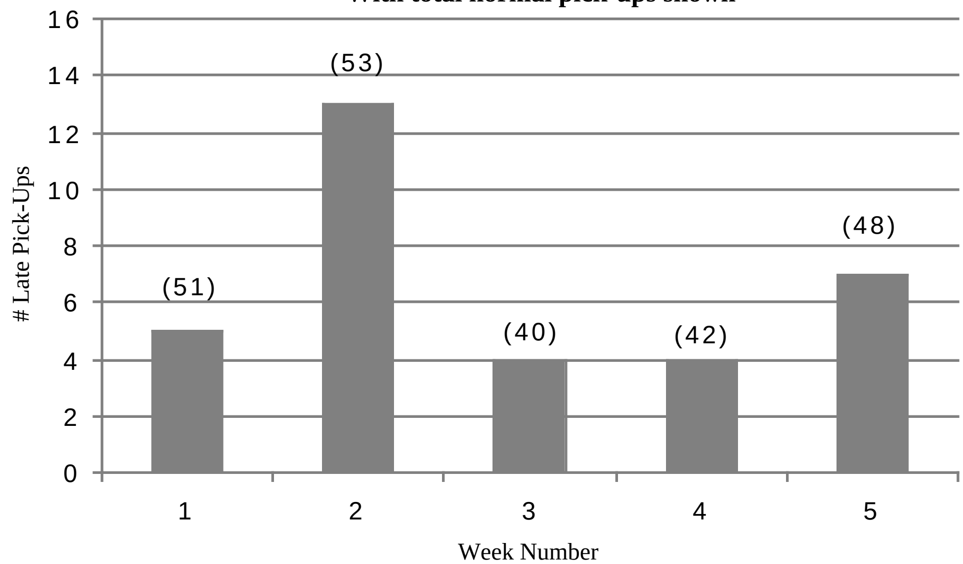
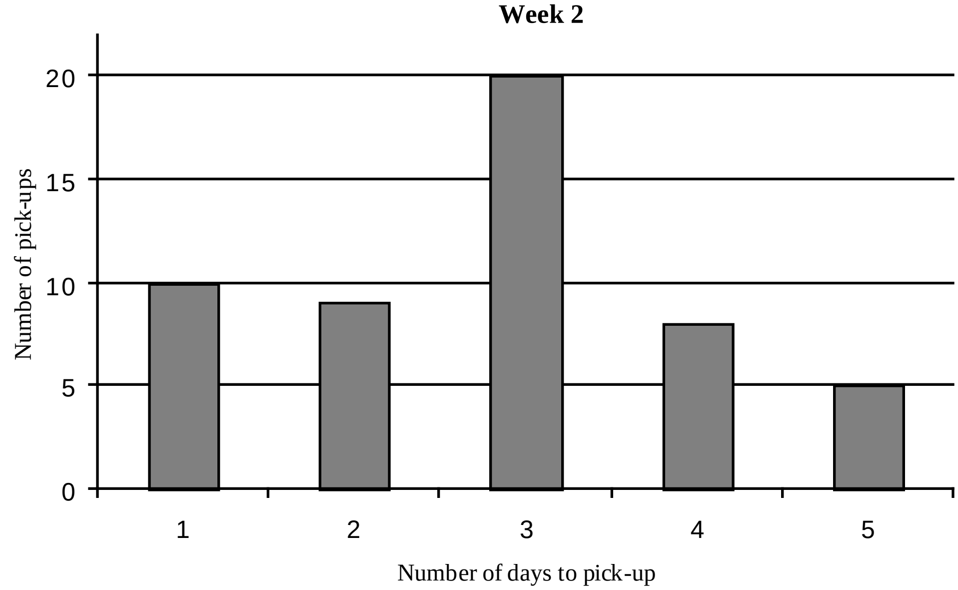


Figure B-9

Variation in Pick-Up Time

Week 2



Step 7: Analyze/Report Actual Performance (continued)

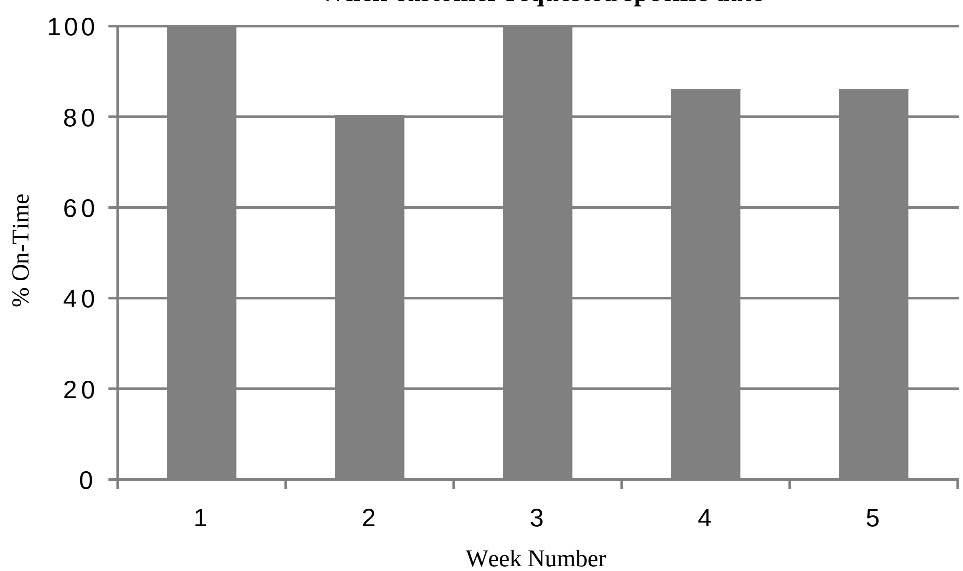
The team continued with Critical Activity 1, Performance Measure B: Number of on-time special pick-ups. The goal was meeting the customer's specific need 100% of the time. We collected the following data:

1. The date the customer requested pick-up
2. The actual date picked-up

This measure looks at how well those customers who want pick-up service provided on a particular day are served. The data could be plotted as late pick-ups as in Figure B-8, or could be plotted as the number of on-time pick-ups each week. Since this performance measure results in a ratio, a bar chart can be used, as in Figure B-10, to measure the percent on-time pick-ups performed each week. The bar chart can show the progress week-by-week.

If it was found that the group was consistently missing their goal, this should be investigated to find out why and some type of process improvement should be performed. A frequency chart, such as Figure B-9, may be useful in the study of the process.

Figure B-10
Percent On-Time Special Pick-Ups
When customer requested specific date



Step 7: Analyze/Report Actual Performance (continued)

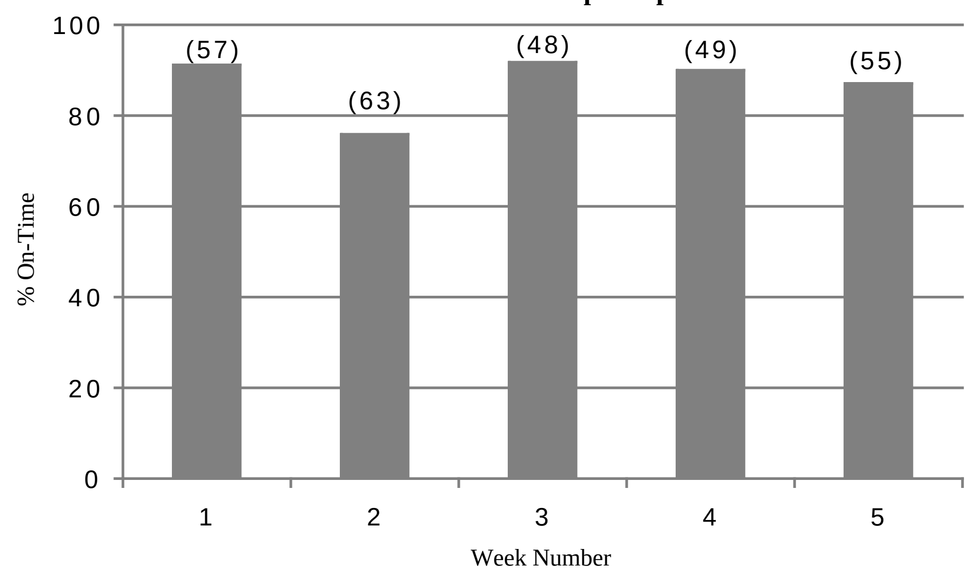
The last performance measure for Critical Activity 1 is C: the number of on-time pick-ups with a goal to have at least 95% of the pick-ups on time.

The team collected the following data:

1. The total number of pick-ups in a week.
2. The number of pick-ups performed in three days or less when the customer specified no date.
3. The number of on-time pick-ups when the customer specified a special date.

This performance measure looks at how well the entire property pick-up process is working. It counts all on-time pick-ups against the total number of pick-ups each week. Like Performance Measure B, this measure also results in a ratio when the data are put in. Likewise, a simple bar chart, such as in Figure B-11, can be used to track these over a period of some five weeks. Progress can be seen at a glance.

Figure B-11
Percent Total On-Time Pick-Ups
With total number of pick-ups shown



Step 7: Analyze/Report Actual Performance (continued)

The team now began to look at Critical Activity 2, Performance Measure A: the percent of error-free line items with a goal of 98% or more of all line item entries to be error-free.

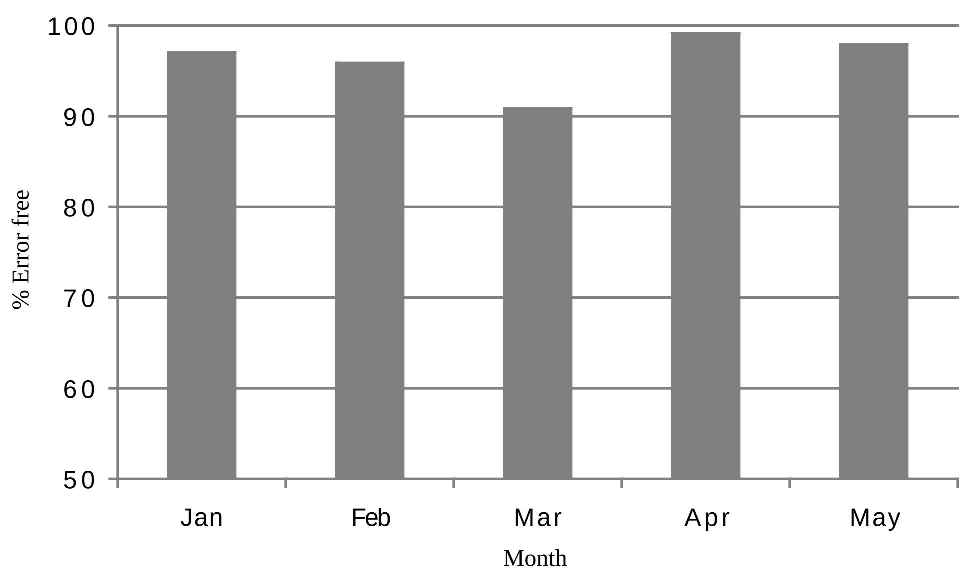
The team collected the following data:

1. The total number of line items processed each month.
2. The total number of line item errors processed each month.

This performance measure tells how well the information on the transfer forms is recorded and transferred to the data base (Activity 6.) It also measures customer satisfaction indirectly because every error made causes customers to investigate the source of any discrepancy. A simple way to display these data is again to use a simple bar chart, Figure B-12, that plots the resulting ratio month by month. It is easy to see if the 98% error-free goal is being met.

The transfer forms generate the data that are used and, therefore, provide additional information for inclusion on the actual volume of transfer forms processed each month as part of the graph. The number could be written in each column and would reveal if the error rate is a function of the volume of forms processed.

Figure B-12
Percent Error Free Line Items



Step 7: Analyze/Report Actual Performance (continued)

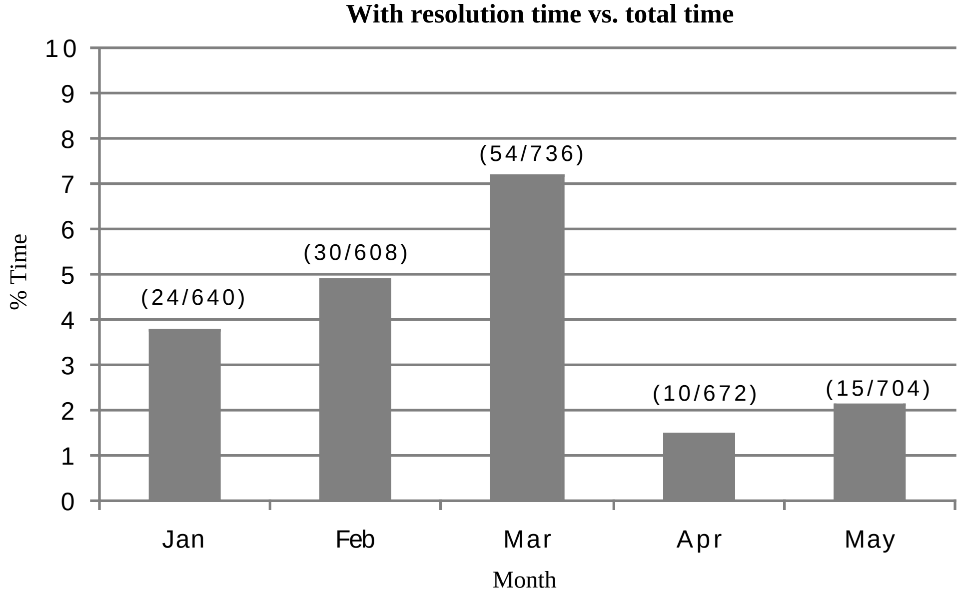
Finally, the team had come to its last performance measure. Performance Measure B was the total hours spent on resolutions with a goal that 5% or less of the team's time be spent on property list discrepancies.

The team had collected the following data:

1. The total number of hours worked by the property specialist each month taken from the time cards.
2. The total number of hours the property specialists charge to problem resolutions each month.

Performance Measure B gauges the cost of the transfer form and reports errors in terms of time spent resolving problems. Like previous measures, this one also results in a fraction that can be plotted on a bar chart. Figure B-13 shows the results of five months of data collection. It shows if a goal is being met, the process being made, and if any trends are apparent.

Figure B-13
Percent Time on Problem Resolution
With resolution time vs. total time



Step 8: Compare Actual Performance to Goal/Standard

The supervisor was satisfied with the team's efforts and results. They had learned a lot about performance measures and now understood their importance and why they needed to measure. They realized that if you cannot measure your process, you cannot control it. If you cannot control it, you cannot manage it. Without dependable measurements, intelligent decisions cannot be made.

They were almost finished with the process. The team needed to compare their actual performance to their goals.

Once a comparison against their goals was completed, the team had several alternatives:

- Forget it. Variance is not significant - economically or statistically.
- Fix it.
- Challenge the goal (or standard).
- Review performance measures. Are they answering our questions?

The supervisor told her team that "if corrective actions are not necessary, the team would continue the data collection cycle."

Step 9: Corrective Action Necessary?

Is corrective action necessary? The supervisor instructed her team that if the answer to this question was yes, they would need to take the necessary action to bring their performance back into line with their goal(s)-the final step in closing the feedback loop.

She further stated that the key objectives of correction are:

1. Removal of defects, which are, in many cases, worker-controllable.
2. Removal of defect causes whether worker or management-controllable, dependent up on the defect cause.
3. Attainment of a new state of process that will prevent defects from happening.
4. Maintenance or enhancement of the efficiency and effectiveness of the process, an essential condition for continuing process optimization and ultimately increasing the competitiveness and profitability of the business itself. The removal of defects and defect causes at the expense of productivity or efficiency is inherently self-defeating.

After reviewing the Performance Measure Report, the team did not feel that Performance Measurement A was answering their questions. Performance Measurement C more clearly achieved their objective; therefore, they decided to delete Performance Measurement A from further data collecting and consideration.

The team also decided to tackle the problem of late pick-ups. They had a goal of 95% on-time pick-ups. They never met their goal. Why? After further discussions, the supervisor and team members felt they would form a quality improvement team to look at this problem and identify the solution(s). They can use a lot of the data they have already collected to assist them in finding the root cause of the problem.

Additionally, they would continue to gather data for another five to six months, review it, and determine if any further action would be necessary.

Conclusion

The Quality Improvement Team has been established and currently is working the problem trying to determine the root cause. Therefore, the team would come back to address steps 10 and 11 after they complete their investigation.

The team members told their supervisor they finally realized the value and importance of doing performance measures on their processes.

The supervisor asked her team to summarize for her why they should measure. The team wrote down the following:

Performance measures can be used for:

1. **Control:** to help reduce variation.
2. **Self-Assessment:** to assess how well our process is doing, including any improvements we may have made.
3. **Continuous Improvement:** to identify defect sources, process trends, defect prevention, and to determine process efficiency and effectiveness, and opportunities for improvement.

The supervisor was very pleased.

Appendix C

Sample Performance Measures

Sample Performance Measures

This, which is a collection from several sources, is included to stimulate your thinking about appropriate measures. However, remember that the measures you select should fit the process, products, and goals.

A. Accounting Performance Measurements

Percent of late reports	Percent of errors in reports
Errors in input to Information Services	Errors reported by outside auditors
Percent of input errors detected	Number of complaints by users
Number of hours per week correcting or changing documents	Number of complaints about inefficiencies or excessive paper
Amount of time spent appraising/correcting input errors	Payroll processing time
Percent of errors in payroll	Length of time to prepare and send a bill
Length of time billed and not received	Number of final accounting jobs rerun
Number of equipment sales miscoded	Amount of intra-Company accounting bill-back activity
Time spent correcting erroneous inputs	Number of open items
Percent of deviations from cash plan	Percent discrepancy in MRB and line scrap reports
Travel expense accounts processed in three days	Percent of advances outstanding
Percent data entry errors in accounts payable and general ledger	Credit turnaround time
Machine billing turnaround time	Percent of shipments requiring more than one attempt to invoice
Number of untimely supplier invoices processed	Average number of days from receipt to processing

B. Clerical Performance Measurements

Misfiles per week	Paper waste
Errors per type page	Administration errors (not using the right procedure)
Number of times messages are not delivered	Percent of action items not done on schedule
Percent of inputs not received on schedule	Percent of coding errors on time cards
Period reports not completed on schedule	Percent of phone calls answered within two rings
Percent of phone calls dialed correctly	Pages processed error-free per hour
Clerical personnel/personnel support	Percent of pages retyped
Percent of impressions reprinted	

C. Product/Development Engineering Performance Measurements

Percent of drafting errors per print	Percent of prints released on schedule
Percent of errors in cost estimates	Number of times a print is changed
Number of off-specifications approved	Simulation accuracy
Accuracy of advance materials list	How well the product meets customer expectations
Field performance of product	Percent of error-free designs
Percent of errors found during design review	Percent of repeat problems corrected
Time to correct a problem	Time required to make an engineering change
Percent of reports with errors in them	Data recording errors per month
Percent of evaluations that meet engineering objectives.	Percent of special quotations that are successful
Percent of test plans that are changed (change/test plan)	Number of meetings held per quarter where quality and defect prevention were the main subject
Person-months per released print	Percent of total problems found by diagnostics as released
Number of problems that were also encountered in previous products	Cycle time to correct customer problem
Number of errors in publications reported from the plan and field	Number of products that pass independent evaluation error-free
Number of misused shipments of prototypes	Number of unsuccessful pre-analyses
Number of off-specifications accepted	Percent of requests for engineering action open for more than two weeks
Number of days late to pre-analysis	Number of restarts of evaluations and tests
Effectiveness of regression tests	Number of days for the release cycle
Percent of corrective action schedules missed	Percent of bills of material that are released in error
Cost of input errors to the computer	Cost of engineering changes per month
Spare parts cost after warranty	Customer cost per life of output delivered

D. Finance Performance Measurements

Percent error in budget predictions	Computer rerun time due to input errors
Percent of financial reports delivered on schedule	Number of record errors per employee
Percent of error-free vouchers	Percent of bills paid so Company gets price break
Percent of errors in checks	Entry errors per week
Number of payroll errors per month	Number of errors found by outside auditors
Number of errors in financial reports	Percent of errors in travel advance records
Percent of errors in expense accounts detected auditors	Computer program change cost

E. Industrial/Plant Engineering Performance Measurements

Percent of facilities on schedule	Percent of manufacturing time lost due to bad layouts
Percent of error in time estimates	Percent of error in purchase requests
Hours lost due to equipment downtime	Scrap and rework due to calibration errors
Repeat call hours for the same problem	Changes to layout
Percent deviation from budget	Percent variation to cost estimates
Number of unscheduled maintenance calls	Percent of equipment maintained on schedule
Number of hours used on scheduled maintenance	Accuracy of assets report
Percent of equipment overdue for calibration	Number of industrial design completions past due
Percent of total floor space devoted to storage	Number of errors found after construction had been accepted by the company
Number of mechanical/functional errors in industrial design artwork	Maintenance cost/equipment cost
Percent of engineering action requests accepted	

F. Forecasting Performance Measurements

Number of upward pricing revisions per year	Number of project plans that meet schedule, price, and quality
Percent error in sales forecasts	Number of forecasting assumption errors
Number of changes in product schedules	

G. Information Systems Performance Measurements

Keypunch errors per day	Input correction on data entry
Reruns caused by operator error	Percent of reports delivered on schedule
Errors per thousand lines of code	Number of changes after the program is coded
Percent of time required to debug programs	Number of cost estimates revised
Percent error in forecast	Percent error in lines of code required
Number of coding errors found during formal testing	Number of test case errors
Number of test case runs before success	Number of revisions to plan
Number of documentation errors	Number of revisions to program objectives
Number of errors found after formal test	Number of error-free programs delivered to customer
Number of process step errors before a correct package is ready	Number of revisions to checkpoint plan
Number of changes to customer requirements	Percent of programs not flow-diagrammed
Percent of customer problems not corrected per schedule	Percent of problems uncovered before design release
Percent change in customer satisfaction survey	Percent of defect-free artwork
System availability	Terminal response time
Mean time between system IPL's	Mean time between system repairs
Time before help calls are answered	Rework costs resulting from computer program

H. Legal Performance Measurements

Response time on request for legal opinion	Time to prepare patent claims
Percent of cases lost	

I. Management Performance Measurements

Security violations per year	Percent variation from budget
Percent of target dates missed	Percent personnel turnover rate
Percent increase in output per employee	Percent absenteeism
Percent error in planning estimates	Percent of output delivered on schedule
Percent of employees promoted to better jobs	Department morale index
Percent of meetings that start on schedule	Percent of employee time spent on first-time output
Number of job improvement ideas per employee	Ratio of direct to indirect employees
Increased percent of market	Return of investment
Percent of appraisals done on schedule	Percent of changes to project equipment required
Normal appraisal distribution	Percent of employee output that is measured
Number of grievances per month	Number of open doors per month
Percent of professional employees active in professional societies	Percent of managers active in community activities
Number of security violations per month	Percent of time program plans are met
Percent of documents that require two management	Percent of employees who can detect and repair their own errors
Percent of delinquent suggestions	Improvement in opinion surveys
Number of decisions made by higher-level management than required by procedures	Percent of time cards that have errors on them signed by managers
Percent of employees taking higher education	Number of damaged equipment and property reports
Number of employees dropping out of classes	Percent error in personnel records
Improvement in customer satisfaction survey	Volume actual versus planned
Revenue actual versus plan	Percent of procedures less than 10 pages
Number of procedures with fewer than three acronyms and abbreviations	Number of formal reviews before plans are approved
Percent of employees active in improvement teams	Number of hours per year of career and skill development training per employee
Number of user complaints per month	Number of variances in capital spending
Percent revenue/expense ratio below plan	Percent of executive interviews with employees
Percent of departments with disaster recovery plans	Percent of appraisals with quality as a line item that makes up more than 30 percent of the evaluation
Percent of employees with development plans	Direct/indirect ratio
Revenue generated over strategic period	Number of iterations of strategic plan

I. Management Performance Measurements (continued)

Number of employees participating in cost effectiveness	Dollars saved per employee due to new ideas and/or methods
Result of peer reviews	Number of tasks for which actual time exceeded estimated time
Data integrity	Warranty costs
Cost of poor quality	

J. Manufacturing and Test Engineering Performance Measurements

Percent of process operations where sigma limit is within engineering specification	Percent of tools that fail certification
Percent of tools that are networked due to design errors	Number of process changes per operation due to error
Percent error in manufacturing costs	Time required to solve a problem
Number of delays because process instructions are wrong or not available	Percent error in test equipment and tooling budget
Number of errors in operator training documentation	Percent of errors that escape the operator’s detection
Percent of testers that fail certification	Percent error in yield projections
Percent error in output product quality	Percent of designed experiments that need to be revised
Percent of changes to process specifications during process design review	Percent of equipment ready for production on schedule
Percent of meetings starting on schedule	Percent of drafting errors found by checkers
Percent error in yield projections	Percent of manufacturing used to screen products
Number of problems that the test equipment cannot detect during manufacturing cycle	Percent correlation between testers
Number of waivers to manufacturing procedures	Percent of tools and test equipment delivered on schedule
Percent of tools and test equipment on change level control	Percent functional test coverage of products
Percent projected cost reductions missed	Percent of action plan schedules missed
Equipment utilization	In-process yields
Labor utilization index	Asset utilization

K. Manufacturing/Shipping Performance Measurements

Complaints on shipping damage	Percent of parts not packed to required specifications
Percent of output that meets customers orders and engineering specifications	Suggestions per employee
Percent of jobs that meet cost	Percent of jobs that meet schedule
Percent of product defect-free at measurement operations	Percent of employees trained to do the job they are working on
Accidents per month	Performance against standards
Percent of utilities left improperly running at end of shift	Percent unplanned overtime
Number of security violations per month	Percent of time log book filled out correctly
Time and/or claiming errors per week	Time between errors at each operation
Labor utilization index	Percent of operators certified to do their job
Percent of shipping errors	Defects during warranty period
Replacement parts defect rates	Percent of products defective at final test
Percent of control charts maintained correctly	Percent of invalid test data
Percent of shipments below plan	Percent of daily reports in by 7 a.m.
Percent of late shipments	Percent of products error-free at final test
Scrap and rework cost	

L. Personnel Performance Measurements

Percent of employees who leave during the first year	Number of days to answer suggestions
Number of suggestions resubmitted and approved	Turnover rate due to poor performance
Number of grievances per month	Percent of employment requests filled on schedule
Number of days to fill an employment request	Time to process an applicant
Average time a visitor spends in lobby	Time to get security clearance
Time to process insurance claims	Percent of employees participating in company-sponsored activities
Percent of complaints about salary	Percent of personnel problems handled by employees' managers
Percent of employees participating in voluntary health screening	Percent of offers accepted
Percent of retirees contacted yearly by phone	Percent of training classes evaluated excellent
Percent deviation to resource plan	Wait time in medical department
Number of days to respond to applicant	Percent of promotions and management changes publicized
Percent of error-free newsletters	Personnel cost per employee
Cost per new employee	Management evaluation of management education courses
Opinion survey ratings	

M. Procurement/Purchasing Performance Measurements

Percent of discount orders by consolidating	Errors per purchase order
Number of orders received with no purchase order	Routing and trace errors per shipment
Percent of supplies delivered on schedule	Percent decrease in parts cost
Expediters per direct employees	Number of items on the hot list
Percent of suppliers with 100 percent lot acceptance for one year	Labor hours per $10,000 purchases
Purchase order cycle time	Number of times per year line is stopped due to lack of supplier parts
Percent of parts with two or more suppliers	Average time to fill emergency orders
Average time to replace rejected lots with good parts	Percent of lots received on line late
Time to answer customer complaints	Percent of phone calls dialed correctly
Percent of purchase orders returned due to errors or incomplete description	Percent of defect-free supplier model parts
Percent projected cost reductions missed	Time required to process equipment purchase orders
Number of items billed but not received	Stock costs
Supplier parts scrapped due to engineering changes	Parts costs per total costs.
Actual purchased materials cost per budgeted cost	Cost of rush implants

N. Production Control Performance Measurements

Percent of late deliveries	Percent of errors in stocking
Number of items exceeding shelf life	Percent of manufacturing jobs completed on schedule
Time required to incorporate engineering changes	Percent of errors in purchase requisitions
Percent of products that meet customer orders	Inventory turnover rate
Time that line is down due to assembly shortage	Percent of time parts are not in stock when ordered from common parts crib
Time of product in shipment	Spare parts availability in crib
Percent of stock errors	Percent of errors in work in process records versus audit data
Number of bill of lading errors not caught in shipping	Cost of rush shipments
Cost of inventory spoilage	

O. Quality Assurance Performance Measurements

Percent error in reliability projections	Percent of product that meets customer expectations
Time to answer customer complaints	Number of customer complaints
Number of errors detected during design and process reviews	Percent of employees active in professional societies
Number of audits performed on schedule	Percent of QA personnel to total personnel
Percent of quality inspectors to manufacturing directs	Percent of QE's to product and manufacturing engineers
Number of engineering changes after design review	Number of process changes after process qualification
Errors in reports	Time to correct a problem
Percent of suppliers at 100 percent lot acceptance for one year	Percent of lots going directly to stock
Percent of problems identified in the field	Variations between inspectors doing the same job
Percent of reports published on schedule	Number of complaints from manufacturing management
Percent of field returns correctly analyzed	Time to identify and solve problems
Percent of lab services not completed on schedule	Percent of improvement in early detection of major design errors
Percent of errors in defect records	Number of reject orders not dispositioned in five days
Number of customer calls to report errors	Number of committed supplier plans in place
Percent of correlated test results with suppliers	Receiving inspection cycle time
Number of requests for corrective action being processed	Time required to process a request for corrective action
Number of off-specifications approved	Percent of part numbers going directly to stock
Number of manufacturing interruptions caused by supplier parts	Percent error in predicting customer performance
Percent product cost related to appraisal scrap and rework	Percent skip lot inspection
Percent of qualified suppliers	Number of problems identified in-process
Cost of scrap and rework that was not created at the rejected operation	Level of customer surveys

P. Security/Safety Performance Measurements

Percent of clearance errors	Time to get clearance
Percent of security violations	Percent of documents classified incorrectly
Security violations per audit	Percent of audits conducted on schedule
Percent of safety equipment checked per schedule	Number of safety problems identified by management versus total safety problems identified
Safety accidents per 1000,000 hours worked	Safety violations by department
Number of safety suggestions	Percent of sensitive parts located

Appendix D

Related References

Related References

There have been many articles published and materials compiled across the Department of Energy complex and industry that contain additional information in the area of measuring performance. These references may provide additional information and guidance to assist you with your programs.

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