2
Equipment Failure Rate Data

To properly use failure rate data, the engineer or risk analyst must have an understanding of failure rates, their origin and limitations. This chapter discusses the types and source of failure rate data, the failure model used in computations, the confidence, tolerance and uncertainties in the development of failure rates and taxonomies which can store the data and influence their derivation.

2.1 Sources and Types of Failure Rates

Failure rate data generated from collecting information on equipment failure experience at a plant are referred to as plant-specific data. A characteristic of plant-specific data is that they reflect the plant's process, environment, maintenance practices, and choice and operation of equipment. Data accumulated and aggregated from a variety of plants and industries, such as nuclear power plants, CPI or offshore petroleum platforms, and are called generic data. With inputs from many sources, generic failure rate data can provide a much larger pool of data. However, generic data are derived from equipment of many manufacturers, a number of processes, and many plants with various operating strategies. Consequently, they are much less specific and detailed.

Both of the sources above contain two types of failure rate data used in CPQRAs: time-related failure rates and demand-related failure rates. Time-related failure rates, presented as failures per 10^6 hours, are for equipment that is normally functioning, for example, a running pump, or a temperature transmitter. Data are collected to reflect the number of equipment failures per operating hour or per calendar hour.

Demand-related failure rates are presented as failures per 10^3 demands and are for equipment that is normally static but is called upon to operate at indeterminate intervals, for example, a switch or standby generator. In this case, data are gathered that can be converted to reflect the number of failures per demand on the equipment.

Both time-related failure rates and demand-related failure rates can apply to and be reported for many pieces of equipment. Both types of rates are included in some of the data tables in Chapter 5. If a piece of equipment is in continuous service, such as a transformer, the failure rate is dominated by time-related stresses compared to demand-related stresses. Other failure rates may be dominated by demands. Take a piece of wire and repeatedly bend it. With each bend its probability of catastrophic failure increases. In a relatively short time, if the bending is continued, the wire will fail. On the other hand, the same wire could be installed in a manner that would prevent mechanical bending demands. In this case, the occurrence of catastrophic wire breakage would be remote. In the first instance, the failure rate is dominated by demand stresses and in the second by time-related stresses, such as corrosion.

Another example is a safety valve in standby service. If demands occur very infrequently, time-related stresses such as external corrosion may have a significant influence. Repeated demands in very dirty service could easily lead to faster degradation and failure, whereas repeated demands in lubricated service might actually enhance performance if the failure mode of interest is failure to open. Failure data based on time or demands can also be skewed if the relief valve is initially damaged or installed incorrectly.

The above discussion leads to the conclusion that time-related and demand-related failures for a piece of equipment cannot be equated through a general mathematical relationship. These issues are better dealt with in a data base taxonomy (classification scheme) for equipment reliability data by defining a unique application through equipment description, service description, and failure description.

2.2 Failure Model

A uniform definition of a failure and a method of classifying failures is essential if data from different sources are to be compared. The anatomy of a failure includes the initiating or root cause of a failure that is propagated by contributory causes and results in a failure mode—the effect by which a failure occurs or is observed. Modes include failure to operate, no output, failure to alarm on demand. The end result of a failure sequence is the failure effect, such as no fluid is pumped to the absorber, or a tank overflows. As discussed in Appendix A of IEEE Std. 500-1984,[1] only the equipment failure mode is relevant for data that are needed in a CPQRA. The failure model used in this book is based upon those in the IEEE publication and IPRDS.[2]

Failures can occur in two general types of equipment—active and passive—explained as follows:

- **Active**: Physical motion or activity in the performance of an equipment's function (e.g., rotating equipment).
- **Passive**: Equipment not physically actuated in order to perform its function (e.g., piping, storage tanks).

Failure modes vary in degree of magnitude, for example, a pump may have no output or may have its output restricted. Consequently, failure modes have been divided into three categories of "severity," which are defined as follows:

- **Catastrophic:** A failure that is both sudden and causes termination of one or more fundamental functions.
- **Degraded:** A failure that is gradual or partial.
- **Incipient:** An imperfection in the state or condition of equipment such that a degraded or catastrophic failure can be expected to result if corrective action is not taken.

There are a number of failure modes for the three failure severities and for active and passive equipment. Figures 2.1 and 2.2 illustrate these failure modes and severities by type of equipment.

			Cata
Change in item or equipment condition	Change in operation		1. Failure to 2. No outpu
	Change of state	Change without demand	A spurio 1. Start, 2. Inser 3. With 4. Actu 5. Resp 6. Open 7. Closi
		No change on demand	Failure t 1. Start 2. Stop 3. Inser 4. With 5. Actu 6. Resp 7. Open 8. Close

Figure 2.1 *Active e with permission of tl*

2.3 Taxonomy

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			Failure Severity		
			Catastrophic	Degraded	Incipient
Change in item or equipment condition	Change in operation		1. Failure to operate (run) 2. No output	1. Low output 2. High output 3. Erratic output 4. Locked in one mode of operation 5. Output above or below specified requirements	Discovered through: 1. Local inspection (overheating, leaks, contamination, noise, severe vibration, odor, cracks, etc) 2. Testing: (output above or below specified limits while in stand-by mode of operation) 3. Monitoring (trend towards failure)
	Change of state	Change without demand	A spurious: 1. Start/Stop 2. Insertion 3. Withdrawal 4. Actuation 5. Response 6. Opening 7. Closing	1. Premature or delayed actuation (an actuation that occurs out of timing sequence) 2. Won't stay open or closed	Discovered through: 1. Testing: Failure or diminished ability to transmit or retain energy during the stand-by mode of operation 2. Local inspection
		No change on demand	Failure to: 1. Start 2. Stop 3. Insert 4. Withdraw 5. Actuate 6. Respond to command 7. Open 8. Close	Improper Response: 1. Partially open, close, etc 2. Oscillation (failure to assume a fixed position)	

Figure 2.1 *Active equipment failure modes. Reprinted from ANSI/IEEE Std. 500-1984, © 1984 by the IEEE, with permission of the IEEE Standards Department.*

2.3 Taxonomy

In order to have readily accessible and retrievable failure rate data that can be compared and aggregated with similar data, a logic to classify and store the data is needed. Such a logic and structure, called a taxonomy, is based on equipment and process characteristics affecting reliability, and it creates categories of equipment having similar failure rates. There are many ways to classify equipment failure systematically and consequently structure a taxonomy. Some of the characteristics that can define these categories are the equipment, its function, size, speed, operating mode, and failure mode. A taxonomy's hierarchy, based on these characteristics, creates a multitude of data cells, each with a unique address to house failure rate data for each specifically defined piece of process equipment and its service. The classification scheme developed by CCPS is presented in Chapter 3.

	Failure Severity			
	Catastrophic	Degraded	Incipient	
Change in item or equipment condition	Failure to retain or transmit energy	Diminished ability to retain or transmit energy	Change in operation	(1) Testing: Failure of diminished ability to transmit or retain energy during the energized mode of operation
	1.0 Breach of pressure or static fluid boundary	1.0 Degradation of pressure or static fluid boundary		(2) Local inspection (leaks, vibration, odor, cracks, etc)
	1.1 Major leaks	1.1 Minor leaks		(3) Monitoring: Monitoring trend towards failure, during the energized mode of operation
	1.1.1 External leaks	1.1.1 External leaks		
	1.1.2 Internal leaks	1.1.2 Internal leaks		
	1.2 Explosions	2.0 Interference with energy transport or exchange capability		
	1.3 Implosions	2.1 Restricted flow		
	2.0 Loss of energy transport or exchange capability	2.2 Reduced heat transfer capability		
	2.1 Blocked or stopped flow	2.3 Minor heat loss		
	2.2 Loss of heat transfer capability (scale buildup)	3.0 Structural integrity compromised		
	2.3 Major heat loss (loss of insulation)	3.1 Reduced support capability	Change of state	(1) Testing: Failure or diminished ability to transmit or retain energy during the stand-by mode of operation
	3.0 Loss of structural integrity	3.1.1 Fracture of part of the structural members		(2) Local inspection
	3.1 Failure to support or brace	3.1.2 Minor physical distortion		
	3.1.1 Fracture (of all members)	3.2 Partial failure to fasten or join		
	3.1.2 Physical distortion (permanent set)			
	3.1.3 Distortion under load (without perm. set)			
	3.2 Failure to fasten or join			
	3.2.1 Removable fastener failure			
	3.2.2 Failure of permanent joint			
	3.2.2.1 Weld failure			
	3.2.2.2 Imbed failure			

Figure 2.2 *Passive equipment failure modes. Reprinted from ANSI/IEEE Std. 500-1984, © 1984 by the IEEE, with permission of the IEEE Standards Department.*

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A taxonomy serves as the receptor of all failure rate data and the model for new data. The descriptors of each data cell govern the collection and conversion of raw plant data and placement of the plant-specific failure rate data into the taxonomy. Having well-defined and generally accepted descriptors for each data cell enhances gathering and combining generic data by ensuring that "apples are compared to apples" when data are aggregated from different resources. Understanding the taxonomy structure provides insight into the characterization of equipment failure rates.

2.4 Confidence and Tolerance

Failure rates are computed by dividing the total number of failures for the equipment population under study by the equipment's total exposure hours (for time-related rates) or by the total demands upon the equipment (for demand-related rates). In plant operations, there are a large number of unmeasured and varying influences on both numerator and denominator throughout the study period or during data processing. Accordingly, a statistical approach is necessary to develop failure rates that represent the true values.

Equipment failure rate data points carry varying degrees of uncertainty expressed by two measures, confidence and tolerance. Confidence, the statistical measurement of uncertainty, expresses how well the experimentally measured parameter represents the actual parameter. Confidence in the data increases as the sample size is increased.

Tolerance uncertainty arises from the physical and the environmental differences among members of differing equipment samples when failure rate data are aggregated to produce a final generic data set. Increasing the number of sources used to obtain the final data set will most likely increase the tolerance uncertainty.

The ideal situation when performing a CPQRA is to have sufficient plant-specific data for each piece of equipment. However, there are many variables in the process, maintenance practices, and data collection that can fluctuate throughout a study period and have a major influence on the results: intensified preventive maintenance can lower and eliminate failures; changes in process conditions may severely exacerbate fouling tendencies or corrosion rates; equipment may be upgraded and even replaced during the study extending operating life; many failures may have been missed; many failures may be wrongly recorded such as a reported pump failure when the push button was really at fault. Since populations and operating time are limited in most plant studies and the number of failures may be heavily biased by the variations noted, plant-specific failure rates may carry little statistical confidence.

Confidence that the calculated failure rate is a good estimate of the true rate can be increased by lengthening the study or sample time. Adding another population of the same equipment under the identical circumstances to the original population will reduce uncertainties and increase confidence in the calculated failure rates.

Plant-specific data are frequently unavailable or are low in their level of confidence. Further, this source of data cannot provide information on equipment not in use at the plant, nor can it do more than suggest how plant equipment might behave under different circumstances. Since data collection is very difficult, using shared or generic data is one way of resolving these problems without the expense of extensive data collection systems.

Frequently, the only way to gather sufficient data for a CPQRA is to build a data set using inputs from other plants within the company or from other available resources. Generic data provide less specific and detailed data, but can draw upon a much larger equipment population, representing more exposure time, and present a much more realistic range of data than that limited to a single plant.

However, the data that are contributed to a generic failure rate data base are rarely for identical equipment and may represent many different circumstances. Generic data must be chosen carefully because aggregating generic and plant-specific data may not improve the statistical uncertainty associated with the final data point, owing to change in tolerance.

2.5 Sources of Variation in Failure Rates

A failure rate generated from collecting data on a system will be dependent upon all the circumstances under which the system operates. Consequently, the failure rate data should only be used for predictions on a system in which the circumstances are identical. Otherwise, the failure rate applicable to the second system will need to be adjusted.

Unfortunately, the circumstances of a data collection exercise are rarely adequately described; and therefore, any data will be based on some explicit assumptions, some implicit assumptions, and some assumptions that are completely ignored.

It is important to appreciate that a failure rate is not an intrinsic and immutable property of a piece of equipment, and an engineer involved either in collecting or using data must fully understand the factors that influence failure rate derivation and use. This section discusses many of the circumstances that can create variations in failure rates.

2.5.1 Equipment Boundary

The various data cells in a taxonomy include a written description of the equipment and a boundary diagram to identify exactly what equipment is included within the cell. Any change in the boundary diagram or deviation from it in failure attribution during data processing will influence the failure rate and its comparability with others.

2.5.2 Taxonomy Level Breakdown

The various levels of the taxonomy represent factors that have an impact on failure rate. For example, lined pipe (CCPS taxonomy number 3.2.2) has a level that groups pipe into 0–6" size and over 6". Unless the pipe size is specified, there is no way of knowing whether a given failure rate came from the 0–6" or the over 6" range.

2.5.3 Process Severity

In the CCPS Taxonomy, four degrees of severity, from "clean" to "severe," are used to characterize the process medium—the material being handled by the equipment—and its influence on reliability. In some cases, the severity will be unknown. Even if a severity is listed, doubt may exist about its value, since the definitions of severity are fairly subjective.

2.5.4 Environment

Another influence on equipment reliability is the environment/application of the equipment. A component working on a rocket into space is quite likely to have a different failure rate from the same component operating in a plant control room. Such things as external temperature, humidity, vibration, external corrosion, and any other external conditions imposed on the system need to be considered by the engineer or analyst.

2.5.5 Suitability for Service

In Table 3.2, a number of factors are listed that were not used as separate levels in the CCPS taxonomy because of assumptions made by the CCPS Subcommittee. The analyst must, wherever possible, try to assess the validity of these assumptions for the particular situation and establish if the equipment represented by the data:

- was properly fabricated;
- used appropriate materials of construction;
- was properly maintained;
- was operated within design conditions;
- was designed to appropriate standards;
- was being used beyond its capabilities.

2.5.6 Maintenance

The maintenance strategy for a system will significantly affect both the number and severity of failures:

- An inadequate maintenance program will prevent no failures.
- A cursory routine inspection program will detect some potential failures; for example, low oil level, which could eventually lead to a seizure.
- A full preventive maintenance program will pick up potential failures as incipient failures rather than delaying until they become catastrophic.

2.5.7 Data Capture

What should be recorded as a failure is very subjective. For example, low oil level may be considered too trivial to record, and yet it is an incipient failure on the way to a lubrication failure and ultimately equipment seizure. A truck backing into a pump would certainly stop the pump from functioning, but has it been included in the data collected?

Sections 2.5.1 to 2.5.7 are not an exhaustive list of equipment, process, maintenance, and data processing factors that influence failure rate, but they are an attempt to make the reader aware of the problems. The following example illustrates some of the points made:

Consider how different systems might treat the following pump failures:

1. Seal wore out causing a leak
2. Truck backed into pump shattering case
3. Pumping against closed head and overheated
4. Foreign matter in pumped fluid chewed up seal
5. Wet product corroded impeller
6. Suction blocked by foreign body

All of the above events would cause a pump "failure" over a period of time. Therefore, the events would qualify for inclusion in the failure rate. So, at one extreme there might be six catastrophic failures per sample time. However, a data analyst may decide that No. 2 is not a relevant failure since the cause was neither a function of the equipment nor the operational application, but was a mistake by an outside agent. The same might be said of No. 3.

If a plant had periodic inspections, the impeller corrosion in No. 5 might be detected before it became a significant problem, thereby altering the failure mode from catastrophic to a degraded or an incipient failure. In a plant with routine maintenance, it is possible that Nos. 1 and 5 may be eliminated completely by routine seal and impeller changes.

It is easy to see, therefore, that in one operating system six catastrophic failures would be recorded whereas in others they would range through a combination of catastrophic, degraded, or incipient failures until, with better filters, better operator, frequent scheduled maintenance, all the failures would be eliminated.

2.6 Time-Related and Demand-Related Failure Causes

Although failures are recorded as time related or demand related, the distinction between the two failure types is not always clean cut. The total failures on any piece of equipment are usually a combination of some that are time dependent and some that are demand related. In other words, a piece of equipment that fails on demand may already be in a failed state when the demand arrives, or the demand may actually cause the failure.

On normally operating equipment, because the demand is continuous, all failures can be considered as functions of time; but for equipment that is operated intermittently, the relative proportion of demand- and time-related failures in combination with the frequency of demands and the type of maintenance and inspection program will have an impact on its total failure rate. This point is best illustrated by an example:

Consider the failure of an unloading hose that leaks on being coupled up. For simplicity, it is assumed that the failures are caused by: (1) atmospheric corrosion while the unused hose is waiting for the next unloading or (2) damage from the act of coupling.

The first is clearly a time-related failure and the second a demand-related failure.

A data collection system, or an analyst wanting data, would simply record the number of failures (the numerator) and the number of demands during the period of interest (the denominator). Dividing the numerator by the number of times coupling had occurred would produce the failure rate in failures per demand.

To illustrate the possible variation in failure rates under different operating requirements and maintenance programs assume the following:

- Corrosion-caused failures occur at a rate of two per year.
- Corrosion problems are eliminated by scheduled replacement of the coupling every 3 months.
- Coupling seal damage is caused at the rate of one every 100 couplings made (10 per 10^3 demands).

Consider four cases:

1. A system with no scheduled coupling replacement and 12 unloadings per year.
2. A system with no scheduled coupling replacement and 365 unloadings per year.
3. A system with the coupling replaced every 3 months and 12 unloadings per year.
4. A system with the coupling replaced every 3 months and 365 unloadings per year.

TABLE 2.1

			No. of Failures Due To				
Case	Scheduled Replacement	Unloads per year	Corrosion (1)	Damage (2)	Total (3)=(1)+(2)	No. of Demands (4)	Failures per 10^3 Demand $(3)\div(4)\times10^3$
1	No	12	2	0.12	2.12	12	177
2	No	365	2	3.65	5.65	365	15
3	Yes	12	0	0.12	.12	12	10
4	Yes	365	0	3.65	3.65	365	10

Table 2.1 compares the expected results of data collection for the four cases for a 1-year period.

As illustrated by the above examples, details of how failures have occurred are needed to fully understand the anatomy of a failure and to distinguish between time-related and demand-related failure rates. Defining and classifying failures is not a trivial task, and, because it is often ignored, the final data must be treated with appropriate caution.

2.7 Using Failure Rate Data

When using failure rate data for a CPQRA, the ideal situation is to have valid historical data from the identical equipment in the same application. In most cases, plant-specific data are unavailable or may carry a level of confidence that is too low to allow those data to be used without corroborating data. Risk analysts often overcome these problems by using generic failure rate data as surrogates for or supplements to plant-specific data. Because of the uncertainties inherent in risk analysis methodology, generic failure rate data are frequently adequate to identify the major risk contributors in a process or plant.

Selecting appropriate generic data requires understanding and judgment. In many cases, the analyst can find a number of generic data points that might be used for a CPQRA. Data points chosen for use must provide the level of confidence necessary without creating an unacceptable tolerance uncertainty. The uncertainties of data selection can be reduced by learning as much as possible about data sets, including the taxonomy and equipment boundaries used; the type, design, and construction of the equipment; the process medium; plant operation and maintenance programs; and failure modes. OREDA,[3] IEEE Std. 500-1984[1] and Reliability Data Book for Components in Swedish Nuclear Power Plants[4] are examples of data sets that provide details of taxonomy, data origin, treatment, and limitations. By knowing the background of the data pool, an engineer can more easily choose appropriate data points.

After data have been selected and combined with other generic data or plant-specific data to a single data point, judgment must still be exercised in their use. The analyst may choose to use the generic data directly if the equipment description, process conditions, and failure mode of the data sources are similar to the equipment being studied. More likely, the analyst will have to adjust the data to account for differences in equipment design, process conditions, properties of the chemicals being processed, severity of duty, and/or quality of the facility maintenance regime.

This chapter has discussed some of the factors that may affect equipment reliability and necessitate data adjustment. At this time, little documented assistance is available to help develop these data adjustments. It may be necessary to get help from experts in some situations. Lastly, failure rates are often reported to several decimal places, a precision frequently unwarranted by the data. It is suggested that only the failure rate's first significant number and associated exponential power be used.

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4. *Reliability Data Book for Components in Swedish Nuclear Power Plants*, RKS 85-25, Nuclear Safety Board of Swedish Utilities, Swedish Nuclear Power Inspectorate, Stockholm

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3.1 CCPS Taxo

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CCPS Taxonomy

This chapter reviews the structure, rationale, and method used for the development of the CCPS Taxonomy and explains how to use it. Key elements of the CCPS Taxonomy that are explained include equipment, service, and failure description. The CCPS Taxonomy is listed in Appendix A.

3.1 CCPS Taxonomy Structure

The hierarchical structure of the CCPS Taxonomy is divided into three major parts: equipment description, service description, and failure description. Figure 3.1 illustrates this organization.

3.1.1 Equipment Description

As indicated in Figure 3.1, there are several levels within the equipment description. Each data cell has a unique taxonomy number, which is determined by the number of levels and its position within each level. For the example highlighted by shaded areas in Figure 3.1, the taxonomy number 3.3.7.2.1.1 specifies the third element of the first level, the third element of the second level, the seventh element of the third level, etc.

The upper two or three levels of the equipment description broadly categorize the equipment by generic type. Table 3.1 summarizes these first few levels for the entire CCPS Taxonomy. The lower levels of the equipment description are based on factors that have a strong influence on reliability. For example, the reliability of piping is a function of its diameter. Therefore, pipe diameter, one of the equipment description levels under piping, is divided into two groups: 6" or smaller; and larger than 6 ". Factors that may define levels within the equipment description include function, drive type, fabrication technique, internals, materials of construction, and design principle. These lower levels are important because they further define the data cells, and, if chosen properly, can reduce the scatter of the failure rate data. The number and nature of the levels varies with each data cell.

The final element of the equipment description is the equipment boundary figure. A boundary figure is included with each data cell to define the components and limits of the equipment associated with that cell. For example, the data cell boundary figure (Data cell 3.3.7.2.1.1) in Figure 3.2 shows that the centrifugal pump, seal system, motor, motor control unit, lube oil system, coupling, and transmission are all components of the equipment in the data cell. The equipment boundary is inherently reflected in the taxonomy number.

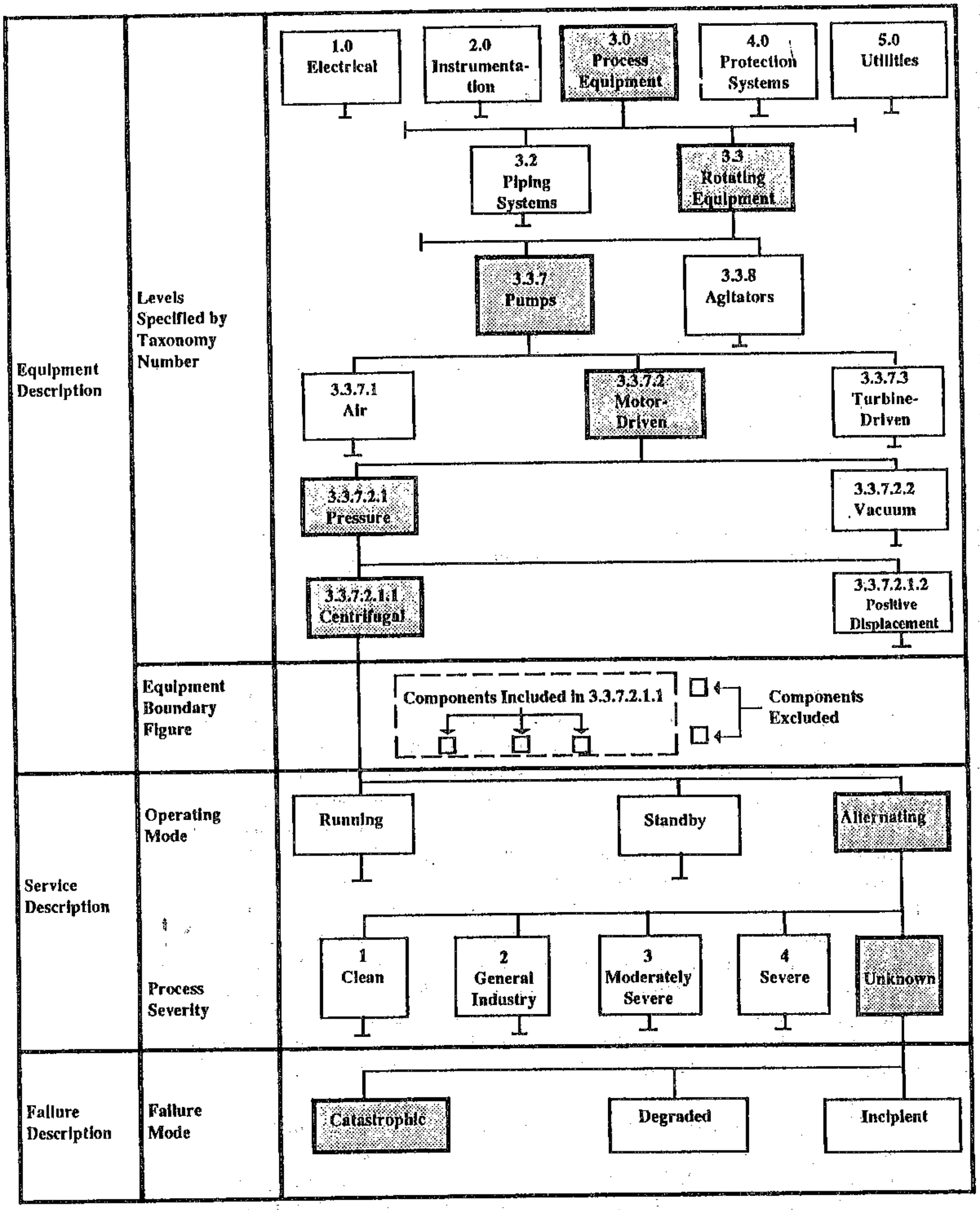

Figure 3.1. *Example of CCPS Taxonomy structure. The shaded areas illustrate the taxonomy number, 3.3.7.2.1.1, used as an example throughout this chapter.*

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  3.3.8 Rotar
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  3.4.1 Bagge
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  3.4.5 Separ
  3.4.6 Size r
 3.5 Valves
  3.5.1 Check
  3.5.2 Manu
  3.5.3 Opera
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  3.6.1 Atmos
  3.6.2 Pressu
  3.6.3 Vacuu
 3.7 Miscellaneo
  3.7.1 Electr
  3.7.2 Seals/
4.0 Protection systen
 4.1 Corrosion
 4.2 Fire
 4.3 Pressure
5.0 Utilities
 5.1 Cooling wat
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 5.5 Heating, ven
 5.6 Incinerators
 5.7 Refrigeratior
 5.8 Steam syster

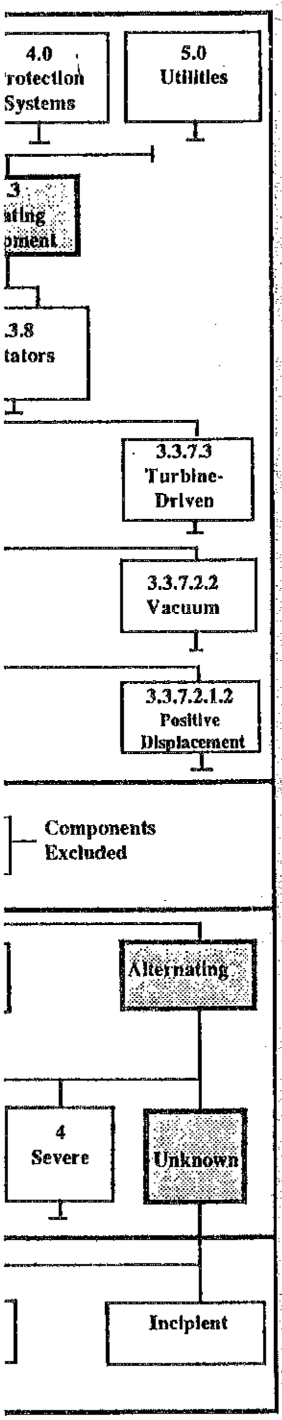

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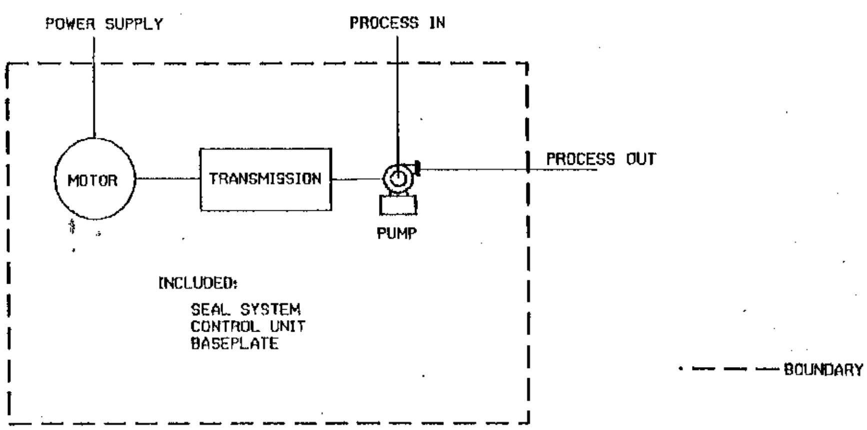
TABLE 3.1
Upper Levels of CCPS Taxonomy

- 1.0 Electrical equipment
  - 1.1 Motors
  - 1.2 Power conditioning and protection devices
  - 1.3 Power generation
- 2.0 Instrumentation
  - 2.1 Process wetted and field instrumentation
  - 2.2 Control room instrumentation
- 3.0 Process equipment
  - 3.1 Heat transfer devices
    - 3.1.1 Fired
    - 3.1.2 Non-fired
  - 3.2 Piping systems
    - 3.2.1 Metal
    - 3.2.2 Lined pipe
    - 3.2.3 Rigid plastic piping
    - 3.2.4 Tubing systems
    - 3.2.5 Hoses
  - 3.3 Rotating equipment
    - 3.3.1 Centrifuges
    - 3.3.2 Compressors
    - 3.3.3 Blowers
    - 3.3.4 Motor driven fans
    - 3.3.5 Extruders
    - 3.3.6 Mixers/blenders
    - 3.3.7 Pumps
    - 3.3.8 Rotary agitators
  - 3.4 Solids handling
    - 3.4.1 Baggers/packagers
    - 3.4.2 Conveyors
    - 3.4.3 Elevator
    - 3.4.4 Feeders
    - 3.4.5 Separators
    - 3.4.6 Size reducers
  - 3.5 Valves
    - 3.5.1 Check valves
    - 3.5.2 Manual valves
    - 3.5.3 Operated valves
  - 3.6 Vessels and accumulators
    - 3.6.1 Atmospheric
    - 3.6.2 Pressurized
    - 3.6.3 Vacuum
  - 3.7 Miscellaneous
    - 3.7.1 Electrolytic cells
    - 3.7.2 Seals/gaskets
- 4.0 Protection systems
  - 4.1 Corrosion
  - 4.2 Fire
  - 4.3 Pressure
- 5.0 Utilities
  - 5.1 Cooling water systems
  - 5.2 Flares
  - 5.3 Gas generators
  - 5.4 Heating systems
  - 5.5 Heating, ventilating and air conditioning (HVAC)
  - 5.6 Incinerators
  - 5.7 Refrigeration
  - 5.8 Steam systems

DATA ON SELECTED PROCESS SYSTEMS AND EQUIPMENT	
Taxonomy No. 3.3.7.2.1.1	Equipment Description ROTATING EQUIPMENT- PUMPS MOTOR DRIVEN-PRESSURE-CENTRIFUGAL
Operating Mode ALTERNATING	Process Severity UNKNOWN

Population	Samples	Aggregated time in service (10^6 hrs)		No. of Demands		
		Calendar time	Operating time			
Failure mode		**Failures (per 10^6 hrs)**			**Failures (per 10^3 demands)**	
	Lower	Mean	Upper	Lower	Mean	Upper
CATASTROPHIC						
a. Fails while Running	43.3	292.0	862.0			
b. Rupture						
c. Spurious Start						
d. Fails to Start on Demand				0.360	10.80	43.0
e. Fails to Stop on Demand						
DEGRADED						
a. Fails to Run at Rated Speed	15.8	920.0	3560.0			
b. External Leak						
INCIPIENT						
a. High Vibration						
b. Over-temperature						
c. Over-current						

Equipment Boundary



Data Reference No. (Table 5.1): 5, 8.1

Figure 3.2. *Example of CCPS generic data sheet.*

Many data c
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units—and functic
controllers. Bounc
become available.

3.1.2 Service Des

The service descri
levels—the operat
the equipment is o
defined as follows

- **Running:** Hardv
  operate to run th
- **Standby:** Hardw
  emergency diese
- **Alternating:** Ha
  installed spare r

The process
by the equipment.

1. **Clean:** Clean f
2. **General indus**
   gas, ethanol, g
3. **Moderately se**
   ging (e.g., dry
4. **Severe:** Severe
   gen chloride, c

3.1.3 Failure Des

The failure descrip
severities, and typ
Data Base for Nu
Report (IPRDS)[1] a

3.2 CCPS Taxon

The development
results of preparin
of equipment to be
over 300 different
Economics series.

Many data cells in the CCPS Taxonomy use equipment boundaries found in available generic data sets in which equipment and service is similar to that in the CPI. The boundaries established for other data cells were generally combinations of normal equipment modules—such as pump, seals, coupling, motor and base plate, or refrigeration units—and functionally interdependent basic and auxiliary components, such as motor controllers. Boundaries may change as greater amounts of equipment reliability data become available.

3.1.2 *Service Description*

The service description is the second part of the taxonomy structure. It includes two levels—the operating mode and the process severity. The operating mode describes how the equipment is operated. The three modes used, running, standby, and alternating, are defined as follows:

- **Running:** Hardware that is usually operating (e.g., an unspared compressor that must operate to run the process).
- **Standby:** Hardware that is normally not running, but must be ready to run (e.g., an emergency diesel generator).
- **Alternating:** Hardware that alternates between standby and running (e.g., a pump and installed spare running a comparable amount of time).

The process severity characterizes the process medium, the material being handled by the equipment. There are four categories in the taxonomy, defined as follows:

1. **Clean:** Clean fluids (e.g., dry clean air, potable water, nitrogen).
2. **General industry:** Noncorrosive, nonabrasive, and nonplugging fluids (e.g., natural gas, ethanol, general service steam).
3. **Moderately severe:** Moderately corrosive, moderately abrasive or moderately plugging (e.g., dry chlorine, anhydrous ammonia, untreated sea water).
4. **Severe:** Severely corrosive, severely abrasive or severely plugging (e.g., wet hydrogen chloride, coal slurry, heavies, uninhibited monomer).

3.1.3 *Failure Description*

The failure description is the third part of the taxonomy structure and involves the modes, severities, and types of failures. These are based on models in the *In-Plant Reliability Data Base for Nuclear Power Plant Components: Data Collection and Methodology Report* (IPRDS)[1] and IEEE Std. 500-1984,[2] which are discussed in Chapter 2.

3.2 CCPS Taxonomy Development

The development of the CCPS Taxonomy was essential, and it is one of the most useful results of preparing this book. The first step in creating the taxonomy was to develop a list of equipment to be included. This was accomplished by reviewing the equipment lists of over 300 different chemical processes summarized by SRI International in their Process Economics series. These lists were used in conjunction with the CCPS Equipment Reliability Data Subcommittee's experience to establish a list of important CPI equipment for inclusion in the taxonomy.

The equipment was then categorized by generic type into the upper levels of the equipment description (see Table 3.1). Each type of equipment was further reviewed in order to establish the lower levels of the equipment description. Factors that were judged to be important distinguishers of reliability were used to define additional levels in the CCPS Taxonomy. Some obvious equipment characteristics were not used as equipment descriptors in the taxonomy because experience has shown they have little influence on reliability behavior. For example, valves were not characterized by type (globe, gate, plug, etc.). In this case, more important distinguishers of reliability are means of operation, such as manual or automatic.

Table 3.2 is a list of factors that were generally not used to establish hierarchical levels in the CCPS Taxonomy. In some cases, the effect of a factor (e.g., humidity) on equipment reliability was insufficient to warrant a new taxonomy level. In many others, criteria established by the subcommittee eliminated them as taxonomy levels. These criteria assumed proper equipment design and specification for the service (e.g., materials of construction, pressure rating, shop fabrication), good installation practices and maintenance programs, and no unusual operating stresses (operating at less than 100% of design).

Many of the data cells defined by the CCPS Taxonomy are not presented in Chapter 5 because no appropriate data were available. It is hoped that this book will promote the development of new data by the CPI to fill these empty cells. As new data are collected, modifications to the CCPS Taxonomy may be required to better reflect reliability influences. The new data should provide better answers to the following questions:

- What equipment should be included in the taxonomy?
- What are the most important distinguishers of reliability?
- What are the proper service descriptions and failure modes of the equipment?
- What are the proper equipment boundaries?

3.3 The CCPS Taxonomy and Its Use

The development of the CCPS Taxonomy provides an enormous number of data cells, each with its unique taxonomy number. To conserve space, the CCPS Taxonomy has been condensed for presentation in Appendix A. Figure 3.3 is an example page from Appendix A.

TABLE 3.2
Factors Not Assigned as Taxonomy Levels

1. External environment, for example, vibration, temperature, humidity.
2. Fabrication techniques, inspection procedures, installation practices (except as noted).
3. Materials of construction (except as noted).
4. Maintenance strategy.
5. Service stress, for example, heavy, medium or light duty.
6. Internal temperature or pressure (except as noted).
7. Design standards.
8. Process type or equipment manufacturer.

3.0 PROCESS EQUIPMENT
3.3 Rotating Equipment

APPENDIX A - CCPS TAXONOMY

EQUIPMENT DESCRIPTION			SERVICE DESCRIPTION		FAILURE DESCRIPTION
			OPERATING MODE	PROCESS SEVERITY	
3.3.7 Pumps 3.3.7.1 <u>Air</u> 3.3.7.2 <u>Motor-Driven</u> 3.3.7.2.1 Pressure 3.3.7.2.2 Vacuum 3.3.7.3 <u>Turbine-Driven</u> 3.3.7.3.1 Gas 3.3.7.3.2 Steam	 .1 Centrifugal .2 Positive Displacement .2.1 Gear .2.2 Piston .1 Centrifugal .2 Positive Displacement	.1 0 - 1000 HP .2 >1000 HP	Alternating Running Standby	1 - 4	1- Catastrophic a. Fails While Running b. Rupture c. Spurious Start d. Fails to Start on Demand e. Fails to Stop on Demand 2- Degraded a. Fails to Run at Rated Speed b. External Leak 3- Incipient a. High Vibration b. Over-temperature c. Over-current
3.3.8 Rotary Agitators 3.3.8.1 <u>Direct-Driven</u> 3.3.8.2 <u>Gear-Driven</u>			Alternating Running	2 - 4	1- Catastrophic a. Fails While Running b. Seal External Rupture c. Seal Rupture - Influx d. Spurious Start/Command Fault e. Fails to Start on Demand f. Fails to Stop on Demand

Figure 3.3. *Example of condensed CCPS Taxonomy.*

TABLE 3.3
Expansion of the CCPS Taxonomy Example, 3.3.7.2.1.1
(see Figures 3.2 and 3.3)

3 Process equipment
3.3 Rotating equipment
3.3.7 Pumps
3.3.7.2 Motor driven
3.3.7.2.1 Pressure
3.3.7.2.1.1 Centrifugal

Equipment Description	Service Description: Operating Mode	Service Description: Process Severity	Failure Description
3.3.7.2.1.1(0-1000 HP)	Alternating	1	*
"	"	2	*
"	"	3	*
"	"	4	*
"	Running	1	*
"	"	2	*
"	"	3	*
"	"	4	*
"	Standby	1	*
"	"	2	*
"	"	3	*
"	"	4	*
3.3.7.2.1.1(>1000HP	Alternating	1	*
"	"	2	*
"	"	3	*
"	"	4	*
"	Running	1	*
"	"	2	*
"	"	3	*
"	"	4	*
"	Standby	1	*
"	"	2	*
"	"	3	*
"	"	4	*

*Failure modes:
1. Catastrophic
   a. Fails while running
   b. Influx of contaminants (backflow)
   c. Spurious start
   d. Fails to start on demand
   e. Fails to stop on demand
2. Degraded
   a. Fails to run at rated speed
   b. External leak
3. Incipient
   a. High vibration
   b. Over-temperature
   c. Over-current

As shown i
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by taxonomy num
Rate Data Base.

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of Electrical and
3. *EuReDatA Proje*
T. Luisi, Comm
ment, S.A./1.0
4. *EuReDatA Proj*
Stevens, Comm
ment, S.P./1.05
5. *Offshore Reliabi*
1984. distribute

As shown in this figure, the format is divided into three main columns labeled "Equipment Description," "Service Description," and "Failure Description." The Equipment Description column may be further divided to show the necessary equipment description levels that make up the taxonomy number. Each column represents one additional hierarchical level and number in the CCPS Taxonomy. Similarly, the Service and Failure Descriptions are divided as needed to fully establish the data cells. An entry or group of entries in a column apply all the way down the column until an additional entry or a horizontal line is reached.

To illustrate the effect of condensing the taxonomy for Appendix A, Table 3.3 shows the expansion of taxonomy number 3.3.7.2.1.1, one part of the taxonomy in Figure 3.3. There are 24 potential data cells in Table 3.3. The first data cell listed has a taxonomy number of "3.3.7.2.1.1," an "Alternating" Operating Mode and a Process Severity of "1."

When trying to locate data on a specific type of equipment in the CCPS Generic Failure Rate Data Base, the reader will need its taxonomy number. Table 3.1 is useful for determining the section of the taxonomy in Appendix A where it can be found. Alternatively, the taxonomy number can be located directly by referring to Appendix B, the Equipment Index with associated taxonomy numbers. To help the reader, Table 5.2 lists by taxonomy number those cells which contain data and are in the CCPS Generic Failure Rate Data Base.

References

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2. *Guide to the Collection and Representation of Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear Generating Stations.* IEEE Standard 500-1984, Institute of Electrical and Electronics Engineers, New York, 1984.
3. *EuReDatA Project Report No. 1, Reference Classification Concerning Components Reliability.* T. Luisi, Commission of the European Communities, Joint Research Centre, Ispra Establishment, S.A./1.05.01.83.02.
4. *EuReDatA Project Report No. 3, Guide to Reliability Data Collection and Management.* B. Stevens, Commission of the European Communities, Joint Research Centre, Ispra Establishment, S.P./1.05.E3.86.20
5. *Offshore Reliability Data Handbook,* OREDA-84. P.O. Box 370, N-1322, HOVIK, Norway, 1984. distributed by Pennwell Publishing Company, Tulsa, OK.