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Clarity, Organization, Precision, Economy: A Technical Writing Guide for Engineers

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Comments

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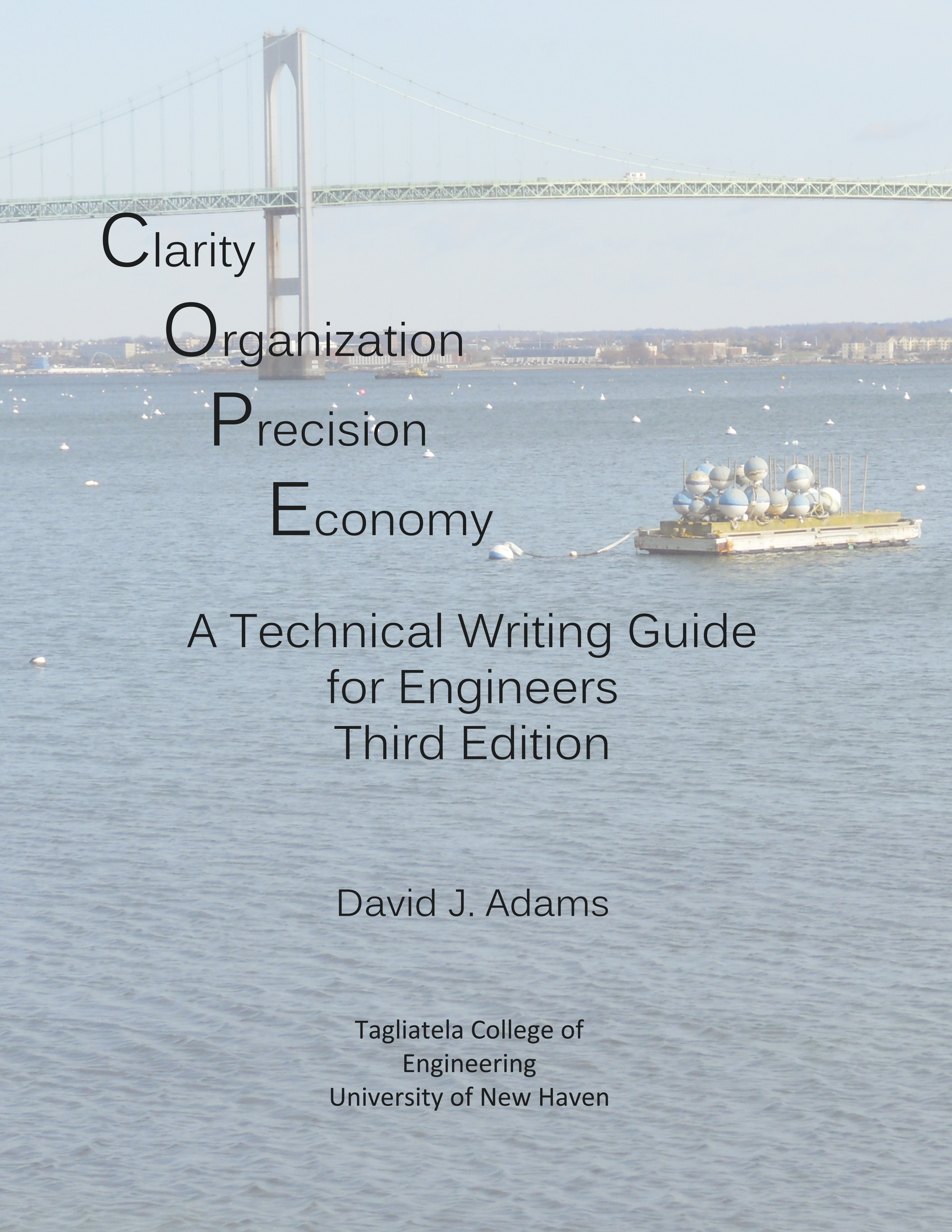

Clarity
Organization
Precision
Economy

A Technical Writing Guide for Engineers
Third Edition

David J. Adams

Tagliatela College of Engineering
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Acknowledgments

This third edition of COPE was sparked by my involvement with PITCH (Project to Integrate Technical Communication Habits) at the Tagliatela College of Engineering at the University of New Haven (UNH).

Over the years I have had the good fortune to work with, and learn from, some exceptional engineers, students and technical writers—more than I can probably remember. But I would like to acknowledge a few of those with whom I have worked closely over the last three decades and drawn from their experience and insights: Frank Wise from Cornell University; Alan Flaherty of Complan; Roger Wallace, David Wiggert, Shu-Guang Li, Rick Lyles and Ron Harichandran from Michigan State University; Will Manion and Per Gårder at the University of Maine; Jean Nocito-Gobel, Mike Collura, Amy Thompson, Sam Daniels, Nadiye Erdil, Eric Brisart from the Tagliatela College of Engineering at the University of New Haven. I owe a special debt to the following colleagues and students from Michigan State, the University of Maine and the University of New Haven who allowed me to quote from excerpts of their work: Ghassan Abu-Lebdeh, Andreanne Simard, Neeraj Buch, Karim Chatti, Kaenvit Vongchusiri, Mathew Diffin, Syed Waqar Haider and Mike Collura.

I owe an even greater debt of gratitude to Dean Ron Harichandran and faculty in the Tagliatela College of Engineering for trusting me to help guide the creation of the PITCH project there, and to the Davis Educational Foundation for supporting the work. I dedicate this booklet to the late Martha Eckman, who founded the technical writing program at Bowling Green State University and tried to get as many poets who would listen to take her technical writing course.

—David Adams

Overview

This third edition of *COPE* came about as a result of work occurring at the Tagliatela College of Engineering at the University of New Haven.

- Faculty and alumni/employers express dissatisfaction with the writing skills of engineering graduates.
- Working engineers spend between 40-70% of their time communicating.
- Faculty and alumni/employers consistently identify the same issues in student writing—weaknesses in clarity, organization, precision and economy. Hence, the title of this guidebook.

I realize that these categories of COPE issues—Clarity, Organization, Precision and Economy—may seem arbitrary, and they overlap at points, but the categories do reflect the daily writing issues we see among engineering students. And this book is *primarily about writing* even though technical communication texts now encompass so many other vital topics. I have tried to frame this little book on fourteen guidelines and numerous examples that students and faculty can use as common ground when discussing writing.

Most of us who work regularly with engineers have come to marvel at the variety and complexity of their professional writing. It is truly writing from which things happen. And yet, despite the complexity of subject and situation, despite the proliferation of media and technology, writing clearly and effectively remains a central skill.

I wish I could give you a simple formula that always produce effective writing—writing that produces the result you desired. I have yet to find such magic. But I do believe that *habits* of writing exist that too often interfere with your ability to communicate effectively. A good engineering analogy might be to think of such writing as having a low signal-to-noise ratio—too many words, too little information. The *COPE* guidelines target that condition. So, reader, I hope your own writing will benefit from what follows.

—David Adams
September, 2014

Table of Contents

Clarity

In the surveys mentioned in the Overview, both faculty and employers expressed particular frustration with a lack of clarity in the writing of students and graduates. But what does "lack of clarity" actually mean in terms of the writing? A good answer might be to think of the amount of *unnecessary* work a reader must do to understand a given piece of writing because you failed to do the *necessary* work of making your sentences clear. If you apply the following four guidelines, you will improve the clarity of your writing.

C1. Maintain a Flow of Related Words.

When you write about engineering topics and processes, make sure you write sentences in which you maintain a flow of related words. In this guideline we examine two strategies for maintaining a flow of related words at the sentence level:

- ✓ Avoid misplaced modifiers
- ✓ Place subjects and verbs in proximity

Avoid misplaced modifiers.

You can confuse readers when you place a modifying word or phrase in a position where it cannot refer sensibly to the noun you intend. Note these examples with revisions.

Misplaced Modifier	Issue	Revision
Studying three-dimensional scaling effects, the processes of joint failure would change continuously.	The "processes" could not study "three dimensional scaling effects."	A study of three-dimensional scaling effects indicates that the processes of joint failure would change continuously.
Using a bench diffusion test with six different cells, a simulation was constructed of the diffusion process on a laboratory scale.	Here we have two issues in one sentence. First, the "simulation" could not be using the bench diffusion test. Second, "a laboratory scale" should modify "simulation."	A laboratory scale simulation of the diffusion process was constructed by using a bench diffusion test with six different cells.
Comprising 70% of bone tissue, researchers have determined that Hydroxyapatite (HA) is conducive to bone growth.	Researchers do not comprise "up to 70% of bone tissue."	Hydroxyapatite (HA) comprises up to 70% of bone tissue, and researchers have determined that HA is conducive to bone growth.

Place subjects and verbs in proximity.

You can sometimes produce unclear sentences when you place too many words between a subject of a sentence and its verb. This separation is a particular problem in long sentences with parenthetical elements. Note these examples with revisions.

Separated Subject and Verb	Issue	Revision
Data at each point, from both the tipping bucket rain gauge and the plastic rain gauge, in order to measure the daily total precipitation, were compared and averaged.	Note that 21 words and 2 prepositional phrases separate the subject "data" from the verb "were compared and averaged." That separation makes it difficult to sort out the relationships.	In order to measure the daily total precipitation, data were compared and averaged at each point (from both the tipping bucket rain gauge and the plastic rain gauge).
Heat and additives that occur when polymers are created, by reacting the small chemical units, or *monomers,* into chains or networks, can either cause additional bond formation or can cause bonds to break. .	Twelve words separate "heat and additives" from the verb "can cause." While twelve may not seem a large number, it does add to the cognitive load on the reader. In this case a revision might require two sentences to improve clarity.	Polymers are created by reacting the small chemical units, or *monomers,* into chains or networks. Heat and additives that occur in this process can either cause additional bond formation or can cause bonds to break.
None of the strategies employed at the Maple Grove site, including over the last two years a diversion channel with filtration and removal, 12 monitoring wells, and a 1.5 acre engineered wetland, resulted in a reduction of the contaminated leachate sufficient to meet BEP standards.	Note that here you have 23 words between subject and verb—a pattern made more confusing by the mixing of *time* with *strategies.*	Over the last two years none of the strategies employed at the Maple Grove site resulted in a reduction of the contaminated leachate sufficient to meet BEP standards. These strategies included a diversion channel with filtration and removal, 12 monitoring wells, and a 1.5 acre engineered wetland.

An exception to this guideline occurs if you have a complex subject, as in the sentence below:

> A high-early-strength Portland cement (ASTM Type III, 438 m^2 /kg Blaine fineness) was used.

In this case you need to designate the type of cement before you get to the verb. You *could* rewrite the sentence, but doing so would have little impact on clarity.

C2. Use Parallel Constructions

Parallel construction, which you may have encountered in earlier study of writing, takes on special emphasis in technical reports. This emphasis manifests itself most acutely within three levels of writing: headings, sentences, and lists. Using parallel construction means that you place equivalent types of information in equivalent grammatical structures, essentially a matter of symmetry. Such symmetry helps readers more quickly grasp the relationships of words within and across those levels. Note the example that follows.

Lack of Parallel Construction	Issue	Parallel Revision
Shallow groundwater flow results from **the surface sand being built up**, the presence of the pond, and the engineered features that contain the pond.	Note that in this list of three causes "the surface sand being built up" has a different structure that the other two causes. In the revision we see three parallel phrases.	Shallow groundwater flow results from **the buildup of surface sand**, the presence of the pond, and the engineered features that contain the pond.

Such parallelism accomplishes two things: 1) helping *your reader* understand the grouping and ordering you employed when organizing your document; 2) letting *you* see how clearly and precisely you have organized your information.

Below are some examples of parallel construction at those three different levels.

Headings. Think of headings as elements of your Table of Contents (or outline). Use parallel headings at equivalent levels in your reports.

Lack of Parallel Construction	Parallel Revision
1.0 Circuit Design 1.1 *Selecting the* preamplifier 1.2 Modulator and demodulator 1.3 Ripple and lead networks	1.0 Circuit Design 1.1 Preamplifier 1.2 Modulator and demodulator 1.3 Ripple and lead networks

Sentences. You can apply the guideline for parallel structure to individual sentences as well—particularly sentences that end with a series of items. Consider the examples below.

Lack of Parallel Construction	Parallel Revision
The pavement sections under study exhibited two common characteristics: a) service life 20-30% shorter than expected; b) having been completed during the 1992-93 construction seasons.	The pavement sections under study exhibited two common characteristics: a) service life 20-30% shorter than expected; b) completion during 1992-93 construction seasons.
We reviewed each alternative to determine relative cost, technical soundness, and whether or not the design was simple.	We reviewed each alternative to determine relative cost, technical soundness, and design simplicity.

Lists. Although lists may fall within a sentence, they often appear as discrete parts of a document as a way to help its visual organization. The simplest way to keep list items parallel is to remember what type of information they represent and begin each list item with the same part of speech.

Lack of Parallel Construction	Parallel Revision
In using the momentum equation applied to deflectors we assume the following: 1. Constant external pressure to the fluid jet so that the pressure in the fluid remains constant as it moves over a deflector; 2. Negligible frictional resistance due to the fluid-deflector interaction so that the relative speed remains unchanged between the deflector surface and the jet stream, a result of Bernoulli's equation; 3. Lateral spreading of a plane jet being neglected; 4. Neglecting the weight of the control volume (the body force).	In using the momentum equation applied to deflectors we assume the following: 1. Constant external pressure to the fluid jet so that the pressure in the fluid remains constant as it moves over a deflector; 2. Negligible frictional resistance due to the fluid-deflector interaction so that the relative speed remains unchanged between the deflector surface and the jet stream, a result of Bernoulli's equation; 3. Neglect of lateral spreading of a plane jet; 4. Neglect of the weight of the control volume (the body force).

Note how item 4 has been changed in the revision to make it parallel with the rest of the list.

C3. Use Pronouns with Care

Give pronouns clear antecedents

Used carelessly, pronouns can confuse readers rather than guide them. Remember that pronouns should have a clear *antecedent* (the word to which the pronoun refers) and that antecedent must be near the pronoun in question. Pronouns should agree with the number and gender of the antecedent. The table that follows illustrates some common problems that arise from careless use of pronouns.

Careless Pronoun Usage	Issue	Revision
Ion chromatography is a form of liquid chromatography that uses ion-exchange resins to separate atomic or molecular ions based on their interaction with the resin. **Its** greatest utility is for analysis of anions for which there are no other rapid analytical methods. **It** is also commonly used for cations and biochemical species such as amino acids and proteins.	Here we have a great example of the "iterative it." The second and third sentences begin with "its" and "it" respectively, but the antecedent (Ion chromatography) appears 23 and 40 words away. The nearest possible antecedent is "resin," but that usage makes no sense here. When you find these uses of "it" spreading across sentences, consider recasting the sentences to preserve the clear reference. Here a list frames that reference and uses order to indicate hierarchy within the list.	Ion chromatography is a form of liquid chromatography that uses ion-exchange resins to separate atomic or molecular ions based on their interaction with the resin. Ion chromatography is commonly used in two circumstances: • analysis of anions for which there are no other rapid analytical methods. • analysis of cations and biochemical species such as amino acids and proteins.
The results show that the probabilistic approach can predict the potential for fatigue cracking when uncertainty (variability) is significant (CoV is greater than 30%), even when the mean deflection levels are not necessarily high. **This** can lead to allowable variation limits for deflections within a pavement section. **These** are very helpful for field quality control in the context of performance-based specifications.	Demonstrative pronouns (this, that, these, those) can be especially tricky when appearing alone. What is the antecedent for "This" in sentence two? For "These" in sentence three? You can avoid this lack of clarity by following a simple rule of thumb. Never start a sentence with a demonstrative pronoun by itself. Pair it with the precise antecedent. If you can't find	The results show that the probabilistic approach can predict the potential for fatigue cracking when uncertainty (variability) is significant (CoV is greater than 30%), even when the mean deflection levels are not necessarily high. **Such predictions** can lead to allowable variation limits for deflections within a pavement section. **These variation limits** are very helpful for field quality control in the context of

Careless Pronoun Usage	Issue	Revision
	that antecedent, you've got some revision ahead of you.	performance-based specifications.
The drag force is proportional to the square of the velocity and depends on properties of the fluid and the object. If the distance travelled is long enough, **it** will reach a constant velocity, called the terminal velocity.	In this case, "it" in the second sentence must refer to distance traveled. Yet clearly the distance travelled is not reaching terminal velocity, but rather "the object" at the end of sentence one.	The drag force is proportional to the square of the velocity and depends on properties of the fluid and the object. If the distance travelled is long enough, **the object** will reach a constant velocity, called the terminal velocity.

A Note on Pronouns & Gender

People today display a heightened sensitivity to the way assumptions about gender roles get revealed through the use of language. The personal pronouns *he* and *she* represent a special instance that should get your attention as writers. You should avoid a situation in which your use of those pronouns draws attention to itself to the point that such usage becomes "noise" in your signal—something that becomes a barrier to a reader focusing on your message.

Problem Usage	Strategies	Examples
When an engineer completes **his** inspection of monitoring wells, **he** must immediately report the results to **his** supervisor.	• When feasible, change the singular *he* and *she* to plural *they*, or rewrite to avoid using a pronoun.	√ When engineers complete **their** inspection of monitoring wells, **they** must immediately report the results to **their** supervisor. √ After inspecting monitoring wells, an engineer must immediately report the results to the appropriate supervisor.
	• If you use the "he or she" construction, vary the order of the two pronouns. This choice can result in some cumbersome sentences, so you might mix these strategies or choose gender neutral terms whenever possible.	√ When an engineer completes an inspection of monitoring wells, **he or she** must immediately report the results to the appropriate supervisor. **She or he** will clean and return all sampling equipment to the main trailer.

C4. Use Consistent Terminology

Somewhere along the line, writers absorb advice about varying their vocabulary. This advice mirrors the thought that repetition is boring, and boring writing does not engage readers. Yet in technical writing, repetition can serve some helpful purposes. When the material is complex, and terms have specific meanings that are tied to specific words, repeating the same word for the same term can help readers as they work their way through a document. Do not call something a "program" in one sentence, and then refer to it as a "system" three sentences later.

Inconsistent Usage	Issue	Revision
This collection **tile** system runs from the park north along the brine pond, where it eventually overlaps with the collection **pipe** system found along the northern perimeter of the pond. Water levels from piezometers located near the collection **tiles** indicate that the system is effectively capturing the shallow ground water.	The switch from "tile" to "pipe" adds a degree of uncertainty that far outweighs the benefits of varied vocabulary. Here the reader must halt and determine whether or not the terms refer to the same thing.	This collection **tile** system runs from the park north along the brine pond where it eventually overlaps with the collection **tile** system found along the northern perimeter of the pond. Water levels from piezometers located near the collection **tiles** indicate that the system is effectively capturing the shallow ground water.
A thorough assessment of the potential of the proposed advanced **control concept** will require significant additional work. This current proposal will be the beginning of a more elaborate effort to evaluate and finally test the new **control technique** in real-world roadway networks.	"Control concept" and "control technique" give us different terms for the same thing. Be consistent.	A thorough assessment of the potential of the proposed advanced **control concept** will require significant additional work. This current proposal will be the beginning of a more elaborate effort to evaluate and finally test the new **control concept** in real-world roadway networks.

Organization

O1. Group and Order Information

In the surveys mentioned in the Overview both faculty and employers expressed frustration with the lack of meaningful organization in reports written by students and recent graduates. Improving your organization may be the single biggest improvement you could make to your writing.

Why is organization so important? When you produce engineering reports you deal with complex technical material. You will produce such reports in a variety of settings and formats, and for a variety of audiences who may have different reasons for reading the report. On a basic level you could define organizing as consisting of two tasks:

- place information in groups.
- put the groups in some order.

These tasks may sound simple, but in practice such grouping and ordering can be your most difficult writing problem. You can solve that problem by making sure your writing employs three organizing techniques: *Summary*, *Superstructure,* and *Subordination*.

Summary	Superstructure	Subordination
Preview the information your reader is about to encounter.	Provide a consistent framework for grouping similar types of information in places where the reader can expect and recognize them.	Indicate the relative links among, and relative importance of, different types of information. Rarely, if ever, is all the information you have of equal importance to your readers. Order is a natural indicator of subordination.

The two versions of the passage in the following table illustrate how difficult it is for readers to mentally reorganize text to place ideas together. Such organization is the writer's job. In the muddled version, the italicized segments are out of order. In the revised version, the forecast elements of the introductory paragraph combine with the section headers to give structure to the passage. Note the visual structure of the passage mirrors the technical content and purpose.

A Muddled Passage

My complete report is attached, but this memo highlights the most significant issues under each safety category. In terms of hazardous materials I found approximately 5kg of beryllium powder left in open containers in Room 25. Employees in this room were not wearing protective clothing and were exposed to undetermined amounts of this powder. No Material Safety Data Sheet (MSDS) exists for this material, and there is no documentation as to its lot number. *I recommend that we institute weekly inspections, as well as a review of our current safety training for new employees*. Safety *Equipment was also a problem. Six of the 25 fire extinguishers in Building A3 were of the wrong class for their location, and two of the six were three months beyond their expiration date.*

In addition to safety equipment problems, there were more problems with hazardous materials. Technicians in the irradiation lab (Room 23) have been storing various isotopes in unlocked cabinets, and it appears that three inventory sheets for these isotopes have either disappeared or were not completed in the first place. This inspection revealed serious safety problems in Building A3, problems that not only put technicians at risk, but also may expose the company to significant penalties from state and federal agencies. Other safety equipment problems included the fact that emergency showers in rooms 21 and 29 failed to operate when tested. Further inspection revealed that the valves were severely corroded and would not function should an emergency arise.

The attached report details these problems, as well as a series of less critical transgressions. The potential consequences for Brown Bear Labs could be dire. We corrected the problems for the moment, although we still have not located the missing inventory sheets. Let's discuss my report at Friday's meeting.

- The passages in italics mark problems with the organization.
- Note the odd mixing of ideas within the first paragraph. The writer jumps from a specific problem with hazardous materials, to a recommendation, to problems with equipment.
- The second paragraph returns to a discussion of hazardous materials and then drifts back to safety equipment.
- The serious potential consequences of these problems get scattered throughout the text where they lose impact.

Revised Passage

This inspection revealed serious safety problems in Building A3, problems that not only put technicians at risk, but also may expose the company to significant penalties from state and federal agencies. My complete report is attached, but this memo highlights the most significant issues under each safety category.

Hazardous Materials

- I found approximately 5kg of beryllium powder left in open containers in Room 25. Employees in this room were not wearing protective clothing and were exposed to undetermined amounts of this powder. No Material Safety Data Sheet (MSDS) exists for this material, and there is no documentation as to its lot number.

- Technicians in the irradiation lab (Room 23) have been storing various isotopes in unlocked cabinets, and it appears that three inventory sheets for these isotopes have either disappeared or were not completed in the first place.

Safety Equipment

- Six of the 25 fire extinguishers in Building A3 were of the wrong class for their location, and two of the six were three months beyond their expiration date.

- Emergency showers in rooms 21 and 29 failed to operate when tested. Further inspection revealed that the valves were severely corroded and would not function should an emergency arise.

The attached report details these problems, as well as a series of less critical transgressions. The potential consequences for Brown Bear Labs could be dire. We corrected the problems for the moment although we still have not located the missing inventory sheets. I recommend that we institute weekly inspections, as well as a review of our current safety training for new employees. Let's discuss my report at Friday's meeting.

- Note that the serious potential consequences come first. The paragraph ends with a forecast statement.
- The use of headings and lists gives both a logical and visual structure to the ideas in the report. The ideas are *grouped and ordered.*
- The last paragraph summarizes the status, restates the seriousness and provides a recommendation, as well as a follow-up suggestion.

You can't *group and order*, or incorporate the features above, unless you can develop organizing principles. In other words, on *what basis* do you put things in groups? How do you decide in *which order* to present things? You may get some help from set formats (say, in a lab report). But within those set formats, much of the work is left to you to find the combination of *Summary*, *Superstructure* and *Subordination* that best conveys information to your readers.

In some cases you might group and order items by *time*, as with steps in a procedure. The steps may occur in an order, and you may group them in stages that make whole process easier to comprehend. Complex procedures might include loops or conditional steps. As the complexity increases, you might find that plain text becomes less effective in outlining the procedure. You might need flow diagrams to capture the variations and complexity.

In other cases you might group and order items by *criteria*, or *standards* by which you judge a procedure or product. Such criteria might include cost, reliability, speed, etc. You might group and order things by characteristics, as with certain qualities of a metal, such as malleability or tensile strength or resistance to corrosion.

You may group and order things by cause and effect (this gets tricky), such as when attributing turbulent flow to a combination of physical features on an apparatus. The relative or summative or probabilistic characteristics of multiple causes and effects can be quite complex. Particularly in such cases strong organization becomes crucial to understanding and might be a case in which you should consider adding some graphic representation of your thinking. Flow diagrams, decision trees or matrices can be useful devices for that purpose.

Many groupings and orders are possible. The best organization is that which makes it easiest for readers to *locate*, *absorb*, and *use* the information you have gathered.

A note on ordering

Within different organizing patterns (in Western cultures) we tend to order items in hierarchical ways—that is we arrange items in order of importance. That order relies on a reader having some familiarity with the topics. But for really complex phenomena, or for unwelcome news, or for cross-cultural communication, an inductive pattern might work better if it serves to hold the reader's attention.

Incorporating visual displays into a document allows you to address multiple patterns of organization for complex material. Such displays might also allow you to meet the expectations of readers from different cultures.

For example, suppose you were asked to examine different valves that might be used in a high-pressure pipeline and report the results to a manager who must decide which valve to select. You could simply discuss the investigation of each valve in turn. Or you might organize the report around the features examined (such as total cost, performance against technical requirements, product warranty, etc.) and then discuss each valve under those categories. The outlines on the next page illustrate the two patterns.

Pattern 1

1) Valve A.
   a) Total cost
   b) Performance against technical requirements
   c) Product warranty
2) Valve B.
   a) Total cost
   b) Performance against technical requirements
   c) Product warranty
3) Valve C.
   a) Total cost
   b) Performance against technical requirements
   c) Product warranty

Pattern 2

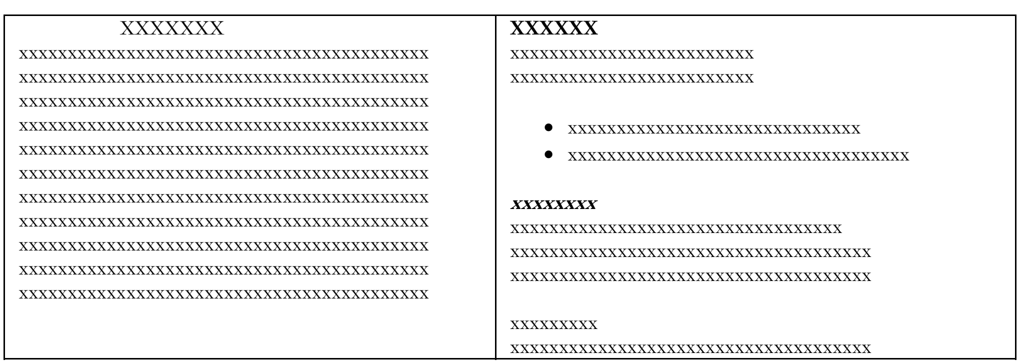
1) Total cost
   a. Valve A
   b. Valve B
   c. Valve C
2) Performance against technical requirements
   a. Valve A
   b. Valve B
   c. Valve C
3) Product warranty
   a. Valve A
   b. Valve B
   c. Valve C

Your challenge is to design superstructure and subordination that make it easy for a reader to compare the three valves, to "see" all the information in a useful way.

Pattern 1 is organized around the different valves; Pattern 2 is organized around the criteria for evaluation. Either pattern become a problem if you have, say, eight valves to examine instead of three. That problem arises from the fact that a reader would have to jump back and forth to make comparisons. The more options or criteria, the greater the jumps. In a complex report you may have many levels of subordination. *Of course, you can always combine patterns and put the information in a summary table. That choice might be best of all.* *(See the example on page xx.)*

These outlines are brief examples, but they lead to another technique that reveals superstructure and subordination—the shape of ink on your page. *A report shouldn't look like a block of black ink*. Remember, some things you write are more important than others; readers should find those differences easily. Contrast the models below. Which one uses visual structure to suggest organization?

Block of black ink model | **Visual structure model**



O2. Use Forecast & Echo Structures

There is an old axiom in technical writing that says:

1. *Tell them what you're going to tell them*
2. *Tell them.*
3. *Tell them what you told them.*

This axiom may seem overly simple today, but it still provides some useful guidance about organizing your writing at all levels. Well-written reports contain forecast and echo statements. As their names imply, these writing techniques weave unifying links between ideas in a report. A forecast statement previews the organization of the material to come. An echo statement points back to the forecast. These techniques should appear at every level of a document. The passage below is from an Introduction, so it previews the organization of the report that follows.

Example of Forecast and Echo Statements	Explanation
This experiment involved using four different *flow meters* to measure the flow of water through a pipe. The purpose was *threefold*: • evaluate the accuracy of various methods for measuring *mass flow*. • understand the *flow patterns* generated by the different meters. • evaluate basic *flow properties* through pipes.	Several forecast and echo statements occur here, noted in italics. The first sentence previews the subject. The second introduces the list of three purposes with the word "threefold." Using the echo word "flow" in the list links the three purposes to the overall subject. Also, the word "meters" echoes the first sentence.

This next passage displays forecast and echo statements within a report.

Example of Forecast and Echo Statements	Explanation
One-dimensional heat diffusion describes the distribution of temperatures along a rod after a heat pulse is applied to a point on the rod. This distribution is controlled by two parameters: volumetric heat capacity and thermal conductivity. Volumetric heat capacity (s) is the amount of heat added to a given volume of material to produce a specified rise in temperature.	"This distribution" echoes "distribution of temperatures." The same sentence forecasts the two parameters to be discussed. The last sentence links the definition of "volumetric heat capacity" to its mention as a parameter

Use forecast and echo statements to help readers manage and absorb what can become highly complex clusters of information, as in the next extended passage:

Example of Forecast and Echo Statements

Use of Network-Level and Project-Level Data

For this project it was necessary to capture the range of variability for a range of pavement cross-sections and climatic zones. To that end, network-level data was used in determining the common trend and general shape of Surface Curvature Index (SCI) and Base Damage Index (BDI) distributions. Additionally, the network-level data was used to determine the correlation coefficient between these two variables. This correlation coefficient (ρ) was found to be 0.873 as shown in Figure 4. Such a value indicates that the SCI and BDI are highly correlated. This correlation between SCI and BDI should be considered in calculating the variance of the performance function.

The mean, standard deviation and coefficient of variation for the random variables were determined by using the project-level data to investigate the performance of a particular section. This use of project-level data will also eliminate the design variability between different cross-sections and environmental regions at the network level—variability that may cause unrealistic uncertainty in the random variables.

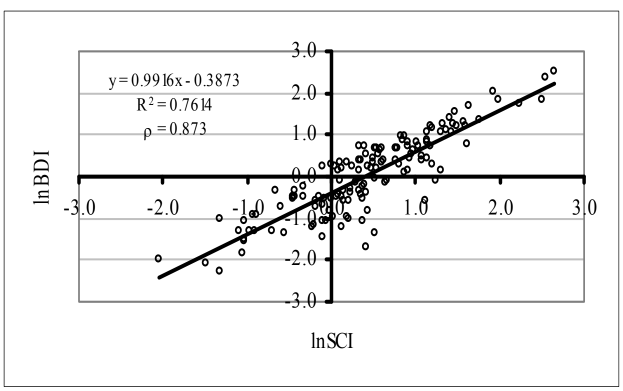


Figure 4. lnSCI - lnBDI Correlation

Explanation

This passage uses many forecast and echo devices. Note some of the major ones:

- The heading accurately forecasts the content of the section. “Network-Level” and “Project-Level” appear as echoes in the passage.
- We can also note a certain overlap in applying our COPE guidelines. Notice how pairing the pronoun “this” with its antecedent echoes an earlier statement across sentences.
- Notice how repeating the term “variability” within a long sentence helps keep the reader on track.
- The reference to Figure 4 forecasts the data seen there, and this reference also appears at a point in the text where one can see the figure.

Note that even a subject line in a memo can preview organization. Take advantage of such things to get your reader's attention. Here's a possible subject heading for the memo on the safety violations.

Vague	Specific
Re: Safety Violations	Re: Serious Violations of Safety Regulations—Building A3

O3. Use Lists and Tables

All good technical writing has a visual structure that reveals and supports organization. Remember, we want our reports to reveal information, not bury it in the volume of words. A list is one way to give structure to information on a page. A table is another way.

Below is an example of information in plain text and in a list.

Plain Text	List
We completed a cost-benefit analysis on the following: replacing the old fleet with new vehicles, installing a computerized distribution and tracking system, providing drivers with cellular phones and hand-held bar code readers.	We completed a cost-benefit analysis on the following: ▪ replacing the old fleet with new vehicles ▪ installing a computerized distribution and tracking system ▪ providing drivers with cellular phones and hand-held bar code readers.

The visual structure you see here is called "chunking," and this structure helps readers to recognize and remember bits of related information. Here are several guidelines to apply when constructing lists:

- Include a lead phrase or sentence.
- Use parallel construction.
- Use hanging indents.
- Use appropriate tags for lists (numerals/alpha letters to indicate steps in a procedure; bullets or other icons to identify items that indicate hierarchy by their position in the list).

Here are two versions of a list. The first ignores the guidelines; the second follows them. Notice that the list on the left lacks hanging indents parallel structure.

Poorly Designed List	Improved List
You must consider the following when you design your proposal. • Will the current facilities support the size and weight of the new equipment? • The cost must be within the capital budget projected over the next five years. • Will current staff be sufficient to manage the project? • Identify construction, zoning, and environmental regulations that may come into play during this project.	You must consider the following when you design your proposal. • Will the current facilities support the size and weight of the new equipment? • Will the cost be within the capital budget projected over the next five years? • Will current staff be sufficient to manage the project? • Which construction, zoning, and environmental regulations may come into play during this project?

In passages with many values that readers must compare, you should consider recasting the values in a table. That way you can use text to comment on the table and readers can see the relationship between the values.

Information in Text Format

Last year (1996) the firm billed for 2,500 hours of heavy equipment operation, a great increase over the previous two years. The budget for hiring heavy equipment operators, however, increased from $72,000 in 1994 at an hourly rate of $30 to $74,000 in 1995 to $78,000 last year. In 1994, the firm billed for 1,754 hours of heavy equipment operation and increased that to 1,835 in 1995. The hourly rate rose to $33 in 1995 and to $36 in 1996. The shortfall of operators in 1996 resulted in overtime expenditures of $32,998 over budget. All wage figures include benefits.

Revised in Table Format

Table XX. 3-Year Budget History for Heavy Equipment Operators.

Year	Hourly Rate[1]	Budgeted	Expended	Overtime Costs	Account Balance
2004	30	62,000	52,620	--	7,380
2005	33	64,000	60,555	--	3,445
2006	36	68,000	100,998	32,994	(32,998)

[1] Includes benefits

Sometimes you can effectively use a table to summarize conclusions or observations in text form—particularly in cases with a large number of variables. The table below appeared following a detailed array of charts. By inserting the table in this form, the writer summarized the major conclusions that derived from her study. By keeping the detailed charts nearby in the text, she was able to link summary conclusions with data in a close reading space.

Table 1. Observations with respect to reduction in the release rates of Cl^-, Na^{2+}, Ca^{2+}, K^+, and Mg^{2+} levels.

Chemical Specie	Observations
Chloride (Cl^-)	• The coarse sand is the *least* effective. • The fine sand mixture is *most* effective.
Sodium (Na^{2+})	• The bentomat cap is *least* effective. • The fine sand mixture is *most* effective.
Calcium (Ca^{2+})	• The coarse sand is *least* effective. • The fine sand mixture is *most* effective.
Magnesium (Mg^{2+})	• The coarse sand is *least* effective. • The fine sand mixture is *most* effective.
Potassium (K^+)	• The coarse sand is *least* effective. • Bentomat is *most* effective.

In other cases, the amount of detail data is so large that putting it in the body of the report might make the distance between words and data too great to be ideal. Then the raw data clearly needs to be in an appendix.

You could still present this type of brief table, but you would want to insert a cross-reference (or a hyperlink if you're producing an e-report) that preserves the connection between the brief table and the full set of data from which it is drawn.

A brief table such as this one might simply appear in the text of a report as a kind of summary of critical information that appears in an appendix as a full table of raw data.

Summary Information in Text Table

Table 2 that follows illustrates a way to use a table to summarize information in an analysis. Such tables are especially useful in reports with recommendations, such as in a decision paper or design report that covers many variables or design options.

Table 2. Performance Summary of Different Roadway Striping Techniques

Product	Performance Criteria: Superior Retroreflectivity (mcd/m2/lux)	Durability	Easy Transition	Cost Effectiveness
Waterborne Paints (in current use)	• ~ 354 for white and yellow	• Lasts 6-12 months, depending on location and traffic volume	• No transition	• Initial low cost of $0.10 per foot offset by shorter performance life
Thermoplastics	• 275 for white • 180 for yellow	• Lasts up to 5 years	• Requires special equipment for application trucks • Perceived as familiar method by motorists • Faster drying time, shorter delays.	• $0.19-$0.26 per linear foot, with substantially longer performance life
Epoxy Paint	• 300 for white • 200 for yellow	• Lasts 3-5 years	• Requires flagging and cones during installation • Not perceived as familiar method by motorists • Longer drying times	• $0.20-$0.30 per linear foot, with substantially longer performance life
Preformed Tapes	• 350 for white • 250 for yellow	• Lasts 4-8 years	• Easy, quick installment with little inconvenience for motorists	• $1.50-$2.50 per linear foot, with substantially longer performance life and lower maintenance
Plowable Pavement Markers	• Varies among products, but usually higher than waterborne paints	• Lasts 5-7 years, perhaps less depending upon the effects of plowing	• Difficult and lengthy installation with motorist inconvenience • Provides motorists with different feel and appearance	• $1.00-$3.00 per marker, depending upon spacing of markers. • substantially longer performance life
Polyurea-based Paints	• 800-850 for white	• Lasts up to 5 years	• Same installation equipment (with modifications) • Same appearance as current striping • Faster drying times	• $0.20-$0.30 per linear foot, with substantially longer performance life

O4. Design for Complexity & Length

Complexity can emerge from the difficulty of a subject or from the reader's knowledge level or situation (reading under stress, for example). Sometimes, both conditions can occur. Long reports can appear complex just because of their length. Organizing a large report (>15 pages or so) presents any number of challenges because the greater length and complexity can create new difficulties for readers.

Probably the best approach for designing long or complex report is to remember the "telescope principle." Imagine how each section of a telescope looks as you pull it out. Each section looks the same, only smaller. Consider each small segment of your report as a report in itself, each part linked to and resembling the whole. The table that follows offers some general advice on this topic.

Advice for Organizing Long or Complex Reports

Use an outline as a blueprint for the report.	✓ Use the "Styles" feature in Word® to create a consistent format for your headings at each level of subordination. Once you have taken this step, you can move to the "References" toolbar and automatically generate a Table of Contents, which you can also use as your working outline of the report. ✓ Use parallel construction for headings and subheadings. ✓ Ensure that your headings and subheadings add up logically and that these headings reflect an appropriate level of development and detail for your situation and subject.
Choose patterns of organization that suit your situation, purpose, and audience.	✓ Understand that "large scale" organizing will not be sufficient if you don't also organize at the subordinate levels. ✓ Respond to expectations and requirements. For example, in an Environmental Impact Statement (EIS), the large categories are defined by regulation. But since an EIS gets read by readers across a wide spectrum of expertise, you may need to provide many plain language definitions of technical terms. ✓ In a lab report, the categories are defined by convention and expectation. But you can keep readers on track by organizing each section of the report upon the original objectives of the experiment. ✓ Adopt patterns that serve your purpose and make logical sense to your readers (chronological for procedures, hierarchical for analyses, criteria-based for decision papers, etc.)
Employ design and organizational strategies that help readers locate information	✓ Make sure headings are formatted for easy searches. Try adding section headers or footers as techniques that will allow readers to find what they are looking for quickly and to keep track of where they are in a longer report.

Advice for Organizing Long or Complex Reports

	✓ Use white space to reveal hierarchy through indentation. Normally that means that subordination is revealed through the left-to-right movement of white space ✓ Always let readers know where they are in a document in relation to other sections or subsections. You might even include such devices as section page numbers (for example, C-1, C-2, B-1, etc.). Use icons or color or format as keys to a particular section or kind of information.

For many long and complex reports you will need to layer information to address a wide spectrum of knowledge in your readers. A brief example of that layering technique appears on the next page.

Sample Page with Layered Information

5.3 Development of Transport Model

*√ **Diffusion** is the process whereby ionic and molecular species in water are transported by random molecular motion from an area associated with high concentrations to an adjacent area associated with a low concentration. Diffusion describes the mass transport due to the random thermal motion of molecules and atoms.*

Diffusional mass transport assumes that the rate of transport is directly proportional to the concentration gradient. In an isotropic medium, this occurs in a direction perpendicular to the plane of constant concentration at all points in the medium. If contaminant concentrations are high in the pore water, a granular cap component would act as both a filter and buffer during advection and diffusion. As pore waters move up into the relatively uncontaminated granular cap material, these cap materials can be expected to remove contaminants (through sorption, ion exchange, surface complexation, and redox mediated flocculation). Pore water that traveled completely through the cap would, in theory, have a reduced contaminant concentration. The extent of the contaminant removal in the cap depends very much upon the nature of the cap materials.

Diffusion causes mass flux down a concentration gradient and thus increases the spreading of a concentration front or peak with time. Diffusion across the interface between the water-saturated and unsaturated zone—the capillary fringe—is also a dominant transport mechanism compared to vertical dispersion. Under transient conditions, diffusion coefficients were derived from sorptive uptake and desorption of solutes by using soil and sediment particles. If the diffusional flux is steady-state, mass transport by diffusion is described by Fick's first law. The mass flux F per unit cross-sectional area depends on the concentration gradient and is expressed as Fick's first law:

$$F = -D\frac{\partial C}{\partial x}$$

(1)

where

D is the diffusion coefficient ($L^2 t^{-1}$)

C is the solute concentration ($M L^{-3}$) which depends on time t and distance x

Transport models are based on contaminant mass balances in the pore water of both the cap and contaminated sediment layer.

Technically expert readers might not need many definitions, but not all readers are experts. Here the writer layers the organization by placing a definition of diffusion outside the main body of text. Depending on the knowledge level of the audience, one might need to define any number of terms in this passage that way. If you have more than three definitions on a page, consider inserting a glossary at the beginning of a section or chapter.

Such techniques can help when your readers have very different levels of familiarity with the subject, and you don't want to interrupt text to define terms. You could even add helpful icons or illustrations in that space. Many Environmental Impact Statements contain such layered organization because the range of readers is so broad. In an e-document, you could create hyperlinks to the definitions. All of these techniques are just variations on the *group and order* strategy.

Precision

Especially in technical fields such as engineering, failure to use terms with precision can yield unfortunate consequences. Readers may doubt your credibility—or worse—make a poor decision from misreading your language. Since people seldom use words carefully in speech, some of that slackness carries over into their writing. Slack writing can distract readers and undermine a technical report by misusing technical terms, using modifiers carelessly, or failing to fix and develop a line of reasoning. These guidelines address three common issues of precision in technical reports

P1. Use Exact Terminology

Most of the time in technical writing, we depend on precise use of terms to identify a specific concept or phenomena. Using such terms properly might require you to slow down and check the language. Demonstrate that you have mastery over your technical vocabulary. Nothing good can happen if you expect your reader to correctly interpret text if your technical vocabulary lacks precision. Here are some simple examples.

Slack Use of Terms	Issue	Revision
Another *mechanism* that weakens the system is the tendency of this material to corrode in saltwater.	Note the real problem comes from equating a *mechanism* with a *tendency*.	The tendency of this material to corrode in saltwater is another *factor* that weakens the system.
This aspect of *composite behavior* may be relevant to civil engineering structures such as bridges that are subject to loads that are more transitory and of shorter duration than sustained loads.	Here the writer has resorted to a kind of shorthand that confuses the actual terminology. *Composite behavior* has become a rearrangement of the precise term *the behavior of composites*.	This aspect of *the behavior of composites* may be relevant to civil engineering structures (such as bridges) that experience transitory and shorter duration loads rather than sustained loads.
Various concrete codes and standards specify the fine aggregate requirements necessary to obtain homogeneous, workable and durable concrete of adequate strength.	"Various concrete codes and standards" leaves the reader without a reference point. Even if the codes are common in the field, you want to make that precise connection with a reader.	Various concrete codes and standards (ACI, BS, CAS, and others) specify the fine aggregate requirements necessary to obtain homogeneous, workable and durable concrete of adequate strength.

P2. Use Modifiers with Care

We use modifying words and phrases to qualify statements in reports. Careless use of such terms can have serious misunderstandings or consequences. Consider this example: "At *colder* temperatures the biological activity in an engineered wetland becomes *ineffective* for remediation of landfill leachate." The modifiers "colder" and "ineffective" lack any precise meaning, especially when used to report design choices or results from an experiment. Used by themselves, such modifiers allow for a far too broad range of possible meanings. When you use such terms, always ask the question "Compared to what?" and then provide answer linked to specific values.

Slack Use of Modifiers	Issue	Revision
The pipes exhibited a **high rate** of failure during peak demand.	What is "high rate?" It could mean too wide a range of frequencies. Attach values to modifiers whenever possible; then characterize them	The pipes failed **more than 20%** of the time during peak demand, when coolant flow exceeded 10,000 ft^3/s. By our specifications that is a **high rate** of failure.
The *National Design Specification* (*NDS*) standard for compressive strength in No. 2 White Pine is 675 psi. **Our** mean tested value was 5741 psi. **In terms of percentage** the tested material was much stronger than the **test** standard. From these numbers we conclude that the weathering of the wood had **no** effect on its strength. These data indicate that the performance of such boards will be **satisfactory for all** purposes.	Oh my! Unfortunately, the issues in this passage are all too common. • The investigators did not have a mean tested value. • The tested material was not stronger than the test standard. • "**No** effect?" "Satisfactory for **all** purposes?" Can you make such absolute statements, particularly when you don't know the initial strength of the sample or the purpose for which the wood might be used?	The *National Design Specification* (*NDS*) standard for compressive strength in No. 2 White Pine is 675 psi. The mean compressive strength of our test sample was 5741 psi, a value many times higher than the **design** standard. These data indicate that the boards from which the test sample was taken still exceed the NDS standard for compressive strength in No. 2 White Pine.

P3. Fix and Develop the Line of Reasoning

You can also add precision to your writing in several ways:

- ensure that you add terms that most accurately fix the meaning of a concept;
- ensure that a succession of sentences develops the line of reasoning;
- make sure you "close the loop" when writing concluding statements and recommendations by linking such statements to the data that support them.

Slack Line of Reasoning	Issue	Revision
The *configuration* of the pond limits the effect of thermal stratification.	*Configuration* lacks the precision necessary to fix meaning. Tying the sentence to actual values provides context for understanding *shallowness*.	The *shallowness* of the pond limits the effect of thermal stratification (average depth = 5 ft., maximum depth = 7 ft.).

Undeveloped Link	Issue	Revision
The choice of Genetic Algorithms (GA) is a deliberate one. GAs offer advantages other techniques do not. These advantages make GAs a potentially useful technique, and the field needs more such techniques. Other techniques fall short of the performance of GAs in this area of research. To this point GAs have performed very well when compared with other techniques used to solve these problems.	*←Such a passage as we see on the left stays on one level of development—the highest, least detailed level. Unfortunately, such single-level writing is too common.* *The revised passage lists not only the specific advantages, but explains each advantage at a second level of detail. →*	The choice of Genetic Algorithms (GA) is a deliberate one. GAs offer three advantages over other techniques. First, the mathematical properties of the objective function and constraints have no influence on the ability of the GA to find a solution. Second, GAs are particularly suited for parallel implementation, which offers an advantage in so far as the time to convergence is an issue, which it is in this problem because we are interested in generating optimal solutions in real-time for online implementation. Third, GAs have done very well in optimizing complex and large scale problems like the one in this research.

Conclusion with No Link to Data

Conclusions

- The contents of No. 6 pond are the spent brine from operations at the XXX Complex. The major components of the brine all follow the same trend in which concentrations increases over time and eventually peak and level off. The fine sand mixture is the most effective barrier and the coarse sand barrier seems to be the least effective.

- High concentrations of TDS were found in the pore water of the sediments. Based on our analysis of the sediment and laboratory release studies, it is clear that the transfer of the TDS between sediments and the water column is a diffusion-controlled process. The fine sand mixture provided the lowest TDS value and was therefore the most effective barrier in this test. The coarse sand mixture is the least effective.

This laboratory study demonstrates the effectiveness of a diffusive barrier. The fine sand mixture provided the lowest diffusion coefficients**.** All of the diffusion coefficients obtained in this project are lower than that of the free-liquid diffusivities.

Revision

Conclusions

- The contents of No. 6 pond consist of the spent brine from operations at the XXX Complex. The major components of this spent brine (Cl^-, Na^{2+}, Ca^{2+}, K^+, and Mg^{2+}) all followed the same trend. Concentrations increased over time and eventually peaked and leveled off at about 20 days. Ca^{2+} showed the highest peak concentrations of 7.62 g/L to 9.2 g/L. These results, detailed in Figure 5, indicate that the fine sand mixture is the most effective barrier and the coarse sand barrier seems to be the least effective.

- High concentrations of TDS were found in the pore water of the sediments, ranging from a low of 34.72 g/L for fine sand to a high of 40.43 g/L for coarse sand. Analysis of the sediment and laboratory release studies made it clear that transfer of the TDS between sediments and the water column is a diffusion-controlled process. The TDS results in Table 4 indicate that the fine sand mixture provided the lowest TDS value and was therefore the most effective barrier in this test. The coarse sand mixture was the least effective.

Diffusion coefficients in each of the barriers were obtained by using a two-layer application of Equation 2. Table 5 lists these coefficients in detail. This laboratory study demonstrated the effectiveness of a diffusive barrier. All of the diffusion coefficients obtained in this project were lower than those for published free-liquid diffusivities. The fine sand mixture provided the lowest diffusion coefficients, in each case less than half the published values.

The extra detail in the revision provides a more precise link to the actual results that form the basis of the conclusion.

Economy

For some reason we grow up with the impression that more is better when it comes to writing. In too many instances we get reports that we ought to weigh instead of read, as if the writers expected us to pay them by the pound. In an age when we are already deluged with information, we can't afford to wade through such grain silos of reports looking for a kernel of meaning.

E1. Cut Unnecessary Words

Given all the pressures of workplace writing and reading, engineers must be as efficient as possible with their writing. One facet of that efficiency consists of cutting unnecessary words. For whatever reason, certain stock phrases infest too many engineering reports. You can make your writing more efficient by eliminating those words that add nothing to the presentation. They just take up space. Here are some of the more common offending phrases, along with their more efficient counterparts.

Wordy	Concise
For the purpose of	for
Along the lines of	like
In the event that	if
Make an announcement	announce
Subsequent to	after
For the reason that	because
With regard to	about, concerning
In view of the fact that	since, because
It is interesting to note that It should be noted that	note that
We are of the opinion that It is our belief that	we believe
Affects an improvement	improves
In a situation in which	when
Makes an adjustment in	adjusts
Are in receipt of	received
Made a report on	reported
Made an investigation of	investigated
Together with	with
Being in possession of	possessing

The next table illustrates two examples.

With Unnecessary Words	Revision
It is often the assumption that due to the fact that our operations may be viewed as being widely dispersed, that connections in real-time for the purpose of meetings might be deemed too difficult. (34 words).	People assume that our widely dispersed operations make it difficult to schedule face-to-face meetings. (14 words).
In the opinion of supervisors, too many times field engineers are required, by virtue of current regulations, to undertake reporting of activities that make insufficient contributions to what is the primary mission of this division. (35 words).	Supervisors contend that current regulations too often require field engineers to spend time writing reports that do not contribute to the primary mission of this division. (26 words).
One interesting point that should be noted is that, in all analyses the thickness of each of the rubblized material and the fractured concrete layers was assumed as 4.5 in. (based on a total concrete thickness of 9 in.). The AASHTO-based and the mechanistic-based layer coefficients listed in Table 6.2 indicate that the structural number (SN) of the rubblized concrete slab is almost the same as that of the rubblized material and the fractured concrete. That is, the pavement designer has the option of using either a 9 in. rubblized concrete slab with a layer coefficient of 0.2 or 4.5 in. rubblized material with a layer coefficient of 0.14 and 4.5 in. of fractured concrete with a layer coefficient of 0.26. This is so because the two methods produce the same structural number as follows: $SN = 9*0.2 = 4.5*.14 + 4.5*.26$ The above observation indicates that the layer coefficients are reasonable and balanced. One word of caution that should be exercised however is that, in the above analysis, the AC thickness was fixed at the actual field value by coring. *(181 words)*	Note that in all analyses of the rubblized material and the fractured concrete layers the thickness was assumed as 4.5 in. (based on a total concrete thickness of 9 in.). The AASHTO-based and the mechanistic-based layer coefficients appear in Table 6.2. These coefficients indicate the closeness between the structural number (SN) of the rubblized concrete slab and the SN of the rubblized material and the fractured concrete. Therefore, the pavement designer has two options: • a 9 in. rubblized concrete slab with a layer coefficient of 0.2 • a 4.5 in. rubblized material with a layer coefficient of 0.14 and 4.5 in. of fractured concrete with a layer coefficient of 0.26 These options exist because the two methods produce the same structural number: $SN = 9*0.2 = 4.5*.14 + 4.5*.26$ The above observation indicates that the layer coefficients are reasonable and balanced. Nevertheless, note that the AC thickness was fixed at the actual field value by coring in the above analysis. *(161 words)*

E2. Use Strong Verbs

Forms of the verb "to be" yield the weakest verbs in English because they only denote that something exists. They do not fix meaning with any precision. And because the verb is weak, you usually have to add more words to sharpen the meaning of the sentence, often strings of prepositional phrases or modifiers. While you might wonder what the meaning of "is" is, it marks the most common verb we use in both speaking and writing. Below you will find the forms of this verb:

is	are
was	were
am	be

These verbs are not incorrect, but when you rely on them too heavily, you can clutter your prose with wordy, ineffective constructions. Normally you might find a perfectly good verb hiding in the sentence as some other part of speech. For example:

Weak Verb	Revision
Permeability and weight **are** the determinant factors in the choice of a new material. (14 words).	Permeability and weight **will determine** the choice of a new material. (11 words—a 21% reduction).
Polymorphism is a technique used by software engineers to eliminate complexity that is unnecessary and to add flexibility to software systems. (21 words).	Software engineers use polymorphism to eliminate complexity and to add flexibility to software systems. (14 words—a 33% reduction).

While three or seven extra words in one sentence might not seem like much, those extra words can really add up over the length of an entire report. Consider the longer examples in the following table.

Weak Verb	Revision
In the last three years it is becoming obvious that major erosion is happening at both Wilson and Headland beaches. One of the major things that is a cause of the erosion at Wilson Beach is the fact that dune grass and plants are being destroyed at an alarming rate, which is allowing the sand to drift at nearly ten times its normal rate. Two of the major reasons for this destruction are increased tourist traffic and a series of unusually severe winter storms. Headland Beach is suffering from changing wave patterns that are the result of new seawalls constructed along the shore that is north of the park. These new wave patterns (which are seen to include an increase of resonance waves in the area of the seawalls) are producing a deposit of beach sand on a bar about 100 yards offshore. This bar is, in turn, accelerating the movement of sand as it is on the increase. Unfortunately, solutions to both these problems are complicated by issues that are political as well as technical. (176 words).	In the last three years both Wilson and Headland beaches have experienced major erosion. At Wilson Beach the rapid destruction of dune grass and plants has allowed the sand to drift at nearly ten times its normal rate. Two major phenomena drive this destruction: (1) increased tourist traffic and (2) a series of unusually severe winter storms. Headland Beach suffers from changing wave patterns that result from new seawalls constructed along the shore north of the park. These new wave patterns (which include an increase of resonance waves in the area of the seawalls) have produced a deposit of beach sand on a bar about 100 yards offshore. The growth of this bar, in turn, accelerates the movement of sand. Unfortunately, political and technical issues complicate solutions to both problems. (130 words—a 26% reduction).

Notice how a list can reduce the number of words. Notice that two "is" verbs remain. That fact is just to remind you that you can use them; just be economical about that use. If you need a rule of thumb, limit your use of "is" verbs to around 33-40% of your sentences. If you find that you need a succession of "is" verbs, consider whether you could recast the sentences into a list or a text table.

E3. Make Good Decisions about Active/Passive Voice

Simply stated, *active voice* describes a sentence structure in which the subject of the sentence performs the action of the verb. *Passive voice* describes a sentence structure in which the subject receives the action of the verb. Here are two examples.

Passive Voice	Active Voice
It *has been found* that fewer pipes were degraded by oxidation than had been expected. (15 words).	We found that oxidation *degraded* fewer pipes than expected. (9 words). *or* Testing revealed that oxidation *degraded* fewer pipes than expected. (9 words).
Object ← Verb ← Subject	Subject → Verb → Object
It *can be observed* in Figure 4 that higher compressive strength *is developed* by G-530 than the corresponding S-530 for the same gel-space ratio. (24 words).	Figure 4 shows that G-530 *develops* higher compressive strength than the corresponding S-530 for the same gel-space ratio. (18 words).

Notice that the passive-voice version contains more words. Passive voice sentences are almost always longer. That extra length can really cloud readability over the course of a report, not to mention wasting space. Plus, you often see passive voice sentences written with the "is" verb as a helping verb, so you find the same issues with wordiness piling up at the end of the sentence. Active voice sentences tend to make relationships clearer since such sentences follow the natural *Subject-Verb-Object* word order that is most common in English.

Most textbooks and style guides now advise authors to use active voice sentences. And, in general, such advice makes sense. Having said that, engineering writing contains many instances in which passive voice would be a better choice. Passive voice is just another choice from your writing tool kit. The instances in which passive voice becomes a problem usually occur when the writer just uses it without knowing the answers to a couple questions:

- What is the stylistic reason for choosing passive voice and what is the effect of that choice on the clarity of the sentence?
- What is the cumulative effect of chains of passive voice sentences on the clarity and readability of a whole report?

When you *can* answer those questions and make revisions based on the answers, you will be on the road to real control of the force and clarity of your writing style.

A Misconception about Passive Voice		Too many writers confuse passive voice with the difference between first person and third person points-of-view. The two terms are not the same thing. You can write passive voice sentences or active voice sentences in either point-of-view. Here are some examples.
Active Voice	*First Person*	We repeated the test four times; in each test we observed structural failure occurring at or above 1260° C.
	Third Person	Four repetitions of the test revealed structural failure occurring at or above 1260° C. or Harris and Chambers repeated the test four times; in each test structural failure occurred at or above 1260° C.
Passive Voice	*First Person*	Structural failures occurring at or above 1260° C were revealed to us in each of four repetitions of the test. (*pretty ugly!*)
	Third Person	Structural failures occurring at or above 1260° C were revealed in each of four repetitions of the test.

For some situations, passive voice is the better choice. Here are a few examples.

Some reasons to use passive voice	*In all of these examples, a switch to active voice could create more problems than it would solve.*
When describing a technical process in which the actor or agent of the action is unimportant or undefined (a common situation).	With no reliable and timely data, little *can be achieved* in this area even with the most sophisticated of algorithms and computation hardware. Data from the Long Term Pavement Performance (LTPP) database for asphalt pavements *were used* to investigate the validity of this probabilistic model. Clay lining, sheet steel walls, a bentonite slurry wall, collection tiles and purge wells *have been installed* to prevent

	or control shallow groundwater migration at the No.6 Brine Pond.
Some reasons to use passive voice	*In all of these examples, a switch to active voice would create more problems than it would solve.*
When pairing an active voice sentence with a passive one provides a transitional link between two sentences. In such cases a term ends one sentence and begins the next.	The project has experienced an unacceptable number of *test failures. These failures have been traced* to the use of non-standard materials.

In most instances you can still recast many sentences in active voice and strengthen your writing by doing so. Try to make those decision based on your command of the language rather on a universal rule. You will no doubt find reasons to use both voices. Here is another example.

Good Decisions about Active/ Passive Voice

Original	Revision
In this investigation, a bench diffusion test, using six different testing cells, *will be used* to simulate the diffusion process on a laboratory scale. The salt release rates *will be evaluated* in a laboratory bench-scale test. The release rates for TDS, Cl, and other chemical species *will be monitored* in closed containers. The release rates *will be determined* in a continuously mixed system in which the water *will be slowly stirred*. Based upon the results of salt concentration changes with time, a mathematical formulation *will be developed* to describe the salt release process and the salt release rate *will be estimated*. (101 words)	Investigators will perform the following three tasks: • Simulate the diffusion process on a laboratory scale by using a bench diffusion test with six different testing cells. • Evaluate the salt release rates in a laboratory bench-scale test. • Monitor the release rates for TDS, Cl, and other chemical species in closed containers. The release rates *will be determined* in a continuously mixed system in which the water *will be slowly stirred*. Investigators will then develop a mathematical formulation based upon the changes of salt concentration with time to describe the salt release process and estimate the salt release rate. (95 words)

The revision retains only two passive vice constructions. Note the reduction in words even though the information takes more space through added visual structure of the list. Really, the revision is a design choice based on whether the extra space improves the organization of the passage. Usually it will. *By the way, did you spot the forecast technique in the lead sentence of the revision*?

Advice on Revision

In order to apply the COPE guidelines effectively, you need to understand the importance of revision. An exaggerated description of workplace writing might say "people who don't have enough time to write things doing so for people who don't have time to read things." But it wouldn't be much of an exaggeration. First draft prose is so *easy* to spot, one has to wonder why anyone would submit such work. At work bad reports have to be redone. Planning time up front for revising and editing will save you energy, difficult consequences, and perhaps embarrassment. Revising and editing can be complex tasks. Where do you begin? You need to develop a system that works for you. These suggestions below may help.

Issue	Advice
Allow some time to pass before you revise.	✓ You need to gain some distance from your words before you can see them with a cold eye. Even 2 or 3 hours away from the work will help, but try and allow yourself a day.
Have someone read your report to you out loud	✓ At work you will seldom write in isolation, so get in the habit of using another person as an editor. Just having someone read your report aloud to you will help you hear problems you couldn't see. Ask this person to tell you what was important in the report.
Look at each page.	✓ Can you see superstructure and subordination in the page design?
Edit in stages	✓ Don't try to catch every type of problem in one pass. For example, edit for organization and detail first. Those sorts of changes will govern the other editing you may do. If you end up cutting a paragraph, why spend time editing it for grammar?
Allocate your energy.	✓ If pressed for time, spend your energy revising the most crucial parts of the report (those parts that readers weigh most heavily—Executive Summaries, Conclusions, Results & Discussion, for example).

On the next page you will see an example of how COPE guidelines were used to revise a passage.

Applying COPE Guidelines When Revising: an Example

<table>
<tr><th>Original</th><th>Revised</th></tr>
<tr><td>Granular materials such as sand are considered as a necessary part of the cap design to physically isolate the contaminated sediments from the water column, to prevent sediment re-suspension and transport, and also to reduce the flux of dissolved contaminants.

Fine-grained caps are more effective chemical barriers due to smaller pore size. It has been shown in previous studies that fine-grained sandy materials can be effective capping materials and have been found to be a better chemical barrier than a coarser sand cap.

The chemical containment afforded by a granular cap material is dependent on the sorption capacity of the material, and sandy (non-cohesive) materials usually have low sorption capacity compared to silt or clay materials. For this reason, a naturally occurring sandy soil or sediment, containing a fraction of finer grain sizes and organic carbon, is a more desirable capping material from the standpoint of isolation than a clean, quarry-run, or washed sand. The porosity is lower in fine sand, therefore making the voids smaller.</td><td>Granular materials such as sand serve three purposes as a necessary part of the cap design:

• to physically isolate the contaminated sediments from the water column
• to prevent sediment re-suspension and transport
• to reduce the flux of dissolved contaminants.

Previous studies have shown that fine-grained sandy materials perform effectively as capping materials and provide better chemical barriers than coarse-grained caps. This superior performance is due to the smaller pore size of fine-grained materials.

The chemical containment afforded by a granular cap material depends on the sorption capacity of the material, and sandy (non-cohesive) materials usually have low sorption capacity compared to silt or clay materials. In terms of isolation, this low sorption capacity provides a more desirable capping material. The low sorption capacity in a naturally occurring sandy soil or sediment makes a more suitable cap material than does a clean, quarry-run, or washed sand because the naturally occurring material contains a fraction of finer grain sizes and organic carbon. Fine sand exhibits lower porosity, which makes the voids smaller.</td></tr>
<tr><td colspan="2">In this case, the revised passage runs four words longer than the original, mainly because the writer made sure to apply guideline P3. The other COPE guidelines in play here include C1, C2, C3, O2, O3, E1 and E3.

You may not always have time to apply all the guidelines during revision. Develop the habit of applying the ones that make the most difference in your writing.</td></tr>
</table>

Appendix: Notes on Tables, Figures & Equations

Tables, figures and equations play crucial roles in technical documents. Most readers will read these features of a document before anything else. Note that the PITCH Web site includes a resource on data displays under the "Student Resources" link:

http://www.newhaven.edu/engineering/PITCH/482611/

Tables

Example 1

Table 1: Random variable moments for pavement sections 19-0101 and 19-0112

Sections	Moments	SCI (mils)	BDI (mils)	H_{ac} (inches)	Ty (ESAL/year)	Age (years)	Dlife (years)
	Mean	1.100	1.464	8.00	130,000		
19-0101	Std	0.487	0.516	0.25	9,750	7.71	20.00
	CoV (%)	44.300	35.300	3.13	7.50		
	Mean	0.144	0.157	21.10	130,000		
19-0112	Std	0.032	0.015	0.25	9,750	7.71	20.00
	CoV (%)	22.100	9.500	1.20	7.50		
Distribution Type		Lognormal	Lognormal	Normal	Normal	Deterministic Variables	

Note: SCI- Surface Curvature Index (D_0-D_{12}) = difference between deflections at center and at 12 inches away from the load; BDI-Base Damage Index (D_{12}-D_{24}) = difference between deflections at 12 inches and at 24 inches away from the load; H_{ac} = Thickness of asphalt layer; Ty = Traffic (ESALs/year); Age = Pavement age in years when deflections were taken; Dlife = Expected design life for pavement.

Example 2

Table 5: Diffusion Coefficients (D)*

Diffusion Coefficients (10^{-5} cm^2 s^{-1})**	**Bentomat**	**Fine sand**	**Coarse sand**	**No cap**	**Coarse sand mixture**	**Fine sand mixture**	**Published values in free-liquid diffusivities**
Cl^- D	0.999	0.945	1.023	1.085	0.921	0.865	2.032
Ca^{2+} D	0.445	0.321	0.441	0.453	0.313	0.292	0.792
Mg^{2+} D	0.411	0.336	0.436	0.498	0.339	0.321	0.706
Na^+ D	0.503	0.452	0.497	0.511	0.436	0.423	1.334
K^+ D	0.893	0.798	0.800	0.967	0.787	0.763	1.957

*D is the diffusion coefficient (10^{-5} cm^2 s^{-1})
**Note that all of the diffusion coefficients obtained in this project are lower than those of the free-liquid diffusivities. The fine sand mixture had the lowest diffusion coefficients.

Note that both these tables follow some basic conventions:

- Appropriate labeling
- Alignment of data on decimal points
- Self-contained structure with explanatory notes. Such notes help readers take as much information as possible from viewing the graphic.

Figures

Example 1 shows the potential effectiveness of combining four separate graphs into an array, thereby saving space while creating a "visual series" of data. Notice how this writer uses the text to comment on or to summarize the critical information in the graphs.

Example 1

The contribution of each random variable to the uncertainty was investigated for performance function and the Reliability Index (β). The Reliability Index is a measure of uncertainty; the higher the value of β the higher will be the reliability of a system. The Reliability Index of one means that chances of failure are about 16%. As shown in Figure 7, the β is sensitive to SCI in the range of 1 to 1.06. Similarly, the β is very sensitive to BDI within a range of 1 to 2. Although the graph for AC thickness shows variability of β with the thickness variation H_{ac}, the variation within a given section is too low to cause any significant change in β. The traffic parametric curve shows that the effect of traffic is significant at low traffic volumes. This result is expected because there will be no traffic to cause damage. Hence, the effect of the random variables on the reliability can be ranked as follows:

BDI>SCI>ESALs/year>Hac

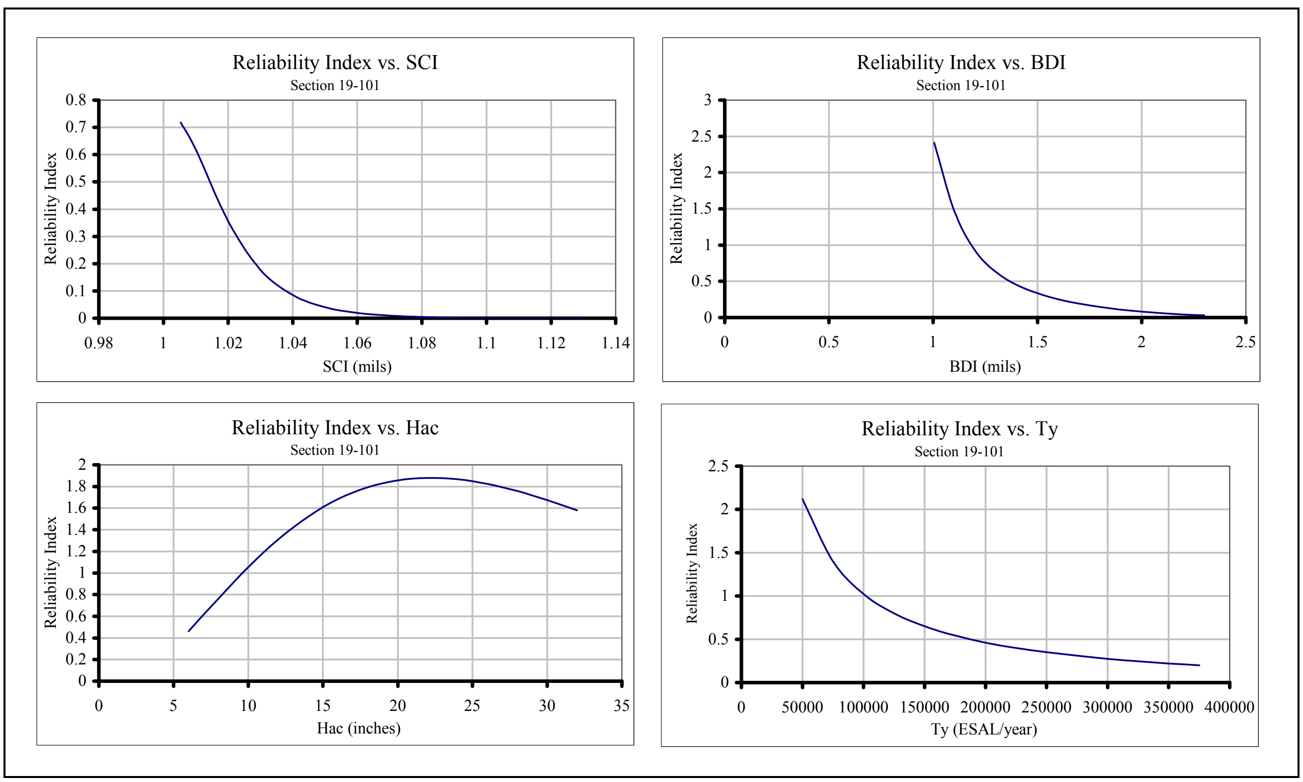


Figure 7 Parametric Analysis for Section 19-0101

Example 2

However, surface deflection is the most convenient and economical way of measuring pavement response. In recent years the use of non-destructive deflection testing (NDT) has become an integral part of the structural evaluation and rehabilitation process. State highway agencies use such equipment such as the Falling Weight Deflectometer, Road Rater, and Dynaflect, which apply different patterns of loading on the pavement surface. Figure 2 shows how surface response is recorded in the form of deflections at several distances from the applied load.

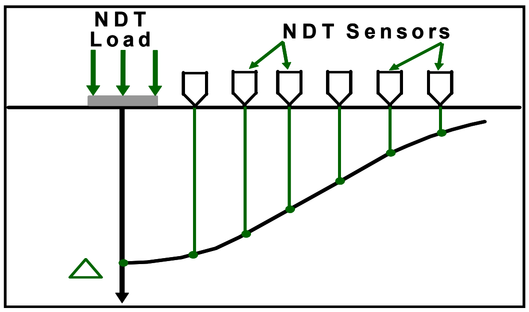


Figure 2. Measurement of Surface Deflection Basins Indicating a Deflection by FWD.

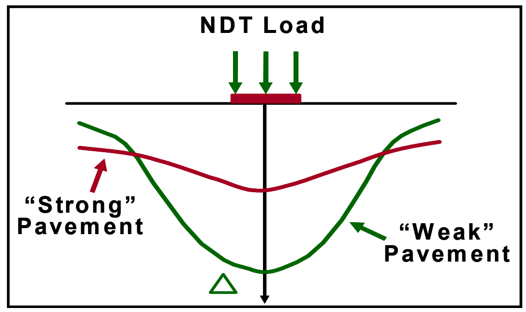


Figure 3. Deflection Basins Indicating a Weak and Strong Pavement.

When the pavements experience some form of distress (such as cracking), variations occur in pavement deflections and the shape of the deflection basins along a section. Figure 3 shows a typical difference in the deflection basin for a strong or intact and weak or distressed pavement. Furthermore, the variation in material properties due to construction and amount of moisture at different locations will also increase the variability in pavement response. Therefore, deflection basins along the same pavement section help to identify the relative in-situ strength at specific locations.

Example 2 shows how you can use figures in combination with text to illustrate a technical process. The combination provides a better context for understanding than either element alone. But the label and title conventions are the same as with data figures.

Equations

While individual journals may have their own formatting conventions, the examples below illustrate generally appropriate ways to place equations in the text of a report.
Keep in mind two things:

- Number the equations consecutively as you would tables and figures, placing the number to the right of the equation. That way you can refer to the equation in the text by its number.
- Clearly define the terms of the equation.

Example 1

The TDS value was determined by the following equation:

$$TDS = \frac{\dfrac{W_{dry} - W_{empty}}{(W_{water} - W_{empty})}}{d(TDS)} \qquad (3)$$

where

W_{dry} is the weight of the crucible containing salt after drying
W_{empty} is the weight of the empty crucible
W_{water} is the weight of the crucible containing the supernatant
d(TDS) is the liquid density at the TDS value

Example 2

This Bernoulli equation can be applied in the following form between any two points on a streamline:

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 \qquad (1)$$

where

p is the pressure (F/L^2)
γ is the specific weight (F/L^3)
V is the velocity (L/t)
z is the elevation (L)
g is the gravitational acceleration (L/t^2)

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Notes