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How to Write About Operations Research

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As an operations researcher (OR), sooner or later you will be expected to write a technical publication. The following exposes and clarifies what will be expected of you as an OR, and what you should expect from yourself. All of this applies to anything you write, from an executive summary to a full technical publication you author, or edit. Hereafter, I call this product your “publication.” You may love the mathematics, but if you cannot explain your results to a non-analyst in plain English, you have failed. As an OR, you will be expected to be better at this kind of publication than anybody else --- and, you will be.

Follow this grand, unified design for any OR publication. There are five simple, essential questions you must answer in your publication, preferably in this order:

- 1) What is the problem?
- 2) Why is this problem important?
- 3) How will this problem be solved without your help?
- 4) What are you doing to solve this problem?
- 5) How will we know when you have succeeded?

If you do not address each of these essential elements in your outline, stop. Revise your outline. If this revision is awkward, you need to reflect on why you think you are ready to publish your work.

As OR's, we naturally focus on what we want to do (step 4). Our analytic enthusiasm sometimes overwhelms our common sense: is this problem important, or not? (step 2). Worse, we sometimes exhibit target fixation so extreme that we neglect to explain the problem we're solving (step 1). We sometimes slight step 3, even when crude, legacy methods are pretty effective. Finally, we must set standards by which our results can be objectively assessed (step 5).

Title your publication. Your title needs to convey the heart of your contribution to as wide an audience as possible. If an executive lacking OR training reads your title, would that executive understand the problem you have addressed? If your parents read the title, would they understand? Save the final wording of your title until the very last step before you submit your publication. When you do craft the final version of your title, focus on the problem and your insights, and omit terms such as “algorithm.”

Abstract your publication. Your abstract will be word-limited (say, 150 words, though this varies by publication), and should convey your problem, its importance, how your problem will be solved without you, your contribution, and how we know you have made a contribution. You can use technical language here, but only if it is essential to set the context

for your publication in our technical literature. Avoid gratuitous technical jargon. Stick to plain English whenever you can. Write a tentative abstract at the outset of your publication, follow this guidance while completing your publication, but save the final edit of the abstract until second-to-last, before writing your final title.

Write an Executive Summary. You must always include an executive summary of your publication. This applies to everything you author during your career. An executive summary is a completely *self-contained*, plain-English survey of your contribution, suitable for consumption of any executive, or your parents. ***Your title, abstract and executive summary will be transmitted to third parties with no additional supporting material.*** An executive summary typically consists of 3-to-9 pages. Illustrations, figures, and tables may be included with legends, but these must add so much to the content that they can be included in your page-count limit. An executive summary cannot include any citations to a reference unless you include the complete attribution in the text of the executive summary. Use language your executive reader can understand, rather than technical jargon.

Use illustrations to tell your story. Use figures and pictures to draw your reader's attention, and to tell your story. The good news is that this is easy: the web offers an enormous volume of material. The bad news is that every illustration (Photo, table, graph, or whatever.) must be titled and accompanied by a very carefully-crafted legend telling the reader what you mean to convey by the display. For instance, a legend reading "Figure 17" is unacceptable, while "Figure 17: F-18 sortie availability during Operation Iraqi Freedom" may be enough. The idea is that a reader can peruse your figure and table titles, and decide what page to look up to retrieve some datum.

You should also use a legend to tell the reader what to see in each display, and how to interpret any symbol or number depicted. For instance, use the legend of a picture to tell part of your story: "The F-18 shown here can carry a wide variety of ordnance..." For instance, in a table, choose some distinctive row, or column, and quote the numeric and/or graphical entries in the legend: "For instance, the asterisk in row 3 indicates that the 88% sortie availability is below fleet standards."

Ideally, the reader can flip through your publication and just look at each of your illustrations, and its legend, and understand your story and what will be revealed by reading the complete text of your publication.

Buy a copy of *Scientific American*, or *American Scientist*. These are very well-edited scientific journals for the general public. Choose an article on a topic you know nothing about. Read the article as you would any document, however you choose to read it. Afterward, reflect on how you approached this foreign topic. Note the figures and their legends. See the method here?

Before you start writing, find a copy of some similar prior publication that is widely admired, and dissect it. For instance, your client, boss, thesis advisor, or mentor (hereafter, your advisor) will be happy to show you an example of the best publication in your field. Pay attention. Ask why this publication is so well-regarded. Read it. Dissect it. What are the

elements that look good to you? What are the bad points --- details that you had trouble understanding? After reading and contemplating, have another meeting with your advisor, and ask for focus on the best elements of this specimen. Reconcile your advisor's opinion with your own (it's better to deal with any differences you have with your advisor ahead of time with somebody else's publication, rather than later with your own). This is not hard to do, and won't take long. This is an excellent way to prepare yourself to author your publication, and to prepare your advisor to help.

Start each paragraph with a topic sentence. Do not surprise the reader by switching topics in the middle of the paragraph.

Make sure that just reading your paragraph-by-paragraph topic sentences conveys all of your publication. Try reading just the topic sentence of each paragraph, and skipping the rest of each paragraph. This is what any busy reader will do. Does this abstraction of your story make sense? If not, you have a structure problem: a busy reader will not likely bother to return and read the rest of all these paragraphs that never made sense on the first pass.

Avoid gratuitous backward and/or forward references. Writing is just like computer programming: you need to define your terms **before** you use them. It's true that any presentation, via any media, should "tell them what you're going to tell them, then tell them, and finally tell them what you told them," but this only means that you need an introduction, body, and conclusion. Do not end each section and/or chapter with a summary of what has appeared, and/or a prediction of what is to follow. These back- and forward-references usually signal structure problems. If you tell your story in reasonable order, you will not need these backward and/or forward pointers.

Never use footnotes. Footnotes interrupt the reader, and make the reader keep his place in your text while looking for some aside at the bottom of the page. Footnotes are a sure sign that you need to refine your outline, because you haven't been able to write a complete paragraph without jumping off your paragraph's topic.

Use (parenthetic) phrases carefully. A parenthetic statement should be an in-line corroboration, not some exception. Be careful to avoid using parentheses to insulate your ideas from any criticism. For example, "I'm right (unless I'm wrong)" equivocates, but "I'm right (and these references that are not quite on my main theme prove it)" may be acceptable. Do not (nest (parenthetic phrases)).

English has exactly one slashed term. The English language includes exactly one slashed term: "**and/or.**" **Do not use slashes with English** unless you are explicitly quoting verbatim some source that exhibits such ungrammatical use, or defines some term that is in common, albeit ungrammatical use. Slashed terms abound in military lexicon, but not in English exposition. Focus on English exposition.

Avoid excessive, repeated use of the same term in the same sentence or paragraph. E.g., "Missiles are difficult to maintain, but missiles are expensive, so we must carefully balance missile maintenance cost with missile availability, lest missile ..." (Laughing, are you? This

is a direct quote of a report I was asked to edit. Guess how I marked it up.) When the repeated term is uncommon, its repeated use is even more alarming. Rewriting: “Missiles are difficult to maintain, but they are expensive, so we must carefully balance their maintenance cost with their availability, lest they...”

Use active voice. Passive voice puts the reader to sleep. It’s easy to change the passive “Missile failures result from poor maintenance,” to active “Poor maintenance causes missile failures.”

Use present tense. Even if your reference is old, if you are drawing some current inference from this reference, **use present tense.** E.g., “Dantzig [1951] introduces a remarkable specialization of his simplex method for transportation network problems.” Use past tense only if this is absolutely necessary to keep the sequence of contributions straight. E.g., “Glover, et al. [1974] *reported* the first fast simplex specialization for minimum-cost, capacitated pure network flow models, but Bradley, et al. [1977] *develop* a faster simplex specialization.” Better, say, E.g., “Glover, et al. [1974] *report* ..., but *later* ...” Present tense carries weight with your reader. If you cannot conjure some phrasing in present tense for a reference, this is a sure sign that this reference is gratuitous.

Avoid puffery. Write direct sentences with minimal wording. Telltale words that add nothing to any well-crafted sentence are “*method*,” “*methodology*,” “*process*,” and frequently “*algorithm*.” Read any document you wish, and underline any phrase featuring any such “puff-term;” rewrite this phrase without this “puff-term.” The result will be shorter, and easier to read. Here is another, too-frequent example and its repair: “~~*It interesting to note that*~~ the sky is blue.”

Define just one. When describing something, define just one. For example, rather than writing “cars have doors,” write “each car has doors.” The latter conveys more than the former: each car has more than one door.

Have somebody else read your text to you. Make two copies of your text, keep one in hand with a pencil, and have somebody with no OR background read your other copy to you out loud. Listen well. Any hesitation, stumbling over words, restatement, or other sign of misunderstanding is a sure sign of trouble. Mark up your copy of the text as it is read to you. Rewrite. Repeat.

Your publication can be as short as it can be. You can win a Nobel Prize in less than two pages (see paper attached at the end of this document, with its key sentence highlighted). Never pad your publication for fear that someone will think you lack content. Try reading each paragraph out loud with one breath. If you get dizzy, your paragraphs are too long.

Adopt this style for references and citations. Examples of the best reference and citation styles appear in Military Operations Research instructions for authors, <http://www.mors.org/publications/mor/edpolicy.htm>

For an article, use the form:

Watson, J. and F. Crick 1953. A Structure for Deoxyribose Nucleic Acid, *Nature*, Vol. 171 737-738.

For a book, cite:

Morse, P. and G. Kimball. 1951. *Methods of Operations Research*. MIT Press, Cambridge, MA,

For an article in a collection, or a chapter in a book, show:

P. Morse and G. Kimball, 1951, *Methods of Operations Research*. MIT Press, Cambridge, MA, Chapter 4, "Strategical Kinematics," 61-80.

For a web reference, list:

Federation of American Scientists [2004] "C-201/HY-2/SY-1 CSS-N-2/CSS-C-3/SEERSUCKER," <http://www.fas.org/man/dod-101/sys/missile/row/c-201.htm>, accessed 14 July.

Note that each citation, for instance Akgul [1998b], exhibits the author(s) and year of publication. This permits your reader to decide whether or not to stop reading your text and look in your references, or just read on. Note that the references feature the author name(s) and year, then the title, then the specifics for a journal article, textbook, chapter in a textbook, or whatever. This makes it fast and easy to match a text citation with the reference entry, minimizing distraction from your text. Akgul [1998b] evidently has two references in that year, and the "b" serializes the second with no ambiguity. The preceding sentence uses Akgul as its subject, thus his name appears outside the brackets.

If you need to cite an email, phone call, or conversation, list in your references the name(s) of those corresponding with you, the year, then "private communication" and the date of this; citing a private communication is sometimes unavoidable, but never preferred to an archival, written reference.

Talk is cheap. Some in our business say "*if it isn't written down, it never happened.*" If you cannot get a written reference, write out your best understanding of the conversation you report, and retain this copy in case someone asks you questions years from now.

Never adopt the citation style, e.g., "[31] reports a remarkable specialization of the simplex method²." Gad.

Web citations are (still) notoriously ephemeral: if you cite a web reference, list the author(s), sponsoring agency, year, title (or your best effort to conjure a title), the complete web address, and the calendar date of your latest access. Retain an electronic or paper copy of the key material in the reference.

For archival purposes, retain personal copies of your key references, and of all web references, and state in your conclusions “all references are available from the author.” Better yet, leave a package with your advisor and state “all references are available from the author and/or his advisor.”

Avoid excessive use of “and/or.” Have you noticed a lot of “and/or’s” herein? Annoying, isn’t it? “And/or” means “both, or either.” This is too often an equivocation. Herein, I have intentionally used and/or too frequently, but always with its exact denotation. You can almost always substitute “or.” I should do so.

Choose a style manual, and use it. I’m fond of **The Elements of Style** (any edition) by Strunk, White and Angell. For just \$8, this is short, well-written, and easy to use. This is where to find advice on “which” versus “that,” “since” versus “because,” etc.

Use a professional editor. An editor can quickly revise your exposition and dramatically improve it. Editors are not expensive. There’s no shame in depending on an expert to tune up your writing --- you do use a mechanic to tune up your car, don’t you?

Take an English composition course. Even though you already hold a college degree and likely a graduate degree too, if you can’t write a complete paragraph to save your life, you can still learn how. Every local community college offers a beginning English composition course. You will be assigned short essays that are personally edited and graded by your instructor. In a matter of weeks, you can remedy your dark secret. Believe me, this works.

Work at it. For most of us, writing is hard work. But, there is no substitute for good English exposition.

Your publication will define your career. Even if this is the only publication you ever author, you will prove that you have earned your place in the company of scholars. If you ever find yourself competing for some position, your publication will be a distinguishing difference between you, and any competitors.

Wayne Hughes and Kirk Yost reviewed this and permit me to say so. I also acknowledge and admire my wordsmith colleagues who make writing appear so natural and easy. I have long wondered why writing is so hard for the rest of us. As an OR, I have analyzed this important problem (sic) for decades, authored, advised and revised hundreds (maybe more than a thousand) theses and technical reports, and respond with the advice herein. I have followed my own advice and coerced my students and colleagues to follow my lead. I also credit INTERFACES’ Mary Haight for her humbling editorial revisions that provide signal lessons in crystal-clear English exposition. Thanks to all of you.

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A structure for Deoxyribose Nucleic Acid

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2 April 1953

MOLECULAR STRUCTURE OF NUCLEIC ACIDS A Structure for Deoxyribose Nucleic Acid

We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey (1). They kindly made their manuscript available to us in advance of publication. Their model consists of three intertwined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate diester groups joining β -D-deoxyribofuranose residues with 3',5' linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's 2 model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There is a residue on each every 3.4 Å. in the z-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 Å. The distance of a phosphorus atom from the fibre axis is 10 Å. As the phosphates are on the outside,



This figure is purely diagrammatic. The two ribbons symbolize the two phosphate-sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis.

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from the other chain, so that the two lie side by side with identical z-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally (3,4) that the ratio of the amounts of adenine to thymine, and the ration of guanine to cytosine, are always bery close to unity for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact. The previously published X-ray data (5,6) on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at King's College, London. One of us (J. D. W.) has been aided by a fellowship from the National Foundation for Infantile Paralysis.

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