AD/A-005 177

WASTING TIME MODELING, EH

F. E. Grubbs

Ballistic Research Laboratories

Prepared for:

Army Materiel Command

January 1975

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: MEMORANDUM REPORT NO. 2436	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: AD/A-005177	
4. TITLE (and Subtitle): WASTING TIME MODELING, EH?	5. TYPE OF REPORT & PERIOD COVERED: BRL MEMO REPORT
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Dr. F. E. Grubbs	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1T161102A14B
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Materiel Command, 5001 Eisenhower Avenue, Alexandria, Virginia 22333	12. REPORT DATE: JANUARY 1975
	13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

PRICES SUBJECT TO CHANGE

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Modeling, research, theory, management of research and technology, cost effectiveness of modeling, bridging the gap between theory and practice.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

We record herein a discussion of the need for and uses of modeling in Army Research and Development work and to some extent generally in science and technology. We bring to the forefront some continuing problems in the management of models with the hopes that rotated managers on one hand and modelers on the other might communicate better for the good of both. Our aim in addition is to provide some preliminary material for appropriate, continuing discussion and especially for faster progress on the general subject.

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Destroy this report when it is no longer needed.
Do not return it to the originator.

Secondary distribution of this report by originating or sponsoring activity is prohibited.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

WASTING TIME MODELING, EH?*

Over a period of many years of working at an Army R & D Laboratory, the writer has found that some of the major or rather critical problems are not of a technical or scientific nature at all, even though our mission is to perform research and development for the purpose of producing better or improved weapons. On the other hand, the type of problems referred to may be of some importance nevertheless, as they are so controlling or severely administrative in character that in many cases they may either limit, retard, or even sap energy from continuing good scientific and technical work. The particular problem that I wish to face here has to do with the use of theory and modeling as useful tools in research, development and analyses, and especially the continuing acceptance of such principles by ever-changing management. This problem should be addressed as an important one in Army R&D because it is necessary for a scientific person to justify the extensive amounts of time he spends on theoretical investigations or modeling, and hence to show that such activities are "cost-effective" and worthwhile. Moreover, the high-level managers and Congress who foot the bill should be convinced and satisfied also. Sometimes, some of the rotated managers of Army R&D are prone to adopt the tactic of "model avoidance at any cost" as the vogue in managing research projects in a practical manner, and I do not refer to <u>all</u> managers, so don't, repeat don't generalize. (Our purpose here is not to criticize management, for modelers may deserve most of the criticism. Rather, we desire to explore some reasons for modeling and hopefully establish a better basis for understanding.) Many knowledgeable people would be quite surprised that there is even a need to discuss the subject of modeling, but there is, for we have had to "start at the beginning" many, many times.

From the beginning, I should make it perfectly clear that all theories or models have to be screened, for some are "good" and others are "bad", or just not suitably applicable and useful. Furthermore, in working for the Army Research and Development Community, managers expect the investigations of technical people to be application oriented, useful and of easily proven "visibility". Obviously, there is a big management problem in screening models or separating the "good" from the "bad", and some managers do not understand all the theory involved, or the possible uses or implications of it, nor is this absolutely necessary if sound reasoning and good advice are followed by them. But they must be

**This is an expository report, expressing no official Army or BRL position whatever, and written in a style hopefully to get certain points across to some readers. Its purpose is to present some of the author's ideas on problems scientific investigations create for management, or vice versa, perhaps as a basis for further discussions and progress on the general yet important subject. Comments would be appreciated.*

Preceding page blank

tolerant and follow certain established principles nevertheless. On the other hand, in Army R&D the scientific investigator or modeler often needs to understand the overall practical or applied problem and solve it in a suitably useful manner. Furthermore, he should be willing to have his models tested or checked for applicability, or even to be able to sell them - sometimes a very difficult task indeed! It is easily seen, in this connection, that there is bound to be a problem of communication between some managers on one hand and the scientific or technical investigator on the other. Moreover, because of the probability of such communication gap, we therefore ask the following very basic questions: Why model? Is modeling worthwhile? Is there a better approach to solving Army R&D problems? Why give modelers so much leeway? Are modelers really needed?

As I reach for the dictionary, I observe that the dictionary is itself a model of good principles in language, writing and spelling, and it is something we are all in need of at times. The dictionary defines model as a minature representation of a thing, or a facsimile, a style of structure, a design, an example for imitation, a pattern of something to be made, and a woman who displays gowns, hats, etc. Modeling might also be defined as a worthy or useful representation, or summary, of reality or nature, which is used to solve the problems. Professor Harvey Wagner, the author of a well known text on Operations Research says, "Model building is the essence of the Operations Research approach. It is the counterpart of laboratory experimentation in the physical sciences" and "The model is a vehicle for arriving at a well-structured view of reality." (We remark parenthetically that the laws of our land are models for people to follow.) So, there are some of the preliminary definitions of model, but that is not enough for us here and we must go further. As we proceed, the reader might well keep in mind that any worthwhile substitute or alternative to modeling would be perfectly acceptable even to modelers, although we must advise him that it is perhaps he who should provide the better tool, for just now we don't seem able to do so.

Is it easy to distinguish between "good" and "bad" models? In answer to that, we must hasten to say that this is not an easy task necessarily, since the review process may get a bit complex and the judgement and wisdom of many qualified people may be called for. Also, we must realize that it is difficult or nearly impossible to predict the future use of a new model. The reader might consider the amount withheld from his pay check for federal and state taxes as an example of a "bad" model, for the "formula" used is such that one's biscuits, butter and molasses don't come out together, and he must either cough up more money at the end of the tax year or be in the position of having too much withdrawn from his daily needs. Again, there was recently much discussion about revenue sharing, and the formula or the many dollars for Mississippi, for example, underwent very extensive review by our legislators and others, hopefully to arrive at the "best" or optimum model (formula.) In fact, even the board meetings of corporations involve much effort and discussion to arrive at suitable "models" or principles for running a business or industry.

The writer ran into a bad model at the Aberdeen Automatic Car Wash. The sign read:

Wash 1.50	Wash & Wax 2.00
Gas	Wash
2.00 Purchase	1.25
4.00 Purchase	.75
6.00 Purchase	.25

(Presumably, wax costs 50 cents extra, no matter what.) Now what I wanted was $6.00 worth of gasoline and to have my car washed and waxed, the total coming to $6.75. But there was a hooker, as my car would not hold but $5.50 in gas and the big burly attendant told me I owed him $6.75. I desperately tried to explain to him that the sign didn't say any such damn thing, and he ought to learn to interpolate. Further, I was so unlucky as to not have a gasoline can handy in the car on that trip to put that 50 cents worth of gas in I had been cheated out of either. The conflict increased in scope and the attendant told me if I had any complaints I should see the owner (but as you know they always have a good way of handling that, since the owner is nowhere to be found!) Now if I had been the attendant and the attendant had been me, then surely he could have appreciated my point, but he couldn't, being the attendant, and he represented the management and that sign meant exactly what it said, being perfectly clear! After having coughed up the unreasonable total of $6.75 anyway, and having had my car automatically washed and waxed, then I got up nerve enough to suggest to the attendant that his own boss had gotten him into the uncomfortable position of probably getting in trouble with the public, so I suggested the following sign:

WASH $1.50		WASH & WAX $2.00
Gas	Wash	
Up to 1.99 Purchase	1.50	
2.00 to 3.99 Purchase	1.25	
4.00 to 5.99 Purchase	.75	Wax .50 extra
6.00 or more Purchase	.25	

The attendant did indeed think about that suggestion for the longest time and finally conceded that it was an improved model! But I have gotten no free car washes yet, and good non-controversial models are damn hard to sell! (Actually, they finally had to sell gasoline quite independently of the wash and wax business, because, as the manager put it, "too many people were caught in the middle.")

Perhaps, we should go now into more practical every day examples. To begin with, would you build a house without a plan or drawing? Now admittedly, a house could be built without a suitable drawing, but it may or likely would change as the builder proceeded with the construction, and it may change greatly! A plan or drawing, i. e., the model of the house, defines the scope of the work, and the plan along with specifications et al indicate the material which should be obtained to build the house; it is the basis for financial negotiation, and it provides a basis for checking details and guraranteeing appropriate communication between the builder and owner during construction. Therefore, it really pays to have a "model", does it not, and if it were not so then would not many, many arguments otherwise develop into unresolvability? Therefore, we have demonstrated in this case an everyday use of modeling. In fact, drawings, specifications and related documents provide a model or set of rules by which builders work. The "model" also summarizes the scope of the activity and provides the basis for changes, revisions, new costs, etc., if they become desirable or necessary.

To proceed with another every day problem, what about travelling over long distances or unfamiliar roads by automobile? Obviously, it becomes highly desirable to get a road map, which in fact is a "model" of the terrain or the highway system we will use, and to follow it. If it were not so, lost-time, lost money, inconvenience, bad roads and other undesirable conditions might all develop. Again, it would seem to pay to have a "model", does it not?

Now let us go to a bank and borrow some money, for example, to build that house we referred to above. Once we decide on how much we need to borrow, we get into a discussion of just what time period for repaying the loan will be allowed and just what each periodic payment will be. Can the reader compute or estimate the payments exactly? Ah ha, you say. Why, that's simple, "the banker simply looks in a table to find out!" This is certainly an acceptable answer to the everyday citizen who borrows the money, since he is aware that most others have the same experience and are "satisfied" with the use of "those tables", but pressing a little further, we ask again, "Can you determine the exact payment?" In any event, the point is that those "tables" were computed from a model of the mathematics of finance, and the results put in a convenient form for the exact answer desired in the business world. Nevertheless, a mathematical model is involved in the underlying process, and it was found that in everyday negotiations the more practical thing to do was to compute, publish and distribute appropriate tables for money lenders to use.

The same or somewhat equivalent principles apply to the problem of determining interest on bonds or savings accounts over a period of years, etc. Again, in the background there is a mathematical model which was used in the process.

Have we convinced the reader that models are quite useful and practical? Probably not, as he might go on to say, "Well, all that is fine but the use of mathematical models in (Army) research and development just doesn't make sense - and furthermore, they only confuse many managers." (This is probably true, too!) But we must look into this just a little also, after another daily example.

In our journey concerning the use of models we might stop off momentarily to mention dress-making and suit-making. Now if a female decides to make a dress she doesn't start out cutting cloth and sewing it together with the unaided eye. As a matter of fact, she must have a pattern for her size, and the same consideration applies to the making of men's suits. In fact, the pattern or "model" is quite critical to the whole process of making dresses and suits. Again, we ask the question, how can man really survive conveniently, economically and satisfied without the process of modeling? Moreover, the patterns come in different sizes, and we ask the question how were these sizes determined, and especially what is the relative frequency distribution of the pattern sizes in American females for dress-making and American males for suit-making? With this question, we approach a rather important phase or characteristic of modeling. In this connection, some men would gladly go out and enjoy taking the measurements of all American females of a given age, for example, but this doesn't really make much (scientific) sense in order to get their general measurements and other characteristics on useful "standard" dress sizes for American females. But how large a sample shall we take and how? This question alone brings up a very important problem concerning modeling. Can we just guess at the sample size and let it go at that? Obviously not. We must decide in some way or the other just how close we would like for our analysis of the sample data to fit the whole population or "universe" of American females. Therefore, we need to know a great deal about the characteristics of the population and the errors or vagaries of sampling that "universe." Indeed, we should sample at "random", and even then we have a huge problem of predicting from the sample to the population or universe, which is a major problem in statistical inference, and this cannot be done inexpensively without theory, modeling or appropriate experience. On the other hand, with a combination of theory and a suitable number of random measurements, which are then fitted by a suitably good model, we may describe the frequency distribution of measurements, or in this case pattern sizes, from a statistical model. Thus, again we point out that man cannot live and conduct his business effectively, efficiently, or economically without modeling, and fortunately he has the brains to know this, or has learned it otherwise by bitter experience perhaps.

We now quote from the book of the Nobel Prize winner, Richard Feynman, entitled "The Character of Physical Law." To introduce the subject, we mention that the Law of Gravitation (which is a model) states that two bodies exert a force upon each other which varies inversely as the square of the distance between them, but also varies directly as the product of their masses. This law, due to work of early astronomers and established theoretically by Sir Isaac Newton, was used to help explain among other things that planets normally travel in "elliptical" orbits. Even in that period of time, telescopes were widely used to observe planets and to take measurements on their motion. In turn, the measurements were used to try and establish general laws or "models" as it were, for our solar system. About that time, and we now quote from Feynman: "Another problem came up - the planets should not really go in ellipses, because according to Newton's Laws they are not only attracted by the sun but also they pull on each other a little - only a little, but that little is something, and will alter the motion a little bit. Jupiter, Saturn and Uranus were big planets that were known, and calculations were made about how slightly different from the perfect ellipses of Kepler the planets ought to be going by the pull of each on the others. And at the end of the calculations and observations it was noticed that Jupiter and Saturn went according to the calculations, but that Uranus was doing something funny. Another opportunity for Newton's Laws to be found wanting; but take courage! Two men, John Adams 1819-92, mathematical astronomer, and Urbain Leverrier, 1811-77, French astronomer, who made these calculations independently and at almost exactly the same time, proposed that the motions of Uranus were due to an unseen planet, and they wrote letters to their respective observatories telling them - 'Turn your telescope and look there and you will find a planet'. Said one of the observatories, 'some guy sitting with pieces of paper and pencils can tell where to look to find some new planet!' The other observatory was more ... well, the administration was different, and they found Neptune!" Thus, two investigators who for the occasion used only paper and pencil and a model, and not a telescope, were able to predict the existence of a planet which was seen with a telescope only after that prediction! Thus, again, is there any need for or use of modeling?

What about man's trip to the moon? Was that done without modeling? Indeed not! This is a case in point for which a very large number of models were used as tools or aids in developing the whole gamut of technology for travel to the moon and return. In fact, one might well say that we could have gotten nowhere without models. Could such a project be undertaken merely through "insight of the layman", or by cut and try methods, testing "everything in the world and solar system" until success was finally achieved? What a ridiculous thought! Can we believe the law of gravitation and Newton's laws of motion, i. e. the "models" referred to above? We better had, for such models certainly save a lot of money, a lot of time, cost of needless experimentation or what have you. Once a rocket attains a sufficiently high velocity to escape the gravitational pull of the earth, and is directed toward the moon, the latter which eventually begins to attract or pull on the rocket, then the space ship gets a free ride to the moon and later another free ride upon returning to the earth. Was this found out without modeling or theory? Just how could some people be so naive as to think that models and theories have no place in our daily lives or in any steps toward progress? Yet some managers at times have told us "all that theory you are working on won't produce anything of practical value, and you had better 'get with it', for otherwise you are not of any real value to the Army." Is it not clear that such managers are the ones who should really "get with it?" This is not to say that modelers or theoreticians always come up with the right answer, because that is baloney, too. The trouble here is that modelers are people also and some people will try to sell others anything whether it is good or bad, or whether you need it or not! In fact, and as well known, some people will steal, lie, cheat or just about do anything one can dream of! Therefore, such comment brings up the question, "What is the fundamental role of a manager?" Is it not his job to select the best or the most useful models developed in his organization and to see that they are used? If he doesn't, who else will, and just how will progress be made otherwise? Of course, we want no half-baked theories, and such questionable models should be weeded out, but whose job is that? It shouldn't be left to the modeler!

Now, let us jump to a very different field of application. Most of us enjoy music and know that the better composers and performing artists are recognized for their contribution to the art and our enjoyment as well. Again, one might be inclined to say there was no need for modeling in the art of music. But tell me, just what in the hell do we have those staffs, clefs, keys, andantes, vivaces, fortes, etc., for, if they are not used to model the melodies the composer had in mind?

Again, would some of the adversaries of modeling go so far as to say that radio and television were developed without theories or modeling? If you like, then go right ahead, Mr. Know-it-all! But would you care to look a little deeper for facts? It just might give credit where it is due.

Man cannot live without water, people know it, and many laymen know that water has a "model" too, i. e. H_2O meaning two atoms of hydrogen for each atom of oxygen in a molecule. Thus, this chemical model gives an accurate, permanent and useful description of water. Furthermore, other chemical models which represent other molecules in nature may be used in chemical equations to explain chemical reactions and to lead to new substances or products. What other approach would you use? We would be glad to have a better approach.

Models explain how things happen, and no doubt large fractions of our national population have some interest in sipping wine or drinking liquor, neither of which would have been possible except for the mechanism of fermentation. Important as it is, the mechanism of fermentation is not completely understood, but the model of the process for the edification of the reader (!) is shown on Figure 1. Just sip it! Better still, why not improve upon our drinking by modeling? Or, if you have the money, by costly experimentation? How much money would you risk?

Atomic weapons, which are not necessarily desirable for humanity, nevertheless came about largely as a result of modeling, but so did atomic energy. In the latter case, would you say that modeling served no useful purpose: Should those damn nuclear theories be discounted or ridiculed?

On 27 August 1972, the Wall Street Journal featured an article with the following title:

FIGURING THE FUTURE

ECONOMETRICIANS SEEK ANSWERS BY 'BUILDING' MODELS OF THE ECONOMY.

BUSINESS, GOVERNMENT SPUR USE OF COMPLEX TECHNIQUE; PIONEER FEARS 'CHARLATANS'

WHICH CHILD LIKES WHEATIES?

The article starts out with an account of a newspaper editor writing a memo to a reporter, which says "I understand the Brookings Institute has a model of the US economy. I think you had better go take a look at it". Then the article continues:

"The editor may have envisioned a collection of minuscule homes, offices, railroads and factories, complete with tiny chimneys puffing smoke. But the Brookings model - and growing numbers of others, built by organizations both outside and inside government, bears not the remotest resemblance to a Lilliputian landscape.

"What, then, is an economic model? Charles Warden, vice president of Data Resources Inc., and an old hand at model-building, offers an explanation in terms of a parent and his children:

"When you try to forecast what your children are going to do, you use a model of their behavior patterns from the past five or ten years. You know which ones like Wheaties and which won't eat eggs. One requires firmness, and another may require extra attentiveness.

"This information provides an implicit model of their behavior, by which you project into the future. The economics profession has merely tried to capture such models of communities, industries, nations and states and convert them into explicit form".

(The full-blown version of the Brookings econometric model has 359 separate equations designed to simulate the entire U. S. economy on a quarter-by-quarter basis, but only an abbreviated model of 216 equations has been used to simulate short-term economic growth and analyze the results of various policy measures.)

The article proceeds to tell the reader that a nation or an industry is clearly more complex than a clutch of kids and that hundreds of factors can influence the course of a nation's economy, including the population and weather, wars, business and consumer decisions, government politics, etc., to mention only a few. Economists have always tried to sort out the more important influences and to determine how they interact with each other to produce prosperity, depression, inflation and other economic phenomena. In other words, economists were modeling, and for a very good reason, i. e. to make predictions about the future. Of course, many people are very skeptical about the mathematical equations, and whether such models are really worth the effort. But, as a matter of fact, how in the world would one make predictions without some form of model? Can he use his unaided mind and glib tongue for all predictions? Econometric type models don't always work precisely, as is well known, and we know that models to predict the course of the stock market have not faired too well either. A basic question to ask therefore would be, "Is the effort to model of any use at all?" In this connection, one invariably comes to the conclusion that until something better comes along efforts to develop econometric models for predictive purposes, or to try and understand the mechanisms involved, will continue. Furthermore, history has shown that indeed there is no better known procedure. In fact, models indicate the interaction of the variables involved, they provide a summary, they are cheap to develop, and can be used for predictive purposes. There is certainly a strong business demand for econometric services and predictions from the best available economic models. There is also a dire need for government use of the models too, of course. Thus, in summary, we record here that modeling is a worthwhile effort and deserves the time used unless someone can develop something better.

Wind tunnels are used to test models of airplanes, airplane wings or components, missile configurations, or what have you, in simulated flight. Is that not cheaper and less hazardous than cut-and-try flight testing? Thus, wind tunnels are valuable and economical tools which are used as models of flight environment to establish general theories -

or models - concerning flight mechanics. The Ballistic Research Laboratories, because of its Scientific Advisory Committee, and the fact that Theodore von Karman was a member, had the wisdom to construct the very first supersonic wind tunnel in the U.S.A. for ballistic research, and this facility has no doubt paid for itself many times. This is an example of great insight into the need for modeling. At the dedication ceremony, it was humorously referred to as a "Wind Funnel" by the dedicator from Washington in a slip of the tongue!

We now make a few observations about modeling and modelers, and fit this in with Army R & D work to some extent.

A just criticism of modelers and their work is that they take too damn long to solve pressing problems in science and technology, and they are invariably late in coming to a good, useful solution. The latter is unfortunately a characteristic of research activities, and the only salvation is that the chance is ever high the same problem finally will recur, so that modelers are sometimes set for the "next time." Managers are always very skeptical of many researchers in their organization, and perhaps rightly so, since in many cases in Army R&D the tour of duty of the manager will have passed long before some investigators will have accomplished an assigned task, and it invariably turns out (as should be recognized) that many research problems are never solved completely, and new problems are always indicated just as soon as one is brought to a temporary point of satisfaction or solution. In much Army R & D work, it may be argued that many research people seem to some managers to have it easy, so to speak, in some of the physical sciences, since they lay convincing plans for research programs which will easily run into many years of effort, and managers might think this is just to guarantee their job! Also, such "scientists" are endowed with powers and prowess to argue adroitly with managers, especially those who are assigned on temporary basis. Thus, there is the big and knotty problem to management of "measuring" research in some way and hence whether the hired scientist has really produced enough. Obviously, this is an involved subjective problem which has no easy, clear-cut or straightforward determination. And the problem is aggravated by the funding system, which incidentally might well stand considerable scrutiny. One has to justify what he is going to do in order to get funds to attempt it, but it is a well-known characteristic of science that many times investigators may solve somewhat different problems than the one actually assigned, and sometimes their new work could break important ground in related or even foreign fields of interest. Moreover, it seems that less effort by management is put into reviewing accomplishments than in frequent justification of what one says he is going to do! To top it all, many of the very best contributions or attainments were never assigned by managers of research and development! Many of us have had bosses, manpower survey teams, inspection teams, and the like, who are stubbornly ingrained with the idea that theoretical work is no good and shouldn't be done unless it is assigned and directed by authority, thereby making it more "relevant." Perhaps, they do not recognize the fact that most people by their nature, including in particular scientists, are willing to help the other fellow solve his problem. In particular, some inspectors think that the very worst thing in the world occurs when an investigator originates his own problem, even though it arises from something that a more knowledgeable person obviously sees the need for it to be done! I once had a boss who made it clear to me that it was more important for me to work on some problem suggested by a GS-5 than to originate any work I thought needed to be done! The communication problem is therefore rather critical indeed. We need a better appreciation of each other's role, and we cannot accomplish this through communication barriers.

We now come to a real dilly. Now how many significant reports or papers should a research man turn out in a year? This is an interesting question, and it might provide some guidance as to whether an investigator is worth his money, but not necessarily so. Many managers might think it very unproductive for a research person to turn out only one significantly good piece of work a year, but some investigators don't even do that much in Army R & D! The "once a year" contribution does off-hand seem very low indeed, but on the average that single accomplishment a year is not a very bad batting average from actual experience. This all goes to say that some managers need better gauges of scientific work, perhaps, or at least some improved understanding. What are your suggestions? Can creative people be better stimulated? What is the best model for the roles of the manager and the researcher?

If Army R & D is to be highly successful and quite cost effective, then could we suggest that it should be a more serious and more stable business? This is saying no more than there should be a good model for it, and the manager of any good modelers should himself be a good or sympathetic "modeler". Is it very cost effective for good modelers to work for unmodeled managers or whimsical managers? Frequent reorganizations, low morale, frequent moves of personnel all over the place, and other costly changes are not healthy signs of a good R&D organizational model. The primary purposes of the organization must be kept in mind at all times. Is it to turn out new scientific work (i. e. models) and provide new weapons, or is it to make its employees servants to more whimsical management practices, put up a front for once-in-a-life visitors (who many times cancel their visit at the last minute!), or relegate modeling to a secondary role? R & D employees should not be slaves to unmodeled management, but they should be slaves to science and technology. Can an unmodeled organization therefore really turn out excellent models? Just take a good look at the more successful scientific organizations.

The fields of statistics and operations research have grown enormously during my years of working in Army R & D, and the demands for some of the methodology have increased by leaps and bounds, so to speak. Also, this very thing has brought with it much skepticism about statistical methods, for example, and just what they prove, in addition otherwise to the wide concerns expressed about the theories in general. However, the era of liars, damn liars and statisticians seems to have run its course, and the sciences of statistics and operations research have taken hold strongly in our present day society. Statistical models may sometimes be used to establish very quickly suitable relationships between parameters and their interaction with one another, whereas on the other hand it may take years of effort to develop the needed or "complete" physical model. This fact alone provides a natural battle-ground for the physicist or engineer on one hand and the statistician on the other, but progress is achieved through communication and understanding. Furthermore, a large number of problems nowadays are necessarily stochastic in nature, so that statisticians and operations researchers are now unavoidable, needed team members. The point we are reaching is that if some managers don't even believe in modeling, then just how in the world therefore could they put any faith in statistical or operations research models? They had better try, nevertheless, for such is now a necessary way of life, and they should "get with it." A few simple examples might clarify the point.

By now, many readers are aware of what a population or universe is and the process of sampling observations from the parent group under study. Also, they know that the sample mean is an estimate of the unknown population mean, and indeed a much better estimate generally than a single observation, and they know that variability is measured by the standard deviation (SD) or probable error, which is .6745 SD, etc. Also, they know well that if σ is the population standard deviation of an individual observation, the standard deviation of a sample average is much more precise, and as a matter of fact is $\sigma/\sqrt{n}$, where n is the number of observations taken. They also know that the population standard deviation is estimated from the square root of the sum of squares of the deviations of individual observations about the sample mean divided by the sample size - or the sample size minus one - for a good statistical reason, and that these concepts from statistical theory may be useful. Some artillerymen, nevertheless, will be quite willing to go out and fire many hundreds or thousands of rounds - at a cost of perhaps $100 or more a round - to establish firing table probable errors or to check an estimated firing table probable error here and there! Now, please pardon me, but from sound statistical theory the standard error of an estimated standard deviation based on the same observations is only $\sigma/\sqrt{2n}$ for just about any population. The sample standard deviation therefore varies less than does the sample average! Can you trust this, or should you go firing thousands of rounds, for example, to prove it? In any event, if the standard error in range is about 50 meters (in which case the probable error is about 34 meters), then for twenty-five rounds fired the estimated standard error of the sample standard deviation is only about 7 meters, and for 50 rounds it is down to 5 meters, whereas for 200 rounds it goes down to a mere 2.5 meters. Does one need to fire more rounds, and just what will be accomplished if you do? Such shoots are never "for once and all" for there is forever an endless stream of people on this earth, i. e. non-modelers, who have to be convinced by actual firing demonstration!

Some years ago, the author was interested in developing simple and suitably accurate approximations for predicting probabilities of hitting various shape targets for weapons. If this could be done, then clearly the costs of many expensive tests which otherwise might be run could be saved. Now the overall problem of estimating probabilities of hitting is not very simple, and it is realized by many that this task is in some cases akin to finding the probability distribution of quadratic forms in normal or Guassian variables. Nevertheless, I was able to provide an approximate Chi-square technique which was surprisingly simple and accurate, considering the very involved mathematical and statistical theory otherwise. Back then, a new boss of mine asked for examples of my recent work, and I gave him a paper on this subject. After the lack of any response for some weeks, the reply did indeed finally come back - a firm and serious statement to the effect that my results were "too mathematical." That one floored me, it is an unforgettable incident, but those new, simple and accurate results have now stood the test of time for many years.

To continue just a bit, we might take a (complex) weapon system and go out and shoot many rounds from it under a variety of conditons, and at different sizes and shapes of targets, just to find out what the chance of hitting "on the average" is. Also, some weapons spurt salvos of 25 or 50 rounds at a time, and we could engage in shooting up many tax dollars of salvos just to find what the chance of at least one hit on the target for a salvo would be; ad infinitum! By all means, continue this nonsense and we all would have to loosen up our pocket books for Uncle Sam, or go to jail. We have just said that the standard error of an average is $\sigma/\sqrt{n}$ and the standard error of a sample standard deviation, the measure of dispersion, is only $\sigma/\sqrt{2n}$, did we not? Would this little information possibly help, and might it not pay to use a model for predicting probability or hitting as just mentioned? I will simply let you, the reader, be the judge. Of course, you may not even now agree with the technique of modeling, and we can't blame you unless you have to open your own pocketbook wide for all those firings. In fact, why don't you "get with it?" I mean, of course, that modeling bit, or produce something better.

Should we try to model everything? It might even help some of the causes of humanity, since history seems to prove that it is a very worthwhile effort. On this matter, though, we must establish good priorities, and that is a function of management, too, is it not? In fact, it can't be anyone else's job!

Now we could go on and on, but if the reader is not convinced by now and won't "get with it" he just as well throw this little epistle in the trash can and live his own wonderful life, much of which was made possible by "screwballs", who engaged in modeling, but that needn't worry him or even stop him from thinking full time about his own little affairs.

For others, we might just dare to summarize that good models and good theories are clearly a necessary way of life. They summarize what is going on, they indicate what needs to be done further, what data gaps need filling in, they are relatively cheap to develop (with proper brains), they provide standards of comparison, they are a permanent history of man's endeavors, they are recorded and easily available (or should be) for mankind to draw experience upon, and how in the world could we otherwise make valid predictions? Thus, in closing, I must say that you must "get with it" or produce something better, as you have so often told us!

Otherwise, your criticisms waste my time and cost too much of my earned money, to say nothing of Uncle Sam's!

In fact, can we not summarize the situation a bit by saying that we are all at fault for not communicating better and acting accordingly for progress? That is, we have the environment where some managers don't manage modeling (or their modelers), since they don't have the time or resources, and modelers can't begin to manage managers, so to speak, but nevertheless the "twain should meet." Indeed, at this point in Army R & D history we have some big problems ahead, especially in view of tightening budgets. To wit, many managers may be right in thinking that we cannot do science for science's sake (in spite of the fact, for example, that nuclear energy is a very favorable case in point), and that we must concentrate only on "approved" work which is "highly relevant". Nevertheless, advancements in science and technology turn up many unexpected surprises, and the risks in supporting all kinds of research are very significant. Therefore, we need to look into such problems more carefully from a managerial standpoint. If there is anything that is clear to the writer, it would seem to be that we are not doing the very best job of transferring new knowledge (based perhaps on competent surveys by highly qualified assigned Army R & D personnel) to the drawing boards for improved designs of systems. Are not such problems relevant to the practice of science management in Army R & D?

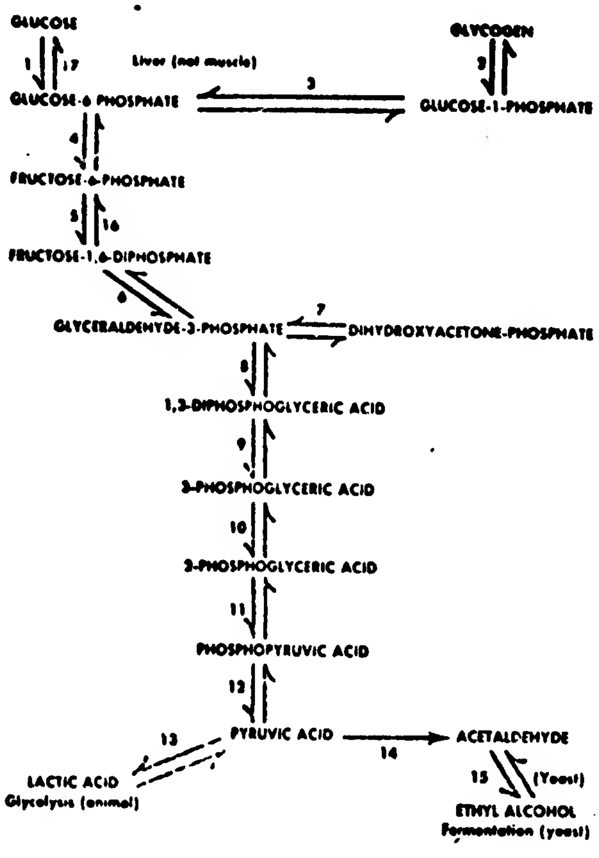
My conjecture: Models are here to stay, we are not, and I'll just leave some non-modelers uneducated in their vainglory, for their existence would have been rather dismal indeed without the modelers! Good R & D managers must learn when to model, what to model, how much modeling should be done, and how to judge models for the purpose of selecting the better or most appropriate ones for their organization's mission, since it is well known that the chance of success in research and modeling type activities is low indeed due to the inherent nature of the beast. Nevertheless, managers and modelers are both smart enough to solve the problem we refer to.

"The other laboratory was more ... well, *the administration was different*, and they found Neptune!"

A final conjecture: While our politicians fiddle around, and our economics advisers politicize their disagreements, the brains will come along anyway to solve the energy crisis and the food crisis - very likely through research and modeling!

Fig. 1. (From Harper's Encyclopedia of Science)

GLYCOLYSIS



Summary of steps leading from carbohydrates to lactic acid (by glycolysis) or to ethyl alcohol (by fermentation). Numbers in diagram represent the following corresponding enzymes:

1. Hexokinase
2. Phosphorylase
3. Phosphoglucomutase
4. Phosphohexose isomerase
5. Phosphofructokinase
6. Aldolase
7. Phosphotriose isomerase
8. Phosphoglyceraldehyde dehydrogenase
9. Phosphoglyceric kinase
10. Phosphoglyceromutase
11. Enolase
12. Pyruvic kinase
13. Lactic dehydrogenase
14. Carboxylase
15. Alcohol dehydrogenase
16. Diphosphofructose phosphatase
17. Glucose-6-phosphatase

form, without an actual "burning" (oxidation) of glucose molecules to carbon dioxide and water. Glycolysis is therefore a means of deriving energy for bodily processes, *e.g.* muscular contraction, under conditions of oxygen lack, as during exercise. Though this is a quick way for tissues to produce necessary energy, it is also an inefficient one: of the total energy obtainable by complete combustion of glucose, only 8% is released on glycolysis (see also OXIDATIVE PHOSPHORYLATION)

The process of glycolysis consists of a sequence of intermediary reactions, each catalyzed by a specific enzyme and some requiring the presence of inorganic phosphate, adenine nucleotides, and DPN (see PYRIDINE NUCLEOTIDES). These reactions, elucidated by Meyerhof, Embden, Neuberg, Warburg, Cori, and Parnas, are shown schematically in the diagram. Glycogen initially is converted to molecules of glucose-1-phosphate by phosphorolysis through the action of phosphorylases. The reaction can also be initiated by the phosphorylation of glucose or fructose by the transfer of phosphate from adenosine triphosphate (ATP), catalyzed by hexokinases. Glucose-1-phosphate, glucose 6-phosphate, and fructose-6-phosphate are further phosphorylated to fructose-1,6-diphosphate, which is then cleaved to form two molecules of triosephosphate: namely, glyceraldehyde-3-phosphate and dihydroxyacetone phosphate. Triosephosphate is subsequently phosphorylated, oxidized (Step 8), dephosphorylated, rearranged and dehydrated (Steps 9-11), and finally dephosphorylated again (Step 12) to yield pyruvic acid. The hydrogen removed in the oxidation of triosephosphate to 1,3-diphosphoglyceric acid (Step 8) reduces the coenzyme diphosphopyridine nucleotide (DPN). Reduced coenzyme (DPN.H⁺) is reoxidized in Step 13, in which simultaneously pyruvic acid is reduced to lactic acid, the end product of glycolysis. The diagram also shows the essential similarity between glycolysis and alcoholic fermentation. In the latter process, pyruvic acid is first acted on by specific yeast carboxylase, resulting in liberation of CO_2. The acetaldehyde which is also produced is reduced by DPN.H⁺ to yield ethyl alcohol, the other end product of fermentation.

The chemical energy which is released during glycolysis is contained in high-energy bonds (see ENERGY) of ATP molecules which are formed by transfer of phosphate from 1,3-diphosphoglyceric acid and phosphopyruvic acid to ADP (Steps 9 and 12). In the absence of oxygen (anaerobiosis), therefore, glycolysis is the only means of deriving energy from the metabolism of carbohydrate ("anaerobic glycolysis"). Aerobically, almost all of the carbohydrate undergoing breakdown passes through the steps of glycolysis up to the formation of pyruvic acid, which is then oxidized completely via the CITRIC-ACID CYCLE; carbohydrate may also be oxidized by way of the PENTOSE-PHOSPHATE PATHWAY. Only a small amount of lactic acid is formed ("aerobic glycolysis") in most tissues under these conditions. With the exception of a very few highly specialized tissues (*e.g.* the retina), significant aerobic glycolysis is encountered only in certain neoplastic tissues. This represents one of the very few known differences in the metabolism of normal and tumor tissue (see PASTEUR EFFECT).

Carbohydrate can be produced from lactic acid, or any other intermediate of glycolysis, by a reversal of the glycolytic process; this reverse process is referred to as glucogenesis. Liver is able to convert the end-product of muscle glycolysis (lactic acid) to glucose-6-phosphate, which may then be stored as glycogen or hydrolyzed by glucose-6-phosphatase to glucose, which is released to the blood and then becomes available to other cells and tissues. Muscle tissue can also form glucose-6-phosphate from lactic acid but, since it lacks the necessary enzyme, cannot liberate free glucose; instead glucose-6-phosphate is converted to, and stored as, muscle glycogen (reverse reaction of Steps 2 and 3). Brain tissue, which appears to be deficient in glycogen, depends for its principal source of energy on glucose supplied to it from other sources by way of the blood stream.

Glucose may be formed from a variety of chemical substances in addition to glycogen and intermediates of glycolysis. This formation of carbohydrate from non-carbohydrate sources is termed gluconeogenesis. Gluconeogenic materials include most of the amino acids (approximately 18), glycerol, and a variety of quantitatively less important substances. In plants, especially in germinating seeds, fatty acids are gluconeogenic. Possibly because of the lack of certain enzymes there is no good evidence of gluconeogenesis from fatty acids in humans and other non-ruminant animals.—*B. J. J. and J. J. O'N.*