Forecaster Workstation Design: Concepts and Issues

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ABSTRACT

Some basic ideas about designing a meteorological workstation for operational weather forecasting are presented, in part as a complement to the recently published discussion of workstation design by R. R. Hoffman. *Scientific* weather forecasting is defined and used as a basis for developing a set of necessary structural capabilities in a workstation. These capabilities include: built-in excess capacity for flexibility, user-defined product menus, interactivity at the level of being able to change the data as well as analyzed fields, and a software suite of operators by which virtually any product can be custom built through concatenation of mathematically defined operations on any of the data resident within the workstation.

The need for user involvement is stressed by showing an example of a real forecaster "workstation" that successfully provided most of these capabilities and, in contrast, by pointing out the flaws in the current National Weather Service operational workstation's development. In order to provide a system of maximum value, the *users* must be intimately involved in the process of system design, which virtually precludes the standard federal procurement process. A process of hardware and software purchases "off the shelf" is advocated, in combination with the establishment of on-site expertise to craft locally tailored workstations. The implications for the future of operational weather forecasting are discussed.

1. Introduction

The very interesting presentation by Hoffman (1991) offers an ergonomic perspective on a critical issue confronting forecasters: meteorological workstation design. As a human factors psychologist, Hoffman conducted a task analysis of forecasting, based on his observations of the weather map discussions by forecasters at the Air Force Geophysics Laboratory and on structured interviews with the forecasters. Using these studies, he made a set of design recommendations for meteorological workstations. These recommendations concern such issues as the ease of use associated with the workstation's operating system, development of color palettes and appropriate color coding for graphic displays, the number of displays available at each workstation, and so on.

I share many of Hoffman's concerns and support many of his suggestions. As a meteorologist, however, I think it is important to consider the detailed meteorological tools that the workstation should make available, and its ability to expand and incorporate new tools as the science of meteorology evolves. That is the focus of this article, with the intent, in part, to complement Hoffman's paper. I hope to suggest ways in which the design specifications for an operational workstation can get closer to the needs of forecasters in the process of scientific weather forecasting. In other words, I am considering the detailed "meteorological factors" as part of a total package of human factors.

In doing this, I present a brief summary of what I envision as an idealized, *scientific* forecasting process. Second, I use this concept to develop another set of recommendations about workstation design; recommendations about the functional capabilities that a meteorological workstation must have. Next, I present an example from my experience that illustrates how a suitable meteorological workstation can evolve from rather modest beginnings. In contrast with that, I then give an example of how the current process of workstation design and implementation can fail to produce a proper workstation. This will involve discussion of the flaws in the current process, some of which are imposed as a result of inherent problems with mandated procurement procedures. Finally, some additional discussion on the evolution of weather forecasting will conclude the paper.

The opinions expressed herein are based on about 25 years of interacting with operational forecasters, including about eight years of my own operational forecasting experience. I have not done anything even remotely resembling a systematic study of human factors, workstation design, or psychology. Generalizations I will make do not necessarily apply to any particular individual or subset of individuals.

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2. Capabilities of a proper meteorological workstation

a. The scientific forecasting process

For a multitude of reasons, I think that operational [primarily, I will be referring to weather forecasting as practiced in the National Weather Service (NWS)] weather forecasting does not have a uniformly firm basis in science. There are exceptions to this, of course, and I do not imply that science-based forecasting does not happen at all in operations. However, I believe that much of operational forecasting done today has little or no basis in scientific understanding.

Many of the reasons for this are discussed elsewhere (e.g., Doswell 1986a) and I shall not repeat them here. The primary one, however, is that educational institutions by and large do not teach scientifically based weather forecasting, per se. This has led to the common perception among forecasters that a large fraction of academic experience is essentially useless in operational forecasting. To a great extent, such a perception becomes a self-fulfilling prophecy; if a student wishing to become a forecaster perceives that meteorological education is of little value in forecasting, then that classroom material is not likely to be well grasped, and any half-hearted attempts to employ it probably will be failures, reinforcing the original notion.

As described elsewhere (e.g., Doswell 1986b), forecasting can be thought of as the sum of a diagnosis of the current situation and a trend, based in large measure on the diagnosis. The essential role of diagnosis in weather forecasting has been described by Doswell and Maddox (1986); the basic notion is that in order to have any hope of anticipating trends, it is necessary to understand the current situation and how it came to be. This, in turn, involves a subjective fitting of conceptual models to data, analogous to the ideas of Thacker and Long (1988), but in a human-based, subjective context. Hoffman's article has, in fact, drawn attention to the crucial role of what he called "mental models" in weather forecasting.

Where do mental models come from? Clearly, they are the result of a host of influences in the background of any particular forecaster, including direct experience, meteorological education, tutoring by a forecasting "mentor," and so on. Given that little or no substantive formal forecaster training is available in the United States,[1] it is not surprising that considerable diversity in mental models can be found.

The structure of these mental models need not conform in any way to formal scientific models. They can be purely personal constructions, meaningful only to the individual, or they can be cast in scientific terms understandable to all practitioners of meteorology, or they can involve a mingling of personal constructs with the formal structures of science. In general, the absence of formal training for forecasters in the task of weather forecasting has reduced the scientific character of their mental models. Many forecasters rely on pattern recognition without understanding the scientific processes implied by the patterns they see in their data.

As Hoffman has noted, the process of fitting mental models to data is iterative, requiring perhaps several attempts to reconcile the model to the observations. The idea is that one formulates a hypothesis (i.e., a model) to explain the data, and evaluates how well the deductions based on that model fit the observations. In general, it is undesirable to reject or modify the data unless faced with compelling evidence that the data are erroneous, because it is fundamentally unscientific to fit the data to the model.

The science of meteorology appears to be the only *common ground* to which forecasters might cling in an effort to establish a widely accepted set of mental models. To the extent that meteorological science forms a common basis for understanding the atmosphere, it seems reasonable to suggest that scientifically based forecasting must be built on the structures used in the science of meteorology. In other words, a forecaster must have at his or her disposal the tools of meteorological science in order to apply that science to the task of forecasting. Any other basis for weather forecasting is not scientific, virtually by definition.

There is a distinction between using scientific jargon and using science, however. One example that comes to mind is the use of indices in weather forecasting. The development of indices for weather forecasting is quite common, especially for convective storms (see, e.g., Showalter 1953; Schultz 1989). That such indices are used in scientific publications and presentations seems to lend them a scientific credibility, such that a forecast based on indices can appear to have a scientific basis. However, if the forecaster doesn't know the inherent limitations of such indices, a forecast based on them (typically making use of empirically derived threshold values for the indices) actually can have no scientific substance at all. Rather, in some cases, it is based on faith: faith that the thresholds selected will provide the answer without requiring any understanding. In my experience, such faith is dangerously misplaced, often breaking down in important, life-threatening weather situations, precisely because conventional forecasting "rules of thumb" often fail to apply in those cases.

Before going on, I need to distinguish between two types of data. At present, operational workstations spend a large fraction of their resources on "data" from numerical weather prediction models, as opposed to *observations*. This is a topic in its own right, but in what follows it should be understood that while I do not deny the value of numerical prediction models in practice, my primary (but not *sole*) emphasis when I

[1] Outside of the military, that is. Most formal forecaster training within the military is not aimed at the post-baccalaureate forecaster, but primarily at high school graduates.

use the word "data" is on observations, rather than model output. Clearly, numerical prediction models are a positive contribution to forecasting, but their value presently seems to be overemphasized, at the expense of capabilities to manipulate observational data.

b. Basic ideas for workstation design

If the tools of meteorological science are to form the basis for scientifically based weather forecasting, this has direct implications about the capabilities of a meteorological workstation. When the employment of any particular meteorological tool is not possible using the workstation, that workstation's utility in scientific weather forecasting is correspondingly reduced. Eliminate enough such tools and the workstation's functional capability eventually drops below some acceptable level.

Anyone familiar with weather forecasting must realize that *data displays* (i.e., weather maps, charts, text, and diagrams) are the cornerstone of most meteorological diagnosis, at present. There can be little doubt that data displays must form one primary element in any meteorological workstation. In virtually all of today's workstations, data displays are generated from *product menus* allowing forecasters to choose among a preselected suite of products, and allowing some overlay of chosen products on the screen, as well as capabilities such as "looping" graphical products by sequential displays.

What is the essential difference between the precomputer era weather map and chart display and a modern meteorological workstation? If all that the computer-based workstation offers is menu-driven data displays, it can be argued that the workstation is actually an *inferior* version of the old stacks of paper maps and charts on the wall. That argument has two essential elements. The first is that it is possible, with the old-style map display, to store many days' worth of charts, and they are all more or less readily available. The forecaster merely needs to lift up the current charts to follow the weather back in time several days, allowing self-briefing when the forecaster has been off duty for more than a day or two. Having this wealth of information readily at hand is beyond the capability of present operational systems and those currently in development (although such a capability is possible with today's technology). The number of digital bits needed to store the content of a month's worth of weather data is truly staggering. In the pencil and paper days, that huge information base simply hung on the wall. Moreover, in searching through the stacks of maps, a forecaster sharpens the perceptual skills and conceptual tools that drive the search. A manual search is not entirely wasted time, even when computerized searching is possible.

Second, the paper chart allows the forecaster to write over the original analysis and reanalyze a situation, to annotate the charts. Products generated at a central location can be modified to facilitate the forecaster's interpretation merely by using a marker or pencil on the facsimile maps. Various alternatives can be superimposed on the charts and explored in terms of what they imply about the situation. Maps and diagrams can be annotated with either standard symbols or special notations that have only personal or locally agreed-upon meanings. Hoffman (1991) recommended that a traditional "chart wall" be set up next to the workstation, and I agree. This sort of flexibility is not currently envisioned for the modernized National Weather Service, nor is it being built into current prototypes for the next generation of operational workstations.

Moreover, a disturbing trend of removing the data from analyzed charts can be seen in operational practice. While it is still possible to have charts with data as well as contours plotted, I have seen all too many chart displays in operational offices where the data plot is omitted and only computer-drawn, contoured fields remain. This is quite consistent with Snellman's (1977) concerns about how weather forecasting could degenerate into parroting centralized guidance.

On the other hand, a digital, computer-based workstation offers a whole new horizon of diagnostic tools that simply were not practical in the old pencil-and-paper days. Quantitative evaluation of diagnostic fields like moisture flux divergence are possible, not only with the observational data but also with the numerical weather prediction (NWP) model forecast fields (see, e.g., Antolik and Doswell 1990). The potential of diagnosis in scientific weather forecasting has only been explored tentatively; such a capability is not yet widely available in operations, although some semblance of it is available in some centralized operational offices.

One problem with scientific tools is that everyone has a different idea of what is the *core* set that must be available. This core set of tools is the basis for developing product menus. However, science is characteristically unsteady, and ideas of what are the best tools for scientific diagnosis change constantly. For example, there currently are movements to incorporate quasi-geostrophic theory via Q-vectors (as developed by Hoskins et al. 1978) in operational diagnosis (e.g., Barnes 1985). The Q-vector approach has become more popular recently than other, related schemes, such as that proposed by Trenberth (1978), that have seen some operational use. Another idea recently acquiring a number of adherents is isentropic potential vorticity (see Hoskins et al. 1985). Given that scientists constantly change their minds about what is important and/or useful in weather analysis, and that individuals are prone to disagree (sometimes vehemently) about what to include in a workstation, how can a workstation be designed to suit everyone? Is it ridiculous to try to satisfy every user?

I believe that every dissatisfied user is a potential loss to the effort to put the operational forecasting community on the path to scientifically based weather forecasting. Every possible effort should be made to allow each forecaster to explore the weather using those tools that are most meaningful to her/him individually. In effect, this means that no simple "menu" of meteorological displays is going to fulfill every forecaster's needs, no matter how large the menu gets.

One argument often used in favor of fixed menus is that products generated on a schedule reside in memory so that they can be called up quickly. No one can deny that a workstation that takes five minutes to display a satellite image or weather map is unlikely to receive rave reviews from forecasters. Nevertheless, a trade-off is involved: flexibility must be sacrificed to achieve speed. This will remain true no matter how fast computers become and no matter how large their memories get. If the entire approach to diagnostic work on a workstation is based on product menus, inflexibility is inevitable.

c. Workstation design recommendations

With the preceding background in mind, I can make some reasonably specific recommendations about what things a meteorological workstation should be able to do and how such a workstation needs to be configured. I hasten to add that, unlike Hoffman's, this set of recommendations is not based on an empirical study, but reflects my experience and the experiences of others that I have learned about by listening to them.

1) OVERALL SYSTEM CAPACITY

Any workstation for the future should be designed with far more computational capacity than is strictly needed (perhaps by an order of magnitude, or more) to do what is presently seen as the day-to-day task of weather forecasting. By capacity, I mean such issues as computing speed (CPU cycle times), memory size, disk space, and off-line data storage (for local research). Multitasking seems like an obvious need and whatever operating system is used should be compatible with a wide range of commercially available software. There needs to be the capacity for broad-band communication, to facilitate high-speed data transfers within the operational system and even with others outside the system, presumably via networking. Standardized formats for data also are needed within the system. Of course, such "excess" capacity is difficult to justify to those cost-conscious elements within the procurement system (the "bean counters"). My argument is that an apparently "oversized" computational resource really is needed to allow forecasters some freedom to tailor the system to serve local needs and personal preferences, and to adapt the processing to suit the inevitable changes in the way scientific forecasting is done.

2) PRODUCT MENUS

I have little argument with the idea that at least some part of the workstation's total capacity should be devoted to the generation of what can be called *routine* products. Since complete agreement about what should be the routine product list is unlikely, there should be considerable flexibility built into the system to create national, regional, local, and even personal menus that would operate to develop and make available for display (and interaction, as discussed below) a suite of products to be *user specified.* This way, the speed advantages of menus could be adapted to suit the unique needs and interests of each forecaster, each station, and each region, rather than forcing everyone in the nation into a single mold. Such capabilities apparently are being built into current prototype workstations, but are not yet operational.

I note in passing that menus may well generate products that rarely, if ever, get looked at. As the menus increase in scope, this becomes quite probable. If no forecaster on the staff is particularly interested in the Q-vector curl on the 312K isentropic surface,[2] then generating and having such a field available for display is essentially a waste of resources. Should it be discovered that no one on the staff has looked at this product during the past year, then it might be plausible to suggest that it be deleted from the product menu. Of course, next year's science may conclude that this is just the product needed to diagnose some process, and so it might have to be added once again. There is a way to minimize this problem, as I shall attempt to describe next.

3) OPERATOR SUITES

A meteorological workstation should have another product-generation capability besides menus. Every system could have a software package of operators, using the word "operator" in the *mathematical* sense. That is, the workstation would allow any user to create a virtually limitless range of new products simply by concatenating operators that would work upon any data (e.g., original observations, gridded fields, digital graphic images) resident within the system. A truncated example of such a suite of operators is shown in Table 1.

If desired, new user-defined operations could be added to increase the diversity of derived products, and the software used to define the operators could be changed by mutual consent among the users. Any field (e.g., gridded pressure values, digital satellite image pixel values, vertical wind profiles) contained within the system would be accessible, subject to mathematical and common-sense constraints, of course.

Modification of the algorithms employed to perform these operations (e.g., that doing partial differentiation) requires that the person doing the modification understands the algorithm and that the modified version

[2] This is a purely hypothetical example, of course.

TABLE 1. Hypothetical examples of operators that work upon data fields that reside within the database of the workstation (subject to mathematical constraints).

Operator	Operand(s)
summation	scalar, vector, array
difference	scalar, vector, array
divergence	vector
curl	vector
inner product	vector, array
outer product	vector, array
product	scalar
ratio	scalar
raise to a power	scalar, array
linear interpolation	scalar, vector, array
weighted averaging	scalar, vector, array
statistical package	scalar, vector, array
partial derivative	scalar, vector, array

should be suitable for its intended purpose. This requirement is, in my opinion, entirely consistent with asking that forecasters be educated and trained so they can use the tools of meteorological science at their disposal. I shall return to this issue briefly at the end of the discussion.

One could construct virtually any product by concatenating operations. If one wished, say, to assess the value of the 640-mb divergence of virtual potential temperature flux associated with the 18-h spectral model forecast (see footnote 2), it should be possible to construct such a field using the basic operators on the gridded model output. This is the way to avoid filling up product menus with esoteric, little-used products: generate them with the operator suite as needed and only add them to the menus if the demand makes such additions appropriate.

As part of the package, a versatile set of display routines would be required.[3] Thus, one should be able to construct and display products on different surfaces (e.g., model coordinate surfaces, pressure surfaces, isentropic surfaces), in cross sections (e.g., as x–z spatial cross sections, or as z–t time sections), on standard meteorological thermodynamic diagrams, or even as animated three-dimensional graphics. Reasonably sophisticated graphic-display software packages are readily available "off the shelf," so this need not be a major problem.

Not having products already available within a product menu would mean that their generation would take time; the forecaster probably would have to wait longer to see them than the products from the standard menus. Presumably, this additional time would be a factor in deciding how important it is to the forecaster to see a nonstandard product when doing real-time forecasting.

It also seems reasonable that a given individual would want to save his or her special product-generating procedures in a personal file, to avoid having to recreate them every time. This would allow each user the freedom to experiment and to save the results to share with colleagues. If all the local users decide a forecaster's personal, nonstandard product is useful, the system should allow its addition to their local, "standard" product suite. If that product is shown to be sufficiently worthwhile and of general interest, it might be added to regional or national product menus.

This wide range of capabilities associated with an operator suite is not available in any current, or current prototype, operational workstation, to my knowledge. Having the ability to create and display new products virtually without limit is not just for the convenience of forecasters, although they might find it to be of great value. The most important aspect of this concept is the flexibility it could provide as a hedge against changing ideas of what is considered useful in scientific forecasting. I believe that a combination of flexible "standard" product menu(s) and a modifiable package of operators, along with suitable communications capability and standardized data formats, will be relatively resistant to obsolescence.

4) INTERACTIVITY

Another element in my vision of a meteorological workstation is interactivity. What do I mean by interactivity? Let me start to define it by saying what it is *not:* interactivity is *not* the ability to call up products from some preset menu; it is *not* the ability to overlay products upon one another; it is *not* the ability to generate animated, time-looping displays; it is *not* the ability to develop displays using existing products and procedures. While these certainly are capabilities that any forecasting workstation should have, they do not represent any two-way interaction between the user and the data.

Interactivity means that the user (i.e., a forecaster) can *alter* the data and/or the displays in order to see what happens. While there are good reasons to protect the integrity of the basic data, one should be able to create *modified* data quickly and easily via a graphical user interface to the data, and to regenerate altered displays using the modified data. The user should be able to save the modified data and operate upon those modified data using any of the appropriate available procedures. For example, if I have a surface wind field analysis and decide it is flawed for some reason (e.g., a bad wind observation at some station), I should be able to change the observation [saving the change(s) in some intermediate file] and redo any of the wind analyses to see what effect the change has. I should be able to redraw contours (perhaps by inserting bogus data) and have the system retain those changes, allowing the application of diagnostic procedures to the

[3] Presumably, a graphics package of considerable flexibility would be required anyway, in association with the product menu.

modified fields. If I decide the changes are what I want, the modified data could be stored in more permanent form; if the changes are not to my satisfaction, they could be discarded (i.e., the file space used for other things).

The basic idea of interactivity is to replace the pencil and paper methods discussed above, but not simply by recreating them in a digital computer. The advantage of a workstation is its ability to manipulate data quantitatively; therefore, I propose that forecasters have to be able to perform diagnostic evaluations of their manipulated data, to explore the implications of their hypothesis testing, to use the tools of science to understand the processes revealed in their data. Failure to provide this interactivity is to miss many of the benefits of a workstation over pencil and paper!

3. A method that works

While I was at the National Severe Storms Forecast Center in Kansas City, Missouri, I had a chance to see how a hardware/software system could be created that was so well adapted to local needs that the forecasters were its most prominent advocates. Rather than begrudgingly accepting a system forced on them from above, they were given the chance to develop and adapt it to suit their desires.

The system was the so-called Centralized Storm Information System (or CSIS—see Anthony et al. 1982). The system as delivered was basically an off-the-shelf McIDAS system (Soumi et al. 1983). As it came into operations, it was clumsy and difficult to use; its commands, for example, were entered as typed character strings with defaults for some parameters and not for others. This meant that users had to become familiar with the details of the command language in order to do anything operationally useful, a difficult task for forecasters in the real world of operations.

However, the system had one big advantage: there was a person on the staff who was quite familiar with the system from previous experience. By working with this person, forecasters could ask for and obtain new procedures (constructed by this on-site system expert) to do quickly and easily what they wanted the system to do. These procedures generally were developed as "macros" from the basic command language to accomplish some end with a single keystroke, by selection from a digital graphics tablet, or typing in a short mnemonically designed command word. Since the software development was done at the request of forecasters to serve their task-specific ends, the forecasters became intimately involved with the maturation of the system. Having been allowed to have a real stake in CSIS, they became its most ardent supporters. The forecasters used it to look at new products they had dreamed up and to decide whether or not those products gave any real value for the effort.

What was remarkable to me was the extremely rapid evolution of what had been McIDAS into CSIS. I believe that the key factor was the continuing presence of a person dedicated to responding to the requests from the forecasters. Within a year, CSIS had become an indispensable tool for the forecasters. Those forecasters initially reluctant to be involved soon were eager to use the system, having observed its operational value in the hands of their peers.

CSIS is still evolving today, as any good workstation should. This does not mean that McIDAS is the only framework in which this could happen; far from it. Any reasonably capable system can serve as the basis for development. The important thing is that *the development takes place primarily in the operational office, with the direct involvement of the people who are going to use it.*

This process is what I believe needs to be implemented in the National Weather Service if truly useful and interactive workstations are to be developed. The vain effort to develop a "perfect" set of preprocurement workstation specifications should be abandoned. In its place should be the recognition that development on-station is the most effective way to obtain useful workstations. Naturally, specifications still need to be written and some centralized control must remain, but the emphasis should be on making it possible to change the system locally via a CSIS-like evolution. On-site development requires the continuous presence of at least one staff member dedicated to the task of making it serve local needs, *over and above* the staffing it takes merely to keep the system operating. This person necessarily must be quite knowledgeable about the hardware and software being used as the basis of the workstation. While a few forecasters with such a background might be found, this job cannot be filled with a forecaster on a part-time basis, in addition to normal shift-work duties. Rather, the job requires a full-time system expert at the beck and call of the forecasting staff.

The CSIS experience indicates that the workstation need not have a finely tuned prototype before it is implemented. In fact, one merely asks of the prototype that it contain a flexible set of hardware and software tools for continuous redesign, and have access to real-time data (with standardized formats). The better the prototype, the more quickly it can converge to a useful system, naturally, so I am not implying that a prototype should be acquired haphazardly. Presumably, there are several candidates presently available "off the shelf." Continuing support from the manufacturer would be all that is required of the contractor.

4. A method that did not work

The most obvious example of a failed attempt at workstation design is the computerized system introduced to the field offices in the early 1980s known as the Automation of Field Operations and Services (AFOS). This system has a checkered history at best and I am not going to dwell on its problems in detail here. However, if looked at carefully, I think it can be seen as little more than a digital form of facsimile and teletype, since it really was designed to replace these old systems. Of course, AFOS was a significant step forward in some important ways, notably in terms of introducing digital computer technology to the operational workplace. Most NWS forecasters, after considerable time and a forced conversion to AFOS, eventually understood that even its limited capabilities above and beyond facsimile and teletype represented a real improvement.

A characteristic of AFOS is its limited capacity in on-line memory, CPU cycle times, and disk storage. Archiving data for on-station research (via 8-inch floppy diskettes incompatible with modern PCs) is clumsy and time-consuming. This limited capacity makes the system vulnerable to "crashes" when it is operating near capacity, which is more frequent than one might wish. Limited capacity means that the so-called "applications programming" ability is reduced correspondingly. The system simply does not allow for much experimentation by forecasters in developing their own special programs to deal with their unique local problems.

What discourages many AFOS users is that they can see the *potential* of digital computer-based workstations, and yet they are frustrated with AFOS's inability to realize that potential. For reasons just described, the applications programming capacity of the system turned out to be much less than was promised, the word processing features of the system were (and still are) incredibly awkward, etc. Rather than being an off-the-shelf system designed by people whose business it is to satisfy customers, it was built to a set of specifications via the standard federal procurement process. The forecasters had little or no opportunity to see for themselves how it might operate in the workplace and to suggest changes. Moreover, forecasters of that era were even less likely to be technology literate than those of today.

The on-site AFOS system manager (ASM) position was created eventually, but it is not a full-time position. Instead, the ASM's task is an ancillary duty added to the tasks of a forecaster, and little or no formal training is given to the ASM. Such an on-site specialist is an inadequate answer to the difficulties of making AFOS work at all reliably in the hostile operational environment. The ASM, in general, has only limited skills, training, time, and authority for the challenge of crafting the system to individual station requirements. That some individuals have been able to make AFOS at all responsive to perceived needs is more a tribute to their individual creativity and dedication than it is to the AFOS design.

Turning to the AFOS system itself, like many other aspects of operational practice, it is replete with "fossilized" experience from bygone eras, mostly because the implementation of new technologies is not being done with imagination and creativity. Nearly every new system is, like AFOS, primarily an updated version of old technologies. One of the reasons for this is that forecasters themselves tend to want the new system to look more or less like the old system. It is not difficult to understand that someone accustomed to a particular system is reluctant to have to learn a whole new system. Thus, the forecasters contribute to this tendency, but they are not necessarily the only contributors, nor even the most important. The procurement and implementation of new technologies continue to reflect old approaches primarily because it is human not to understand all the implications of a new system until one has had some experience with it. That is why I am so adamant about allowing for evolution on site, rather than revolution by centralized procurement.

Design and testing of workstations more advanced than AFOS are already underway. Yet, I see only limited evidence that forecasters are involved in more than a token way. The basic design of the new workstation is solidifying once again without giving most forecasters much of a chance to ask for and, most importantly, to have a reasonable expectation of affecting major changes. Being offered the chance to provide "input" is quite distinct from being offered a real chance to influence the design. Some of the people involved with the new prototype system are ex-forecasters, which at least offers some hope for the next generation of workstations. From the prototype systems I have seen here in Norman, however, it is not clear that these people have been able to affect a qualitative, major difference in the overall process of workstation development.

5. Problems with federal procurement

An important reason for concern at this point is the outmoded and incredibly inefficient federal procurement process. Naturally, this is beyond the control of the meteorological community, so I cannot dwell at length on this point. However, ignoring this problem leaves the question of dealing with technological volatility unanswered. For that, I want to make what probably are some radical suggestions, in view of the legally required procurement process. Nevertheless, if laws are put in place by humans, they can be changed.

In a technologically volatile world, the cumbersome and inflexible procedures forced on the National Weather Service make it likely that any system so acquired will be hopelessly obsolete by the time it is in operation. Even in the public marketplace, most of today's technology is slated for upgrading and replacement by the time it becomes available to potential users. When the time needed for federal hardware system acquisition is added in, obsolescence is virtually guaranteed, even when hardware is bought "off the shelf."

However, federal acquisitions for major systems like forecasting workstations across the country almost never are acquired off the shelf. Rather, in the typical acquisition, a complex set of specifications must be developed and manufacturers are invited to bid the development of systems to meet those quite detailed specifications. Normally, unless extraordinary efforts are made, the contract is awarded to the low bidder, with all that low bid implies about quality. Following the contract award, it still may be years before the hardware is available in the field. Of all the elements of this process, I am most concerned with how specifications are produced.

The development of the specifications is fraught with perils. One such peril is that manufacturers understandably work to find loopholes in the specifications that allow them to cut costs and thus achieve the required "low bid" forced on most major federal procurements. It is virtually impossible to design specifications without leaving some loopholes. Thus, a system built to any given set of specifications usually contains hidden problems even when those specifications formally are met.

Another peril is that the specifications may not be perfect; any imperfection in the system specifications will be "frozen" into the system and will have to be worked around by the forecasters, at least until the next round of procurements, unless software "patches" can be found. This likely failure to develop "perfect" specifications suggests that the forecasters, the eventual users of the system, should have a large role in the development of the specifications. As already noted, apart from token opportunities for "input," forecasters are offered few opportunities to make major contributions to system specification.

Of course, one may argue (as is often done) that system specification is a highly technical issue in which forecasters have little or no expertise. This is only partly true in today's world, where sophisticated computers and digital technology are within reach of every middle-class income; many forecasters recently have become quite technology literate. Even if some (or many) forecasters may not be able to offer useful technical suggestions for the specifications, this ignores the fact that forecasters are the ones who will have to make the system function. One needn't know technological details to be able to state what a system needs to do to suit forecaster needs. The conspicuous absence of forecasters from the specification development process makes it hard to imagine that the specifications will be anywhere close to "perfect" from a functional, operational perspective.

Given the volatility of technology, even as specifications are made they tend to become obsolete. For example, workstations designed around minicomputers are essentially obsolete today; the microcomputer of today is more powerful in many ways than the minicomputer of only a few years ago. System specifications for centralized minicomputers with clean rooms and large technical staffs and with workstations slaved to them, are no longer even close to the proverbial "cutting edge" of workstation technology.

Yet another pitfall associated with the development of hard specifications is that detailed notions of how the new technologies should be applied in the operational workplace do not exist until they actually are implemented. The new technologies (and new developments in the science) have the potential to change the ways in which forecasting tasks are done, but the specifications typically involve having a new system reproduce the tasks and techniques associated with the old system. Of course, this makes the user feel more comfortable, because the new systems look like a flashy version (speedier in execution, more fancy displays, etc.) of the old. It is unfortunate that the perceived need for this "compatibility" with the older techniques tends to limit the value and productivity of introducing new systems. Would forecasters wish to see the WSR-88D datasets degraded in resolution and scope in order to be compatible with existing systems and archived WSR-57 datasets?

6. Discussion

If there is to be a future in which the science of meteorology provides the primary basis for operational weather forecasting by humans, the scientific forecasting concept must be reflected in the design of weather forecasting workstations. This implies quite a bit about the type of forecasters who will be using the workstations, of course. They will have to be technology literate, as well as capable of assimilating and using new scientific understanding (and *participating* in its creation). This forecaster of the future cannot be content with workstations having only the capability to create and display fixed product menus, no matter how good such workstations are at those limited tasks.

If forecasters of the future are still doing the same things that most forecasters of today are doing to generate weather forecasts, the current NWS modernization effort will have failed. This means that the task analysis done by Hoffman is incomplete. Rather than focusing on what goes on in map discussions, the task that needs careful, systematic analysis is that of scientific forecasting by humans. Such a study remains to be done. No matter how such a study might turn out, I do not think that the truly basic tasks of weather diagnosis and prognosis will change, but the capabilities and potential of workstations, new observing systems, and new numerical prediction models will dramatically alter our view of the weather and how we use that new perspective to create forecasts.

We shall have to change the way we operate in a changing operational working environment. Data of a sort and quantity never before available will be pouring into the forecast offices of the future. New and powerful capabilities will be at the forecaster's disposal, even up to and including running complex forecast models on local computers. If forecaster involvement with these innovations remains at the level of simply calling up and looking at the plethora of new data, without being able to invent new ways of diagnosis and without being able to interact with the data, then the modernization will have been for naught.

To design *yesterday's* notions of what a forecast meteorologist should be doing on the job (which is what *today's* tasks really represent) is to do the future a great disservice. Unfortunately, it is not yet possible to specify precisely what the future will look like; we have only limited experience with the systems that, however slowly and hesitantly, eventually will be implemented. Nor are today's forecasters ready and able to mandate what the future should look like; they have no experience base upon which to make recommendations. Does it make sense to set down a precise specification of what a workstation should do in this situation? I think not.

All of the problems I have been describing for hardware apply to software, as well. In fact, software has become the most important factor in development of workstations. The notion of "user friendliness" has been so overused that it has become a cliché in the computer industry; nevertheless, its overuse is an indication of its importance. I have little doubt that most AFOS users would give AFOS software quite low marks with regard to its ease of use. Its software design was not well conceived at the beginning, and its basic architecture has remained a limiting factor throughout the many revisions of its operating system. It is a measure of the dissatisfaction expressed over many years about the AFOS software that the prototypes for the new software do not resemble the AFOS package at all. Certainly, Hoffman's recommendations for software (e.g., his Table 2) are quite praiseworthy. To his recommendations I would add that every station needs a software "technician" on site, as well as the ubiquitous electronics technician. To leave software development and maintenance to the forecasting staff is unconscionable.

However, a basic assumption that underlies AFOS seems to apply to the new prototype systems as well. This assumption is that forecasters do not need to *interact* with the data that resides in the system. The interactivity (as I have defined the term) of AFOS and current prototype workstations is virtually nonexistent (apart from some observational data-editing capability). Interestingly, a new software package has been developed recently to do truly interactive sounding analysis. This package, called the Skew-T Hodograph Analysis and Research Program (SHARP), is an excellent example of the interactivity I have in mind. One can make changes to the analysis relatively easily using a mouse, and the system automatically recalculates its diagnostics from the altered analysis, allowing the user to retain the modified files as well as saving the original data. It is a confirmation of my belief in the burgeoning technological literacy of forecasters that the SHARP package was developed by field forecasters (J. Hart and W. D. Korotky at Charleston, West Virginia), not "systems experts" in some isolated technology development center far from the center of real operational forecasting activity. Forecasters are developing such systems on their own because of the lack of responsiveness within the confines of the normal system-acquisition process.

The emergence of local or regional applications programs raises an important issue for a national system of workstations: maintenance and compatibility. If one buys hard/software more or less off the shelf, the manufacturers typically offer maintenance contracts. In fact, such contracts may well be a factor in deciding upon which system the workstations will be based. Compatibility is a much bigger question.

Do we really want the system(s) in every office to look the same? I think not, especially with respect to software, since the needs of each weather office are different in important ways from those of every other office. If a software package is set up to serve the specific needs of one office, it is not clear that that package should operate without modification in every other office. I see no inherent problems with this diversification if the hardware and operating system basis for the workstation is the same in every office. However, considerable effort must be made to maintain compatibility in *data-file formats* and in *communication protocols*. Probably the communications systems are the most ripe for standard procurement procedures. The specifications for a broad-band communications link among forecast offices (and, hopefully, into the networks of the future) ought to be fairly easy to develop, although this statement admittedly is made in ignorance of all the technical issues.

If file transfer and communications can be ironed out properly, then the software differences that develop in the local offices would not damage the integrity of the national system. The individual workstations might differ in software detail but they should be able to exchange information with ease if the data-file formats are the same and everyone is using the same communications package. In effect, this is the way our forecasting system is evolving anyway, through the ad hoc intermediary of personal computers that have proliferated among the offices.

Basically, what I am suggesting is that our current approach to development of workstations in the face of a volatile technology is unworkable. The way in which one adapts to rapid change is to maintain flexibility, and the current approach is unlikely ever to adapt to changing conditions easily. Hoffman's article supports the importance of flexibility; for example, he recommends that "AMP [Advanced Meteorological Processing] system users should be able to manipulate color and color coding schemes" to suit their needs. I interpret this to mean that no one color scheme will suit the needs of all users, and I endorse Hoffman's caveat that forecasters "need to appreciate the potential effects, vis-à-vis interpretation, of ill-conceived experimentation with color schemes." This is but one example of how a forecaster's workstation should be flexible and yet maintain standards. I have suggested several other ways, but this discussion is by no means exhaustive.

I am concerned about workstations because it is through them that forecasters will have to deal with the new data streams coming on line. It is via workstations that the potential exists for meaningful application of new (and old) science to the task of forecasting the weather. If we do not recognize the importance of forecaster involvement in the process, the resulting top-down workstation designs will never be accepted with anything but foot-dragging and complaining. We need to have systems in the field quickly, not years after the technology has passed by, and we need to learn from having systems, however initially imperfect, in the field so that successive systems can suit the changing needs of a changing forecaster workplace. A great deal of the modernization initiative currently underway in the National Weather Service depends on this sort of evolutionary feedback.

I cannot resist noting, in closing, that a full exploitation of the capabilities of workstations also hinges on having adequately educated and trained forecasters. I do not believe that this lofty ideal has been attained, nor do I believe that a process is yet in place that will achieve this goal in the foreseeable future. If this oversight continues, it will more than offset any hard/software gains, ultimately compromising any purely technological response to technological change.

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