A NUMBER OF THINGS

*Oration delivered in accepting the position of Professor in
Applications of Decision Theory at the Faculty of
Technical Mathematics and Informatics at the Delft University
of Technology, Delft November 8 1995 by*

Dr. R. M. Cooke[1]

Esteemed Rector, and other members of the University Directorate, worthy
colleagues and other members of the university community, honored guests,
ladies and gentleman:

Introduction

I hail from the United States, a country where the custom of delivering an
oration is unknown. From the all no–nonsense Yankee business jargon currently
emanating from Dutch university administrations, I inferred that the oration,
had come to resemble a Medieval morality play, somehow out of step with the
times. I am a parvenu Dutchman, and people whom I judge much wiser than myself
have convinced me, not without a certain impish pleasure, that I too must give
an oration.

But how? A study of the genre reveals that the ideal oration opens with a
quote; a quote which surprisingly explains a seemingly nondescript
title by linking the Aspirant Professor's field to large themes from,
preferably, Dutch history; and this all with a bombastic intellectual swagger
which somehow stays entertaining. I shall try to perpetuate this tradition.
A nondescript title was easily found. Long did I search for the quote. It
appears that history's key figures seldom refer to mathematics. Has
mathematics had nothing to say to them?

Some hope could be gleaned from Max Weber's *Die protestantische Ethik und der
Geist des Kapitalismus.* Weber uncovered a strong link between the origins
of capitalism, the industrial revolution and the emergence of Dutch
Calvinism. The Calvinist doctrine of predestination, as you know, had the
effect of devaluing the most important asset of the Catholic Church, real
estate in the Here After. The decision who would go to Heaven and who would
not, had already been taken, and the Church could not intercede. Moreover,
those who had been elected for salvation could not be identified by any outer
or inner property. What is then the point of this short life on Earth? Our
only earthly goal must be to nurture hope for an undeserved salvation. In The
Netherlands, that translated to earning as much money as possible without
enjoying it. There was no alternative but to apply the unspent gain to garner
yet more gain, and capitalism was born, according to Weber. The hallmark of
the spirit of capitalism, says Weber, is that everything, but then really
everything, should be calculated in terms of capital. As spokesman par
excellence of this new spirit, Weber cites an erstwhile compatriot. *"The good
paymaster"* says Benjamin Franklin

*"is lord of another man's purse. He that is known to pay punctually and
exactly to the time he promises, may at any time, and on any occasion, raise
all the money his friends can spare"*[2].

---

[1] Translated from Dutch be the author

[2] Weber, M   The Protestant Ethic and the Spirit of Capitalism, Scribner's
Sons, New York, 1958, p. 49

Perhaps Prince William of Orange recognized in this spirit of capitalism the possibility of an alliance between Calvinist ministers and the Dutch sea pirates, from which the State of The Netherlands eventually emerged.

If such calculation does lie at the basis of the Dutch nation state and the creation of modern credit worthy man, then the large themes emerge; religion, the origin of nations, and numbers. What hidden relations bind these concepts? How is the earth divided into "We's" and "They's"? Why are there nations and Gods, why so many, and for how long? Though Franklin's quote conjures all these questions, in no way does it cover the activities of the Chair of Applications of Decision Theory. We must dig deeper.

It appears from the first European national anthem[3] that the founding of The Netherlands is intimately bound up with the gift of God to David of "a kingdom in Israel, most great".

How was that exactly? The founding of Israel is symbolized in the founding of the Temple of King David in Jerusalem. The story is told in the Bible, First Chronicles, chapters 20–22. In his last battle, David defeated several Ammonite cities. He led the inhabitants out and "cut them with saws and with harrows of iron and with axes", in accordance with the wishes of the Lord. Shortly thereafter, however, he listened to Satan and ordered the Israelites to be *counted*. The wrath of the Lord was immediate. David was given a choice, "either three years famine, or three months to be destroyed before thy foes,... or else three days the sword of the Lord". David chose the latter, and seventy thousand Israelites were laid low by God before David repented (he was allowed to count the dead). The angel of the Lord showed David the spot where he should build an alter to the Lord, and on that spot the Temple of Jerusalem was built.

The roots are laid bare. Imagine, ladies and gentlemen; the pictures are familiar from the daily news. Naked children torn from their mothers' breasts, children scream, mothers plead; but the Lord is implacable and the saw teeth of the Lord chew on. For indeed, those children would have grown up worshipping a different God. David need show no remorse for this ethnic cleansing. He is unfaithful to the Lord only when he counts the number of his own people. David counted the Israelites because, like any commander, he wanted to know his military strength, but he should have known that his strength came solely from the Lord. The Lord would deliver him if he put his faith in the Lord. Trying to take his fate in his own hands was high blasphemy. Sawing the children of the enemy to pieces did not incur the Lord's displeasure.

At a technical university we count, calculate and measure to gain control over our fate. In my field of risk analysis we attempt daily to frustrate the 'acts of God'. Is that too high blasphemy?

The founders of nations renounce existing earthly law, and appeal to incontrovertible supernatural authority. That's the way it has always been, and that's the way it is today. How does science *ultimately* relate to the fruits of such labor? This is the old question of the relation between reason and authority, between science and faith. During the Enlightenment the ethical basis of modern constitutional democracy was negotiated by, among others,

[3] The Wilhelmus van Nassouwe; see Schama, S. (1987) The Embarrassment of Riches: an Interpretation of Dutch Culture in the Golden Age, Fontana Press, London, p. 103. The Dutch often emphasized the analogy between the Israelites and their own quest for nationhood, as reflected in the eigth stanza of the Dutch National Anthem, the first European national anthem.

Immanuel Kant. Kant's answer came down to an armed truce between reason and faith. Each was assigned its own territory and instructed not to pester the other. Can this compromise hold its own in the face of the continual re-allocation of the earth? If I believed that, I should have chosen a different subject for this oration. The problem is that the various incontrovertible authorities cannot leave *each other* alone, and if reason is kept out, then only the saws, iron harrows and axes remain.

The question of the relation of reason and authority receives a much more radical answer in a casual aside of the Danish physicist Niels Bohr. His comment also perfectly describes what we in Applied Decision Theory try to do.

One day, Bohr visited the Danish Parliament as guest of an eminent politician. A heated discussion was under way, and his host remarked "...this is certainly quite different from the discussions at your institute, is it not Professor Bohr?" Bohr answered that discussions at his institute also became quite heated. He paused for a moment and added "...but there is one difference, at our institute we *try* to agree" [4].

"Is that all?" I hear you ask. Yes, that is *all*. Gods do not try to agree. Allah and Jehovah will never agree which incontrovertible authority is the true one. Politicians make compromises, that is, they find power equilibria. Scientists, on the other hand, *agree*. If the founding of nations is bound up with appeals to incontrovertible supernatural authority, then science is building a sort of anti-nation. Science creates a "we" which is not based on mutual recognition via a commonly recognized authority, but it is based on something else. And what is that ladies and gentlemen? Numbers. Numbers are the things on which homo sapiens can agree. We in decision theory try to replace discussions about power and authority with discussions about numbers.

Applications of Decision Theory

Let me explain. When my daughter studied at the Royal Conservatory of Ballet, we once took a vacation in the mountains. We chanced upon a deep ravine over which a large tree had fallen. Dear daughter jumps on the tree and starts across. "If you fall off you will never dance again" advise I. "But I won't fall off" she answers indignantly. I could have appealed to my parental authority, but then I would always remain the father who forbade the tree. Instead, I applied decision theory. "Okay, go ahead if you must, but first estimate the chance that you will fall, is it one in a hundred, one in five hundred? tell me." Daughter reflects for a moment and climbs off the tree.

Once we start counting people, we don't stop. I have here a graph showing the world population from 10,000 years ago up to the present [5]. The graph begins with a population of 10 million in 8,000 BC and creeps slowly upward until the year 1650, then suddenly it shoots up. Before 1650 the world population grew at the rate of 50% per thousand years, every 1000 years it increased by 50%. After 1650 it increases at the rate of 2000% per 1000 years.

[4] Personlal anecdote of Prof. H.B.G. Casimir

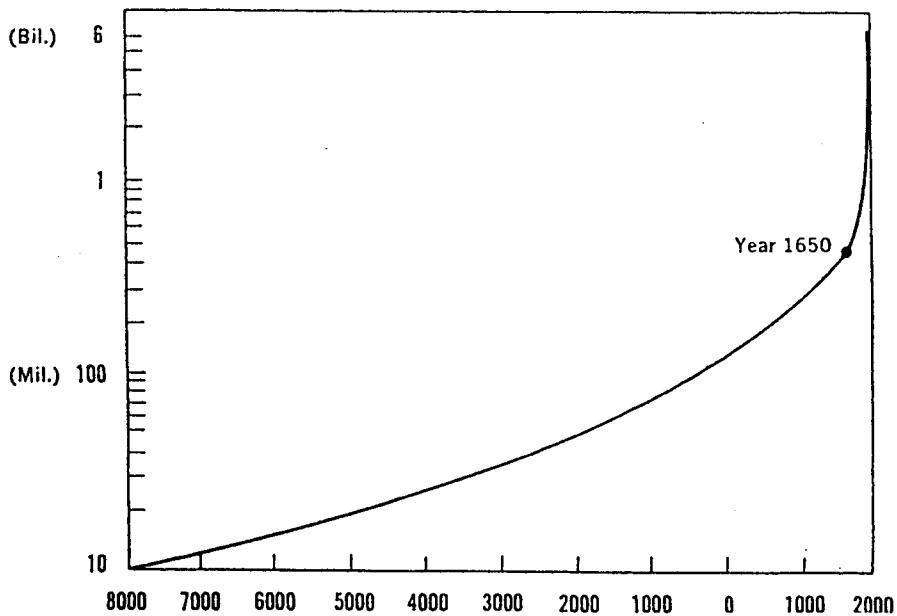[5] Hauser, P.M. (1975) "World population problems" Headline Series Foreign Policy Association no. 174.

Figure 1
World population from 8000 BC

What explains this kink around 1650? Dutch Calvinism perhaps? Alas I must
disappoint you. On a scale of 10,000 years there have been hundreds of
Hollands, hundreds of Calvins, and hundreds of people who returned from the
Dead. Yet there is only one kink. We are dealing here with the anni mirabibles
between the publication of Copernicus' De Revolutionibus Orbium
Caelestium in 1543 and the Philosophiae Naturalis Principia Mathematica
of Newton in 1687. These are the years in which modern science and the
industrial revolution were born.

What is going on? During the anni mirabiles a unique event occurred in the
West. Everywhere there was technology, the fabrication of tools, and many
cultures possessed some form of science. At this time in the west, however,
the two came together. The marriage between science and technology meant in
the first place that scientists acquired better instruments with which they
could discover natural laws. Knowledge of these laws enabled them to make more
accurate instruments, with which they could discover still more laws, make
better measurements, etc. Better instruments served not only for better
measurements. They also provided better navigation, better methods of
production, better agriculture; more people could be fed with less labor.
There was more free time for still more improvements, and thus 2000% per 1000
years.

The 'scientization' of technology is an event which is visible on a time scale
of 10,000 years. The activities of applied decision theory are not visible on
this scale, but they are visible on a scale of 30 kilometers.

The figure below shows the lateral spread of a plume of airborne radioactive
material after a hypothetical accident at a nuclear power station under stable
atmospheric conditions in northern Europe. Despite intensive efforts of large
research laboratories like Kernforschungzentrum Karlsruhe [6]en de National

[6]Fischer, F. Ehrhardt, J. and Hasemann, I. (1990) Uncertainty and Sensitivity
Analyses of the Complete Program System UFOMOD and of Selected Submodels.

4

Radiological Protection Board[7]; the prediction of such a plume spread still requires a raft of uncertain parameters.
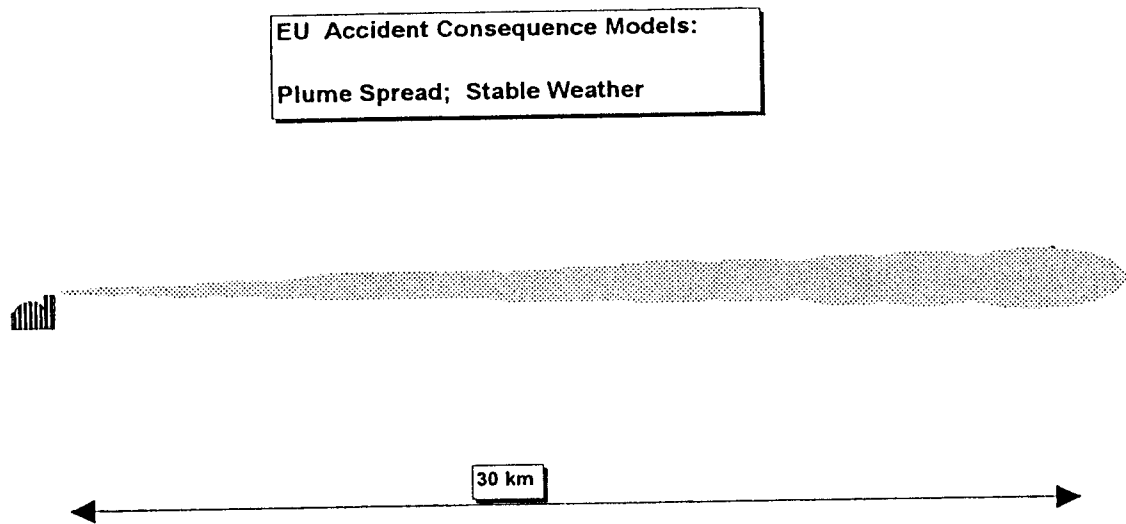

Figure 2
Lateral plume spread under stable atmospheric conditions

In the 1980's the research labs performed various 'uncertainty analyses' of consequence models. The uncertainty in the input parameters was quantified, usually informally, and propagated through the models. The resulting uncertainty in model predictions can be summarized in 90% uncertainty bands. The next figure illustrates the 90% uncertainty bands for lateral plume spread under stable conditions. According to these analyses, we may be 90% certain that in a real accident under these conditions, the lateral plume spread will lie between the upper and the lower plumes.

Kernforschungzentrum Karlsruhe, Report 4627.

[7] Crick,, J.J., Hofer, E. Jones, J.A. and Haywood, S.M. (1988) Uncertainty analysis of the Foodchain and Atmospheric Dispersion Modules of MARC. National Radiological Protection Board, report 184

```
EU Accident Consequence Models
Plume Spread: Stable Weather
90% uncertainty bounds
(NRPB, KfK, 1990)
```
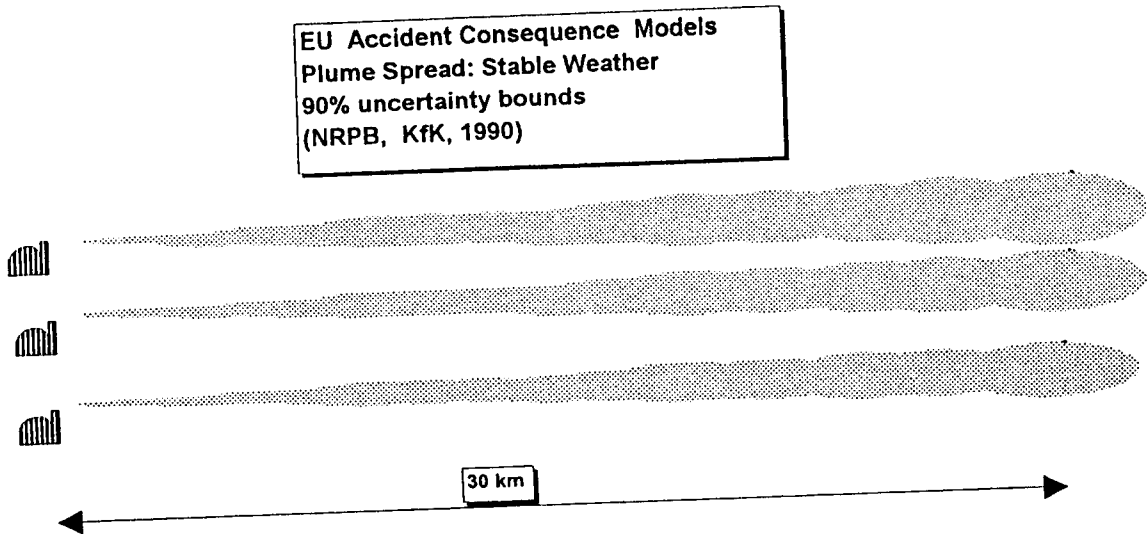
30 km

Figure 3
90% uncertainty bands for lateral plume spread under stable
atmospheric conditions

It will be noted that these uncertainty bands are rather narrow. The
scientists are quite certain of the degree to which they can predict the plume
spread. Is this degree of certainty justified? Such questions can easily
degenerate into discussions of power and authority.

In 1990 a joint research program was initiated between the European Union
and the American Nuclear Regulatory Commission (USNRC). The goal was to
redefine the state of the art regarding the uncertainty analysis of large
scale consequence models. In the course of this project, uncertainties for
input and output variables for European and American models are being
determined. A large number of European research labs participate, and overall
coordination of the European effort rests with the Safety Science group in
Delft. The chair of Applications of Decision Theory provides mathematical
support.

The analysis of uncertainties in large risk models involves many interesting
mathematical questions. One of these lends itself for illustration this
afternoon. By way of introduction, I show our results for the uncertainty in
lateral plume spread under stable conditions [8].

[8] Cooke, R.M. (1994) "Uncertainty in dispersion and deposition in accident
consequence modeling assessed with performance-based expert judgment"
Reliability Engineering and System Safety no. 45 35-46.

Cooke, R.M., Goossens, L.J.H., and Kraan B.C.P. (1995) Methods for CEC/USNRC
Accident Consequence Uncertainty Analysis of dispersion and Deposition.
EUR-15856 EN.

EU Accident Consequence Models
Plume Spread: Stable Weather
90% uncertainty bounds
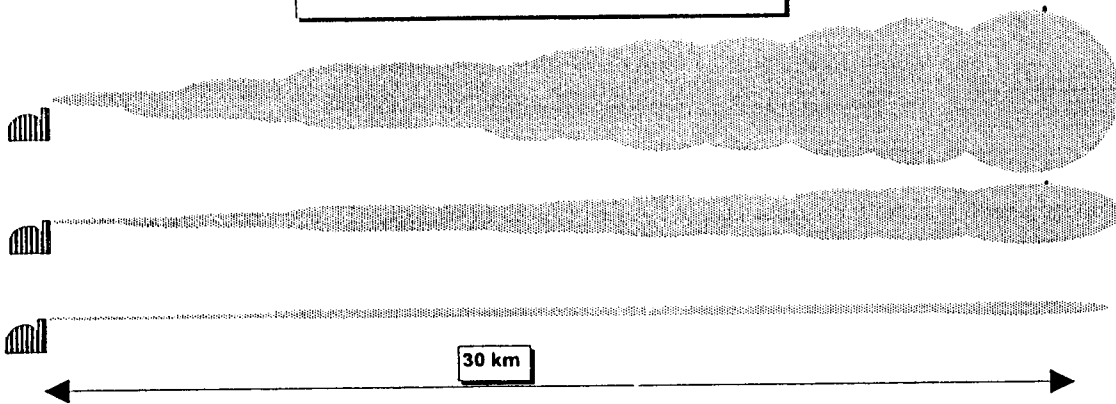**TU Delft - EU 1995**

30 km

Figure 4
90% uncertainty bands for lateral plume spread under stable conditions;
TU Delft method

Comparing the previous two figures, it is evident that a new picture of the uncertainties has emerged. If you reflect that the seriousness of an accident is determined in large measure by the degree to which the plume does *not* spread, then you can imagine the consequences of this new picture for emergency planning.

How has this new picture emerged? Our first problem was to clarify what exactly the accident consequence models were supposed to predict. It soon became clear that the model builders themselves did not all share the same views. Should the models predict the consequences of an accident, or the consequences of an 'average' or 'typical' accident. A clear picture of the uncertainty in model predictions could never be attained so long *that* remained unclear – 'untypical' accidents are more likely than 'untypical averages'.

Why was the community of model builders unclear as to what exactly their models should predict? Simply because this question had never been clearly posed. For an uncertainty analyst this may seem incomprehensible, but I dare to assert that for most applied mathematical models, the question 'what exactly does the model predict' never gets posed. Let this argue for a greater use of uncertainty analysis in applied mathematical modeling.

One of our first tasks was then to obtain a clear statement from the responsible authorities in Brussels what the accident consequence models should predict, an accident or an average accident. If they predict an average accident, then, we asked, over what shoud the average to be taken? The answer was that the models should predict the consequences of an accident and not an average accident.

Havingthat cleared that up, the following picture could be composed. You see here the model predictions from previous studies (as in figure 3) indicated with "#" for the lateral and vertical plume spreads under various atmospheric conditions. The 90% uncertainty bands for these predictions are also shown

as "[————————]". A realization is given beneath each prediction; these are
results of measured plume spreads in tracer experiments performed under the
relevant atmospheric conditions. In this exercise there were 36 probabilistic
predictions for which realizations were available; 20 of the 36 realizations
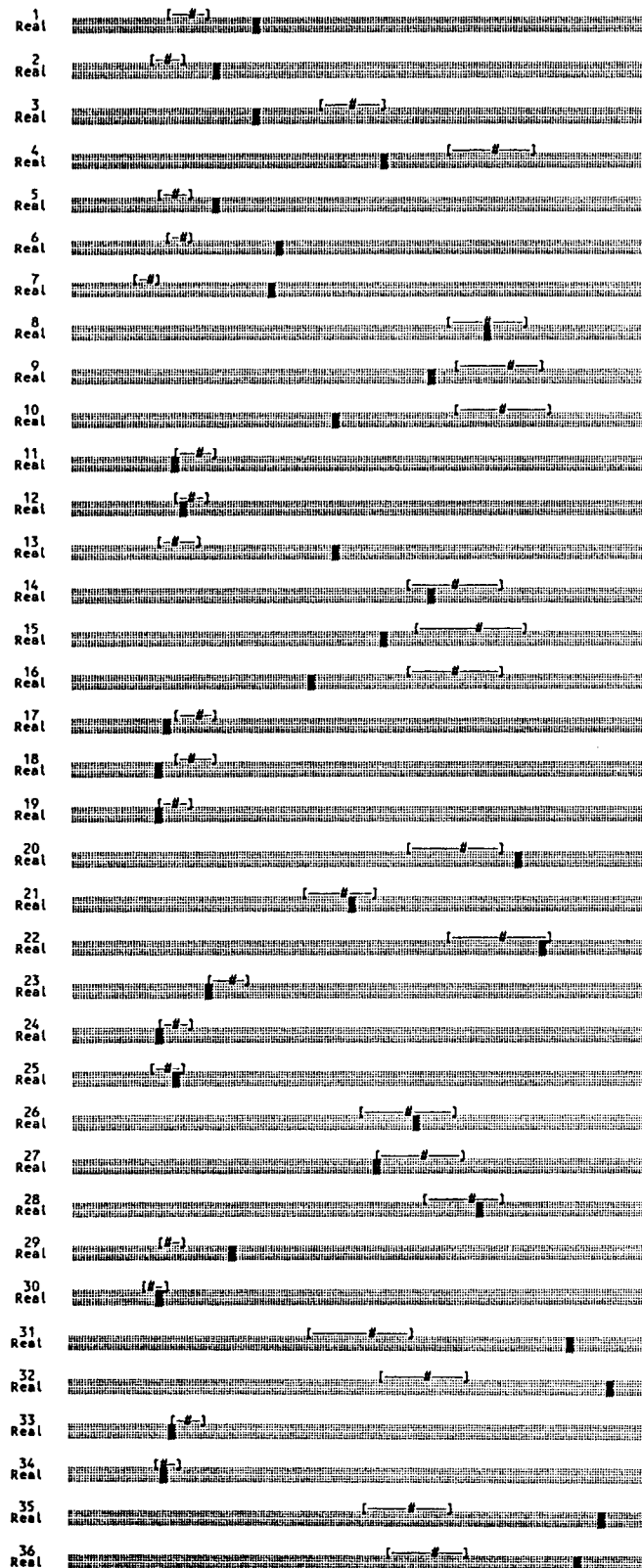fall outside the respective uncertainty bands.

Figure 5
Predictions of plume spread with uncertainty, and realizations

We went to work applying the 'performance based' combination of expert judgments developed in Delft[9]. The distinctive feature of this method is that uncertainty, in this case the experts' uncertainty, is treated as a scientifically measurable quantity. Different experts are asked to quantify their uncertainty with regard to results of physical measurements. The questions must be chosen so that some of the measurements are actually performed. This enables us to measure the performance of experts as probabilistic assessors and subsequently to combine their judgments so that the performance of the 'combined expert', i.e. the decision maker, is optimal. This optimization involves many interesting mathematical issues, some of which I indicate in a non–technical fashion. The measurement of performance must:

i)   reward experts' statistical accuracy (e.g. 90% of the realizations fall within the 90% bands, in the long run)

ii)   reward experts' informativeness (e.g. the 90% bands are narrow)

iii) not encourage experts to state judgments at variance with their true opinions

The last point is of special interest for this afternoon. High measured performance entails large influence on the optimized decision maker, power if you will. The last point says that an expert maximizes his/her expected influence only by saying what he/she really thinks. He who wants power must be honest.

The following figure shows the results of a number of probabilistic predictions of lateral and vertical plume spread. Eight international experts participated in this research, and their median estimates and 90% uncertainty bands are pictured, together with those of the optimized decision maker.

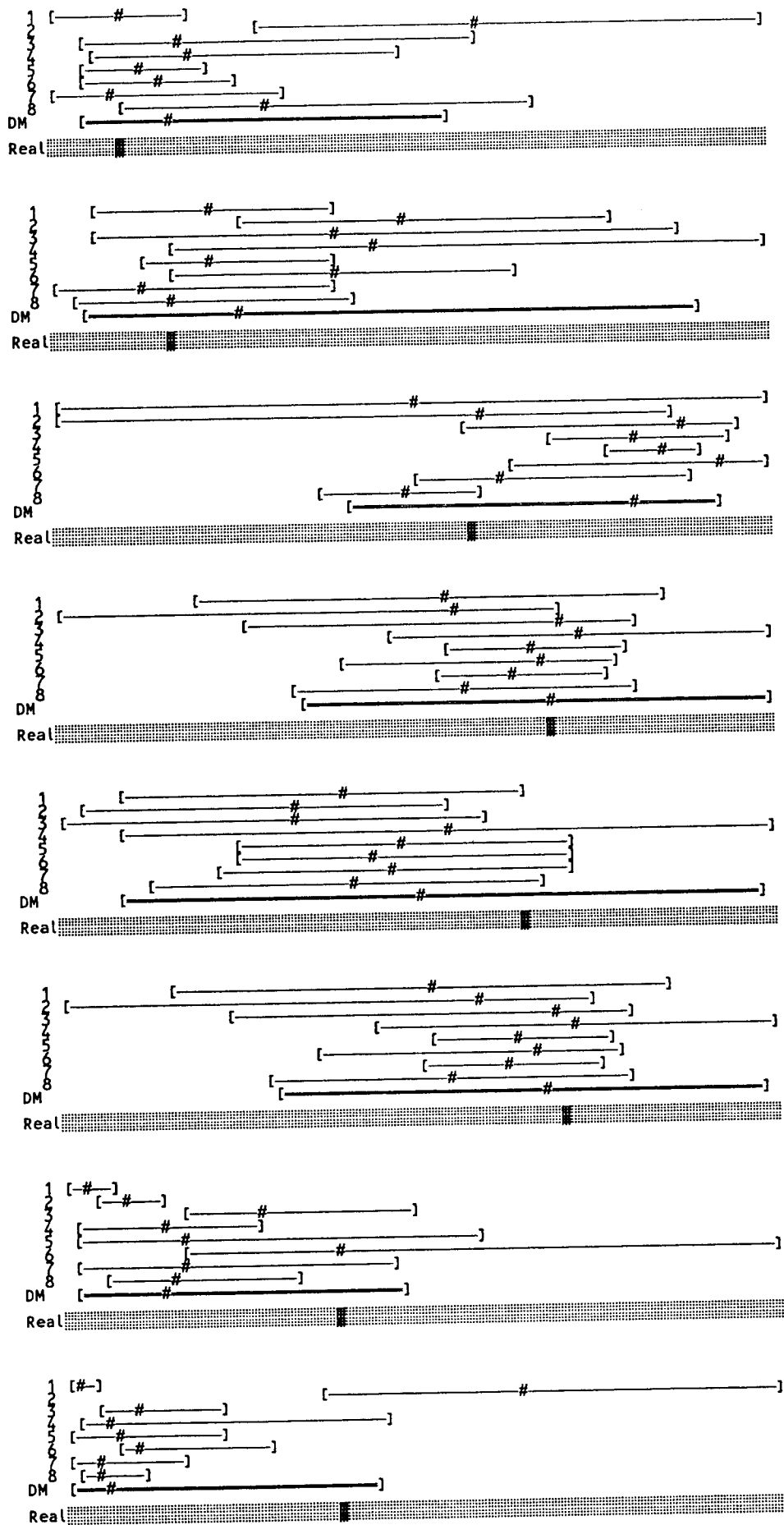[9] Cooke, R.M. (1991) Experts in Uncertainty, Oxford University Press.

Figure 6
Eight experts and performance based decision maker
for lateral and vertical plume spread, EU–TU Delft study

It is also interesting to compare the optimized decision maker with the 'equal weight decision maker', that is, with the result of simply averaging all the experts' uncertainty distributions. The following figure shows the probabilistic predictions for these two decision makers for all variables for which a realization was available.
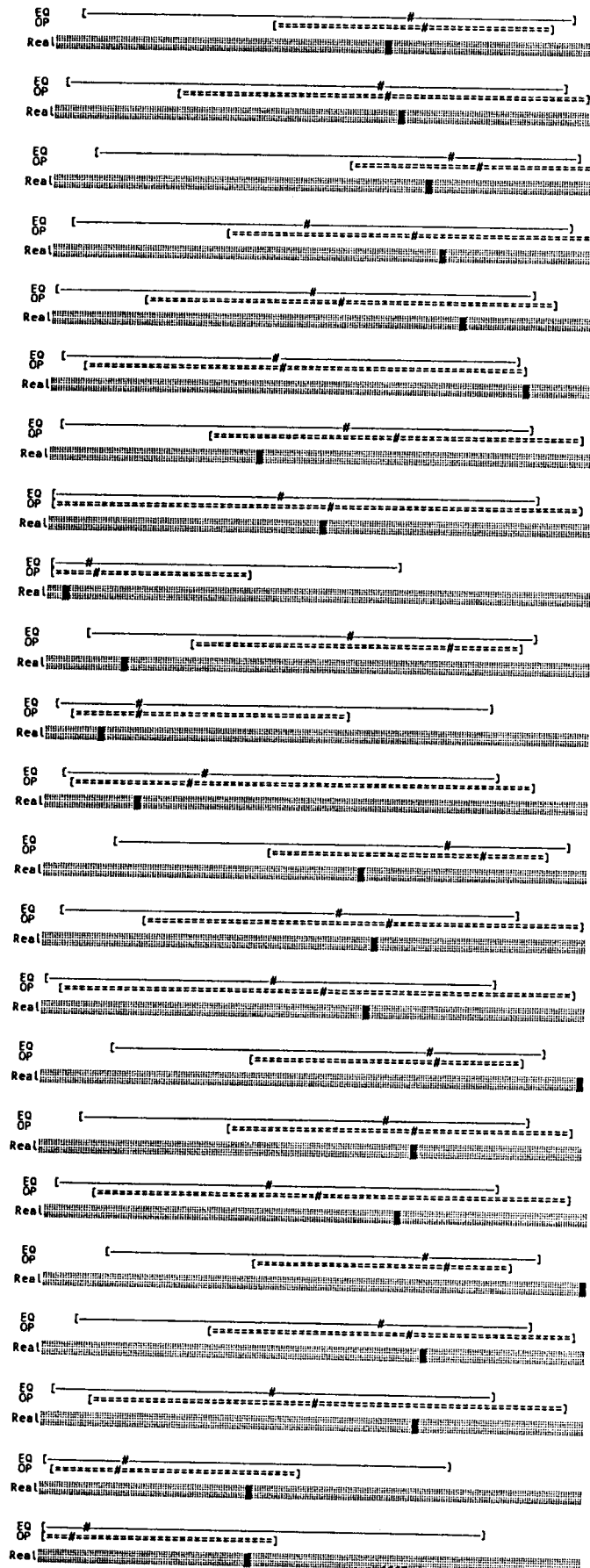

Figure 7

Dispersion predictions for optimized and equal weight decision makers

11

The optimized decision maker is more informative (i.e. has narrower uncertainty bands) and also has greater statistical accuracy (this last is not apparent to the naked eye, but emerges from the calculations). Of course, one data set by itself says little. Confidence in the value of this method grows as it proves itself in many different problems. This method has been applied in many problems in risk analysis, optimal maintenance and environmental modeling. The value of performance measurement and optimization has been proved in each case; sometimes the improvement relative to the equal weight decision maker is marginal, sometimes it is dramatic.

An example of such a dramatic improvement relative to the equal weight decision maker emerged in this research with the USNRC in regard to the dry deposition velocities of aerosols. It concerns the speed with which airborne radioactive particles deposit onto various surfaces. Of the eight international experts, the optimized decision maker opted to neglect seven of them and to go completely with one single expert. The difference in performance between this one expert and the equal weight decision maker is shown in the following figure. The median assessments of the equal weight decision maker all lie below the realizations. This would lead to significantly more optimistic predictions of the consequences of a possible accident.

CEC-USNRC DRY DEPOSITION VELOCITIES

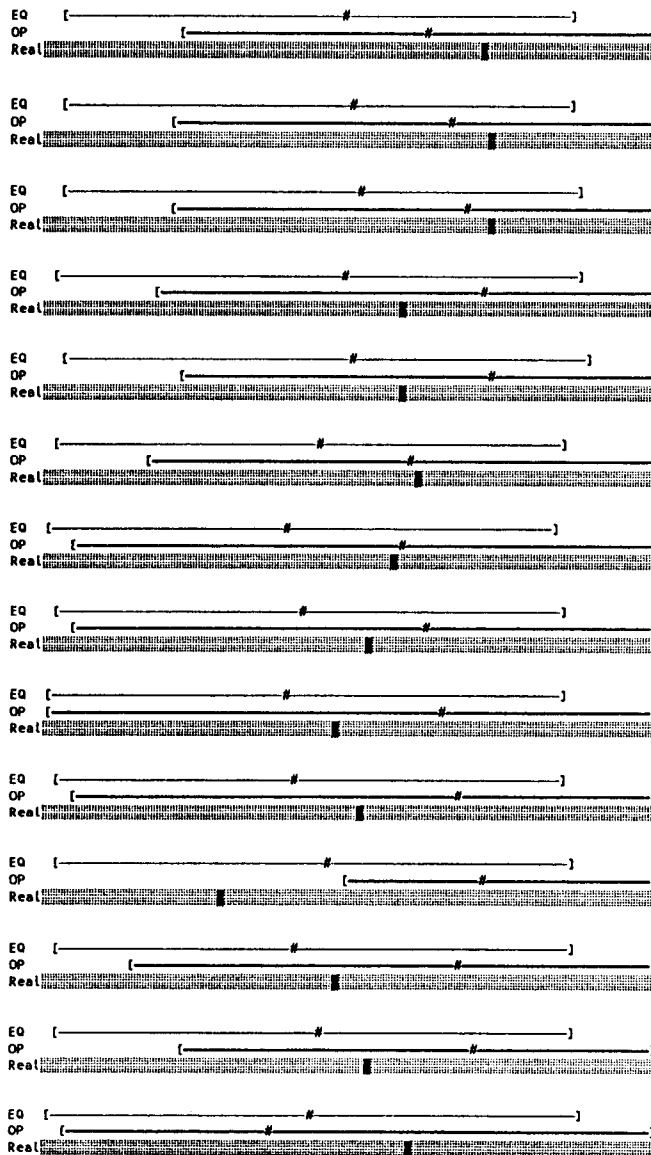Equal Weight and Optimal Decision Makers

Figure 8
Dry deposition predictions of the optimal and equal weight decision maker

It is no exaggeration to say that our American friends had some difficulty with this outcome. As a result, they had difficulty with the phenomenon of performance based weighting. Our European sponsors stood firm, however; and authorized us to proceed with performance based weighting in the uncertainty analyses. They also decided to award us a contract to write a European procedures guide for uncertainty analysis of accident consequence models with expert judgment. We are hard at work on this. Our American friends have since recovered from the shock and are now fully back in the game.

Permit me one last remark on this example before I conclude. Colleagues, especially colleagues in the social sciences often wonder how world renowned experts can be scored on performance as if they were school children. People without a background in the empirical sciences are surprised to hear that the experts actually *enjoy* this. The overwhelming majority of experts appreciate any attempt to replace discussions of power and authority with discussions of numbers, even if it concerns their own power and authority. They would all feel very much at home in Bohr's institute.

In Conclusion

Our culture still needs symbols of incontrovertible authority. A striking example of this is closer than you may realize. During a recent 'professors dinner' I learned that when a professor dons his/her cap, then he/she exercises his/her official function and cannot be contradicted. By delivering this oration with my cap, I am an accomplice in this symbolism. Is that entirely consistent with the aim of replacing discussions of authority with discussions of numbers? After extended internal debate, I concluded that I could consistently wear this cap, for the following reason. Challenging symbols of incontrovertible authority does not reduce the need for such symbols. If this need emanates from fear, then such a challenge only amplifies the fear and thus intensifies the need. What is the antidote for fear? Socrates prescribed irony. After all, what is more ironic than a scientist with a cap posing as incontrovertible authority? Socrates made a distinction between irony and hypocrisy...by drinking the hemlock[10]. In the long run, however, there is only one cure for fear, and that is knowledge.

But how long is the long run? I return to the picture of the world population from 8000 BC. I have here the same picture, but now the time axis is extended out to 8000 AD. Mathematicians like to extrapolate; how should we extrapolate the world population line out to the year 8000 AD.

---

[10] The Dutch expression "ergens gif op innemen" (to take poison on it) means roughly "to bet your life on it". The play on words in this context is intranslable. Socrates' irony was in deadly earnest. After being found guilty of corrupting the youth by teaching them to question authority, he surprised his followers by refusing escape and drinking the Hemlock poison.
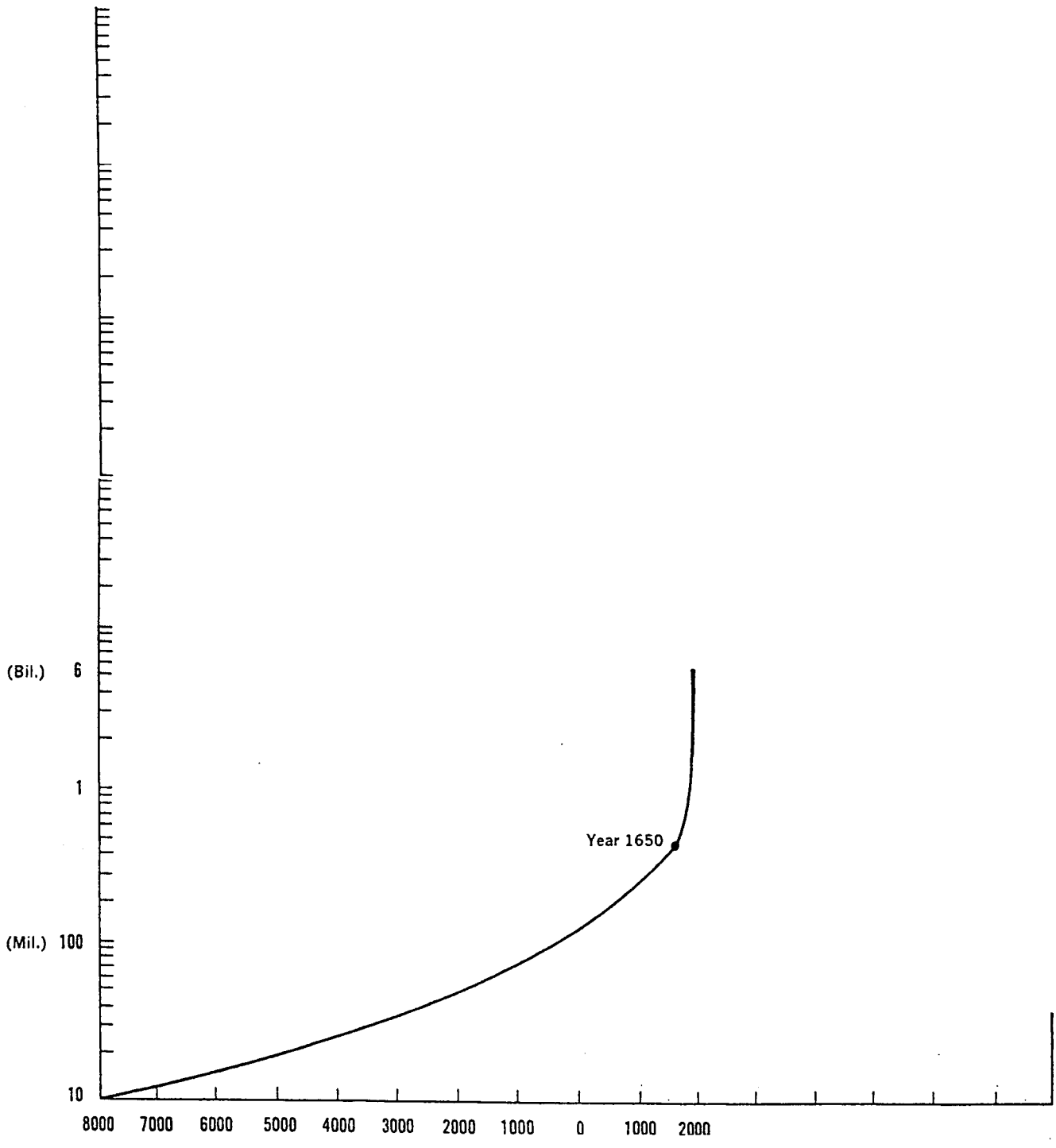
Figure 9

When the population line reaches the top of the graph, then there will be one square meter of the earth's surface for each person. A little while ago I said that the marriage of science and technology was visible on a time scale of 10,000 years. I can predict that there will be another event visible on a scale of 10,000 years. No one can say what event that will be, but I can tell you, it depends on a number of things.