KH. B. KORDONSKY: RECOLLECTIONS AND SHORT REVIEW OF SCIENTIFIC RESULTS

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memoirs

Professor Khaim B. Kordonsky was my Ph.D. advisor, my teacher and also my personal friend. I was lucky that during many years I had the unique opportunity to work with that fine man of outstanding intellectual courage combined in him with extreme modesty and personal charm. The notes below is my tribute to his memory.

1.Aircraft Fatigue Life.

Being the leading AEROFLOT expert in aircraft fatigue problems, Kh.B. Kordonsky was often faced with extremely difficult real-life problems. One such problem was aircraft life prediction after a fatal fatigue failure.

In the mid 1960's, one aircraft of the type IL-14 (if I am not mistaken) suffered a catastrophe as a result of fatique break of the wing. In total, AEROFLOT had several hundred similar aircraft in active use. According to the existing rules, the entire fleet of the IL-14 was grounded and the wings were inspected to reveal the presence (or the absence) of fatigue cracks in the wings. The data gathered after this inspection had the following form:

$$i, \text{flight time } T_i \text{ hours; } \delta_i, i = 1, \ldots, 240, \tag{1}$$

where $\delta_i = 1$ if the crack was present, and 0 - otherwise.

In this messy situation, experienced practitioners were absolutely unable to say anything about the lifetime of fatigue crack, neither theoretically nor by commonsense since the exact time of crack appearance was unknown.

The approach suggested by Kh.B. Kordonsky was elegant and novel for those days when the statisticians did not know how to process censored and grouped data. Suppose that the random time τ of fatigue crack development has the cumulative distribution function $F[(t-a)/b]$, of location-scale type, which included both lognormal and Weibull distributions, two principal models used to describe fatigue life.

Then the likelihood of the $i-th$ event described in (1), equals

$$L_i = [F((T_i - a)/b)]^{\delta_i} \cdot [1 - F((T_i - a)/b)]^{1-\delta_i}, \tag{2}$$

and the overall likelihood is expressed as

$$Lik = \prod_{i=1}^{240} L_i. \tag{3}$$

The estimates of the parameters were obtained in a standard way by solving the set of equations

$$\partial \log Lik/\partial a = 0, \ \partial \log Lik/\partial b = 0. \tag{4}$$

Having estimates of a and b, the lifetime prediction for a particular time in the air became a routine calculation. A crucial point in that method was establishing the uniqueness of the solution of the equations (4). In [1] published in the leading Soviet journal in 1970, it was proved that under mild conditions (at not all δ_i are zero or 1) the unique solution always exists.

2. Aviation Schedule

In the period 1965 - 1971 Prof. Kordonsky was the chief scientist and senior manager of an ambitious project on constructing computerized central aviation schedule for AEROFLOT. This schedule was the main document of the Ministry of Civil Aviation (MCA) which determined the transportation and commercial activities of a giant AEROFLOT company having a fleet of more than 600 aircraft and servicing more than 200 airports. When I compare contemporary computers with those available in the USSR in the sixties I realize that only a person of outstanding intellectual courage could accept and carry out this challenging job. Amazingly, the first computerized schedule was composed and implemented in AEROFLOT already in 1971 and continued for 16 years until the collapse of the Soviet Union.

When our work on scheduling started, the MCA schedule was composed manually by a small group of experts specializing in that work for many years.

To us composing the schedule looked like playing a giant game of patience with an unclear set of rules ranging from absolutely strict to quite "soft". These rules included partial optimization of the fleet size, safety regulations in airports and in airspace, and many other written and unwritten instructions. Nobody of the experts was ready and willing (nor possibly able) to explain to us what and why he was doing what he did, which rule was to be followed and which may be violated.

Needless to say, that neither Kh. Kordonsky himself nor any one else in his group had any idea how to compose the schedule. "You will able to formalize the scheduling process for a computer only when you will able to do it manually" he said to us. So we went to the Scheduling Department of MCA in Moscow and closely watched two three-week sessions of schedule composing. These sessions took part every six months. Our team included several very smart and devoted young people who returned to Riga after these sessions with numerous observations and ideas. For several months all our group, including Kh. Kordonsky himself, participated in absolutely exciting brainstorming sessions which eventually allowed us to understand and to formalize the principal heuristics which governed the process of schedule composing. The total absence of pressure of the "boss" upon his subordinates was the key element to the success of our work and characteristic of Prof. Kordonsky.

Without going into too many technical details, the basic principles of scheduling were the following. First, it was necessary to optimize the fleet size for each local company in the limits of its fleet and to produce trip-chains which served as a raw material for further work. The second principle was that the schedule should be composed sequentially, using a greedy-type algorithm. The crucial feature of this algorithm was determining the priorities among the trip-chains. At that point Kh.B. Kordonsky suggested using *probability - based* priority rules, a totally novel idea in scheduling. All trip-chains were evaluated according to the probability of positioning the trip-chain without violating basic safety and commercial rules. Afterwards, the trip-chains were ordered in the ascending order of these probabilities and the highest priority for their actual scheduling was given to the trip-chain with the *smallest probability*. The combination of greedy algorithm with probabilistic priorities were later used in many other areas of scheduling, for instance job-shop scheduling [7].

All the above principles were implemented in software and by the winter of 1967 the first successful trials were made on a computer URAL-4 which was located in the giant hall of an old neglected Russian Orthodox church in Riga. (Let me mention that URAL-4 was a second generation computer with ROM 4K).

In 1970 our group was able to produce a schedule which was in some aspects even better than the existing one made manually. In that year, following the death of the head of Scheduling Department in the MCA from cancer (the name of this outstanding man was Sharkevich) and the inability of his subordinates to proceed without him, the MCA asked for our help. The first computerized schedule was composed for the winter years 1971-1972. Later on, schedules were made yearly and their size increased considerably.

3. Time Scales

In the period 1988-1999, Kh. B. Kordonsky worked on the problem of *lifetime scales* in reliability, see [2]-[5]. Traditionally, the approach to system failure analysis is based on assuming a certain failure model derived from a hypothetical scheme of damage accumulation. As a rule, this process is considered in one, "most appropriate" time scale. For example, the number of loading cycles is the intrinsic time scale for fatigue-type failure.

It is widely recognized today that this intrinsic time can be chosen (and observed) in several ways. For example, two times scales prevail in aircraft reliability analysis: the total flight time and the total number of operation cycles (landings and takeoffs). This fact was the motivation and the starting point for Kordonsky's research in multiple time scales. Once there are at least two observable principal time scales (say for a car - the mileage and the time in use), it is always possible to introduce a family of new time scales by considering a weighted sum of the principal time scales. Proceeding along this line, Kh. Kordonsky suggested an ingenious definition of the "best" time scale [2]: the best time scale is defined to be that time scale which provides the minimal value of the *coefficient of variation* of the time to failure. Suppose T and L are the two principal time scales. Each individual object "lives" in two time scales simultaneously. Its "life history" is represented by a trajectory in the $[T, L]$ -plane. It is called by Kordonsky *operational characteristics* (OC). As a first approximation, the OC's are straight lines whose slope reflects the individual damage accumulation rates in both scales. The notion of the

OC was used also by Lawless and Cao [6]. It is very strange that many people worked in the field of reliability but no one before Kh.B. Kordonsky paid attention to the choice of the most relevant time scale for lifetime data analysis.

To illustrate the importance of multiple time scales, let us consider a hypothetical example from the field of preventive maintenance. Let for a certain device T be the scale of operation hours and L be the scale of operation cycles. 25% of all objects have the OC with a slope $L/T = 5$ and fail when the number of operation hours reaches 1000 hrs (and therefore the number of cycles reaches 5000). 50% of all devices have an OC with a slope $L/T = 1$ and fail when $T = 3000$ hrs. The rest 25% of objects have an OC with a slope 0.25 and fail at $T = 5000$ hrs. So, if we observe failures in each scale *separately*, we see a discrete distribution with probability mass 0.25, 0.5 and 0.25 in the points 1000, 3000 and 5000, respectively.

Now suppose we want to carry out a preventive renewal (PR) of the system for a cost of \$1000 and suppose also that no failures are permitted. Then obviously we will carry out the PR just before 1000 hours or 1000 cycles, according the scale we use. Then we would pay \$1000 each thousand hours, and the cost per unit time will be \$1/hr. Is it possible to do better ? At first glance, there is no way to do better. But now look at the both scales together. We immediately observe that the system fails when the value of $L + T$ reaches 6000, on every OC. The new time scale $K = T + L$ is the "best" one according to Kordonsky's definition since the c.v. in this scale equals zero. Now let us carry out the PR just before the K-time reaches 6000. Simple calculations show that now our cost per unit time will be equal $0.25 \cdot 1000/1000 + 0.5 \cdot 1000/3000 + 0.25 \cdot 1000/5000 = 0.47$. There is a reduction of costs by a factor of two !

[1] Artamanovsky, A.V. and Kh.B. Kordonsky. 1970. Estimate of maximum likelihood for simplest grouped data. *Theory Prob. Appl.,* **15**, 128-132.
[2] Kordonsky, Kh. and I. Gertsbakh. 1993. Choice of the best time scale for the reliability analysis. *European Journal of Operational Research*, **65**, 235-246.
[3] Kordonsky, Kh. and I. Gertsbakh. 1995. System state monitoring and lifetime scales -I, II. *Reliability Engineering and System safety*, **47**, 1-14, **49**, 149-154.