

C. RAYMOND KNIGHT

An Interview Conducted by

David Morton

IEEE History Center

January 17, 1999

Interview # 352

For the

IEEE History Center

The Institute of Electrical and Electronics Engineers, Inc.

and

Rutgers, The State University of New Jersey

Copyright Statement

This manuscript is being made available for research purposes only. All literary rights in the manuscript, including the right to publish, are reserved to the IEEE History Center. No part of the manuscript may be quoted for publication without the written permission of the Director of IEEE History Center.

Request for permission to quote for publication should be addressed to the IEEE History Center Oral History Program, Rutgers - the State University, 39 Union Street, New Brunswick, NJ 08901-8538 USA. It should include identification of the specific passages to be quoted, anticipated use of the passages, and identification of the user.

It is recommended that this oral history be cited as follows:

Raymond Knight, Electrical Engineer, an oral history conducted in 1999 by David Morton, IEEE History Center, Rutgers University, New Brunswick, NJ, USA.

Interview: Raymond Knight
Interviewer: David Morton
Date: 17 January 1999
Place: Washington D.C.

Morton: Why don't we start. If you could tell me where and when you were born, a little bit about your childhood and early education.

Knight: You want to go back that far?

Morton: Maybe to childhood, including a little bit about how you got interested in engineering or technical things; then, how you became an engineer.

Knight: That goes back a long ways. I was born September 25, 1918, in Salt Lake City. As a kid in high school I became interested in physics, chemistry, and math. I was quite good at math, particularly in junior high and high school. I started taking mechanical drawing and things of that nature. I was very interested in that. I also started playing with crystal set radios back in those days.

Morton: Those are crystal receivers?

Knight: I built crystal sets myself, then graduated from that into building a regular tube operated receiver, a short-wave receiver. I eventually got licensed in amateur radio and built a transmitter; I built both my own receiver and transmitter. I also got my license as a radio-telephone first-class operator while I was still in high school. Then I went to college. While in high school I decided that I wanted to go to college to become a physicist. As a matter of fact, I enrolled in the University of Utah. Of course, times were kind of tough then. It was in the Depression years. I struggled in many ways to try to get enough money to make it through and went into washing dishes in university restaurants.

Morton: Why did you go into physics instead of electrical engineering?

Knight: Well, I was quite interested in the theoretical side of things. Physics appealed to me very much that way. Turns out that later my sister married one of the professors in the Physics Department at the university. He was somewhat older than I, and he told me, after I had finished two years in preliminary physics, that unless I could see my way to go on to my Ph.D. in physics I would do better to go into engineering. Since I couldn't earn my keep until I got a Ph.D. in physics, I changed over after about two years. It took an extra year to make it, but it turns out that I did enjoy engineering, of course. Though electronics wasn't even a word in those days, radio was. But universities didn't have much in the way of radio. I did that on the side with a three-tube radio that I built myself and a one-tube transmitter, and learned to operate it. I worked all continents as a radio amateur; almost completely with what in amateur parlance is called C. W. (Morse code). As I got on in college there just wasn't time for amateur radio. But in my junior year, the end of my junior year, I got a job, fortunately, because of my license (radio first class). I got a job as a radio operator at the station KSL in Salt Lake City, a 50 kw station.

Morton: Was it a commercial or university station?

Knight: No that wasn't a university station. That was one of the big major stations in Salt Lake. I earned my way through senior year at school. So that was a Godsend. Well that is why I was interested in the technical things of engineering. I guess I was always somewhat of a frustrated physicist because 20 years later, after I was living in Washington, I went to the George Washington

University and got my master's degree in physics, making up a lot of physics work. I enjoyed that. I still do. As a matter fact, I was reading Stephen Hawkings' *The History of Time* just before coming up here.

Morton: When and from where did you graduate?

Knight: In 1940 from the University of Utah. While I was still in school I was offered a job in the student engineering program at GE and instructed to report in June or July following my graduation. In June of 1940, I entered GE at Pittsfield, Mass. Though I had said that I was interested in radio, I was assigned to the power transformer test program. Despite the detour, I enjoyed it, except for climbing into the top of a power transformer that was about two stories high after it had been taken off a heat test and still had hot oil fumes inside. But anyway, you're able to gather that from there I rotated through other test assignments for a year and ended up in the radio transmitter division of GE in Schenectady. I was there for three months. I started there testing a Navy 50 kw transmitter. Again, this was a CW transmitter (keyed as opposed to voice modulated), that was being constructed for war efforts. I mean pre-war efforts. This was in early 1941. Then, I was offered, even before I was off the test program, a job in the tube division of the electronics department in Schenectady. The company was not in the large-scale receiving tube business at that time, but was in the some of the special things like ultra-high frequency tubes. I don't know if you are familiar with any of that, Magnetrons and Lighthouse tubes for some of the WW II efforts such as Radar. I mean in the C-band, that is, 3,000-megahertz area. I worked in this field as a tube application engineer for most of the war years.

Morton: By applications you mean? What kind of engineering?

Knight: Tube application engineering. I worked closely with people over at the Radiation Lab at MIT and Division 15 of the NDRC at Harvard. At Harvard they were working on electronic warfare under Dr. Terman (of Stanford University). I worked with them applying lighthouse tubes in some rather exotic tricks to receive enemy radar signals and play them back with a planned delay to give incorrect range information.

Morton: Just pursue that from an employee's view. How did they do that? What was the technology for recording that stuff? Or was it just a straight delay?

Knight: Just a straight delay. Just a delay line.

Morton: Oh, I see.

Knight: When the war was over, I got involved in the ordinary receiving tube market. GE at the end of the war bought out Kenrad. That was before your day.

Morton: Now I'm a historian.

Knight: You are involved in history. So that was 1945. I was made manager for Application Engineering for all the tubes that GE made at that time, including the Kenrad line. I had a group of about five engineers that were responsible for tube Application Engineering with our major customers. It was as a part of that work that I got interested in the possibilities for uses of tubes other than in home radios. I felt that the real future in electronics wasn't in home radios. It was in industrial applications, basically. If they were going to be used in industrial applications, they had to be a hell of a lot more reliable than they had been. So, I made a survey in the late '40s, between '45 and '47 I guess it was, of various

industrial users. Everybody wanted more reliability, but nobody was willing to pay a dime for it. Typical commercial! Until finally I contacted (and this was in 1948) Aeronautical Radio Incorporated, which was owned by the airlines and was then writing specifications for new airline communication and navigation equipment. This was shortly after the war while the airlines were still using military avionic equipment and experiencing serious reliability problems with it, problems they hoped to correct, at least in the new equipment they were preparing to buy. They were very interested in getting more reliable tubes and were willing to pay more for them. We would analyze the failures and attempt to design improved types. This program resulted, largely, from experience with prior attempts to use so called "more reliable tubes," such as the Navy's post war ruggedized tubes usually called "W" types. This airline program proved to be far more successful than any of the previous attempts based on popular assumptions of what the problems were - not really knowing, not really analyzing. So much of the reliability area at that time was work generated by way of buzzwords. And there are still too many buzzwords in it.

Morton: What were examples of some of the typical problems tubes were having?

Knight: Well it was commonly thought, particularly in the military, that lack of vibration and shock resistance was the problem. So they ruggedized! We found in the airlines that shock and vibration were really not a large part of the problem. There were some vibration problems, but we found there were design ways to solve them without making them so you could hit the damn things with a hammer. We also found that there were horrible misapplications in the range of

applied heater voltages. For example, a typical tube was rated for operation at a heater voltage of 6.3 percent volts plus or minus 10 percent. They were being applied in series - parallel strings operating from 20 to 28 volt supplies. There was just no real consideration for operating things within the limits specified by the manufacturer. So we made definite recommendations in regard to application as well as to the structure of the tubes involved. We found that certain kinds of heater designs, for example, were far more reliable in these applications than others. Specifically, spiral wound heaters as opposed to folded heaters were found to be superior.

Morton: As opposed to the what type of heater?

Knight: A folded type of heater wire. I'm talking about heater wire within indirectly heated cathodes.

Morton: Right. Okay.

Knight: We also found that double micas instead of single micas solved the vibration problem pretty darn well. (Mica spacers were used in tubes as the insulating structural material separating electrodes.) There were a number of other things. Further analysis of failed tubes lead to better designs and cooler cathode temperatures, and better-controlled ones, which we did and then provided the samples of those. As a mater of fact, at first ARInc bought them for the airlines and distributed them. This was done with the understanding that the airlines would take data on them, would let us go out and measure the conditions they were being used in, and they would keep track of the hours of operation. Further, they were to return any failures to us.

Morton: If I could ask a question - I'm sorry to interrupt but before you move on - I think you are leading on to something new. The stories you usually hear about tubes in this area is that there was pressure to miniaturize them, and you don't often hear about reliability issues that were involved in design. Were your clients, or were you' also under pressure to make these things smaller at the same time you were making them more reliable?

Knight: They were pretty small already. These were miniature tubes. Subminiature tubes had been used to some extent during the war particularly in military applications like artillery shells and fuses. But there was no real pressure on us to make them smaller. That was not a major factor. A major factor was getting rid of the heat. That was another application factor that was very poorly done in most equipment designs up to that time. We ran some experiments with various kinds of tubes shields. The type of tube shields being used made no contact with the tube envelope at all. I mean they were heat shields as well as electrical shields, and were holding the heat in rather than dissipating it. There was very little consideration given to thermal design in electronic equipment. Again, here is where I think application engineering was very important. I mean, heat problems aren't a one way street. For example, tubes generate heat but their reliability and other components in the vicinity can be jeopardized by excessive temperatures. I think we contributed quite a bit in that area.

This program within the airlines went on from about 1948 until 1950-51. The program was very successful within the airlines. The military had been following this airline effort right along, and so they asked ARInc if they would

take on a similar program to do the same sort of thing for the military. That was in 1951. And ARInc talked to GE and asked if they could borrow me. So I went down on a two-year leave of absence and never left - until I retired.

Morton: You started to tell a story earlier about the gathering of data on tubes that you provided, and I thought you were leading up to something. You didn't say what I expected you to say after that. But what was the result of that? Did that contribute significantly to reliability?

Knight: Yes. I have covered much of that in some papers I have written recently. Well, not terribly recently.

Morton: We don't want to rehash what you have produced already but ...

Knight: Well, you don't have to. It is not a matter of rehashing I think to call your attention to it. I don't know, I think I had prepared it for this special issue of the Transactions.

Morton: Oh yes.

Knight: I seem to have misplaced it and the most important ones. It's here somewhere. Some of the electronic tube picture there. It is not my participation with it.

Morton: Can I take this?

Knight: Let me say this. These two are my only copies.

Morton: Oh, okay.

Knight: You can borrow them as long as you return them.

Morton: Okay. Why don't you make copies of them and send them?

Knight: Well. I don't have facilities to do that.

Morton: I would be happy to do that.

Knight: I would appreciate it if you would.

Morton: All right, I'll make sure to get them back to you.

Knight: I think these too. The trouble with these is the military contract that I started to tell you about provided for our preparing reports for a rather widespread distribution. As a result, a lot of these things did not get into the technical press. They were printed by the company under these contracts and distributed rather broadly, quite broadly. It definitely had an effect on the development of reliability engineering. Particularly this one. I'm extremely proud of this one. But it seems to have been forgotten. I think it was one of the seminal contributions, you might say, in the quantization of reliability - showing the theoretical connections between various aspects of reliability.

Morton: You are going to hate this next question, but can you summarize this for a sort of layman? You said this was influential. What was the feel before, and how did this change it? Maybe you can answer that.

Knight: Before, reliability was talked about in general terms, loose terms. Failures were just failures. It was not quantitative. I think that was the important part. This provided the theoretical basis for quantizing reliability.

Morton: What kind of data were you gathering? Was it announced as a failed tubes or satisfactory operation?

Knight: We did both. We gathered failed tubes - not only tube failures but records of their operating hours (the hours of satisfactory operation up to the time of failure), which is really the basic essence of reliability, isn't it? It is the relationship between operating time and failures. We were able to do that as far

as tubes were concerned within the airlines. However, if you tried, for example, to get time information on tubes in military equipment, you had to face the likely fact that in the course of normal usage none of the tubes started their operating life at the same time in a given piece of equipment in the field. So we made special arrangements with the military and they were extremely cooperative. We completely re-tubed many pieces of equipment. We had our own field people out in eight or nine different military locations: a good many Air Force ones, Navy ones, and Army ones, even over in Europe. We replaced and decaled them, so we could determine, not only the time on the equipment but on the individual tube. Then we could relate that data with physical analysis once it failed. But we not only had the information on the ones that failed, we had the operational information on those that didn't fail. So we had the whole picture.

Morton: Did the data you gathered get fed back into the design or process, or was it just for maintenance?

Knight: Both. That was the whole purpose. We wrote many reports on maintenance procedures and equipment design and tube design. That lead into many things in that regard. We broadened the scope of our work after the first few years from tubes into total systems reliability. As a matter of fact, this project that I started became first, the Research Department of Aeronautical Radio, Inc. and later, a separate subsidiary company, the Arinc Research Corporation, and I ended up as Executive Vice-President. At the time I retired, in 1979 there were about 500 engineers at several locations.

Morton: What was the name of that company again?

Knight: Arinc Research Corporation. A subsidiary of Aeronautical Radio, Inc (ARInc.) You probably have never heard of it. You've never heard of ARInc characteristics for airborne - I mean airline avionic equipment? Basically, they are design specifications. They began with equipment like the early VOR receivers and DME immediately after the war. Are you familiar with all of this? VOR and DME were essential elements of the air navigation system. More recently the company has gotten further into the airline electronic business, designing, installing, and operating common systems like communication, inter-communications, and data systems at airports. For example, the flight arrival and departure information on the TV monitors - that entire system has to be designed and maintained by somebody. ARInc is doing a lot of this type of thing now. They did a similar design for the new airport in China. ARInc procured or built all the electronics for the new airport. It is a logical outcome of the whole picture. Reliability was extremely important to the airlines, and they were willing to pay for it, which is to say a lot of others were not at that time. A lot of people, of course, have taken a much more realistic outlook since then, the computer industry in particular. Then, of course, electron tubes are no longer familiar to you and others of your generation.

I presented a paper not too long ago in which I talked about electron tubes, and said to the engineers present, "I imagine that most of you around here don't even know what an electron tube is." They kind of chuckled at that, but that is probably getting to be true. So much for that.

Morton: The other couple of questions for you may be backtracking a little bit. How did that work? And did that have any connection to the ...

Knight: Oh yes. It started out this way. Both the Radio-Television Manufacturers Association (RTMA) and the National Electrical Manufacturers Association (NEMA) had had interest in tubes. They set up what they called JETEC (Joint Electron Tube Engineering Committee). Each of the companies that were manufacturing tubes at the time had representatives on the committee. I was the GE representative. We prepared JETEC specifications for receiving tubes and provided engineering coordination between the various companies. For some reason or another, IRE wasn't interested in specifications of that sort at that time. I guess they still aren't really, as far as detailed specifications are concerned. But I was involved in it. At that time some work was being done to try to get reliability requirements more explicitly incorporated into tube specifications. So after I came to ARInc and got deeply involved in reliability I kept in touch with the people in the RTMA, and then later when it became EIA. They were very interested in promoting reliability in the early stages. Much more than I would say the IRE was.

Morton: Why do you think?

Knight: I don't know why. Well, I think basically due to their financial links to the industry. A lot of the early conferences on reliability were cosponsored by EIA or RTMA and the IRE. Well, as you see, even this present conference is still co-sponsored by a number of other engineering societies, ASQC and so on and so forth. So they asked me to write up a - I mean to do some committee work to

prepare a guideline for reliability for what I think was the EIA at that time. I believe it had just changed its name from the RTMA. So I formed a committee and put together a report. I don't have a copy of that one, but it was somewhat along the lines of some of this. Gradually in the early '50s, after I moved to Washington I became more active in the IRE. I won't say I started the Reliability Chapter down there; one had been chartered but never really activated. I activated it along with Hal Jones, who at that time was at the University of Maryland. He and I started the local chapter of the Reliability ---- -, at that time it wasn't a society. It was a Reliability -----.?

Morton: Professional group.

Knight: Professional group on Reliability in Washington. At that point I also got involved in the Symposium. The first one was in about 1955.

Morton: '54. Late '54.

Knight: '54, yes. I was on the Paper's Committee. No. Not for that one. For the second one, I was on the Paper's Committee. I mean Program Committee. I later got involved in the international aspect from inviting international participation. I had some airline work that involved international contacts. Then I became chairman for one of the committees called Special Guests. I continued to do that until 1980, about 15 or 16 years. In 1980, I became Historian, which I still am. I just submitted my resignation.

Morton: Now when you first got involved with this group, it was a professional group on quality control and later changed to reliability.

Knight: Well, when I first got involved it was not that. It was - if you remember I said I

didn't get involved with it right at the beginning when it was strictly quality. Actually, I got involved in the early '50s after it had become quality and reliability.

Morton: Well, my follow-up question still holds, I think. Are there two camps? What was the transition like - clearly quality control passed out of this society? How did that happen, and why?

Knight: Well, largely, I think, the reliability people felt that quality people had totally ignored what happened after the stuff was shipped out the door. That was reliability's primary concern, what happens to the product after it's out the door, the manufacturer's door. Not only that, the quality people at that time did not view engineering as important as manufacturing. The quality emphasis was on controlling manufacture, not engineering design for quality or engineering design for reliability. That's where the approaches differed. There wasn't the engineering content to the early quality picture. It was more of a matter of statistical control.

Morton: In what sense then?

Knight: Well, the bell curve, or the "normal" distribution - controlling manufacturing processes to assure that product characteristics stay within a normal range of variation, whereas reliability people were interested in controlling the life and maximizing it. Well, not maximizing, but making the lifetime good enough to fit the application, and seeing to it that the products were not only designed to do that, but that they were used in a way that they could do it.

Morton: To me it seems like both of those had a lot to do with design and the

manufacturing stage.

Knight: Oh. They do.

Morton: You have to build in a ...

Knight: Reliability people don't have a chance if the manufacturers fail. In other words, certainly you can't make it last if it doesn't work when it goes out the door. But when it goes out the door, is it good enough to last?

Morton: Right. Right.

Knight: That's the difference.

Morton: Were there major sorts of methodological differences between the two groups? Were there - you mentioned the statistical methods that the quality control people used.

Knight: I think the real reliability emphasis was on application more than on process control. As a result, most of the early reliability engineers were the application engineers within the system design groups. Parts application was my basic background too.

Morton: Who was this group at this time? Were the people involved in it developing a new theoretical body of knowledge? What were the important theoretical advances?

Knight: That is what is in this. (Pointing to two reports)

Morton: That's what's in there?

Knight: I think it's here.

Morton: Yes.

Knight: It is in both of these really, but this is the one that I think is most definitive.

Again, it is one that has gotten relatively little recognition, openly, but it is the one accomplishment in my time that I feel the proudest of.

Morton: So let's talk about that.

Knight: I mean, look at it now and it doesn't seem like it is important at all. But it is, because at the time it was written it was totally new.

Morton: What was new about it? In other words, give me sort of an explanation for the layman. I don't know anything about this field. So how would you describe it to somebody like me?

Knight: How would I describe what?

Morton: What was different about this than what was happening before?

Knight: Well, it tied everything together. I mean it tied the ideas of failure rate, time to failure, and such terms as people were using, and still do occasionally, calling what we defined as availability as reliability also, which involves not only time to failure but the down time as well. It was all kind of a hazy mishmash of ideas, whereas this definitized the picture. It showed the mathematical interrelationships between those things. It also gave methods for estimating these things within reasonable statistical limits. More than that was in here.

Morton: You mentioned that this was widely circulated. How did it get out? What was the – you say this was an influential if under appreciated work – how was this distributed? Did it go out to...

Knight: Well, first of all let me say this, this one we did submit to the IRE. At that time the reliability part of it was not a society but rather a group, a professional group and wasn't terribly well-organized in terms of putting out publications. The IRE

proceedings at that time said this was too long an article and was too specialized for their interest. So we put it out as a company publication under the contract and distributed about four or five hundred copies.

Morton: Did people seek these things out or ...

Knight: Oh, yes. There were a lot of people at that time on our mailing list. They had been put there because of their interest on the military side of things. We had a good following of the people working in the industry. They got not only these reports, but most of the others we put out.

Morton: So all the index says (seems?) to sort of follow here in the normal IRE places. This is almost the same audience that sort of received it. So people out in the industry actually working with this study read this and incorporated it somehow into their work.

Knight: Now there is one paper that is mentioned in there that, basically, was actually published.

Morton: How did you start to see the effects of this? How did you start to know that this had been influential?

Knight: Seeing people using the terms just the way we had written about them, presented them here, without attributing them to this report.

Morton: Why do you think it happened like that? Normally people ...

Knight: Well, these things that are not strictly in the technical press - I mean company documents like this are not - don't get the same respect that something in the technical press does that way.

Morton: It's surprising that people wouldn't cite something if they took ideas from it or

something like that.

Knight: There are a lot of people around today that will remember this I'm sure. They may not remember this itself but they will remember. But these ideas were also put forth this way. First of all, this was very poorly laid out and printed. I had a copy of this at one time, but it was so poorly printed and everything else that I wouldn't have referred to it in anything other than this. I think it was published by the early professional group on reliable - professional group on quality control. That was before they were societies. That was in April 1955. I don't know if that's even available at IEEE Headquarters now, that publication.

Morton: Oh yes, the Transactions? Oh that - usually that stuff is preserved. It's some of the newsletters and things that have gotten lost, but almost everything is still out there.

Knight: Okay. You might look that one up. Again, I say it was very poorly done. We were not given a chance to criticize the way it was laid out or printed. But it did come out and I don't think anybody ever bothered to look at it. It was in the very early days of those publications.

Morton: Yes. Was it the societies themselves printing that? Or was it the IRE?

Knight: I don't remember that. I think the society was doing it itself. It was not the editorial department of the IRE. I'm sure they wouldn't put out a thing like that.

Morton: Can I ask you a question I've asked a couple of people today who were involved in reliability and related fields in the '50s? The story that the public knows about reliability, and maybe I misunderstand as I probably do, but the story the public knows is about the Japanese and their manufacturing. Was there any hint

that techniques developed in the United States, for example, were going to be employed so successfully overseas, particularly in Japan? Did you get any sense of how that unfolded? I mean you get the sense, for example, that overseas manufacturers were able to learn enough from reading to transform their ...

Knight: Well, they were interested. No question about that. As a matter of fact, as I told you, one time I was Chairman of the Special Guest Committee and even arranged at one time through a Naval Office – well, the Office of Naval Research to pay the fares - I mean to arrange for transportation for some Japanese to come over to the reliability meetings. There is a reliability society under the IEEE, or chapter organization in Japan. I think the Japanese certainly learned from reading technical publications, but they did more than that. They took the work of Demler and - well, I think he was over there too. I think he helped them to really put these things to work. Not only that, but it had their management support. So I think one of the places where in our world reliability was a little short - I mean slow in coming - was because it didn't have management support, really, in the first place. It did at the top level in the military, but not in industry.

Morton: Now essentially when you say lacking management support, are you talking about the companies that were - I guess there were obviously complex relationships between some of these companies and the military. But was there a difference in attitude on these things between companies that were maybe primarily military contractors and had that special relationship with military

verses companies that were making consumer goods where the whole structure of pricing and funding for experiments and things like that is different? Or some sort of combination?

Knight: Well. Just a minute. I had a comment on that number one. I'm still very upset about the fact that I don't have one of my papers here that I thought sure I had included. I've got it at home.

Morton: Is it one of these? This is your 50 year - is that it?

Knight: Yes. No, no.

Morton: Is this? This is the thing given earlier to - and the last page.

Knight: Oh, yes, yes.

Morton: Sorry. I stuck this on the pile over here earlier.

Knight: Here I think is the summary in conclusion to this part. It's just this page and top of the next page. I think you might find that interesting.

Morton: Okay. So we'll skip that question?

Knight: Well, I think the question that might be answered in there is all I'm saying - the question you asked.

Morton: Well, we'll skip that one for the purposes of the taped interview.

Knight: Okay.

Morton: I noticed that you were involved in the society but didn't get to be president until the ...

Knight: Wait a minute. If I may go back...

Morton: Yes.

Knight: I think this puts it in a nutshell - that question. Possibly the most gratifying

observation in my 50 years association with reliability has been the relatively recent voluntary adoption of reliability engineering by the automotive and electrical utilities industries as well as some others, in contrast to the mandated and too often perfunctory attention found in the defense industry.

Morton: That's interesting.

Knight: One does not need details to see tremendous gains in reliability all around us. Despite equally impressive increases in performance and complexity, automotive electronics, and personal computers are two of the most obvious examples. I think that voluntary adoption was the answer. In the military industry they were mandated into paying attention to reliability. As a result, a lot of it was not wholehearted. It didn't have the motivation that the automobile industry had when they found the Japanese were stealing their thunder by better reliability. That's motivation. That is a different kind of motivation than the military's.

Morton: I guess it is. I'm curious. I keep pressing on this ...

Knight: Management is the real answer to a lot of it.

Morton: It's interesting to me that we don't hear much about the electronics industry. You get this story of the ascendancy of the Japanese manufacturing. All you hear about is the automobile industry, and they often mention that Japanese were also doing this in electronics. But actually they are two different industries both of which the United States followed in both of those fields. But you don't often hear the story of the electronics manufacturing in the '50s and '60s.

Knight: Well, I think that certainly the computer industry was reliability conscious

because they must live with their, IBM particularly, had to live with their product. They didn't just ship it out the door and forget it. They were one of the leading industries in improvement of system reliability and still are. I don't think one had to expect much more of that part of the electronic industry than what we got. I mean the advances in computers, considering the way complexity has increased the reliability, have been phenomenal. Again, I touch on this in this paper.

Morton: What about the other branches of the electronics industry, the consumer stuff for example, where you saw a decline in American manufacturing right at this time. What, previously has been related to management decisions and ...

Knight: In general I think the competitive marketplace was the driving force. Again, the Japanese lead the way in a lot of the competitive marketplace. But just from the standpoint of staying in business, much of the electronic industry had to follow suit in this country. I say in this paper that this motivation had to be produced by foreign competition applying in a common-sense-manner methods and principles long known and even developed here.

Morton: I'm just curious, not knowing much of the history of this stuff. You see the automobile industry in the '70s and '80s, or I guess in the '80s, fighting to hold on to its manufacturing capability, whereas in the consumer electronics industries sort of throwing up their hands and saying, "Oh, we'll have them manufactured overseas," and someone over here wondering well - I mean the story as I understand it was one of economics and management. I'm wondering if there is also a reliability related side to this? If manufacturing wasn't - if the

electronics manufacturers in that segment of the industry weren't really willing to change their methods.

Knight: The electronic industry is hardly a single thing. It is very diverse. You'll find the differences, all the differences in the world, between computer manufacturers, like the IBMs and the Hewlett Packards. Hewlett Packard has been well-known for reliability, and so has IBM, and they have always been that way. Then you get down to the companies that may be making PacMan, or well, not PacMan, but the radios that some of these runners use to jog with. That's a different world. I mean they are different worlds, not just extremes. You cannot expect the people that are making stuff that sells for fifty cents or a dollar or even five dollars today to pay the same attention to product quality and reliability, certainly not reliability, as a company making a computer. This goes back to the days when I was in the radio business back in the forties. Manufacturers were making some radios, I mean the little old AC/DC radios at a price that if it failed it was cheaper to go out and buy a new one than to improve the quality of it. Economics controlled that too. But now if you have a mainframe computer from IBM, if that fails you don't go out and buy a new one. The same is true with the automobile. There was a time when you almost did that with automobiles. They almost got too cheap. But that's hardly the way anymore. I think economics actually drives a lot of this business.

Morton: I guess - it seems. I don't know if this is really true or not but the perception is that the Japanese were able to make them cheaper and improve the quality, and they got the American manufacturers on every possible front. I guess that's the

question. I wondered whether there was something ...

Knight: In essence the Japanese were heavily influenced by Demler, an American quality assurance consultant. His approach, overly simplified, was this: reduce variability. That was the essence of his approach. Not only reduce it, but continue to reduce it. I mean consider it to be an eternal process. I think this approach of reducing variability has gained recent popularity here. I am sure you have heard some of the people, including the CEO of GE, touting Six Sigma. Now, I'm not sure they know what that means.

Morton: I know; but I've at least heard the term.

Knight: I'll bet you I do. And I think I know why they are using it like that. It simply means this: do not be willing to accept a process that controls variation to three sigma limits, which means you are rejecting five percent. You do not have good quality control if you have that much variation in your product. Reduce that variation so that the same limits represent six sigma, which means one failure in something like 100,000 verses 2 in 100. This was the essence behind Demler's approach. Don't be satisfied just in reducing it a little bit but work towards perfection. This is the way that the Japanese did it, and they still are.

Morton: That's interesting. How do you compare that sort of idea to what was going on in say your own career? Were those two different lines of inquiry, or was that more or less...

Knight: I think it is part of the same thing. The Six Sigma approach not only does this to control a product, but also emphasizes designing a system and its use so that your chance of - I mean so that you can accept a component even beyond the six

sigma limit but it essentially never happens. Do you follow what I'm saying?

Morton: I think so.

Knight: I mean keep your variations down, but design the system so that it can accept wide variations in the product. That's the reliability side, if you wish, versus the strictly quality control side, but they go together. This is what GE's approach to six sigma means, and is also Motorola's approach to Six Sigma. I mean, it's this close to part of what was called by another buzzword, TQM, Total Quality Management. It's not just the product, I mean, controlling the manufacturing process and the quality of that the product you have, but controlling the way you use it and the way you design it into your system. That's reliability engineering, designing it into the system, versus quality control.

Morton: And was that sort of stuff developed much later, or does that have its roots in the '50s and '60s, or even '40s?

Knight: Well, I think it's all a part of the whole system. Frankly, I'm not sure everybody understood it that way. Let's see. Again, this is rather technical. But the relationship between "part failures and system failures" I defined in here as dependence. A popular word for that today is robustness, if you wish. In other words, designing your system so that it is fault tolerant, or not failure prone, so that it can accept a lot of weakness in the components and still work. I think a lot of that is handled right here. Maybe a little too esoteric for some people.

Morton: I see, formulas. That may be too much for me. Well let me - we should probably wrap it up. It looks like they want to get into the room here. If I left out anything or, well, I'm sure I left out a lot. But is there is something burning

we need to get on tape in parting shots before we quit?

Knight: I think you can answer that better than I can.

Morton: I don't have anymore questions so why don't we stop there.

Knight: Okay. Fine.