University of Dayton Presentation
October 30, 1991©

by

Arthur M. Schneiderman

Presentation date:	Venue:	Text:
10/30/91	University of Dayton Leadership In Manufacturing Conference Dayton, Ohio	Transcript

New Performance Measures for Manufacturing

Good morning everyone.

Over the next hour and a half, I would like to join you in a discussion of some of the work that we've done at Analog Devices over the last five years. I think that there are probably many of you in this room who have never heard of Analog Devices so I'm going to spend ten minutes telling you about Analog Devices, who we are and what we do. I think that that will help put the things that we've done right and the things that we've done wrong in a context that might be more easily related to your own companies.

One of the things that we've learned in our efforts in TQM is that there are things that work in one organization that because of the nature of another organization might not be appropriate there. So you'll have to apply your own filter to everything that we've done to understand what part of it might be appropriate in your organization.

I'd also like to take a few minutes telling you a little bit about the history of TQM at Analog Devices because although most of my presentation is going to deal with success, another lesson that we've learned in TQM is that because you've succeeded in the past in implementing TQM, it doesn't necessarily mean that you will succeed today. Nor does it mean that you'll succeed necessarily in the future. And so, I'd like to share with you today, also, what the challenges are that we face as a company today and some of the things that we're hoping will help us address those challenges in the future.

Now I'd like to go off track for a little bit and talk to you about a tool that we've developed in Analog, that we've find extremely useful, that you might find interesting. You might think of it as a benchmarking tool, but it's a benchmarking tool in a very unorthodox way. Because rather than

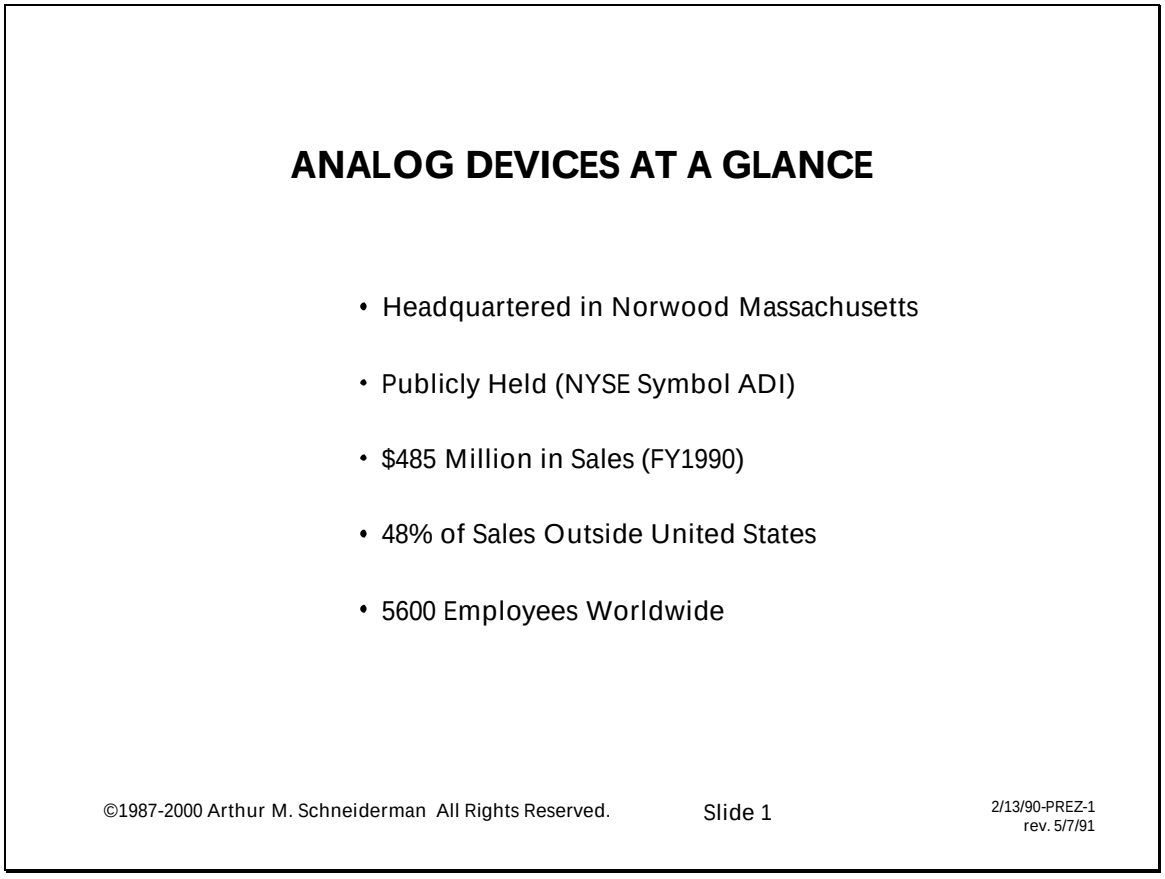
Revised 8/27/00 9:41 PM

benchmarking the results that have been achieved by the best in class companies throughout the world, we've benchmarked the rate of improvement that has been achieved by people. And that has been very important to us as a tool for setting goals and for tracking and monitoring the effectiveness of our problem solving process within Analog.

That should take me about half way through my allotted time and then I'd like, having gotten that behind us, to talk about how we've gone about at Analog Devices identifying what the right things are for us to be working on; particularly the right things as they relate to the needs of our customers. Then about performance measures because, as I will repeat later on, we've learned at Analog, and we very strongly believe, that if you don't measure it, it will not improve. And I'd like to show you the measurement system that we've developed that helps us in achieving the goals that we set through our goal setting process.

And then finally, I'll talk about the results that we've achieved; both the results as we see them and also the results as our customers see us. So that's the roadmap for the next hour and a half.

Slide 1

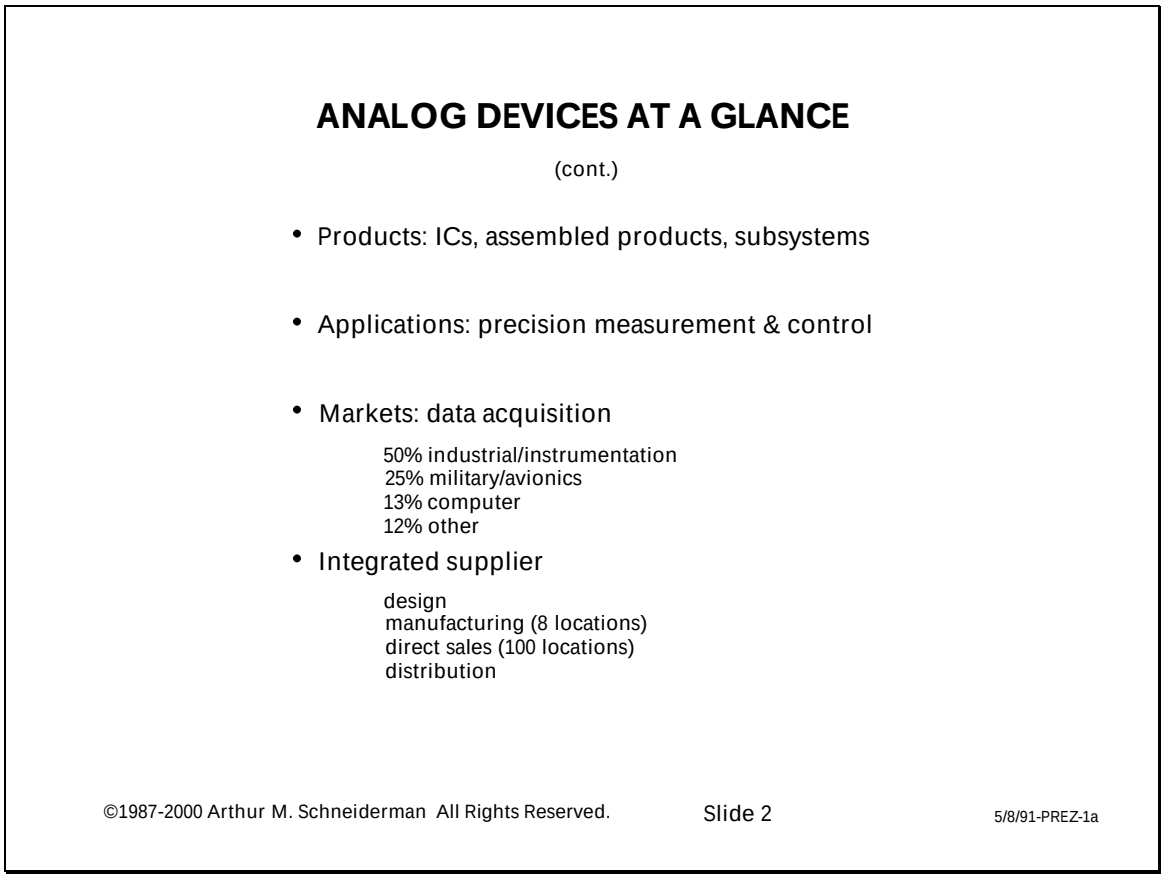


Analog Devices, I guess, would be called a mid-sized high technology company. We're headquartered in Norwood, Massachusetts, just a little south of Boston. We're a publicly held company. Our stock is traded on the New York stock exchange. [We're] about a half a billion dollars in annual revenues. Half of our business is within the US and half outside of the US. And in fact our business in Japan, which I think is a relevant piece of information for you, is a very strong part of our business. We're a very successful supplier in Japan and that happens to be the fastest growing geographical area in which we do business.

We actually today have a little under 5000 employees worldwide. Like many of you we have been going through major restructuring over the last eighteen months and a downsizing of the company. I'm going to return to that on my very last slide because that raises a dilemma that anyone on the TQM journey has to face. That is the inconsistencies between some of the things that you do in downsizing an organization and the some of the messages that you send out to people as being the essence of TQM. So we'll return to that toward the end.

Revised 8/27/00 9:41 PM

Slide 2



The products that we make are principally integrated circuits. Our integrated circuits are not the ones that you generally are familiar with. They're not microprocessors in general. They're not the digital circuits that are in the PCs that you see. Our circuits basically are ones that reside in the world between real world sensors, between things that are measuring temperature, pressure, position, and computers that end up processing that information. And they also reside on the other side of that, when a computer decides what it is that it wants something to do, the controls on an airplane for example, it has to convert that back into the analog world. So we're basically analog integrated circuits suppliers.

Our products are used in precision measurement and control applications. Our customers are principally in industrial/instrumentation, military, and avionics. Any of you that flew here today really relied on the quality of our products which are behind the various instruments that the pilot and copilot used to bring you here. A very fast growing portion of our business is the computer business. The other segment is consumer products. And, that has represented a major challenge to Analog Devices and is very much related to

what we're doing in TQM. We have a very different kind of customer that we're dealing with today then the one that we have traditionally dealt with in the past.

We're also an integrated supplier, which means that there is a great deal of complexity in what we do. We design our own parts. We manufacture them in eight locations throughout the world. We sell them principally through our own sales organization at 100 locations throughout the world. So we have the same amount of complexity that ten or fifty billion companies have, but we're relatively small in size and therefore relatively small in the kind of resources that we have available to us.

Slide 3

TQM at ANALOG DEVICES

Period	*Accomplishments*	*Key Weaknesses*	*Corrective Action*
1984-1986	CEO awareness of TQM	TQM organization TQM goal setting process	established Corporate TQM staff
1987-1990	established goals/metrics QIP teams 10x improvement "it's real"	top management involvement focus on management not everyone involved incomplete TQM infrastructure training slow progress -> plateau	seek outside help expert: Professor Shoji Shiba networking: CQM
1991-1992	business restructuring financial focus TQM planning	TQM activity on "back burner"	revitalize TQM implement TQM infrastructure
1992-1994	*Creating the New Analog >10x improvement*	?	?
today	Better understanding of the challenge	• TQM skills of senior managers • Alignment of TQM with business goals • Low quality of management systems • Total participation	• CQM course(s) • Rigorous Hoshin deployment • Baldrige self-assessment, benchmarking, process redesign • TQM diffusion

 Slide 3 9/12/91-09121-1.doc

Our TQM journey really started in the early 1980's. We are very fortunate at Analog to have a CEO, who is also a cofounder of the company back in 1965, who is very visionary in his approach to things. And, he was one of the first people in the electronics industry in the US to see the writing on the wall in terms of the implications of quality on the future business of our company. At that time, in the early 1980's, we all knew what was going on in the automotive industry in the US. We all knew what was going on in consumer electronics in the US. But, he was one of the first people to see that eventually the semiconductor industry in the US would be faced with the same sort of problems.

So he became aware, and his awareness involved going out and going to Phil Crosby's Quality College down in Florida, coming back, working with a group of people in human resources to prepare a TQM manual, going out and giving that as a gift to the various divisions, and saying to the general managers of those divisions "Here's how to do it. Now go away and implement TQM and come back in a year and tell me what you've done." And any of you that know about that realize that that basically doesn't work. The weakness during that

period of time is that we had no organization within the company and we had no goal setting process. We had no way of focusing people's TQM efforts in terms of what we wanted them to do.

So in 1986 we established a corporate TQM staff; that was me. Ray hired me to help provide the organization and the goal setting within the company, to essentially assist our TQM implementation. The period of 1987 to 1990 is really what I'm going to talk mostly about today. But in fairness to you, I'm going to have to also talk about what's happened over the last year and a half.

During 1987 to 1990, we established goals and metrics, and those are the things that I'm going to talk about. We created throughout the organization probably up to 500 quality improvement teams. Now remember we're a company of 5000 people. So 500 teams, on the average with five people per team, we had a very significant portion of the organization involved in what we call QIP teams. QIP stands for "quality improvement process." And those teams worked on the goals that we had identified and they did their job, and they did it well. And along all of the dimensions that we considered to be critical, we made essentially order of magnitude improvements during that period.

In addition to that, we demonstrated to the organization that TQM is real. Now I have to put that in the context of the kind of company Analog Devices is. About 30% of our employees, 30% of those 5000 employees have engineering degrees. And to engineers, TQM is very foreign. Engineers tend to think that spontaneous, hands off, undisciplined, unconstrained problem solving is the way to do business. And so the initial reaction to what we were trying to do was: "it won't work here." Over the period of 1987 to 1990, I think that our most important internal accomplishment was convincing everyone in the organization that it will work here; that it will work in the kind of environment that existed at Analog.

On the other hand, we had some very major weaknesses. Top management was not involved in our quality improvement efforts. As Ray Stata, my boss, the CEO of the company often says, "I was a wonderful spectator. I sat out there and I applauded the accomplishments of others. But I didn't participate in things myself." Our focus was also on manufacturing. We didn't involve everyone in the organization. We had very little involvement of the direct labor force. These were generally second and third line managers that were involved in these kinds of activities.

We didn't have a complete TQM infrastructure. In other words we didn't have all the elements in place needed to successfully implement TQM. And as a consequence of that, toward the end of this period our progress began to slow and it began to slow dramatically. The solution to that was to seek outside help. We basically had exhausted all of the things that we could think

of doing ourselves and so we began to work very closely with a professor from Japan by the name of Shoji Shiba, who also has helped us setup a consortium of companies in Boston called the Center for Quality Management. And so we've relied very heavily on the Japanese-Deming influence, the Japanese-Deming approach, rather than the Baldrige approach, which many of you may be more familiar with, in terms of figuring out what we would do next in TQM.

Which brings us to the current period 1991-1992, and as I mentioned earlier that's been a period of major business restructuring at Analog. We have moved from a very highly decentralized organization to a very highly centralized organization. Also, because of immense pressure from Wall Street … and I say that because that's the reality of world that we live in … everything doesn't work as simply as stated in the TQM textbook. There are business realities, and those business realities in today's environment create immense financial pressures even on successful companies like Analog Devices. We've had to respond to those and we've had to basically redesign our TQM system within the company. And that's what we're currently working on.

But as a result of that, with all of the other things that we were involved in, I've got to honestly tell you that we made a conscious decision 1991 to put TQM on the back burner. We had other things that we needed to focus our attention on. And one of the lessons, which you will see very vividly in the measurements that I will show you, is that you can't put TQM on the back burner. You either are doing it you're not doing it. And if you're not doing it, for some reason, you'll see the results in a moment of that kind of activity.

Q: How was pressure from Wall Street made visible to the company?

A: Our stock price. In fact Bob Kaplan at the Harvard Business School has written a case on this metric the we use and at the end of that case, he posits this [situation] to people: in 1986 when we started this, Analog Devices stock was trading at $25 a share. In the end of 1990 it had dropped to $5 a share.

In fact the cash flow that we generate, the discretionary cash flow that we generate as a company because we are a very successful company, could pay back somebody that wanted to make an unfriendly takeover of Analog Devices, in a period of three years. In other words, they could buy Analog Devices and just out of our cash flow pay back any debt that they occurred, in a three-year period of time.

Now if that's not scary, I don't know what is. Because all of us read the newspaper and all of us realize that are opportunists out there that are looking for those kinds of opportunities. You can't say in that kind of situation that our stock price, which is really reflective of our very short-term current performance, is unimportant. This really changes your thinking and says what good does TQM do us if we don't survive? And so much of our focus during

the 1991-1992 period has been reversal of that process; to get our stock price back up, to get our stock price up to the point where we can feel secure that we won't be an opportunistic takeover by somebody out there. And this has really very much affected the reality of what we've had to do.

Q: What prompted you to go from a highly decentralized to a highly centralized period?

A: Two reasons, one the last one that I told you. Highly decentralized organizations are very costly. And the only way that you can justify having redundant manufacturing facilities, for example, that are way underutilized, is if you're growing and you're accommodating what is currently in inefficient use of assets, by growth. One of the problems that Analog has faced, partly because of things we've done ourselves, but mostly because of the business environment that we're in today, is that our grow has slowed significantly. So one way to get our financial performance up is to consolidate things.

The other problem is I told you that we have eight manufacturing locations. Analog Devices is really in one business, and in fact for many of our divisions, their largest competitor is another division of Analog Devices. And so the other side of that coin means that we have customers that are doing business with multiple divisions of Analog Devices. Now all of you probably know this concept of vendor consolidation; reducing the number of vendors that companies are working with. The message that we got from customers is that they were not going to consolidate to eight Analog Devices, with eight different measurement systems, with eight different definitions of quality, with eight different policies with respect to returns, with respect to failure analysis, with respect to … one company. So the second reason was to provide one voice to our customers.

Both of those are good reasons. The first reason, the financial reason, is good because that helps you survive to really bring the benefits of TQM to your employees and your customers. The second reason is critical if you're going to meet the needs of your customers. So these were good reasons, these weren't bad reasons. But we thought that we could put TQM on hold and, as you'll see, that's probably not something that you can do. So we're in the process now of revitalizing our TQM efforts, implementing a new TQM infrastructure within the company and really moving into what we call at Analog Devices "Creating the New Analog." And that's creating, basically, a new company that is going to be able to compete as effectively in the 90s and in the year 2000, as we have been able to compete in the past. But, we can't compete as the same company that was successful over its first 25 years.

Q: …the link you have between your goal setting and your existing… am I to assume that all your teams have … are from the top down basically are given the assignment to work on a specific metric?

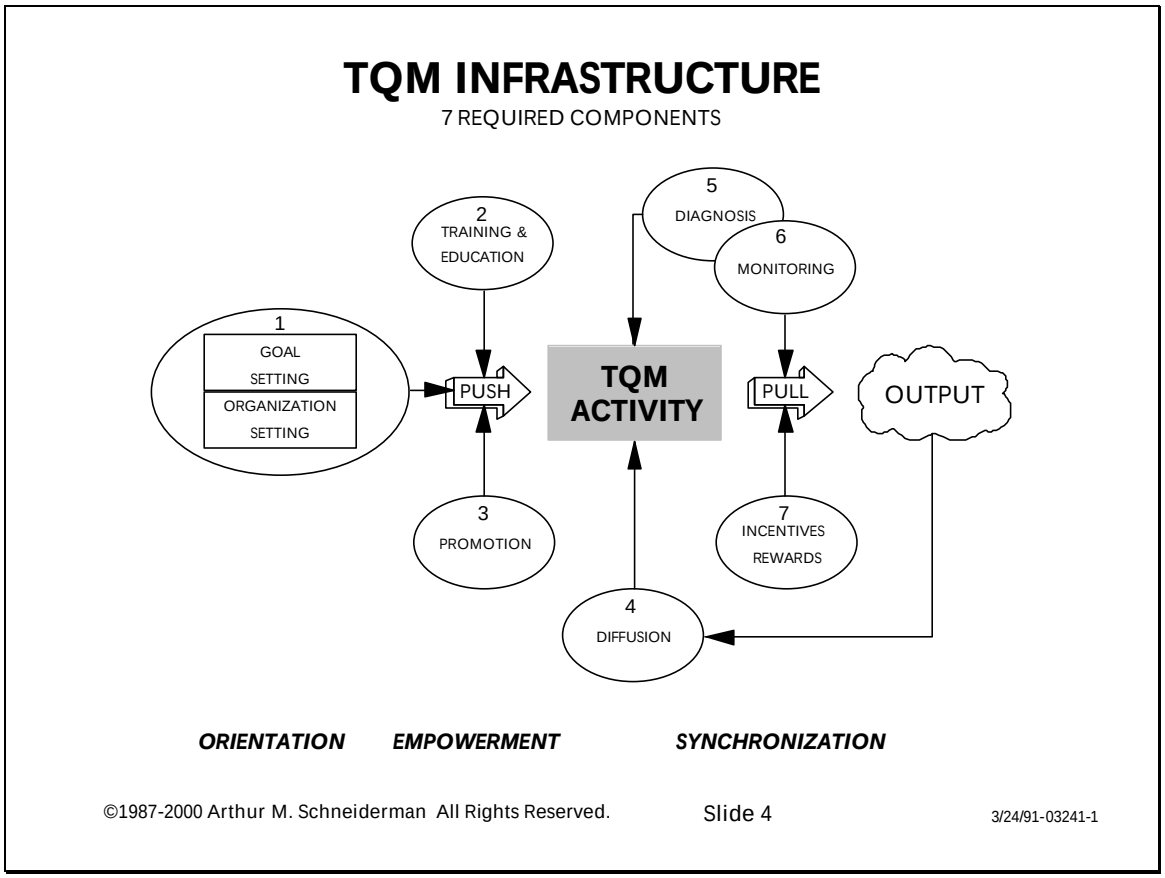
A: yes

Q: Is it voluntary…?

A: No it's not voluntary.

I'm going to cover that a little bit more, and I think you'll see that a little more clearly in a few minutes.

Slide 4



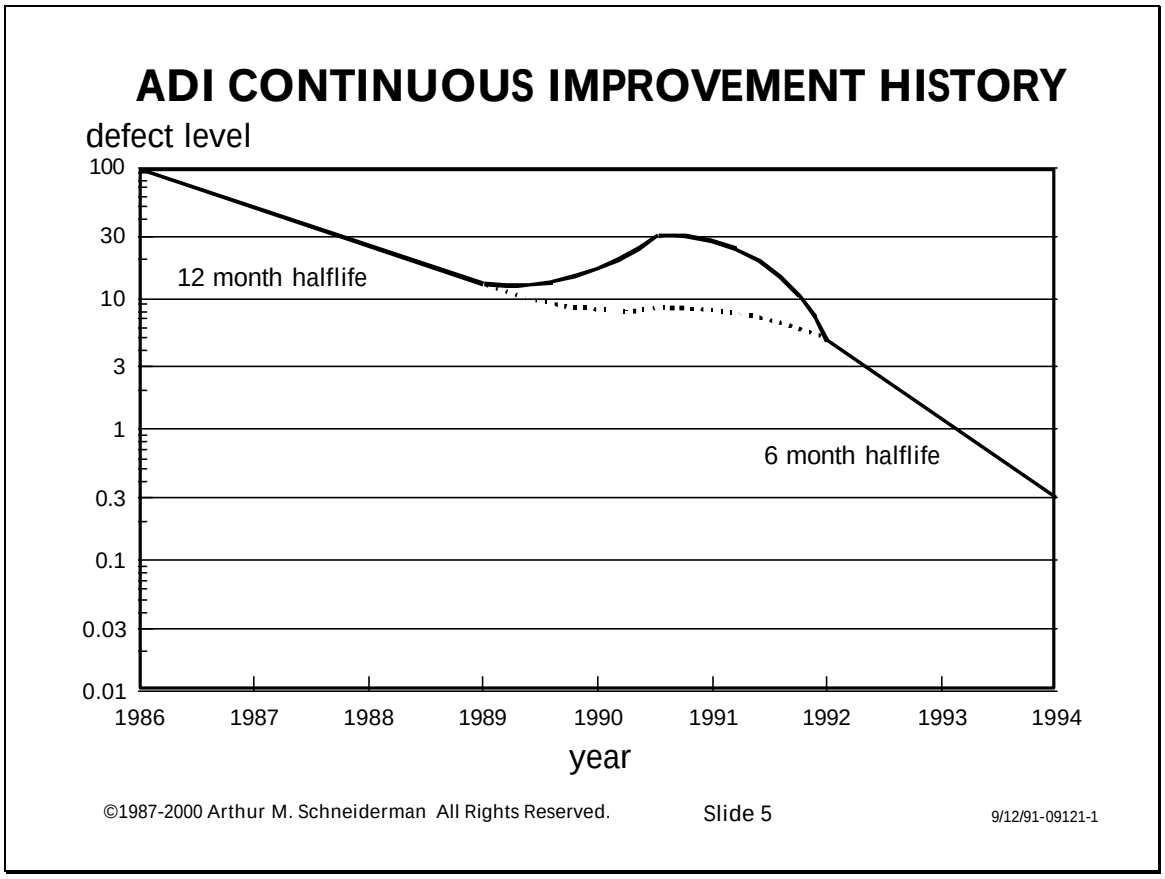
Let me just hit on what the elements are of the infrastructure we've now settled on. Many of you have seen the Baldrige criteria. This is slightly different. You can map this into many of the elements of the Baldrige criteria, but it involves goal setting, organization setting, training and education, and promotion, basically, as a way of pushing TQM activities. Diagnosis, monitoring, incentives and reward and diffusion of success stories, are a way of pulling TQM through the organization. And we are now putting all of these elements together in terms of what we're doing at Analog.

I think that the keys to what we did during are last four or five years have been in the goal setting area and in the monitoring area. And that's what you're going to see a lot of today.

The weaknesses that we have are principally in the areas of training and education. Up until now we've had no formal training and education programs at Analog Devices in the area of TQM. It's all been done by facilitators working with individual teams, kind of on the job training rather than group training. And it's often done using what ever happens to be their

version of an appropriate problem solving methodology. So that's the road map that we're working on.

Slide 5



Now I need to, as we move into the next stage of the discussion, put this all in a context because as I start showing you some of the results there are things that are going to look very confusing to you. There are things that are going to look like they're going in the wrong direction. And the answer is, they are. Ok? So don't be confused. I'll show you some things that really look at what happened during the period 1986-1990, that first stage of our TQM implementation at Analog.

As I said earlier, we kind of ran out of steam in that effort because we didn't have all the elements in place that we needed to do things. There's a wonderful model that has been created by a man by the name of Duncan McDougall at Boston University in which he points out that all of the levels and all of the functions in the organization can be thought of as being connected to one another. Just, if you can imagine, like a kind of bowl of spaghetti. All with loose strings, slack strings. And therefore any level of the organization or any function within the organization can operate over some space autonomously before it ends up having to interact with either another level of the organization or another function.

The thing that we learned during this period of time, and the thing that we accomplished during this time is that we took the slack out of the system. And as we start talking about some of the results and some of the things that happened during this period here, I'll give you examples of ways that management inadvertently stopped the improvement process. And I'll give you examples of how lack of cross-functional coordination of efforts eventually slowed up the rate of improvement. There was a question back here?

Q: At which point did you get the Japanese connection? At which point did you bring in Shoji Shiba?

A: Here [pointing to ~1990], at this point here. And by the way, he was extremely critical, which I had a little difficulty with since I was kind of the architect of this part, he was very critical of what we did during that period of time, because he focused on what we were not doing rather than on what we did, which happens to be a very characteristic approach by the Japanese. The Japanese are very weakness oriented in their analysis of things, which is very, very difficult for Americans to take. It's very difficult for someone to come in after you think that you've accomplished a lot, and focus on the things that you're doing wrong, yet those are the opportunities for improvement. What you do right doesn't lead you to improvement. What you do wrong is what leads you to improvement. And if you can get the finger pointing out of that process, it ends up being incredibly constructive and very rapidly leads you to the kind of things that you need to do in improvement.

Now as I said there were two things that are going on today. One is that we've gone through this period in which we kind of ran out of steam in terms of what we were doing. And, by the way, I spend a lot of time visiting customers, I spend a lot of time visiting Baldrige award winning companies and Deming prize winning companies in Japan, and let me tell you this is not an uncommon phenomenon. It is not uncommon for some of the best companies in implementing TQM to suddenly slow up in their rate of progress. We'll talk a little more about how you can actually see that in their results and how you can measure that in their results. But we have that phenomenon going on and we also have the phenomenon of having put TQM on the back burner. And that's led to what I call "bubble." And a lot of the data that I'm going to show you has really represented backsliding at Analog in terms of things that are important to our customers and things that are important to us internally.

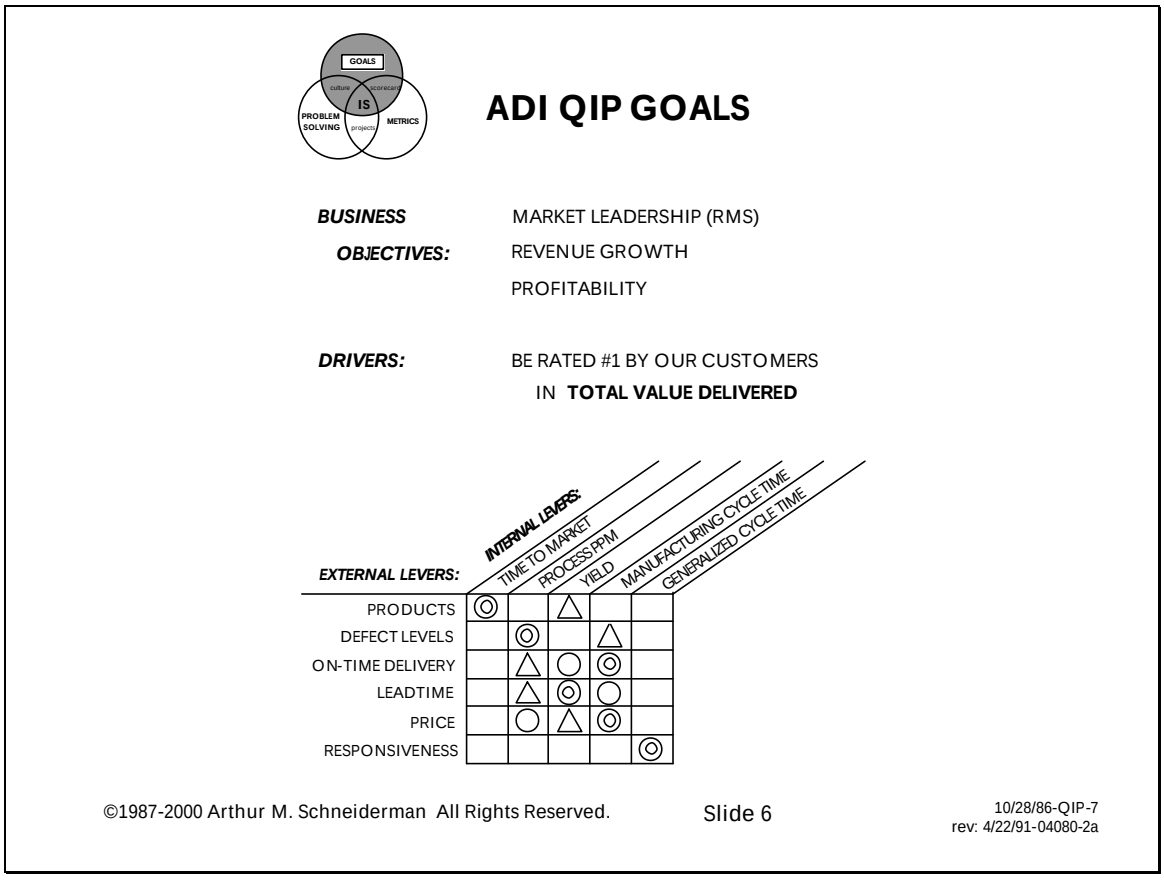
We recognize that and believe it or not that backsliding had some positive effects, because it really forces you to reevaluate what you're doing. And I think that we're on the verge of a new burst of improvement. This thing that you see, half-life here is what I'm going to turn to shortly as being the way we measure the rate of improvement. The half-life is the number of months it

takes to reduce the defect that you're working on by 50%. So, the lower the half-life the faster the rate of improvement that you're achieving. And so we very much expect that we are on the verge of moving into a new era of even more rapid improvement at Analog than what we have historically experienced. But keep that in the back of your mind because that really is something you have to think about because most of what I'm going to focus on now is what has happened during that period of time, the earlier period of time.

The theme of this morning's presentation is really linking non-financial performance measures to business objectives. And we're very fortunate at Analog because that's where we started from. A lot of companies that go about implementing Total Quality Management approach it as a religion. They basically say that "I need to do this cause it's right." And they don't step back and think about the connection of TQM to business objectives.

At Analog Devices, we believe that TQM is right. But, our principal objective is to use TQM as a tool, not an end; as a means of better achieving our business objectives.

Slide 6



And the business objectives that Analog has settled on … and this slide is a slide that dates back to 1986-1987 when we were first putting in place our TQM activities … is:

- to continue to be market leaders in the areas in which we compete, as measured by our relative market share.

- to continue to be a growth company, and in the period in which we made that statement, we had just come out of an error of nearly 20 years of growth at just under 30% a year. So we said "We like that! We feel good in that kind of growth environment." That's part of our business objectives.

- and, to maintain the historic levels of profitability that, for example, have allowed us to invest 15% of our revenues back each year in research and development … a very high investment in R&D.

In fact, if you asked back in 1985 and 1986 "what do we need to do to achieve those business objectives?" The answer was incredibly simple. Analog

Devices was a technology leader. Our products sold themselves on the basis of a data sheet. Our customers were engineers. They buy our products. They design them into circuits that they were building that they would then go on to sell to their end customers. And our products really had no equal. In a little integrated circuit you could get the functionality that you could get from our competitors on a whole board or whole rack of equipment. And so our products sold themselves on the basis of their specifications.

And if you asked "what are the keys to doing that?" It was "just continue to be the technology leaders." But around 1985, we began to hear other things from our customers. And although we didn't hear this word "value," we basically decided that that was the word we would use to characterize what our customers were telling us. They were beginning to tell us that there was more to their purchasing decision than just the date sheet. And in fact, back in that period of time, they said "oh yes, your products still have to be the best in terms of the data sheet, but, quality is a problem."

Now thinking back to that earlier slide when I told you about who our principle customers were: industrial, instrumentation, military, they had very different purchase criteria. As any of you who do business with the military know, there are incredible inspection requirements with respect to military products. So you know if you start off with basically poor quality products, that you can filter through that process and come up with the ones that work, and those go on to the military and they pay very high prices for them.

But for an increasing number of our customers, quality became a very important consideration. Just-in-time, give you an example, Apple Computer. Apple Computer is a customer of ours. They have a five-day factory. Six days late, you shut them down. You don't shut them down twice. You shut them down once, they start the design out process. So suddenly delivery became important.

Lead-time, again, our customers said, "we don't want to depend as much on forecasts. Forecasting is hard to do. We want to build to order. We want to move from building to forecast to build to order. We need short lead-times."

Price became an important consideration. Perhaps to the latter part of the 1980s, when people really started meeting quality and delivery requirements, then customers began to turn back to price, saying "your products are valuable. They don't incur additional delivery costs. They don't incur additional quality costs. But, your prices are too high."

And I think that the message we hear more and more from customers today is "responsiveness" as being the way that they will differentiate one supplier from another supplier as we move into the future.

Now that's a very nice list. And, we could add to that list. There are other things that people might also consider important. The problem is when you start going back from talking to customers and you turn around and walk into Analog Devices and you face the manufacturing people and you say to them "these are the things that customers want to work on," they'll say "but that's not my job." Companies are not organized along these dimensions. They're organized along a different set of dimensions.

So that forces you to go and say what are the internal processes that exist within the organization? Because the internal processes don't match up one-to-one to the external processes. So you go and you do that.

Now these are names; consider these names. For example, time-to-market is the name that we use for the whole new product development process. I know that a lot of people use a metric, but in the context of what you see up here, it's a name for a process: developing new products. Process PPM, process parts-per-million defective, is the name that we use for the capability of the manufacturing process to produce defect-free parts. We could use other names, but that's the name that we use. Manufacturing cycle time, basically, is how long does it take us to manufacture the product.

And, in fact, in thinking about manufacturing cycle time, it's not just the time from when vendor parts arrive at our door until we finish the manufacturing process. It's the time from when we send out orders to our suppliers for parts, when we commit to our suppliers as to what we want, to when we get paid by our customers. And so this is a very generalized process that we're talking about.

Yield basically is a measure of the internal quality of what we're doing. And, you'll see in a few moments that's a very important number at Analog Devices. And generalized cycle time is really a generalization of manufacturing cycle time: it says, "let's talk about everyone in the organization." Everyone in the organization, as part of their daily job executes a process. They sometimes execute more than one process. To the hourly workers or the direct labor people, it's pretty obvious what their process is. It's usually a standard operating procedure that hangs there on a piece of equipment that tell them if the order is for part "A," this is what you should do. And sometimes they have process flow diagrams. But in every case, the idea of generalized cycle time is finding ways to change the process so that you can do that job in a shorter period of time.

Now the thing that's intriguing about this matrix is that there's no one-to-one relationship between these things. The symbol set that you see here is one that we've stolen from the Japanese. They very often do it when they create matrices like this. The double circle represents a very strong correlation; the single circle, moderate correlation; the triangle, a weak correlation; and blank,

no correlation. And in the case where there are negative correlations, they have things like x's, and double x's, and symbols to show that as one thing improves, something else gets worse; as an anti-correlated effect.

Now what you see here is that there certainly are dominant processes. For example, in terms of the products, a dominant process is how long does it take us to get new products developed? That will tell us the state of the art we will be bringing to the market place at any point in time. But if you take another area, like manufacturing cycle time, that very much effects our product development process because our products are prototyped on the actual manufacturing facility in which they're going to be manufactured in volume. So manufacturing cycle time affects how long it takes us to develop new products. On time delivery, lead-time … so you can see there's a linkage between all of the internal processes and things that are important to customers.

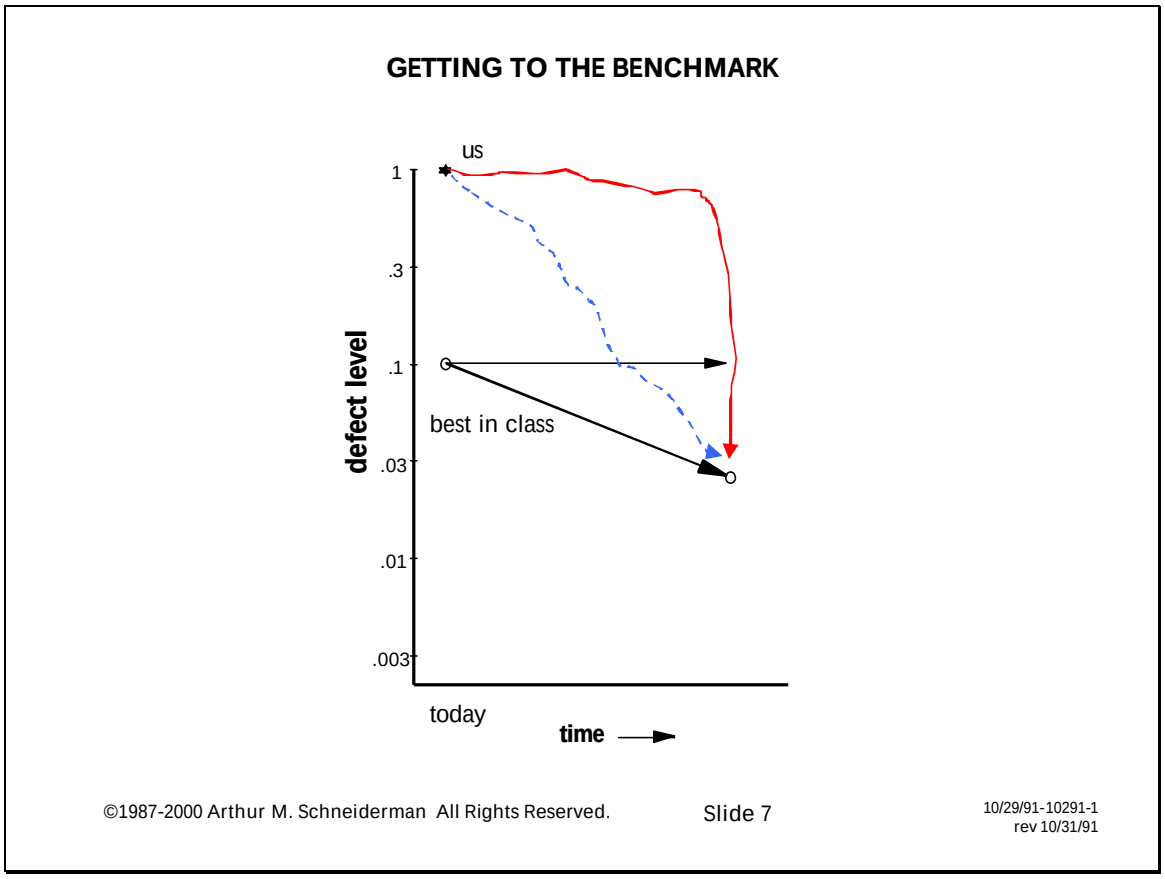
Now one of the things that we think is very critical at Analog Devices is that nobody ever looses sight of this linkage; that the people that are working on these internal processes do not loose sight of the fact that they're doing that to benefit a customer. Because if they do loose sight of that it is likely that they will inadvertently make tradeoffs that do not create value for customers. If they only focus on manufacturing cycle time, without understanding the impact of manufacturing cycle time, for example, on on-time delivery to customers, then they can, as we have experienced, inadvertently reduce manufacturing cycle time … by eliminating in-process inventory … below the level that variability in the manufacturing process requires. In other words, there's good inventory. Good inventory is inventory that's in place to cover fundamental variability in the manufacturing process. You're trying to eliminate variability but if you drive the inventory down too low, you can adversely affect on-time delivery.

If people aren't aware of this map, and aren't aware of the possibilities of doing things along the dimensions of internal processes that could adversely affect things to the customer, than you can run into trouble. And my definition of trouble is when everybody in the organization thinks they're getting better and customer thinks you're getting worse. [It's a] very easy thing to do. And so this is chart we always make visible to people because we want them to think about the impact of what they're doing on external customers.

There's a lot of talk about internal customers and external customers in TQM. I think that we ought to think about that as a cast system. Internal customers are important, but they are a surrogate for external customers. It's the external customer that pays the bills; that generates the revenue; that generates the profits to the company.

OK, we now know the right things basically to work on within Analog. We know the things that are important to customers. We know the processes that drive that. And, we also know people like to have goals. So the first problem we face is how do we go about setting some goals?

Slide 7



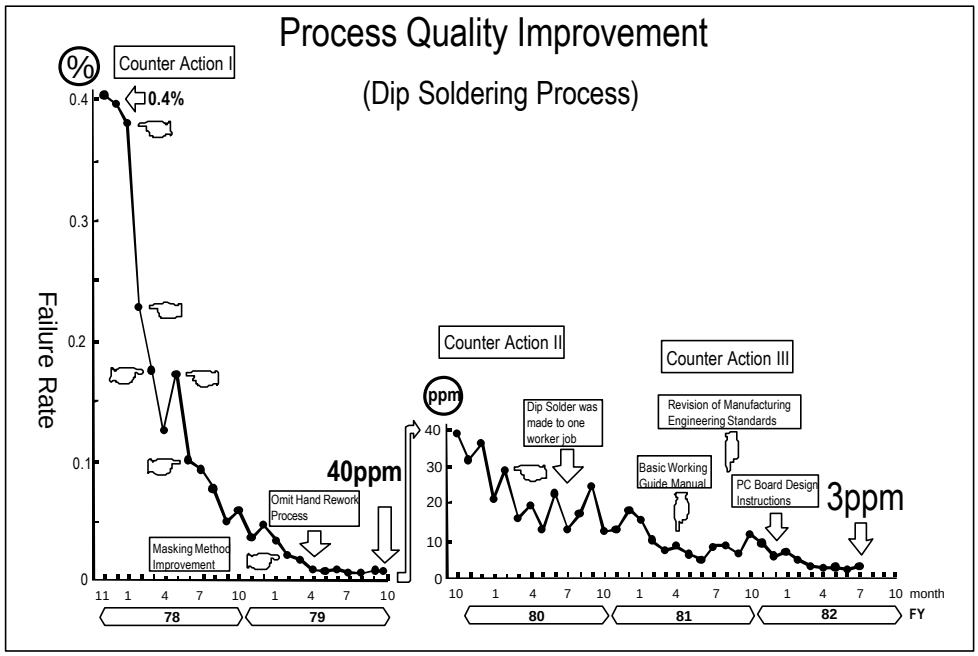
If you look at this chart, you could go out and do some benchmarking, which is what we did at Analog. And, you could say in some areas we're up here and the best in class [is here]. And we do it the way that we're told to do benchmarking, for example, by the people at Xerox. We find out what the best in class is. Then we face a little bit of a problem, because we realize that we can't get to best in class instantaneously. It's going to take us some time to do that. And the first thing we recognize is that we can't assume the best in class is going to remain constant over time. We've got to assume that the best in class is also the best in class at improvement, because that's how they got to be best in class; it wasn't by miracle. So they're going to be improving.

The first dilemma we have is what do we set as a kind of course, a set of goals, in getting from where we are to where they are or are going to be. And there are a couple of models for doing that. One model basically says we're going to do it by breakthrough. So we're going to sit around and think for some period of time and then we're going to come up with a breakthrough and that breakthrough is going to bring us down here [red/solid line]. That's one model.

There's another model that says, "No, we're going to do continuous improvement … continuous improvement." You've all heard that word. "We're going to incrementally improve the way that we do things so that we can do them better and better." And maybe that will do something like this [blue/dashed line]. And then there are other companies that are struggling with "Well maybe we can do both at once."

What I'm going to talk about next is not the breakthrough side of this, but the continuous improvement side of this. And I'm in particular going to ask the question: "given that we're here, and given that we're going to use the best methodologies that people have identified for continuous improvement, what is the trajectory that we can expect to follow from where we are to where we want to go?" using the best improvement techniques available.

Slide 8



Source: Kenzo Sasaoka, President
Yokagowa-Hewlett-Packard 7/84

 Slide 8

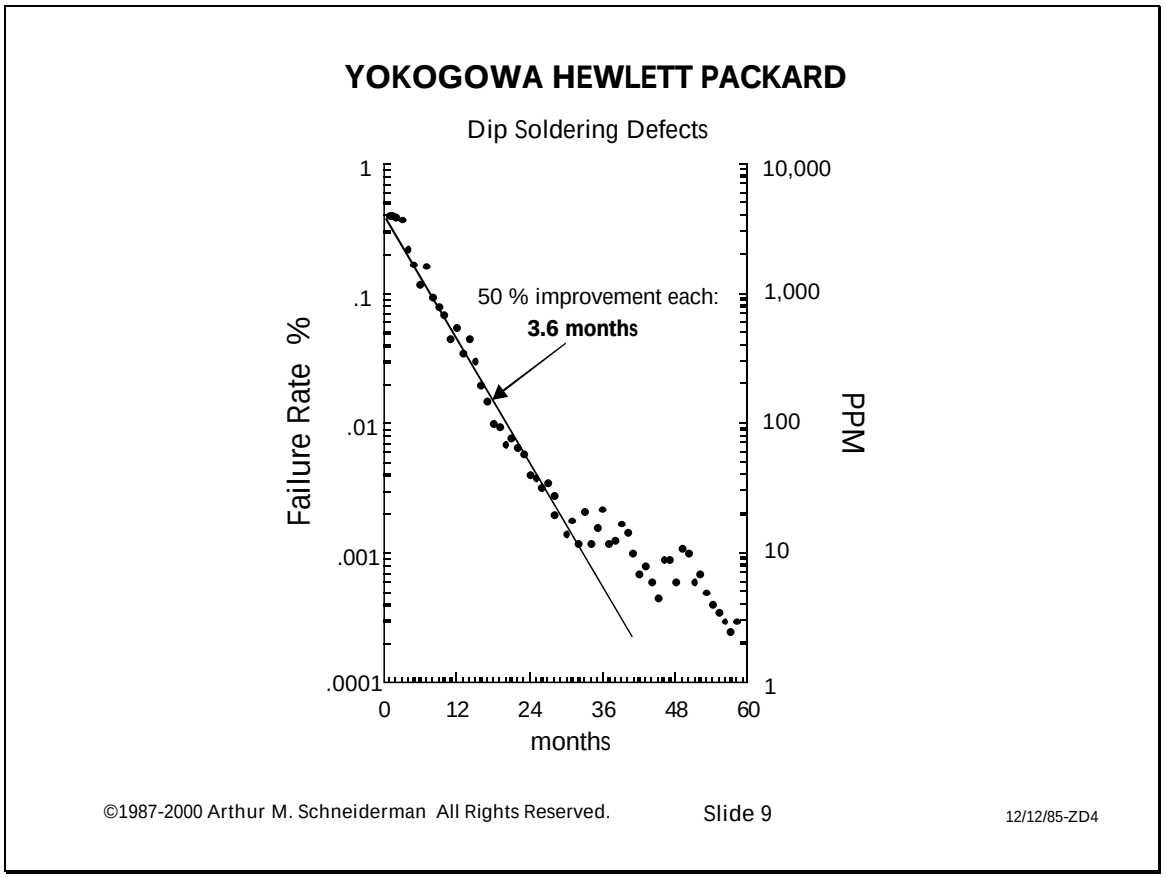
Now this chart here is one that many of you may have seen. This was a chart that was given to me at a visit to Yokogawa Hewlett-Packard in Japan back in the early 1980s. And this was a chart that characterized the results of one of their Quality Circles. It's a Quality Circle at the dip soldering process step in their manufacturing process. This is where they took printed circuit boards; printed circuit boards have holes in them, they have components that stick into those holes, and they dip them into hot solder in order to solder the leads of the components to the printed circuit board. And this is what percent of those connections were defective. And so they started off back in 1978 .4%, 4000 parts per million, defective, and these are the little incremental improvements that occurred over time in that quality circle. These are the little things that they implemented to improve the way they did their job.

And they got don't here and they really couldn't see improvement anymore, although they knew they were improving. They couldn't see it so someone got the bright idea to change the y-axis on this graph and they changed it to parts-per-million and lo-and-behold they saw that they continued to improve; a very vivid example of continuous improvement.

Now as I said they gave this chart to me. I was at Yokogawa Hewlett-Packard in Japan, and any of you that has visited Japan and lives on the east coast of the US know that you have to face this flight back. And although I have a relatively large capacity for martinis, I don't have an infinite capacity for martinis, and so about a quarter way through that flight I began to get a little fidgety and started looking for something to do. And I opened up my briefcase and this happened to be one of the things that I grabbed first and I said "how can I myself for the next ten hours with this little piece of data?" And I said, "well I know one thing I can do, I can re-graph this onto semi-log paper, and I can fit both graphs onto one graph."

Isn't that a good plan? Ten hours, right, it's a good plan. So the first challenge was I didn't have any semi-log paper. So two hours spent with a calculator and a ruler which I did have, I made myself some semi-log paper and then transposed each of these data points with the ruler. I went across and read the value and I re-graphed the data. And about six hours later, something like this appeared. This is the same data.

Slide 9



Now I've got to admit when I looked at this and I saw that this data all lay on a straight line for about three years worth of improvement, that I didn't know whether it was the martinis of the data that had to be credited with this. But when I got home and re-graphed it and checked everything out it turned out to be real.

Now let me tell you what this means, it's very interesting. This is a Quality Circle team working on continuous improvement activities and they are able to continuously improve at a rate that reduces the defect level that they're working on, the failure rate, by 50% every 3.6 months. That means that they started off back here, they were at .4% defective, 3.6 months later they were down to .2%. In the next 3.6 months they were down to .1%, half of the .2%. In the next 3.6 months they were down to .05%, half of the .1. So each 3.6-month period they were able to reduce the defect level by 50% in a very continuous way.

It turns out that radioactive decay works the same way so it became very logical to call this a "half-life," or the half-life of the defect, the rate at which

the defect decays when you subject that defect to the quality improvement process.

Now I'm going to come back to the fact that this flattened out a little bit in a minute, because at a subsequent visit to YHP, I showed them this data and I asked them "what happened? Why did things suddenly flatten out after three years? Why did it move to a slower rate of improvement?" That, by the way is about seven or eight months as the rate of improvement there.

Slide 10

OBSERVED HALF-LIVES

DESCRIPTION	HALF-LIFE (months)	IMPROVEMENT CYCLES	R^2
operations sheet errors	0.6	4.2	0.834
days late in delivery	0.8	7.6	0.774
rejects due to bends and dents	1.3	1.7	0.590
process sheet errors	1.4	2.1	0.535
PCB photo imaging resist flake	1.9	3.3	0.748
errors in purchase orders	2.3	1.5	0.531
aluminum smears from IC test pads	2.4	5.1	0.717
yield loss, die coat inspection	2.4	2.3	0.733
scrap costs, die coat inspection	2.4	2.0	0.754
defective stockings	2.7	2.2	0.843
yield loss, PCB photo imaging	2.9	2.3	0.843
typing errors in bank telegram dept.	2.9	2.0	0.754
late orders to customers	3.0	2.7	0.838
defects in PCB edge polishing	3.3	1.9	0.188
insertion defect rate	3.3	3.4	0.738
failure rate, dip soldering process	3.7	8.6	0.980
down time of facilities	4.5	1.3	0.562
COPQ, goggles manufacturer	4.7	1.9	0.942
scrap and repair costs	5.0	1.6	0.918
scrap and repair costs	5.0	0.8	0.746
in-process defect rate	5.3	1.1	0.550
late spare parts to customers	5.3	1.1	0.471
defects due to pits, piston rings	5.5	3.5	0.968
defects in vacuum molding	5.6	4.6	0.882
vender defect level, capacitors	5.7	6.3	0.812
customer returns due to admin. error	6.3	3.8	0.941
WIP	6.3	1.1	0.979
accounting miscodes	6.4	2.5	0.709
manufacturing scrap	7.0	3.9	0.530
vender defect level, transformers	7.2	5.0	0.842
vender defect level, IC linears	7.4	4.9	0.906
WIP	7.5	2.1	0.759
failure rate, line assembly	7.5	3.2	0.886
manufacturing cycle time	7.6	2.7	0.741
defects per unit	7.6	4.6	0.948

Slide 10

3/11/87-IMPDATA1

But in any case, I went back and started collecting data. And the criteria was: any group that was willing to stand up at a conference like this and talk about their quality improvement efforts and say that they have a systematic, focused effort at continuous improvement and these are the results that we've achieved. I took that data, I calculated the half-life, I then put them in order that you see here and 66 examples later, from all different kinds of sources, this was page two of that table:

Slide 11

OBSERVED HALF-LIVES
(cont.)

DESCRIPTION	HALF-LIFE (months)	IMPROVEMENT CYCLES	R^2
rework rate	8.0	1.4	0.801
off-spec rejects	8.8	5.1	0.513
set up time	9.5	0.6	0.690
vender defect level, transistors	9.6	3.7	0.997
defect levels, customers incoming QC	10.1	7.1	0.989
defects	10.4	5.2	0.965
software documentation errors	10.5	1.2	0.173
error rate, perpetual inventory	12.1	3.0	0.862
customer returns due to product	12.4	2.9	0.974
missing product features	12.5	2.9	0.947
equipment downtime	13.1	2.1	0.940
scrap costs	13.8	1.7	0.805
absenteeism due to accidents	14.8	4.0	0.956
defects at turn-on	14.9	1.3	0.624
manufacturing cycle time	16.9	2.5	0.937
defects on arrival	16.9	2.0	0.848
non-conformances	16.9	0.7	0.666
vender defect level, microprocessors	18.5	1.9	0.838
post release redesign	19.0	2.5	0.842
field failure rate	20.3	1.3	0.857
accident rate	21.5	2.8	0.907
defective lots received from vendors	21.6	1.7	0.976
failure rate, PCB automatic test	23.7	0.5	0.182
first year warrantee costs	27.8	2.6	0.950
computer program execution errors	29.9	0.4	0.364
late deliveries to customers	30.4	0.8	0.994
warranty fail rates	36.2	2.5	0.769
failure costs (internal + claims)	37.9	1.9	0.909
product development cycle time	55.3	1.1	0.733
AVERAGE:	**10.9**	**2.8**	**0.77**

Slide 11
3/11/87-IMPDATA2

It turned out the average for all of these examples was about eleven months. They had gone through, on average, nearly three cycles of 50% reduction. So a half times a half times a half. They had reduced the defect that they were working on by a factor of eight.

Now those of you who like myself have been involved in improvement activities for many years, have said “what do you think I’ve been doing since I came out of the cave? Standing around doing nothing? No improvement?” Of course we’ve improved, but a factor eight improvement in a period of under three years is really a remarkable rate of improvement, compared to what we’ve done in the past. So something’s interesting here. Most of us will talk 5% per year improvement. That’s pretty good. This is 50% a year improvement. This is an order of magnitude faster rates of improvement than people are use to.

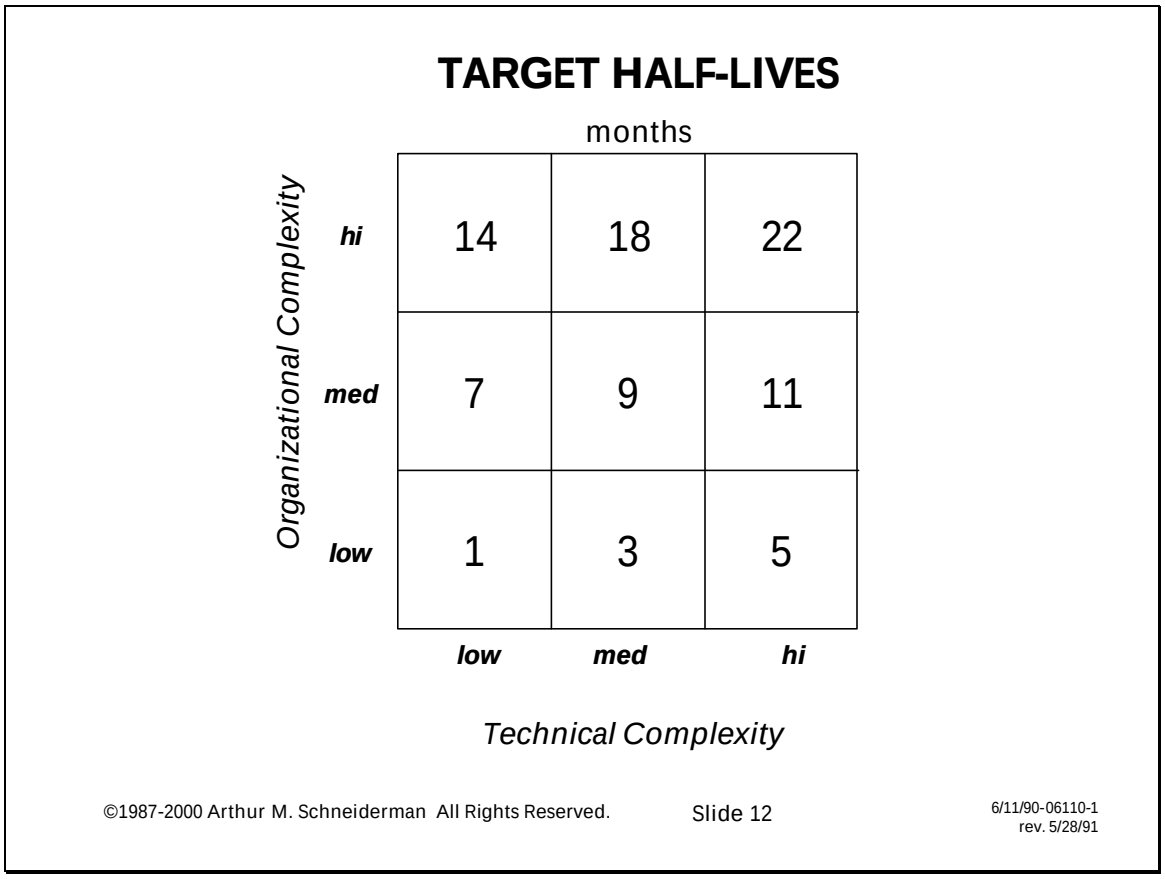
Now the last column by the way here is a statistical measure of how well this model fits the data. If this number was zero, it would say the model doesn’t fit

the data at all. If the number was one, it would say the model fits the data perfectly.

To give you a benchmark, when you go and get a prescription filled at the pharmacy, the test that the Food and Drug Administration applies in order to allow that drug to be used for that particular malady is a .33. The model fits the data better than the model used in determining whether or not that drug will work on the malady that you have.

Now, any time you see a statistical measure like that, you know it's the left side of somebody's brain at work. You may remember, left-brain/right-brain. The left-brain is the analytical side; the right brain is the artistic side. That was the left-brain. I've got to show you part two, which is the right brain. And the right brain side takes those two charts, puts them up on a wall, and stares at them, and says, "What is this data trying to tell me?" This is what I heard, looking at that data. So you can argue with me, although it does make sense at the end.

Slide 12



It turned out that the half-life seemed to depend on how complex the problem was that was being worked on. And the dimensions of complexity were: organizational complexity and technical complexity.

Now organizational complexity, let me explain what I mean by that. If you've got a QC Circle team, it's made up of a supervisor and all the people in that group. It's relatively simple from an organizational perspective. Imagine how more complex things become if you now have to take people from different functions and bring them together. And how even more complex they become if you have to take people from different organizations. You have to get your supplier involved, you have to get your customer involved in this process.

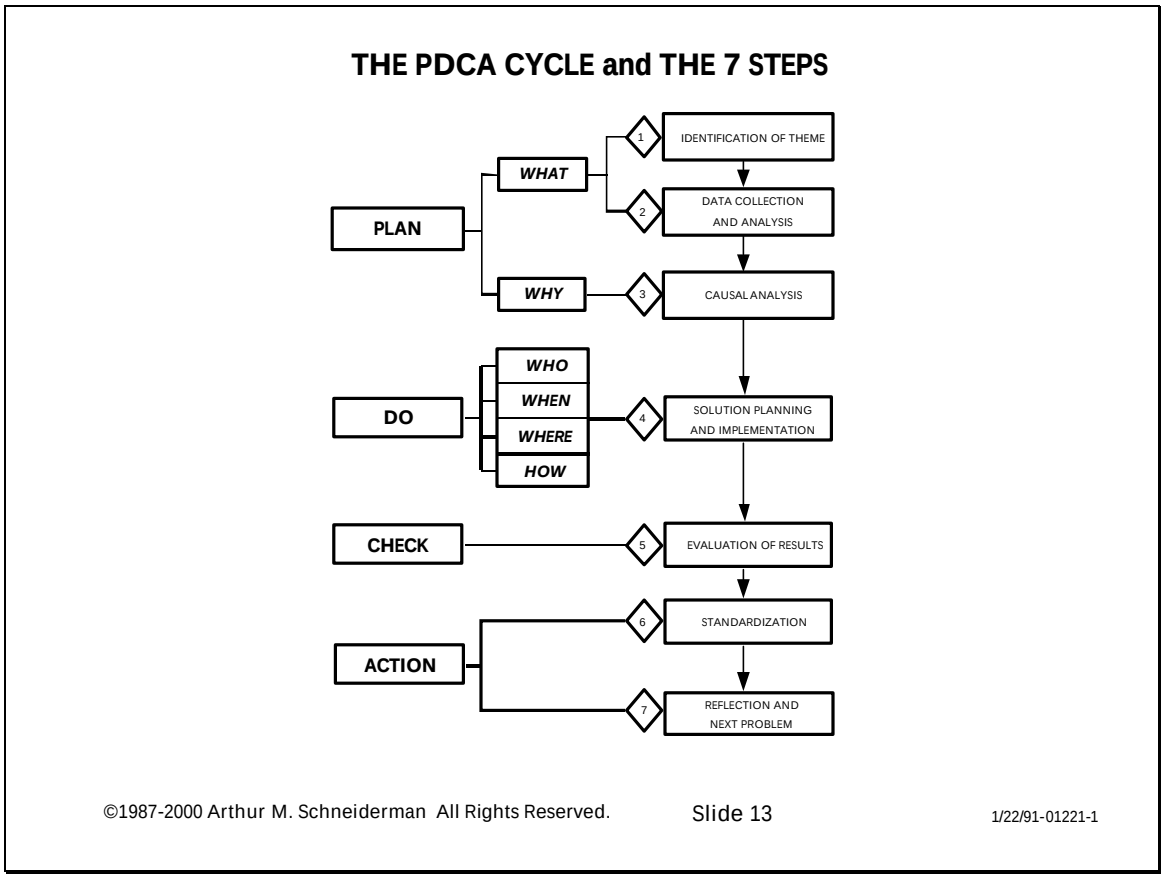
So the complexity gets greater and in fact what we have going on right now in terms of international negotiations is even a higher level of complexity. It [involves] not just different companies, it's different countries. So the higher the level of complexity, the more slow the rate of progress you would expect to get in terms of organizational complexity.

The same thing holds in technical complexity. There are some problems that you look and you say "these are no brainers." And there are other problems at the other end of the spectrum where you get a feeling that you're kind of pushing the fundamental limits of technology, the laws of physics. So there's a spectrum there.

You'll also notice as you go from left to right here, you go through a factor of five. In other words it's five times harder to solve a hard technological problem than it is a simple technological problem. But it's about 15 times harder to solve an organizationally complex problem vs. an organizationally simple problem.

A lot of the work that's going on right now in terms of organizational simplification: empowering the workforce, eliminating levels of middle management, I think are going to greatly help in reducing the organizational complexity associated with problem solving and will speed up the rate at which people are able to solve problems. So, basically this has become a way of having a group of people sit down and say, "Where do we think we lie in the spectrum of organizational complexity? Where do we think we lie in the spectrum of technological complexity? What is the kind of half-life we might expect out of the continuous improvement process?"

Slide 13

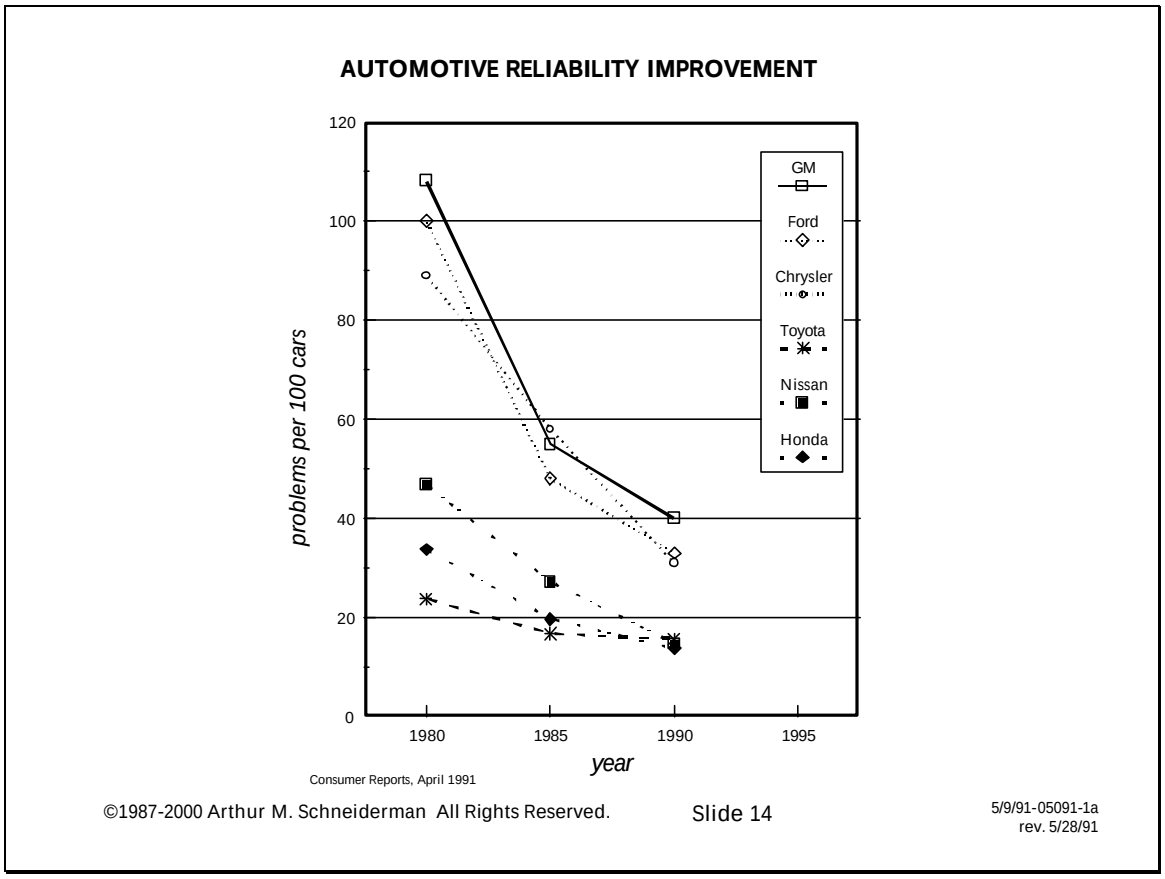


Now at the low levels of the organization, the method that's used by those teams is well defined. There are a number of methods around that date back even to Kepner-Tregoe, which is a method that maybe many of you are familiar with. That is a very structured way of problem solving. This happens to be the one that we use at Analog in terms of continuous improvement activities. It comes from the Deming/Shewhart plan-do-check-act, PDCA cycle, and it maps into 7-steps that range from identification of the problem, "do we have a clear understanding of what the problem is that we're working on?" Data collection, understanding the root causes, coming up with solutions, and implementing them, evaluating the results, did it work? Standardizing the results and then reflecting on the team's effort at problem solving.

Now this may look naively simple. Let me tell you there's an immense amount of richness in this process, and if you look at those steps and ask "how many times have I jumped from the problem to the solution without bothering to collect data? How many times have I implemented a solution and then not gone back to see if it worked? How many times have I not standardized it so

when somebody got moved to another job the solution moved with them? And, how many times have I sat in a group and seriously asked a team, what can we do to improve the way that we solve problems?" So it's not naive, it's a very, very complex process.

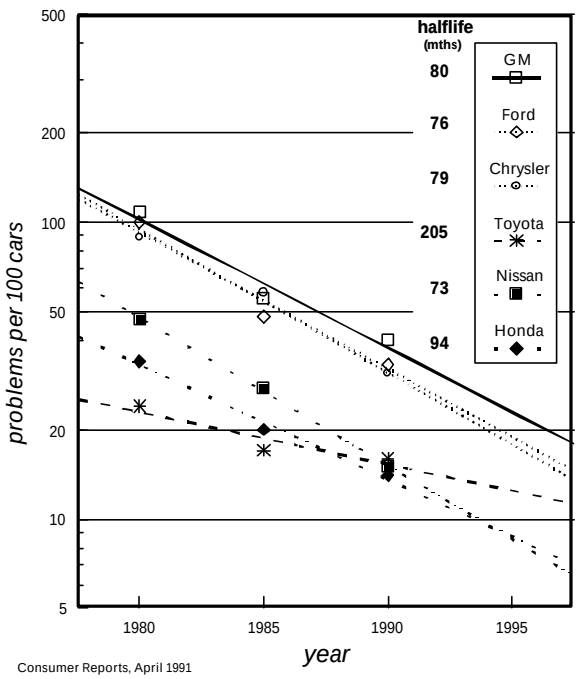
Slide 14



Let me show you one example of the half-life concept, which a number of people have found interesting. It's a very practical example for me. This is some data that was taken out of the April issue of Consumer Report, and it deals with the defects that new car owners experienced in the first year of ownership of a new car. This is something they do every five years.

And, I was in the process of getting ready to buy a new car. So, I looked at that data, this is a re-graph of that data, and I showed it to my wife and my daughter and I said, "what do you think, should I buy another Japanese car or can I now buy American?" And they looked at it and they said, "well, the gap is narrowing and we're kind of in this mid-period of time, the difference between Japanese quality and American quality is basically not important any more." There're certainly a lot of messages; turn on the TV, that's what they tell you.

Slide 15



Slide 15

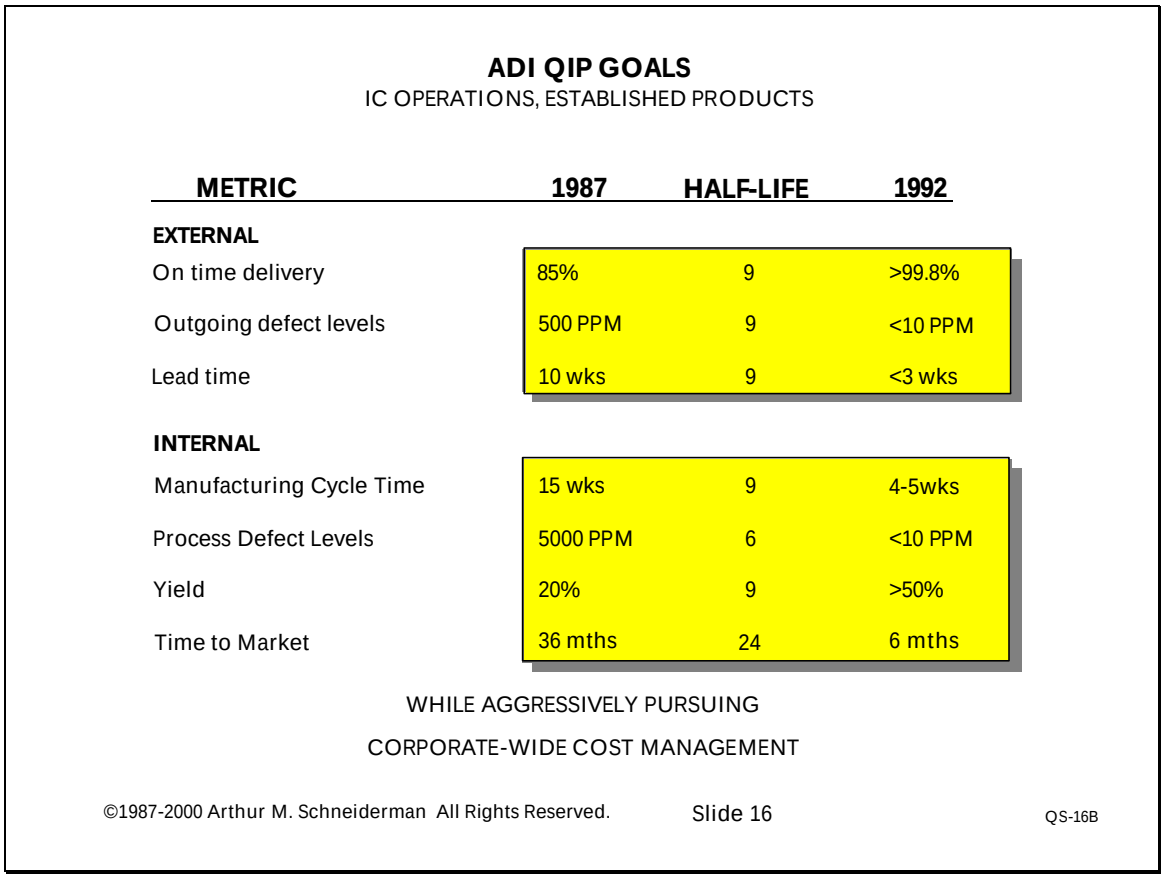
5/9/91-05091-1
rev. 5/28/91

But now, if we apply this half-life method, what do you do? You take that same data and you re-graph it on semi-log paper and you get a very different picture. The message that comes out of this is that we're improving, but the Japanese are improving too. And in fact, the ratio of this line to this line is about a factor of three. So it says, even today, that the Japanese automobiles have one-third the problems that US automobiles have. And if you're going to have a problem, you're three times likelier to have that problem with an American car versus a Japanese car.

I think that the encouraging thing here is that the rates of improvement are about comparable, between American and Japanese manufacturers. But looking at things from the half-life perspective, rather than looking at them from the linear perspective, very often gives you a very different insight.

Revised 8/27/00 9:41 PM

Slide 16



ADI QIP GOALS

IC OPERATIONS, ESTABLISHED PRODUCTS

METRIC	1987	HALF-LIFE	1992
EXTERNAL			
On time delivery	85%	9	>99.8%
Outgoing defect levels	500 PPM	9	<10 PPM
Lead time	10 wks	9	<3 wks
INTERNAL			
Manufacturing Cycle Time	15 wks	9	4-5wks
Process Defect Levels	5000 PPM	6	<10 PPM
Yield	20%	9	>50%
Time to Market	36 mths	24	6 mths

WHILE AGGRESSIVELY PURSUING

CORPORATE-WIDE COST MANAGEMENT

 Slide 16 QS-16B

Let's turn back to goals here, and I'm going to quickly move through this part of things. You recognize all the things here. These are the key things that we said were important to customers and these are the key internal processes.

At Analog we went and first of all had to put in a measurement system, because if you asked people in 1985 "what is our on-time delivery to our customers?" they said, "I don't know." If you said, "Well, what are our yields?" they said, "I don't know," because those aren't in financial measuring systems. They know what their labor variance was. But they don't known what their yields were, they don't know what their manufacturing cycle time is. So a lot of effort had to go in to putting in place measurement systems for the things that we felt were important. It took a about a year and a half to really come up with these measurement systems.

We than did three things: we used that benchmarking concept to say, "Where is the best in class? Where are the likely to be in 1992?" We have the half-life model; we can make some sort of estimates. We went and asked our customers "what are your expectations for your best suppliers in 1992?" And

then we had to wing it. We went into that matrix. We said "What is the complexity involved with yield improvement? What is the appropriate half-life to assume?" We assumed an average value and we asked the question "Can we achieve what we think competition will be doing and what we think our customers are going to want by 1992 by the continuous improvement process."

And the good news was in each case we could get to where we needed to be in 1992 through continuous improvement which meant we didn't have to rely on breakthrough, because, frankly we didn't know how to predict breakthrough. We didn't, and don't today know how to manage a company for predictable breakthrough; breakthroughs seem to come spontaneously.

Slide 17

ADI QIP GOALS

IC OPERATIONS, ESTABLISHED PRODUCTS

METRIC	1987	1990	1992
EXTERNAL			
On time delivery	85%	96%	>99.8%
Outgoing defect level	500 PPM	230 PPM	<10 PPM
Lead time	10 weeks	5.4 weeks	<3 weeks
% CRDs matched	31%	50%	n/a
excess leadtime	3.9 weeks	2.8 weeks	n/a
INTERNAL			
Manufacturing cycle time	15 weeks	8 weeks	4-5 weeks
Process defect level	5000 PPM	1100 PPM	<10 PPM
Yield	20%	38%	>50%
Time to market	36 months	?	6 months

 Slide 17 11/12/90-11120-3.doc

Well the pre-bubble, now you all know what I mean by bubble, the pre-bubble results, 1990, were dramatic. We got our on-time delivery up from 85%. When we talk about on-time delivery, we talk about the most rigorous definition you can have. Because up until very recently, we didn't go through distribution, we have 20,000 active customers worldwide and 10,000 products in our product line. A late shipment is when a customer orders ten pieces and [we] say, you can have it by a certain date and they don't get all ten pieces by that date. So nine pieces, you get zero for that.

So we made much progress in terms on-time delivery. We made progress in terms of quality. We made progress in terms of lead-time. And our lead-time progress, by the way, turned out to be not so much numerical, as conceptual. Because what we discovered as we started going through this process is customers don't care about your lead-time. They care about something simpler than that. They care about your saying "yes."

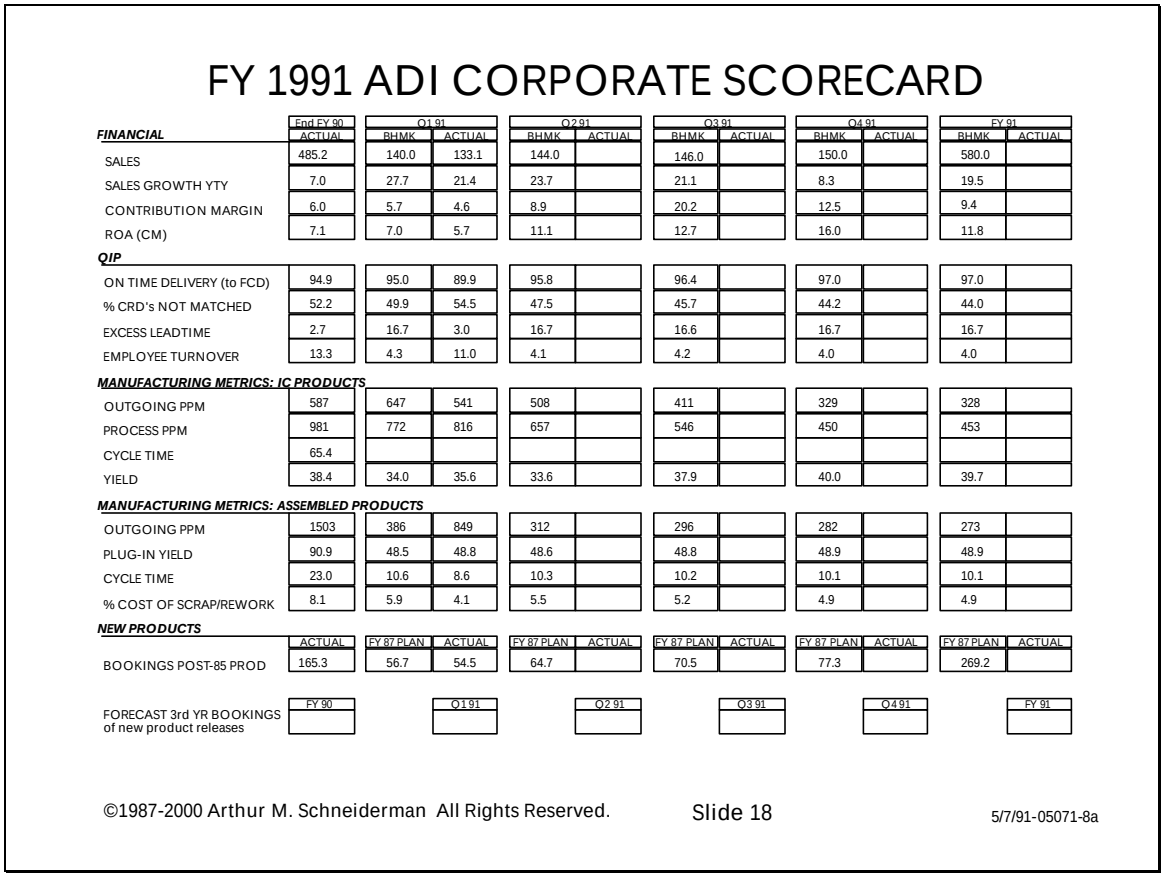
That means if they have an order and they have plenty of lead-time: "we want it a year from now." Yes! "We have a great opportunity; we can sell 50% more

product if you can get us 1000 pieces the end of this week." Yes! So what customers want from you is not lead-time, they want "yes." So we measure: what percent of the time do we say "yes" to customers. What percent of the time they say "I would like it by this date" and we say "you can have it by that date." And when we can't, how much do we miss by? In other words, how much pain do we create when we can't meet a customer's expectation. So in that particular area, we learned the metric was wrong.

This is a very dynamic process. You don't very often go in and say you want to restructure a balance sheet, or restructure an income statement or sources and uses of funds. But in the area of non-financial performance metrics, you have to be able to change this side of things, as you learn better what it is that's appropriate to measure.

Now you can guess that in terms this earlier slide [slide 16], if we had stopped basically here, and said we're going to come back in 1992, the end of the year, and see how we've done. You know what would happen. Most people, up until the fourth quarter of 1992 would do nothing. [They have] lots of other things to work on. They've already got a job. You're now giving them an additional job: to improve. So you get this "hockey stick" at the end, or at least this attempt at this hockey stick at the end. "We'll still get there; we've got one more quarter, we'll get there." So what we did is we decided that we needed some sort of intermediate measures and we created a scorecard.

Slide 18



FY 1991 ADI CORPORATE SCORECARD

	End FY 90	Q1 91		Q2 91		Q3 91		Q4 91		FY 91	
FINANCIAL	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL
SALES	485.2	140.0	133.1	144.0		146.0		150.0		580.0	
SALES GROWTH YTY	7.0	27.7	21.4	23.7		21.1		8.3		19.5	
CONTRIBUTION MARGIN	6.0	5.7	4.6	8.9		20.2		12.5		9.4	
ROA (CM)	7.1	7.0	5.7	11.1		12.7		16.0		11.8	
QIP											
ON TIME DELIVERY (to FCD)	94.9	95.0	89.9	95.8		96.4		97.0		97.0	
% CRD's NOT MATCHED	52.2	49.9	54.5	47.5		45.7		44.2		44.0	
EXCESS LEADTIME	2.7	16.7	3.0	16.7		16.6		16.7		16.7	
EMPLOYEE TURNOVER	13.3	4.3	11.0	4.1		4.2		4.0		4.0	
MANUFACTURING METRICS: IC PRODUCTS											
OUTGOING PPM	587	647	541	508		411		329		328	
PROCESS PPM	981	772	816	657		546		450		453	
CYCLE TIME	65.4										
YIELD	38.4	34.0	35.6	33.6		37.9		40.0		39.7	
MANUFACTURING METRICS: ASSEMBLED PRODUCTS											
OUTGOING PPM	1503	386	849	312		296		282		273	
PLUG-IN YIELD	90.9	48.5	48.8	48.6		48.8		48.9		48.9	
CYCLE TIME	23.0	10.6	8.6	10.3		10.2		10.1		10.1	
% COST OF SCRAP/REWORK	8.1	5.9	4.1	5.5		5.2		4.9		4.9	
NEW PRODUCTS											
	ACTUAL	FY 87 PLAN	ACTUAL	FY 87 PLAN	ACTUAL	FY 87 PLAN	ACTUAL	FY 87 PLAN	ACTUAL	FY 87 PLAN	ACTUAL
BOOKINGS POST-85 PROD	165.3	56.7	54.5	64.7		70.5		77.3		269.2	

	FY 90	Q1 91	Q2 91	Q3 91	Q4 91	FY 91
FORECAST 3rd YR BOOKINGS of new product releases						

Slide 18

5/7/91-05071-8a

What you see on this scorecard, on the left-hand side here, are a few financial measures, our quality improvement measures, and some measures with respect to new product development. Analog Devices is the kind of company in which growth depends exclusively on the introduction of new products, that's the driver for us.

What we do each year is we look at where we ended up the previous year along each of these measures. This happens to be the aggregate scorecard for the corporation. Below this, in the same sense that organizations have financial measurement systems, each of our entities has a scorecard. Those scorecards consolidate to this scorecard.

But what we do each year with each of the entities is we look at where they ended up the year, we keep in mind where want to be in 1992, we use the half-life concept to generate…where it says BHMK, that stands for "benchmark," but it's not the same benchmark that you think about, that's the name we happened to have introduced ten years ago for our annual planning process. We call them benchmark plans. So this is the plan. This is the plan for the first quarter, second quarter, third quarter, and we use the half-life concept in

order to go through and negotiation…we're in the midst of doing that right now, this week is the week that we will close with the divisions.

It's tops-down … I'm the one that sends out the original "strawman proposals" to the divisions. Then they come back and say, "that's too expensive, I don't have the time, I don't have the resources." Then I go back and say "how's it going to affect your business if you don't improve your delivery performance; if you don't improve your costs?" So we go through a negotiation. It's really not a negotiation because I have no leverage. I'm a staff person. It's really more of an educational process forcing people to think through the implications of not setting ambitions goals.

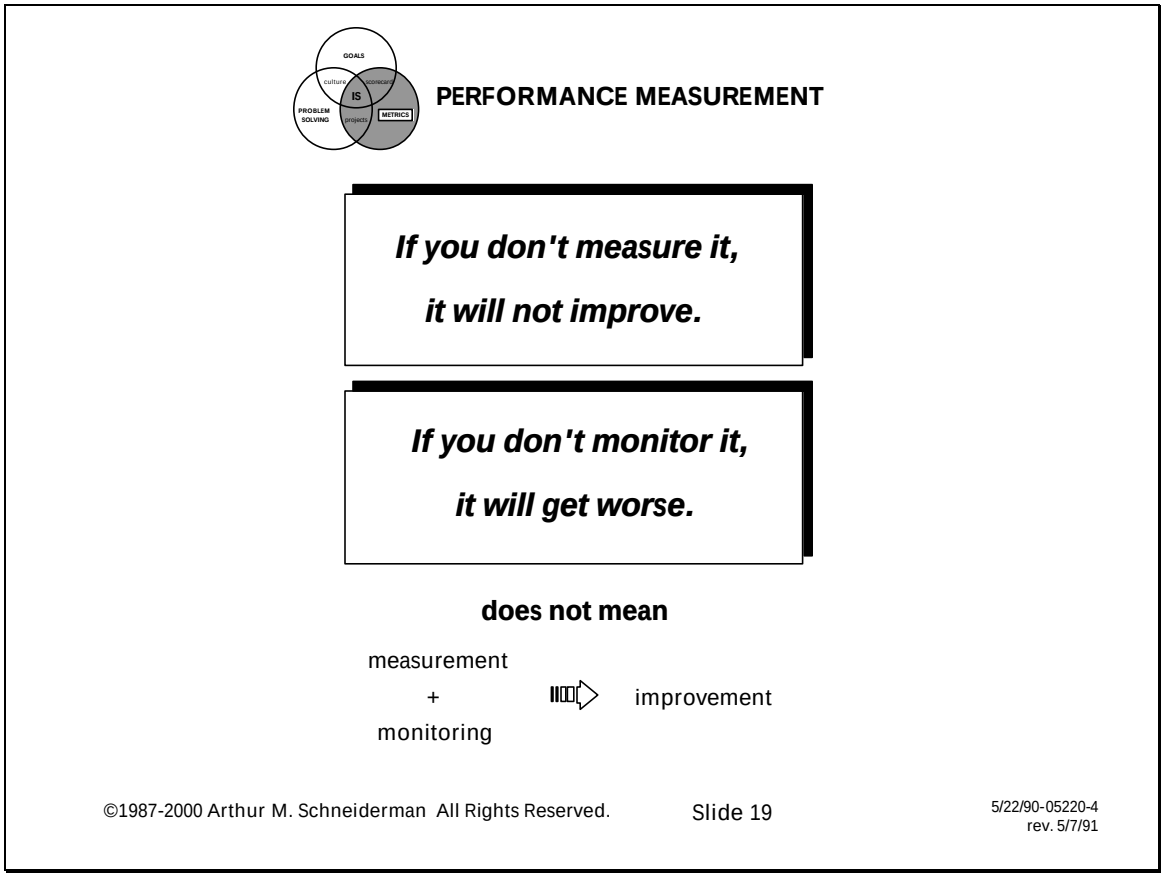
But we end up generating goals for each of the divisions and then each quarter we fill in the actuals and then each quarter we have one of our meetings of the executive group. Each person responsible for a scorecard has to stand up and they have to explain things that have been circled on the scorecard.

Now we have a number of things that are widely understood codes at Analog Devices. If it's circled with a red pen, it's "unfavorable." If it's circled with a green pen it's "favorable." So my job is before that meeting, with appropriate warning, not too much – not too little, to circle these things. I circle one or two. There're usually more reds than greens. And what happens is the manager responsible for that scorecard stands up in front of his peers and says "these are the root causes," remember that 7-step process, "these are the root causes of the variance. These are the ones that were controllable, these are the ones that were not controllable, short term." For example, uncontrollable ones as an international company: exchange rates. You can't predict with certainty exchange rates, so you can't predict with certainty revenues and expenses on their foreign shipments.

But on the ones that are controllable, what is the corrective action and what are the milestones in terms of implementing that correction: who is going to do what when? So we try to close the loop in terms of an improvement process with this measurement system. We try to make certain that it is not used in a threatening way; that it's used in a way to make sure that people, when there are variances between plan, and those variances are sometimes green, sometimes positive. Very often the green ones are breakthroughs. Very often somebody has achieved a breakthrough, because most of these goals are set on what we think are continuous improvement kind of activities.

So they have to share that breakthrough with everyone. Breakthroughs are very easily transferable from one division to another. And this provides a great opportunity for people to share their breakthroughs. So we use this scorecard on a quarterly basis in order to drive our improvement efforts.

Slide 19



Now there's a slide that I use to use as I now got into the detailed measurement systems that we have in place, that said what I said earlier: "If you don't measure it, it will not improve." We've added to that slide that "If you don't monitor it, it will get worse," because in the years 1990 and 1991, although we had a tendency to put this on the agenda of our meetings, it got put at the end of the agenda. And, there were so many of these issues around reorganization, around changes in our planning system, we never got to it: "Sorry Art, no time this time."

And so we stopped monitoring it. And I think the answer is, if you have perfect measurement system and nobody looks at it, or not the right people look at it, you're not going to get the improvements that you're after. So you have to have a good measurement system, and you have to have a forum for looking at those measurements, and you have to have a non-threatening set of rules around how that discussion goes on: "What are the root causes? What are the corrective actions? Who's going to do what when? Who's taking responsibility for making this problem go away?"

Slide 20

GOAL:
IMPROVE CUSTOMER SERVICE

CUSTOMER SERVICE METRICS

ON TIME
% late
% early
⇨ % on time

RESPONSIBILITY
factory credit
warehouse customer

LATENESS/EARLINESS
shipped late, how late?
shipped early, how early?
still late, how late?
months to ship late backlog

LEAD TIME
customer requested lead time
% CRD's matched
excess lead time

RESPONSIVENESS
time to schedule an order

 Slide 20 4/8/90-04080-3 rev 5/13/90

I want to give you one example of our performance measurement system and it's around the subject that we call "Customer Service Metrics." And they really are delivery related metrics. The things that you see on the slide here are the things that we measure. Now this set of measurements, the measurements in terms of delivery, was really a test challenge. The test challenge here was could we come up with a corporate-wide measurement system that has the same level of integrity of a financial measurement system.

Financial measurement systems have been developed over a hundred years. Over a hundred years, every time an ingenious manager finds a way around the system an ingenious accountant finds a counter-measure. So you've go a system a hundred years old that has nearly all of the holes plugged. Sure there are things that you can do short term. You can play games short term in terms of deferring costs and things like that, but long term, financial measurements systems will tell people the right things.

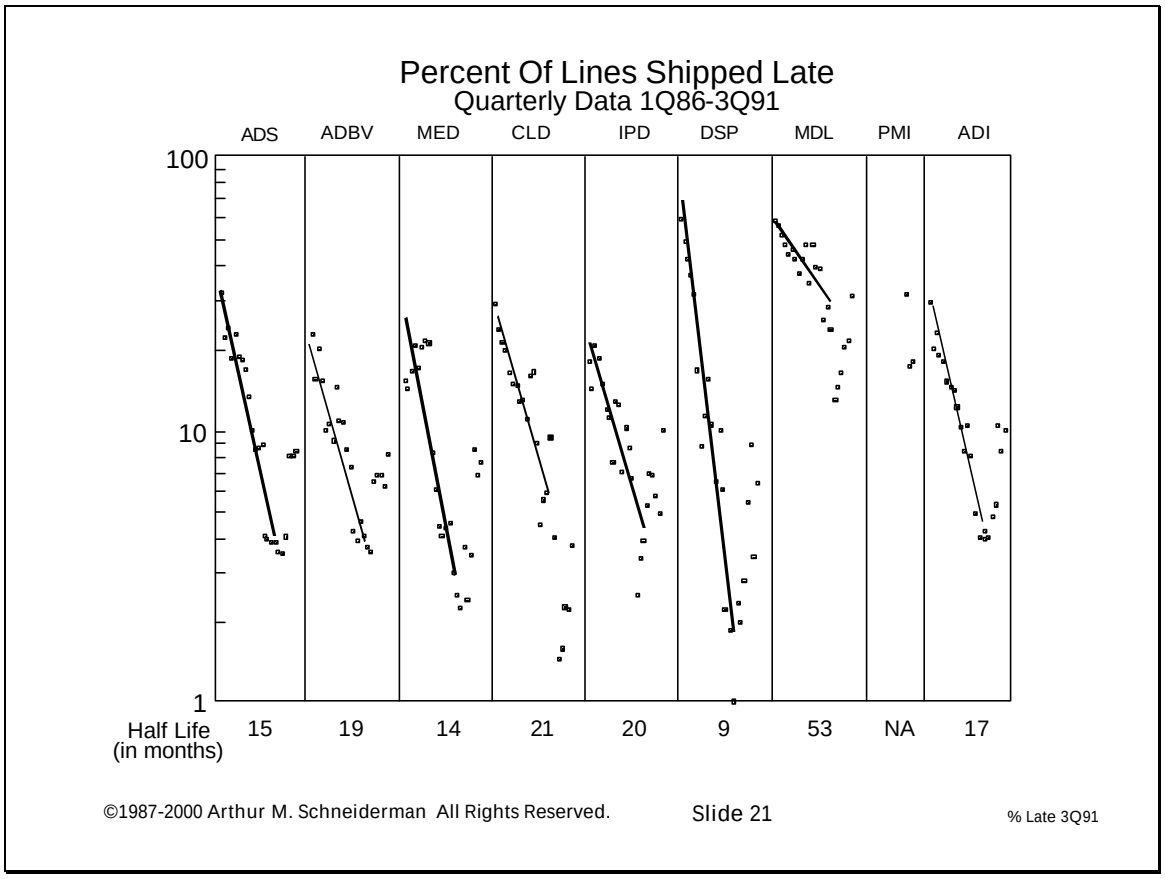
So the challenge here was to come up with one that could not be "gamed." And when I say gaming, I don't mean in a negative way. People like simple

measures. They like to have you say to them "this is the measure I want you to improve." It's very hard to have them make that vague step back, and by the way, "we're going this to improve satisfaction to customers." Day-to-day, you tend to focus on the measure, so if you don't have a comprehensive set of measures, you create an opportunity for people to look to themselves as though they're improving and look to the customer as if they're getting worse.

So a lot of effort went into designing this. Not only looking at on-time delivery, but also looking at late shipments and early shipments, when we're late, how late are we, who's responsible for late shipments? And in fact in this whole area of responsibility, we break it down even finer than that, we break it down into 13 categories. We make it easy for people to do a Pareto analysis of what the root causes are of late shipments.

We look at late shipments: how late were they? We don't just forget about a shipment when it goes late. When it's finally shipped, we look at how late was it was finally shipped? We look at the whole process of scheduling orders. We had one ingenious division that didn't make a commitment to a customer until they were ready to ship. Customer places the order and they wait; "well when are you going to ship it?" "We'll tell you soon." "Oh, by the way, we shipped it yesterday." Here's our commit date. So we look at the delay between when the customer places the order and when we get back to them with a shipment date. So they're a very comprehensive set of data.

Slide 21

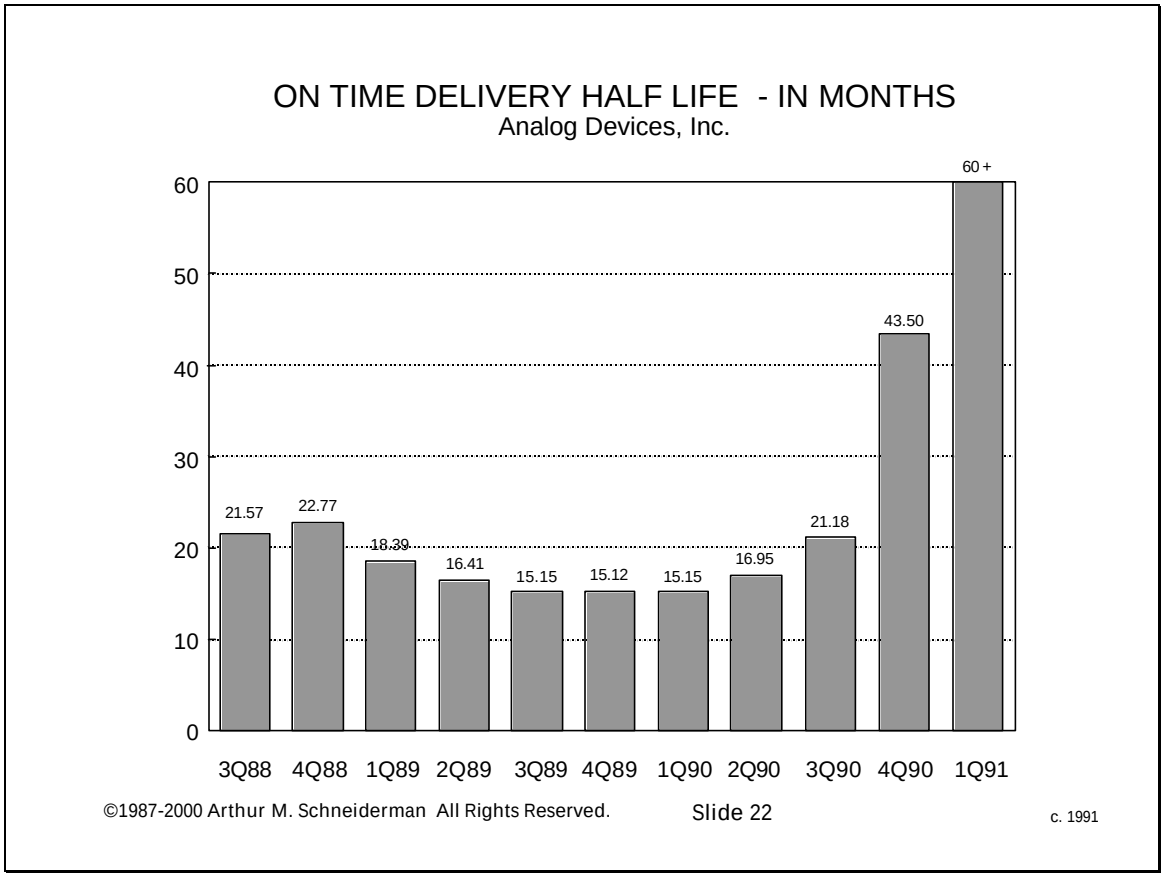


Now the next chart I'd like to show you looks a little bit complex. It's not as complex as it looks. This happens to be a history of improvement of the performance with respect to delivery starting in first quarter of 1986, going to the third quarter of 1991. Each of these columns here represents a division of the company. The last column is the corporate aggregate. The numbers that you see down here are the half-life. The lines are computed during that period of time in which we were making significant improvement.

So if you look here, for example, at the last column, and look across this slide, you will see that in the first quarter of 1986 we were about 30% late to our customers, and here we got up as high as 97% on-time in one quarter. In fact, for the year 1990 we averaged 96% on time. And, here's that bubble, here's that backsliding as we began to focus on other things. And in fact, if you conceptually click on these numbers here, you can get a time history of the half-life.

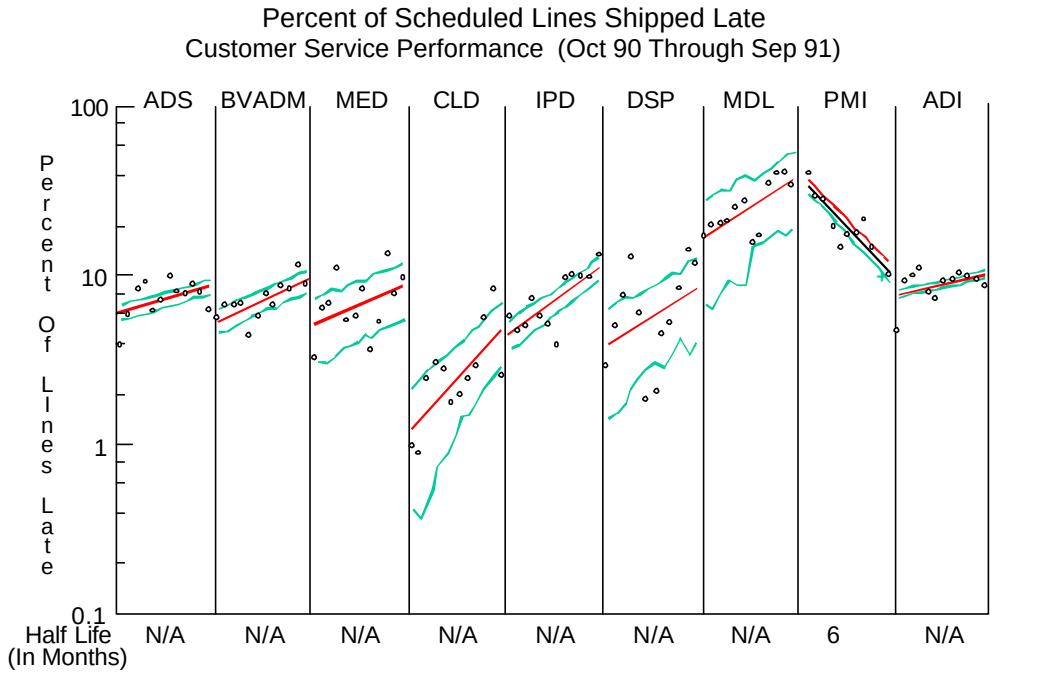
Revised 8/27/00 9:41 PM

Slide 22



And from a performance measurement perspective, in a sense, this is the action line. This is what we're looking for. If we've identified the right things to improve, then the metric is how fast are people improving? And so, we look at the half-life. And we watched during this period of time, we said nine months was our goal for this particular metric; this is pretty good, we're getting there. Some of the divisions did have nine month half-lives for significant periods of times. But this is the point at which the half-life, the rate of improvement, flattened out (I don't acknowledge negative half-lives. I won't honor the unlearning process). So we look at the rates of improvement.

Slide 23



Now this happens to be a more operational chart. The one that I just showed you, looking over that long period of time is suitable for meetings like this. But it's not very suitable for managing a company. And so what we do is we look at the same kind of data, this is now monthly data, rather than quarterly data. Each of these columns, again, is a different division of Analog Devices. The last column is the corporate total.

Yes, you're right, most of them are going in the wrong direction. Things are getting worse. This happens to be a newly acquired division. In the process of doing all of this reorganization, all the changes within Analog, we also made a major acquisition of a company about a third our size. That is a very big dinner to eat, let me tell you. And there's a lot of indigestion that ends up following that, and a lot of distraction. But, they're learning the system and they're making immense progress in terms of coming down. The red line is a fit of the half-life model through the data. There's twelve months worth of data on each of these. Each month we add a point and we drop the oldest point, or the thirteenth point.

The green lines are very interesting. Many of us in total quality management are also involved in statistical quality control. And what statistical quality control teaches you is that there is variability that is the result of the process. And there's variability that represents an out-of-control situation. Why don't we apply that to our measurement system? Doesn't it make sense to apply things to the measurement system so that we are not constantly chasing little random variations? Before we did this, we wrote a report every month when we sent out this data and if the division went up a little bit better we congratulated them. If they got a little bit worse than the previous month we identified them as a division that was not doing well.

And yet, from a statistical point, if Dr. Deming were here talking to you he would say that those are systems related. That's the randomness in the system. So we do the same thing. We put control limits on. We look at the latest three months. If you're above the upper control limit, the upper green line, we change your dot to a red plus sign. And if you're below the lower control limit it becomes a green plus sign. And we use it the same way we use the scorecard. It gets put up at the same meeting along with the other related charts.

All of the metrics that we have, all of the ones I've showed you in terms of delivery are in the same format. They 're in an on-line executive information system; the data is available on a monthly basis. There are daily downloads to each of the operations managers of every line that didn't ship that was scheduled for shipment the previous day. So they get daily information, which is how they are able to find out what the root causes are.

Well you might guess that we're a little bit paranoid at making sure that we connect what were doing internally with what' s important to customers. We would not quite feel as if we had a full meal until we went and listened to what our customers had to say about our performance along the dimension we think they think are important. So we have a database that we maintain. It now has actually close to a hundred customers in it.

Slide 24

64 CUSTOMERS IN VENDOR RATING DATABASE

ABF
AGFA
AirResearch
Allen Bradley
Allied Signal
Amdahl
Ametek
Analogic
Apollo
AT&T
Becton Dickinson
Bendix Avionics
Brown Engineering
Compugraphic
Coulter Electronics
Digital Instrument
Eaton
Electronics & Space
EMC
Finnegan
Fluke
Ford (Aerospace)
GEC
General Dynamics
General Electric
Gould
Hewlett-Packard
Honeywell
Hughes
Instron
JET Electronics
Kodak
Litton
Loral
Lucas
M/A-COM
Marquette Electric
Martin Marietta
Masscomp
McDonald Douglas
Measurex
Microcircuits Semiconductor
Parker Air & Space
Penastar
Perkin Elmer
Pitney-Bowes
Raytheon
Recognition
Reliance Electric
Rockwell
Sanders
Siemens
Sikorsky
Spectra Physics
Tektronix
Teleco
Teledyne
Teradyne
Texas Instruments
Trillium
United Technologies
Walkins-Johnson Co.
Waters Associates
Westinghouse

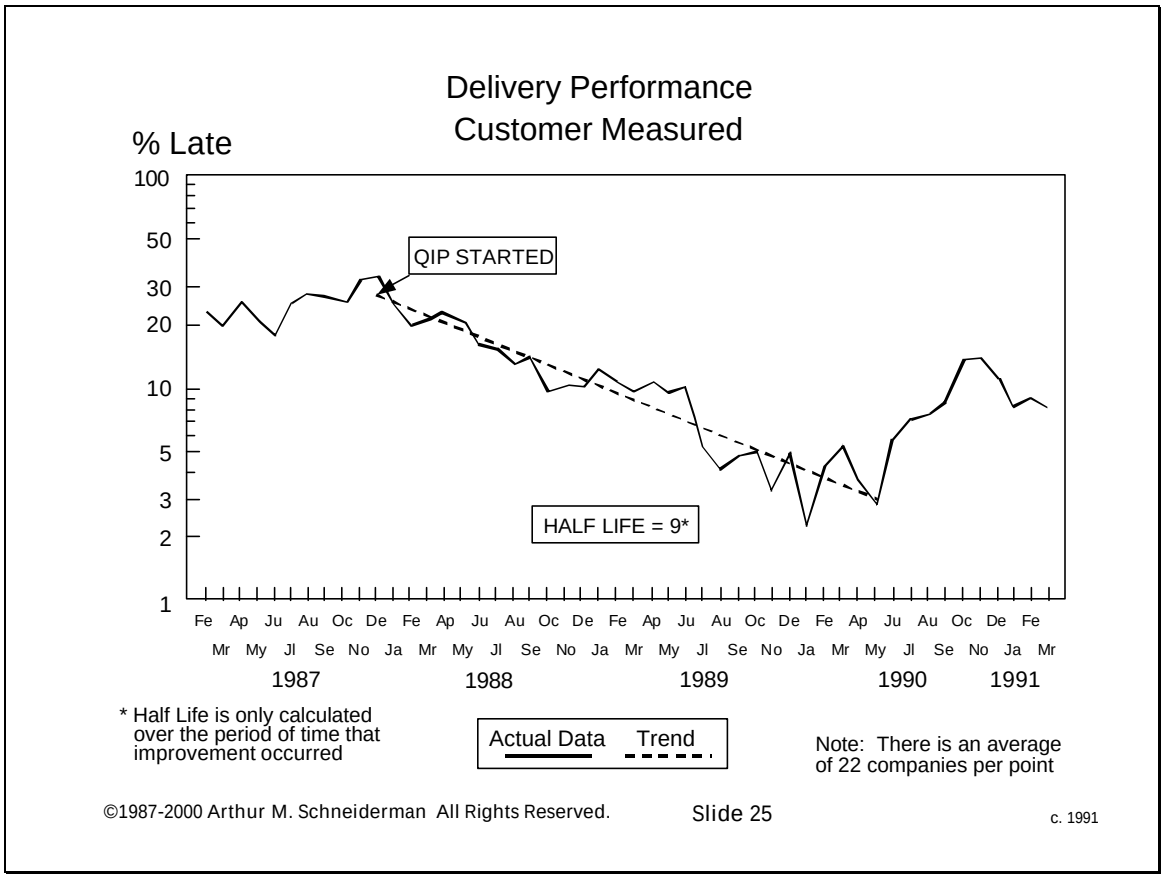
 Slide 24 3/91-VRS Database

These are customers that have what are called vendor-rating systems. They measure various aspects of the performance of their suppliers, and they rate them in someway or another and sometimes they actually provide that information to their suppliers. It's amazing the number of customers that we have that have vendor-rating systems that measure quality and delivery and then they don't send that information to their suppliers. So they know how well their suppliers are doing but they don't tell their suppliers.

Those that do and those that make their way into this database on a quarterly basis we publish a report and right now that report has two charts in it. It has our delivery performance and our quality performance as measured by those customers. We do no adjustment of the data. Even though we know that our customers make mistakes. We know for example in one of our customers that has a three day acceptance window for on-time delivery but occasionally material sits on their receiving dock for four days before it's logged into their system and we're able to track down the fact that we did get it to you on time.

It's just that your system did not accommodate it. It was there; you just did not know it was there. So we don't correct the data for that, and this is what it ends up looking like.

Slide 25



Again this is something we publish quarterly. On average there are 22 companies in each data point. So it is a statistically significant group of customers. It's the percent of late shipments as measured by our customers. And it makes us feel very good because there's a very strong correlation between what they measure and what we measure, even though very often they have different measurement systems.

Some people have forgiveness windows of a week; if you're a week late we'll call it on time. Some people have three-day windows; there's one particular customer that had three-day windows said they're going to change it to a one day window and the next time we'll be talking about acceptance windows in hours. They all have different systems, but as you can see during the period of time at which we thought we were between 20 and 30 percent late, low and behold our customers thought we were between 20 and 30% late. They saw improvement; they saw a little more rapid rate than we do, and we think that that's because their systems are a little more forgiving than our measurement

system. They've also seen the bubble. They've seen our performance get worse over the last 18 months; it's something you can't hide.

Well, as you remember on an earlier slide I said our goal was to be number one; rated number one by our customers in the value of the products we deliver to them. One customer that we have that actually does a very good job of taking all of the elements on the left side of that matrix: delivery, responsiveness, technology and really quantifying them and rank ordering their supplier is Hewlett Packard and Hewlett Packard does tell their suppliers how they rank.

Slide 26

HEWLETT-PACKARD VENDOR RATINGS

year	*ADI rank*	*total suppliers*	*category*
1986	8	16	linear IC suppliers
1987	5	8	linear IC suppliers
1988	5	15	all IC suppliers
1989	1*	12	all IC suppliers

*tied with one other supplier

 Slide 26 5/22/90-05220-1

In 1986 they told us we ranked #8 out of 16 suppliers. Now your first reaction to that might be "Whew, that's good, we're in the middle of the pack," but the second thing they told is "By the way, we're going through a vendor consolidation and we're going to reduce our supplier base of linear ICs from 16 to 8." So, in 1987 we made the cut. We made it; they did it, they reduced their supplier base to eight and we made it to fifth. Then they said, "By the way we've thought about this linear vs digital ICs and since they end up going on the same board and since the people in manufacturing don't know the difference we're going to group them all together."

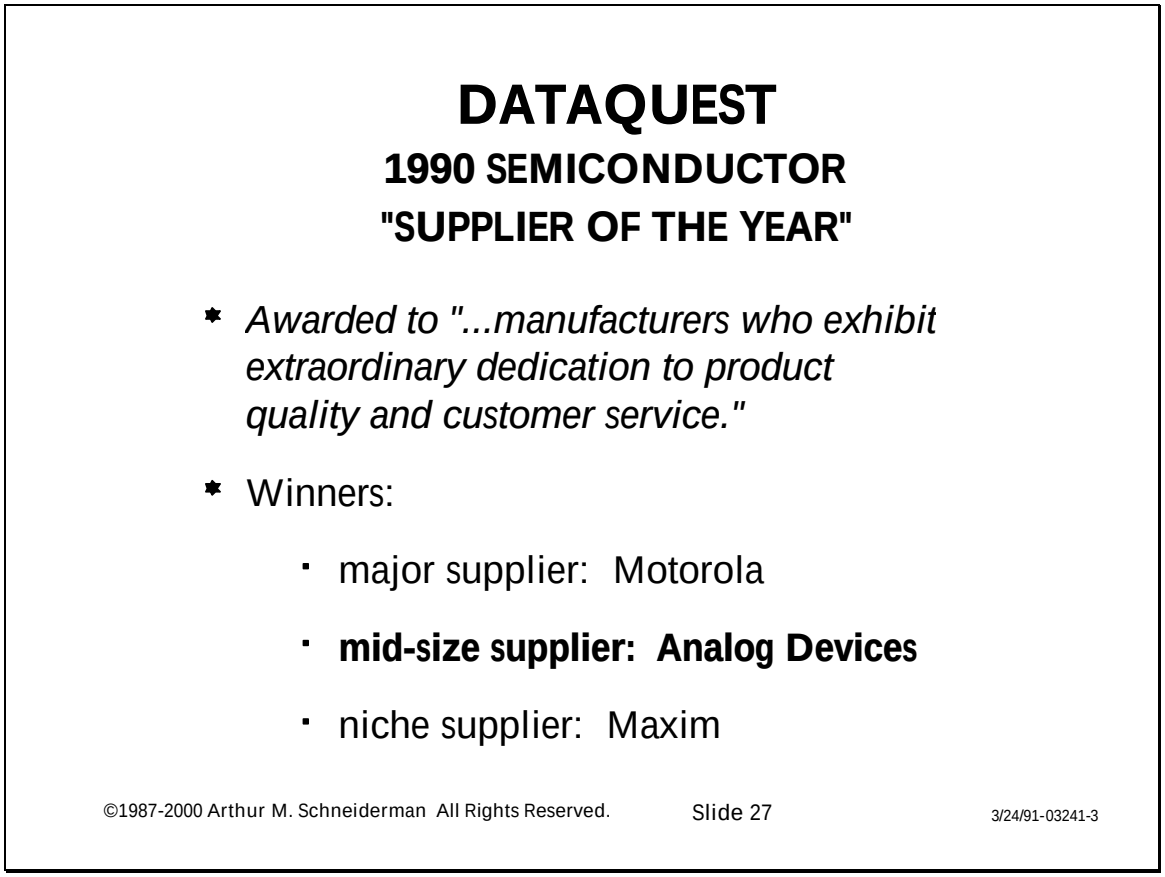
Now that was very important to us because linear IC suppliers are companies you probably have not heard of. You probably haven't heard of Analog, and since most of our linear IC competitors are much smaller than us, you probably haven't heard of them either. But the digital IC suppliers are Motorola, Texas Instruments, National Semiconductor, Toshiba, NEC; a different group of competitors. And their performance has always been

Revised 8/27/00 9:41 PM

significantly better than linear IC suppliers. So we got real nervous about that. But we kind of held our own. They grouped them together; there were now 15 and we were fifth.

By 1989 we had tied for first place. By mid-1990, we actually reached first place. But, the bubble. We have dropped in their ranking system of suppliers since then. And that's something we need to correct because they know what's going on. Customers know what's going on in your own organization.

Slide 27



Well, my next to final slide is another measure, because again you've got to close the loop on this whole performance measurement system. Dataquest happens to be an independent industry organization. One of the things that they do is a semiconductor supplier of the year award that goes out to the manufacturers who exhibit extraordinary dedication to product quality and customer service. They identify those by poling 300 purchasing decision-makers: 200 in the US, 50 in Europe and 50 in the Far East. And in 1990, we were selected the mid-size semiconductor supplier of the year. So, again another piece of evidence that suggests we've got the right things on the left side of that matrix and we're improving the processes that drive that and our customers are getting greater value from us as a consequence of that.

The Japanese model is that you have to be more weakness oriented than success oriented, but I can't help telling you that there is a payoff if you do these things right.

Revised 8/27/00 9:41 PM

Slide 28

SOME LESSONS LEARNED

(One Person's Opinion)

- **"97% is good enough" -> no planned improvement**
- **It's easy to be distracted (even by the right things)**
  - PMI acquisition
  - Reorganization (centralization)
    - Manufacturing, QA
    - Consolidation
      CLD+MDD+MED+IPD=IED
      (ACE+LSP)+DSP=SPD
      ADBV+ADS+PMI=?
  - New business planning process
    - Product/Market/Function Strategy Managers
    - Input / Output Data Base
  - TQM / CQM
- **Eventually, you run out of "slack"**
  - need for cross-functional problem solving
  - need for management participation

- **If you don't monitor it, it will get worse!**
  - anti-Hawthorn Effect
  - 7 steps weakness -> standardization -> control

- **Fundamental re-evaluation of our QIP efforts**
  - Center for Quality Management (CQM)
  - Shoji Shiba

Slide 28
3/25/91-03251-1
rev 4/1/91

I think the things that we've learned, and again this is my opinion; this is not necessarily something that others agree on, is that when we got up to 97% in terms of, for example, delivery performance, we said "Hey, that's good enough. Let's hold it there." My lesson is you can't hold it there. You either get better or you get worse. Those are the two states. Now maybe somebody will figure out a way of "holding the gains," that's a term that Juran uses. But, we haven't figured that out. My belief is that if you're not on one of those half-life curves, if you try to back off: instead of meeting once a month, meet once a quarter to work on quality improvement, you'll get worse. So I think that it is not an analog process, not a continuous process. It's digital: you're either improving or getting worse.

Secondly, it's very easy to get distracted, even for the right reasons. We talked earlier about why we were centralizing. Those are the right reasons. This division that we acquired, that in fact caused us a bit of indigestion, was the right decision. It rounded out our product line in a very important way from

the perspective of our customers. Right decisions. We're changing our business planning process; it's the right decision. On the other hand, doing all of these things, recognizing that there is finite human capacity in an organization, people can do only so many things. As a consequence of that it's very tempting to put TQM on the back burner. The success almost leads to complacency, that you can kind of hold your own. I don't think you can do that. I think that this other area here is a very critical one that we're only now beginning to understand.

I mentioned the slack rope model from Duncan McDougall. It is there; let me tell you. Let me give you an example of it. Financial pressure: one way of dealing with financial pressure is cut back on capital investment. The accounting system says the utilization rate is about 70%, just cut back. Don't replace that piece of equipment.

What happened is that our unit volumes have been increasing more rapidly than our revenues have been increasing. And our capacity [utilization] started rising in manufacturing. Many of you are from manufacturing. You know what happens as you start getting to 80% utilization, 85% utilization, 90% utilization, now you have a problem. That happened, yet no capacity to recover. If you try to recover [from] that problem then you're going to late on the new batch of shipments because you don't have the additional capacity.

So a simple decision made up the organization to cut back on capital investment inadvertently affected our ability to deliver on time to our customers. So that slack is out of the system. We have to understand the linkage between vertical decision-making and the result that it has on the things that people are working on.

Horizontal: we're to the point now where we can't improve our yields without redesigning our products. So it's no longer a manufacturing process engineering exercise, it's an exercise that brings the design community into the process. You can't improve without getting other functions involved. So the slack is out of the model.

I know you've got a question here, but let me just finish this one slide and say that what it really leads you to is this last point of monitoring. I said that before. The best measurement system in the world, if you don't make it highly visible, you won't get any results from it.

And finally, I think that the TQM implementation process itself represents a series of breakthroughs. You put in one paradigm for continuous improvement, eventually you run out of steam; you now need a breakthrough. You need to now fundamentally change the way you're implementing TQM. There are many companies that are at the first stage; there are few companies that are at the second stage. I don't know of any companies anywhere in the

world that are at the third stage. I don't even know what the third stage is. But I'll tell you there are stages, and one of the things that we all have to begin to recognize is that we're dealing with a world that is going to be continuously changing. Whether it's performance measures that we're talking about; whether it's manufacturing that we're talking about, the targets that you set are moving targets and they're going to be shifting over time.

And, there's a new approach that people have to take. That there are no anchors; there are no things that you can say "this is a stake in the ground, this is a way that I can think about my business for the next decade." It's going to change.

So let's now talk about more questions and I know that there was one over here.

Q:

Oh yes. I think that people capacity is an issue that people have not talked about nearly enough. But there's actually another interesting dimension of that. Just imagine for a moment a quality improvement team working on yield improvement. They meet every week for an hour; a group of five or six people, and they sit around there and they go through that 7-step process.

There's always a critical creative moment in that process when people now understand what the rood cause is and somebody has to trigger the process of coming up with corrective actions. There are these five people. We've been meeting for three years. In fact if you looked at our yield numbers there, between 1987 and 1990, we doubled the yield. Now, from a manufacturing perspective what that means is the effective capacity of our equipment doubled. Equipment that was in place doubled in capacity because our yields went up. We were getting twice as much good product each hour that we operated that machinery.

Now as a consequence of that, what happens to the financial accounting systems? Labor variances go up because you're not generating enough product to absorb the costs. So the message comes down from the accounting department "Lay off people. You've got too many people." And in fact, you do! If you don't grow the volume of your business as rapidly as you're improving, then your utilization rate goes down, not up. And so in some areas, our utilization rate went down.

Suddenly it's time for our weekly meeting, only four people! "What happened to Sally? She got laid off! Why'd she get laid off? Well because we improved. Oh, I know what to do next about that." This whole restructuring issue raises a whole bunch of questions in terms of conflicting signals. And when you talk about the Japanese in terms of lifetime employment, and you talk about Deming in terms of lifetime employment, and you experience

continuous improvement and the effect that layoffs have on the whole incentive associated with continuous improvement, you realize that there is an issue that management has to face. They have to manage that issue, because if you don't manage it turns off the improvement process.

So there are all kinds of issues around human capacity, equipment capacity. Right now, what I'm arguing with our accounting people is that we ought to justify capital investments in manufacturing based on 70% utilization rate until we are able to eliminate variability from the manufacturing process, which probably won't occur during my career. We need to say that you don't design a factory to operate at 90%; you design a factory to operate at 70%. So if you have the capacity in place, both people capacity and equipment capacity, to deal with variation in the system. And you can take that 30% of the time with people, you can train them, you can have them work on continuous improvement activities. There are lots of very useful things that you can do with people that aren't producing product.

Chairman: We have time for a couple of more questions.

Q: When your utilization went down, your profit didn't necessarily follow, for example, and could you not have shown that to the executive people?

No, our profit didn't go down, but it didn't go up. And so here's a great opportunity to increase profit: eliminate people. The fact that direct labor…

Q: How could you make that decision?

Well, we made that decision. That's an "up one." The slack is out of the rope when you start making decisions at the executive level that send conflicting messages, partly because you're a spectator. Now I think we've passed that point at Analog. I mean this is a very exciting time at Analog because all the issues that I'm sharing with you are issues that we talk about every day at Analog. And we're struggling with them. They're not simple issues. On the one hand we've got survival of the Corporation. It doesn't do any good to have lifetime employment for people when the net result is nobody's employed. There are all kinds of very complex issues here and they can only be addressed when you start driving TQM up the organization and get those people to be debating the kinds of issues that we're talking about here.

Q: Do you have automated systems for collecting the data or do you have hordes of people collecting the data?

Good question. On the on time delivery metrics we did that through our corporate centralized order entry system. There was a team that I put together of five people who worked for a period of about two years in putting together that measurement system. Very detailed, very comprehensive, very expensive.

Now I told you that Professor Shiba, when he comes to visit us looks at some of the things that we've done that I'm particularly proud of and he says "bad." His model is very different and any of you who have dealt with the Japanese may have experienced this. That model basically is you don't need a fancy information system in order to collect TQM data. You do little experiments. Go out, pick 50 orders out. Look at those 50 orders. Were they all on time? Were they not on time? If 50's not big enough, pick a hundred out. Do an ad hoc experiment. Don't build big systems. Now, that's another open issue.

We've got a lot of very exciting open issues. One model basically says, and it's the model I use… the slide that I normally put up to start my presentation has information systems right in the middle of it. It's three over-lapping circles, right in the middle is information systems, because I've always felt that information systems is the key to accelerated improvement. But the Japanese model' s very different: ad hoc, no formal systems, no big systems.

Q: Art, you said you hand out some copies of your …

Yes, there's a sign out sheet out there. I'll be making copies of all of the slides that I showed you. They will go out to you. If any of you want more details on this half-life method drop off your business card and I'll put together a little package that has a very interesting Harvard Business School case that has been written on the pros and cons of that approach.