The Analog Devices Story

c. March, 1990©

by

Arthur M. Schneiderman

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By early 1990, the requests by our customers to have me describe how Analog Devices had achieved such remarkable improvement as a supplier to them far exceeded the time that I could dedicate to that purpose. But there was no one else fully qualified to tell the entire story and answer the resulting detailed questions. Those who came closest to qualifying were the members of my small support staff. At their request, I made the following videotaped "typical" customer presentation using the well-worn set of overheads that I had developed during the previous two years. It represents a snapshot of a constantly evolving story.

Revised 8/12/00 10:30 PM

Slide 1

The Analog Devices Story c. March, 1990

Arthur M. Schneiderman

(From a Videotape)

 Slide 1 Title

Hello, I'm Art Schneiderman, Vice President of Quality and Productivity Improvement at Analog Devices, and I'm here today to describe to you our quality and productivity improvement efforts.

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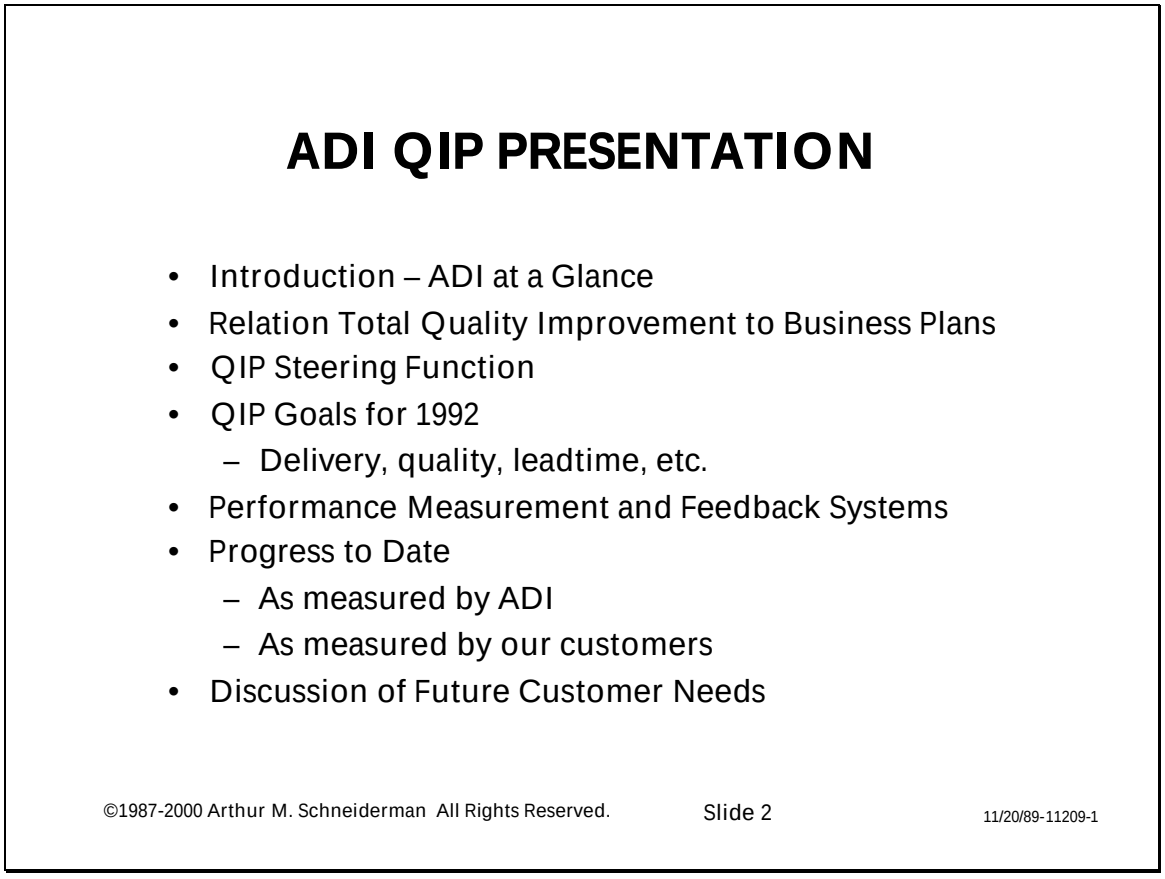

The presentation that I'd like to give to you today will start with an introduction of Analog Devices. I'd like to give you about a five or ten minute overview as to who and what we are as a company. And then I would like to talk about some features of our quality and productivity improvement efforts that are unique to Analog Devices, or perhaps nearly unique to Analog Devices. I'm not going to spend a lot of time telling you things that you already know about the Quality Improvement Process or Total Quality Control. Instead I'd like to focus on those things that might be a little bit different in terms of what we do.

And, among those are the fact that we very closely relate our quality improvement efforts to our business plan, and I'd like to show you that linkage and how we manage it at Analog Devices. I'd then like to introduce you to our Quality Improvement Process function. Those are the people that I'm actually representing as I present to you today. Then I'd like to turn to our very specific 1992 goals and tell you what we are expecting our delivery, quality, lead-time and other performance parameters to be in 1992, what they were in 1987, and what they are today. And I'd like to describe to you our performance measurement and feedback system and how we use our

measurements in order to manage the company. And finally, I'd like to describe to you our progress to date both in terms of how we measured our performance and how you, our customers, measure our performance. And then I'd like to have an opportunity to discuss with you what your future needs might be so that we can begin the process of integrating those needs into our planning process. Let me start with a description of Analog Devices.

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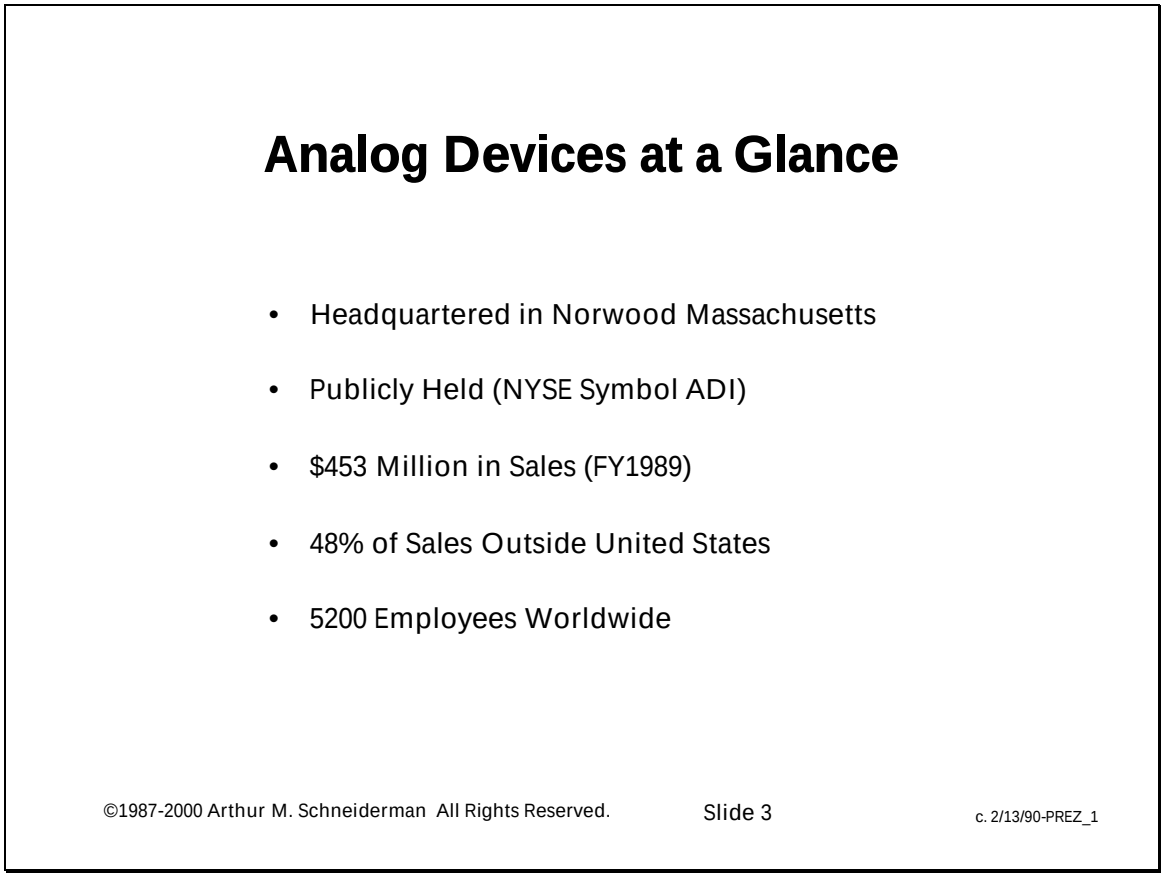

Analog Devices is a corporation headquartered in Norwood, Massachusetts. We are publicly held and traded on the New York Stock Exchange. Our 1989 revenues were a little over $450 million dollars of which a little under half came from outside of the US. So we are an international company, and I'll show you a little more about that in a moment. We currently have 5200 employees worldwide.

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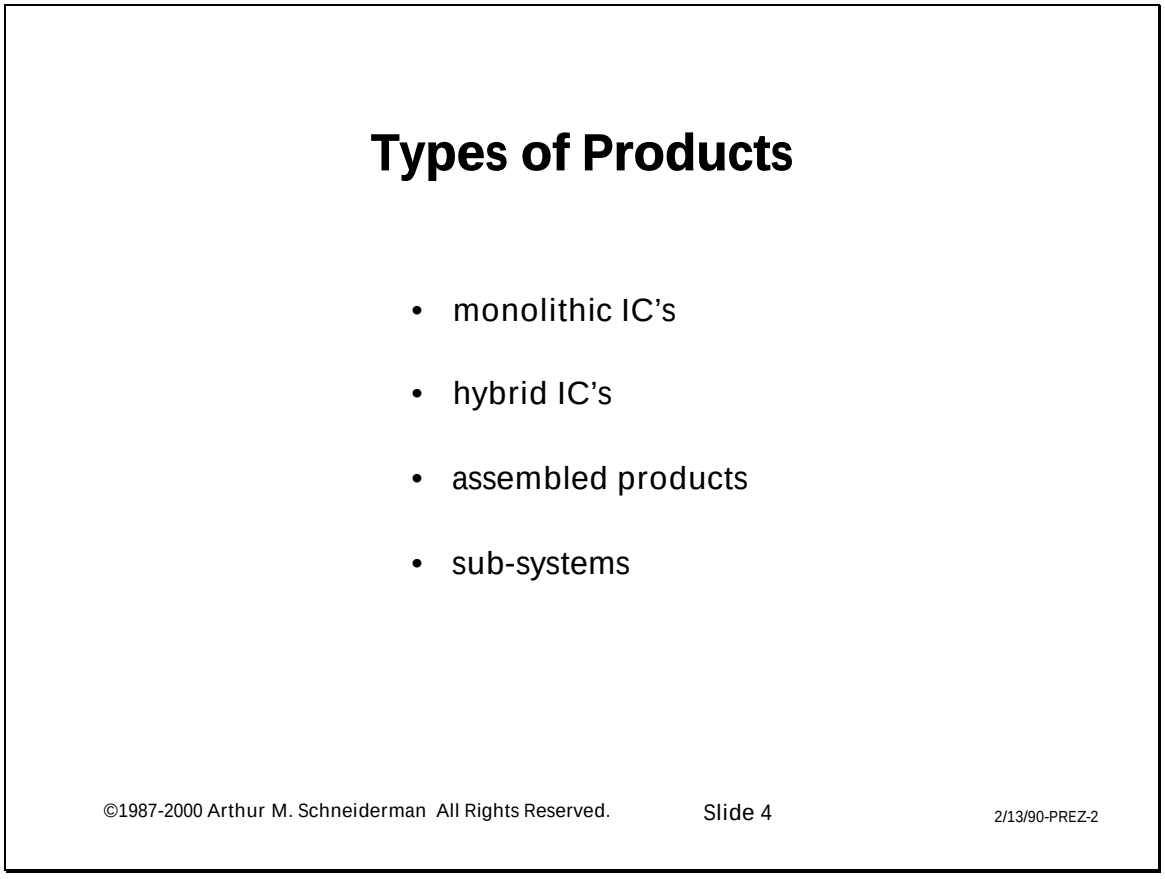

The products that we manufacturer fall into the category principally of monolithic integrated circuits. We also manufacture hybrid ICs, assembled products, and a small number of subsystems.

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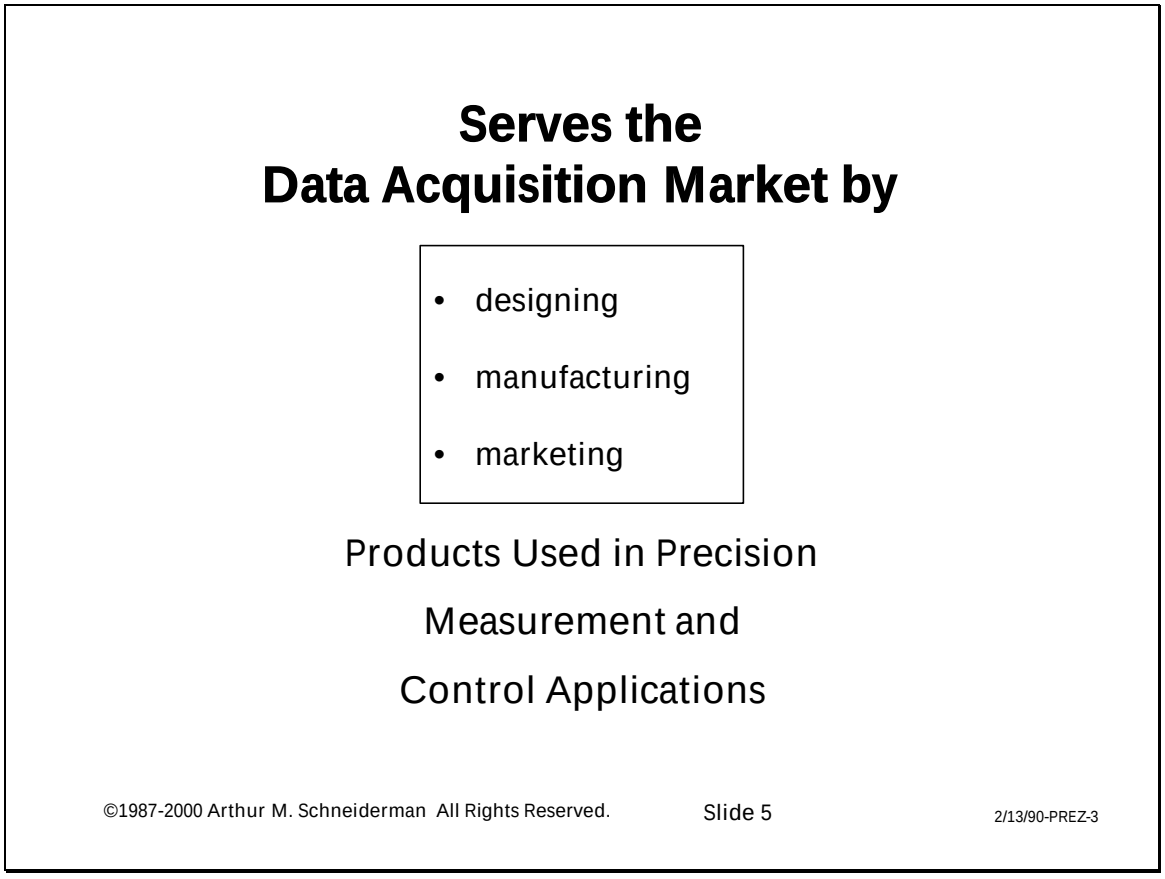

Analog Devices products serve the data acquisition market and we serve it by designing, manufacturing, and marketing our products. We're an integrated manufacturer of these products. They're used principally in precision measurement and control applications, and I'll give you some more details of that in a moment.

Slide 6

Analog Device Manufacturing Facilities

Wilmington, MA	Surrey, England	Tokyo, Japan
Andover, MA	Limerick, Ireland	Manila, The Philippines
Norwood, MA		???
Greensboro, NC		

 Slide 6 2/13/90-PREZ-6

Our manufacturing facilities are located throughout the world. In the US we have our largest wafer fab, our bipolar wafer fab, located in Wilmington, Massachusetts. We also have hybrid facility in Wilmington. Subsystems are manufactured in Andover, Massachusetts. We have board level and hybrid products manufactured in Norwood, as well as our DSP products. And we have modules and board level and hybrid products as well as a wafer fab in Greensboro, North Carolina.

In Europe, we have a division in Surrey, England which designs our synchro-converter product line, that's angle to digital converters, and in Limerick, Ireland, we have our second largest IC facility, a CMOS wafer fab and assembly facility. The products that are manufactured in Wilmington are principally assembled in a facility in Manila, The Philippines that employs about 700 people. In Japan, we assemble and test products for sale to the Japanese market.

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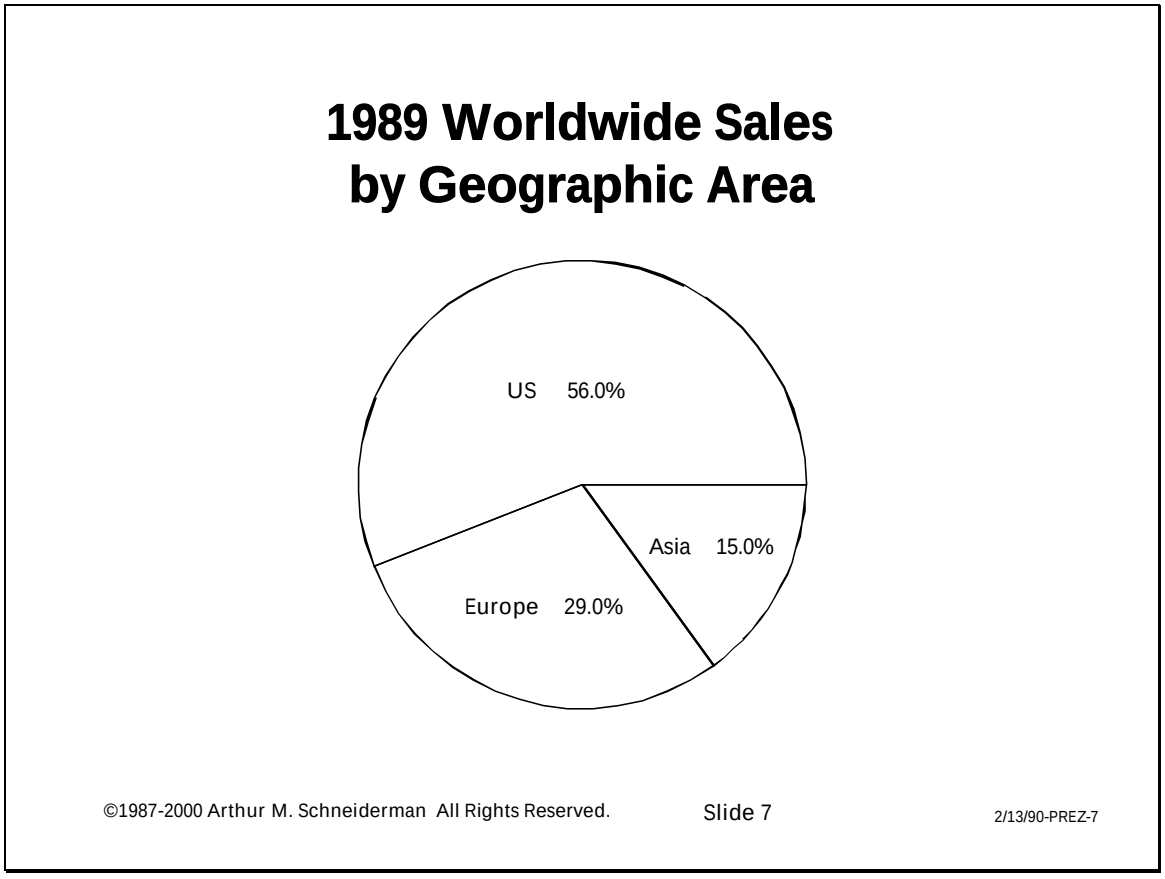

As I said earlier, our products are sold throughout the world; a little over half in the US, and nearly a third in Europe and the rest in Asia. We'll talk a little bit later on about our customers in Asia and I'll show you who some of those customers are and you'll understand with respect to those customers and with respect to the fact that this is one of the fastest growing geographic areas in which we are doing business, how that might relate to our quality achievements at Analog Devices.

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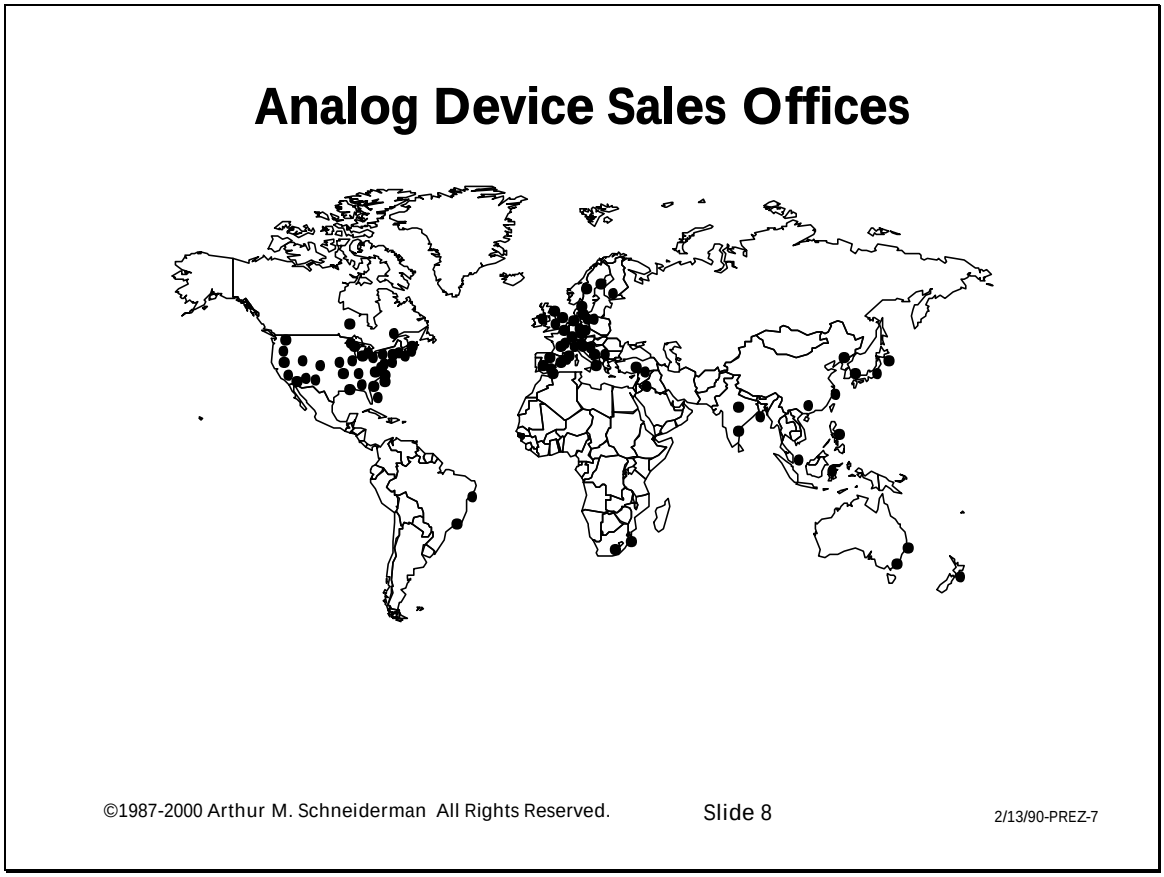
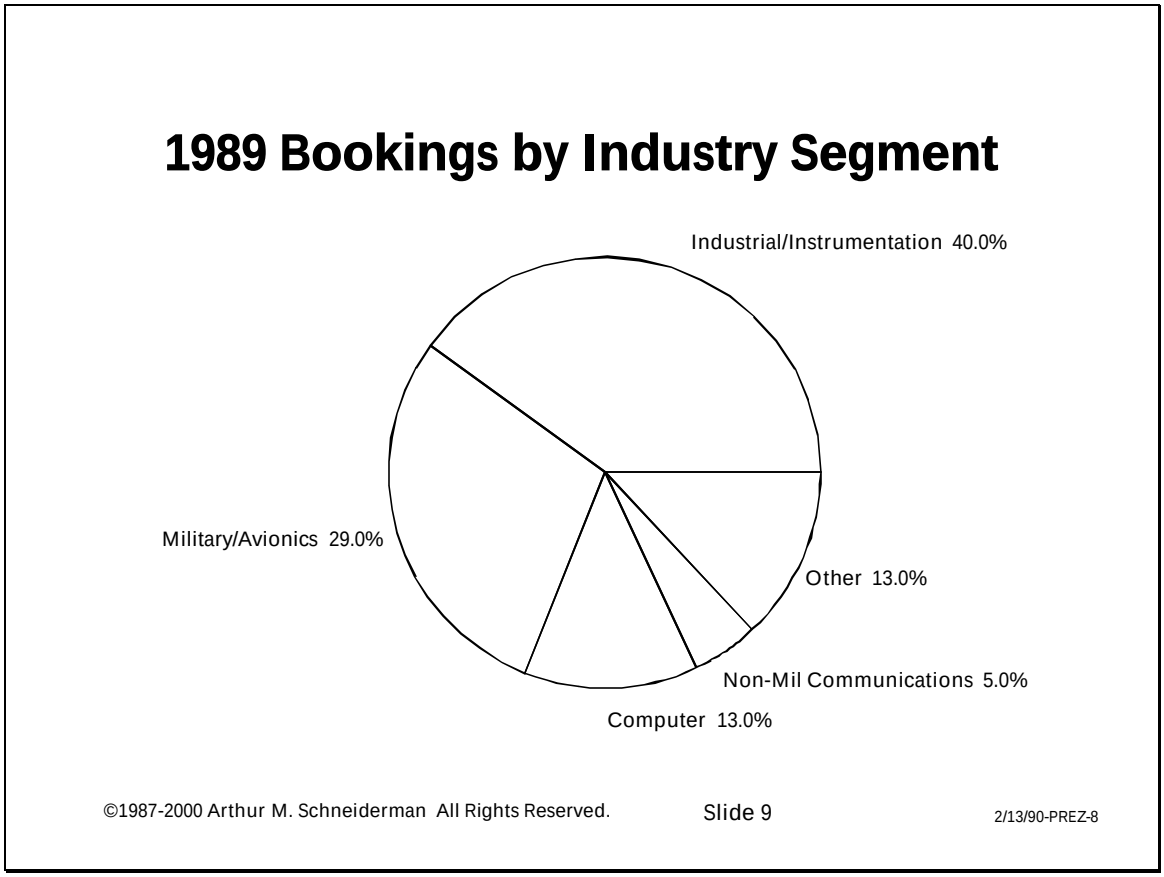


I said earlier that we are an integrated manufacturer. We also sell our products through our own sales and marketing organization worldwide. We generally do not use distribution. I will not go through each of these dots and tell you where they are because I'd flunk that test, but as you can see from this chart we do have sales offices all over the world.

Slide 9



Our customers, because we're in the high performance portion of the data acquisition market, tend to be in market segments that make most use of high performance products. Our largest market segment is the industrial and instrumentation segment, about 40% of our customers are in that area, followed by military and avionics at 30%, computers at 13%. And the computer applications here are principally in large mainframe disk drives. We make a lot of products that are used by IBM, as you'll see in a moment, in their large disk drives. We also have a small but growing portion of our business in non-military communications products.

Slide 10

1989 Top Customers Worldwide

Customer	*Bookings $M*	*Cumulative %*
IBM (US, Japan & France)	26.8	6.0
GE/RCA	10.5	8.3
Fuji (Japan)	10.3	10.6
HP (US, UK & Germany)	9.1	12.6
Honeywell (US, Germany)	7.4	14.2
General Dynamics (US)	5.4	15.5
Raytheon (US)	5.1	16.6
Siemens (US, Germany)	5.1	17.7
TI (US)	4.1	18.6
Mitsubishi (Japan)	4.0	19.5
Fujitsu (Japan)	4.0	20.4
Toshiba (Japan)	3.7	21.1
Marconi (US, UK)	3.6	22.0
Hughes (US)	3.4	22.8
Rockwell (US)	3.3	23.5
Hitachi (Japan)	3.3	24.3
Westinghouse (US)	3.1	25.0
Philips (US, Europe)	3.1	25.6
Motorola (US)	3.0	26.3
DCASR (US)	2.7	26.9

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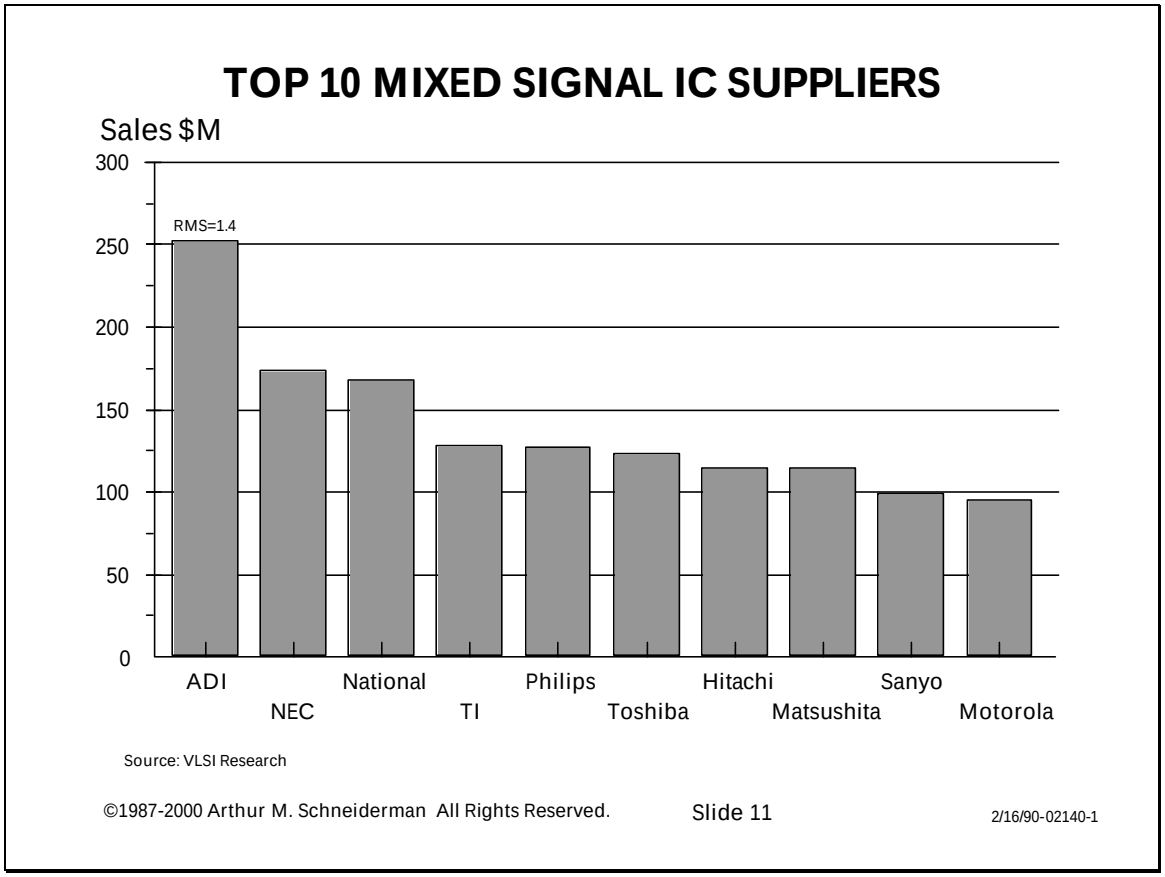
You can get a very good sense as to the quality of our customers, which I think again I think is reflective of the quality of our products, from this chart. This is a list of our top 20 customers worldwide, showing what our 1989 bookings were for each of these customers and what the cumulative percent these represent. I think that one thing that you might notice as you get down to the bottom here, our top 20 customers account for a little over a quarter of our total bookings. And, I think that's indicative of the nature of our business; there are very few companies in which this number would not be significantly larger. The majority of companies this number would be significantly larger, perhaps as large as 80%, but our customers are very fragmented. We basically have a very large customer base, approximately 10,000 customers worldwide, and that is one of the reasons that we are described as a niche supplier of our products.

Now if you look through the list of customers here, you see among the most prestigious manufactures of electronic equipment in the world, ranging from IBM and Hewlett-Packard in then US, Honeywell, General Dynamics and Raytheon as we get into our military customers. Siemens in Germany, Siemens is our largest customer in Europe and one of the largest electronics

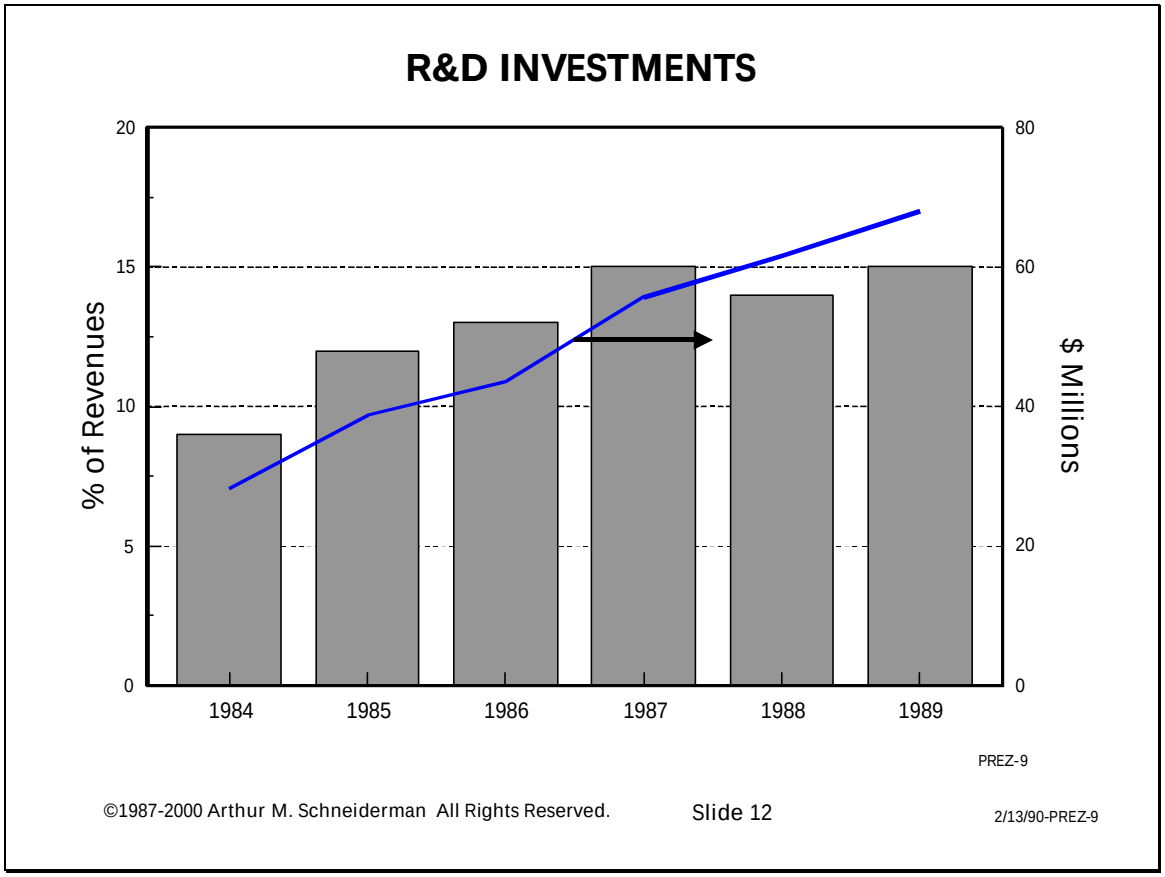
manufacturers in the world. But I think another thing that you see as you go through this list is the number of large Japanese electronics companies, starting with Fuji here, going through Fujitsu, Toshiba, Hitachi, all of the major electronics companies in Japan are major customers of Analog Devices. And I think that that's a very important measure of the quality of the products that we're able to provide. You'll find that in Japan there seems to be little interest on the part of Japanese semiconductor manufacturers to try to compete against Analog Devices. And we believe that the principle reason for that is that we're already been able to achieve the levels of customer service, the levels of quality that they demand of their suppliers. So they realize that there's no need for them to enter markets and compete against us in order to get better quality products.

Slide 11



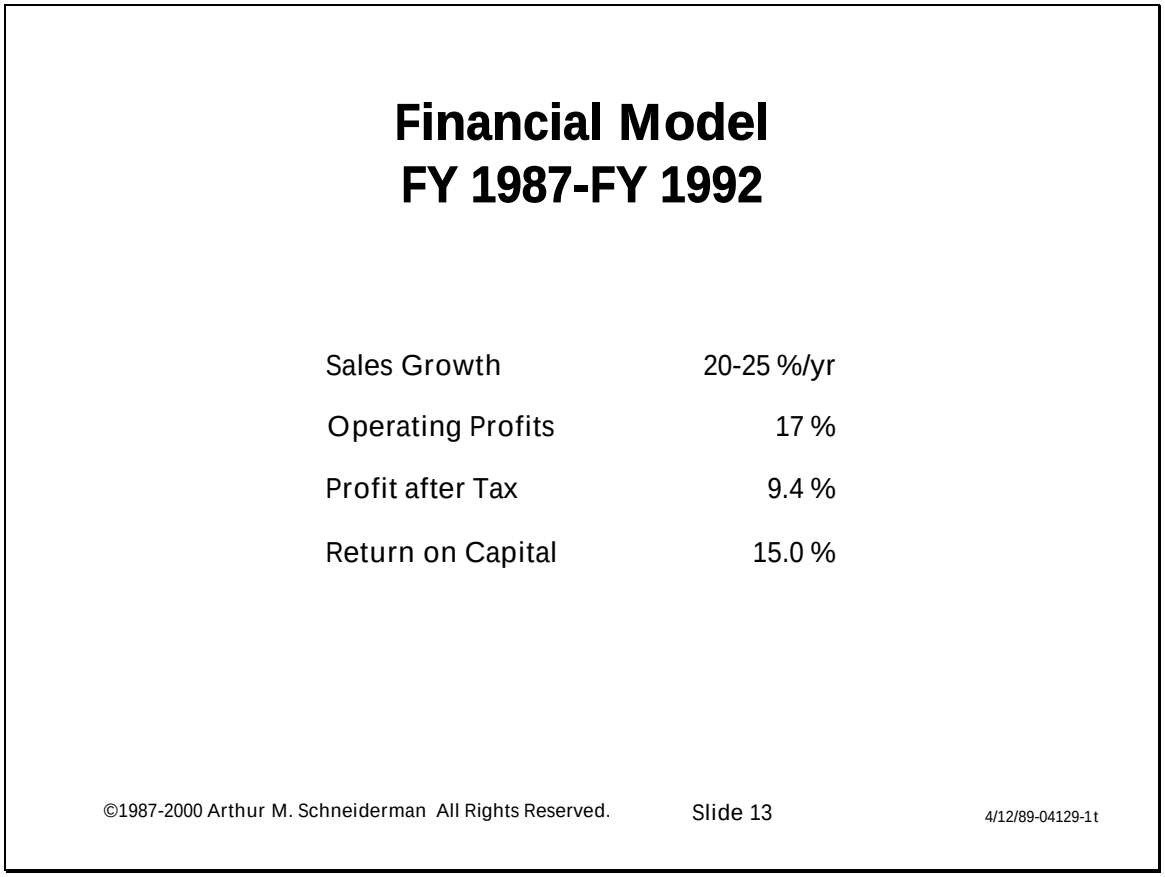
One thing that might come as a surprise to many people, it certainly came as a surprise to some of us, is that if you define mixed signal integrated circuits to include converter products in them, than Analog Devices is in fact the largest supplier of mixed signal integrated circuits in the world. As you look at this list you see that NEC, which is our closest competitor, is about $175M in revenues and the ratio of our market share to their market share is about 1.4. It's a very strong competitive position. So although ADI is a small semiconductor manufacturer, you can see that our major competition is among the largest semiconductor manufacturers in the world. And again, the fact that we are able to maintain a dominant competitive position, I think is a test of the nature of our products, the nature of our relationship with our customers.

Slide 12



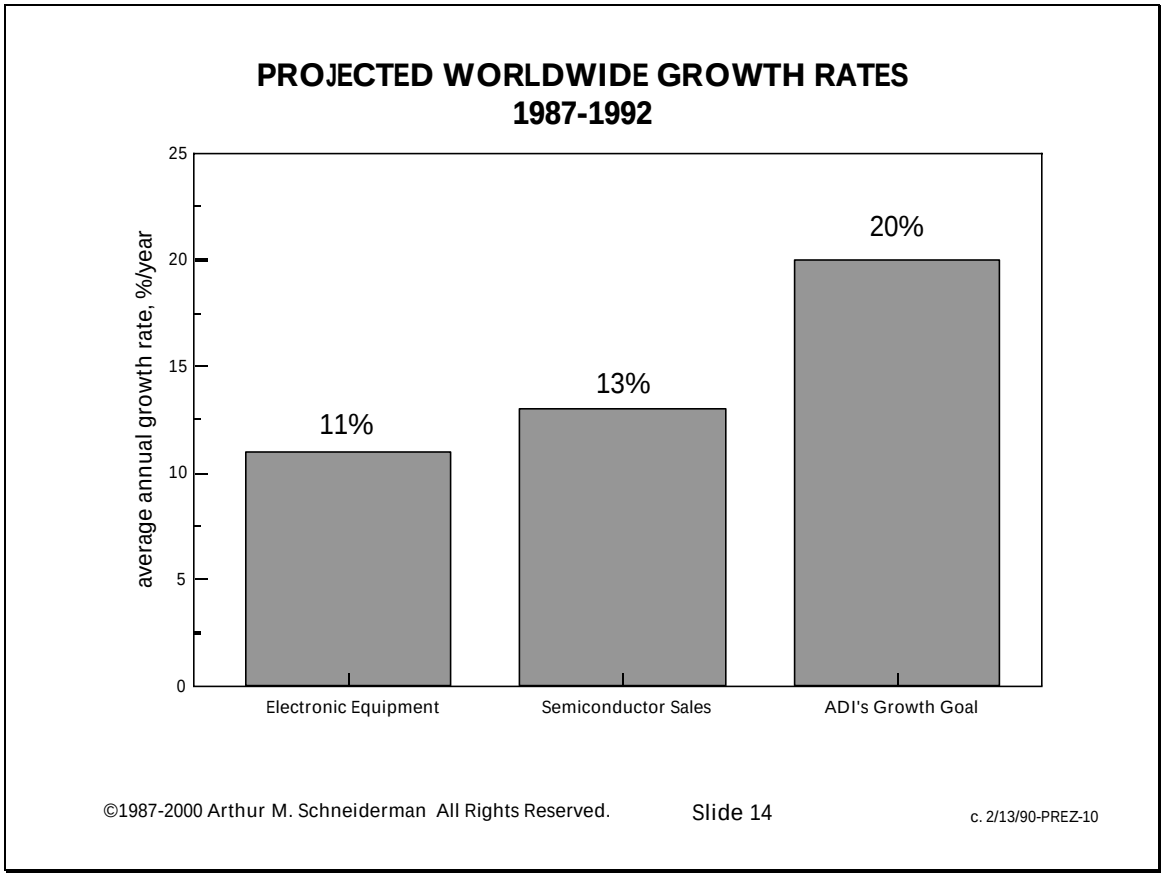
One of the most important things that we've used in order to achieve that level of performance is very significant reinvestment of our revenues in R&D. And as you can see from this slide here, that in recent years we have been reinvesting between 13 and 15% of our revenues back in the business in R&D. During this period of time in here, much of that investment was in the development of new manufacturing processes. We transitioned from this period to this period by bringing on line a very large number of powerful mixed-signal processes and in the period of 1989 and on in the next five-year period, we're going to be bringing the fruits of that development to the marketplace in terms of a whole series of new products based on these new mixed-signal process and new high-performance linear processes that we've been able to develop. So a lot of the reasons that our customers recognize the performance of the products that we're able to bring to the market place is because of the nature of the investments that we've made in order to do that.

Slide 13



Analog has been fortunate in that it has been a continuous and reliable performer in terms of its financial measures. This represents our 1987 to 1992 financial performance model and as you can see we would like to be moving into the future at a growth rate of between 20 to 25% a year. I'll talk more about that in a moment. Operating profits running around 17%, profit after tax about 9%, return on capital of 15%. I think that this level of profitability is what has allowed us to achieve the levels of R&D investment and the levels of new product and new process development that I showed you earlier.

Slide 14



The top line there, the sales growth of 20 to 25% a year is a particular challenge for us at Analog Devices. And it's a challenge because our traditional markets, electronic equipment, have relatively slower growth as we look into the future. We're looking for growth in the electronic equipment market of about 11% a year, the percent of the semiconductor content increasing, in terms of the content of components in electronic equipment. We can see that grow to 13% a year. But we have a minimum growth objective of 20% a year. This represents a major gap that we need to fill. And a lot of our strategic focus is on filling this gap. As we proceed and I talk about some of our goals you will see that we are beginning to do, and succeeding in doing, the things that are necessary in order for us to move into new product areas, related to our existing product areas and new customer areas related to our existing product areas in order to fill this gap. You'll understand how this all comes together as I proceed.

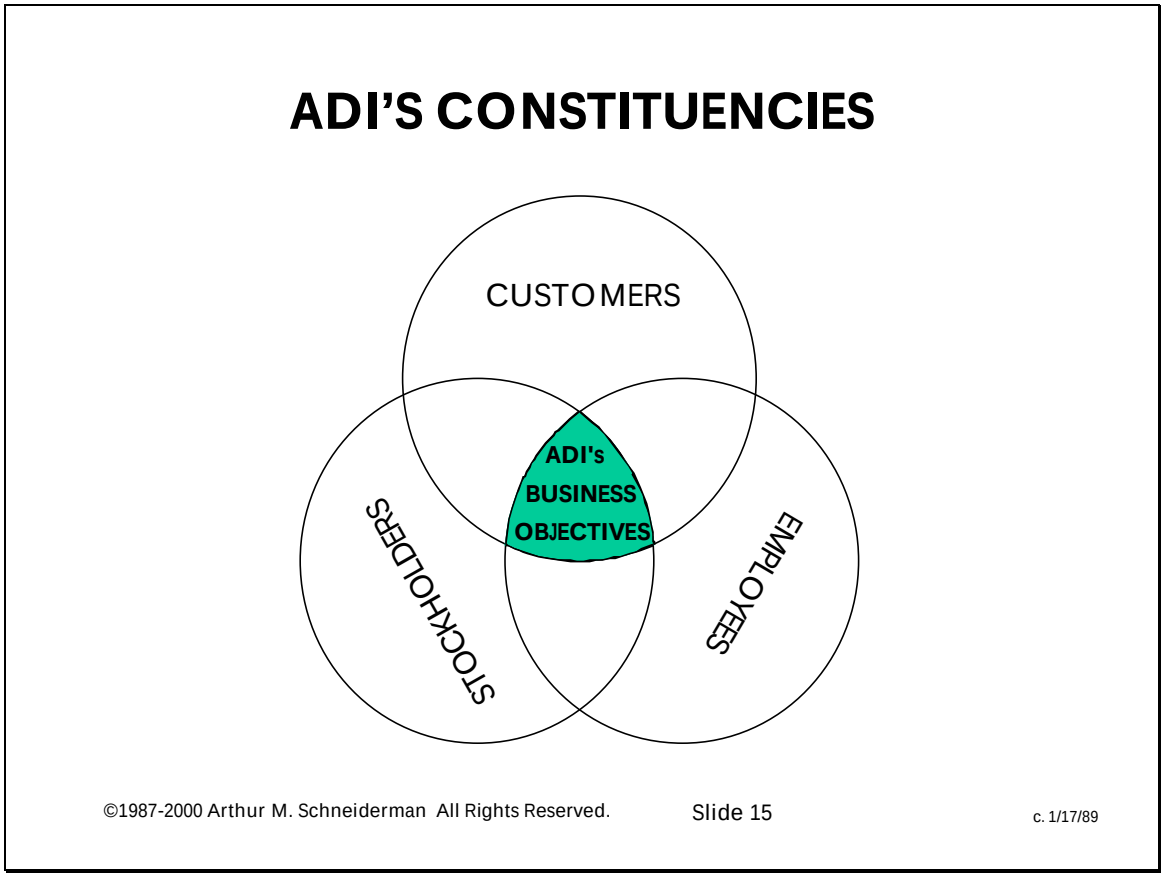
(Show slide 1 again)

I want to go back to our agenda slide. This is now going to turn to the question of how we go about relating quality improvement to our business plans.

(show the Corporate Objective brochure to the audience)

Analog Devices overall Corporate Objective is captured in a document that was developed in 1975 first and has been updated several times called the Corporate Objective. And the Corporate Objective is a relatively succinct brochure that describes what Analog Devices reason for being is.

Slide 15

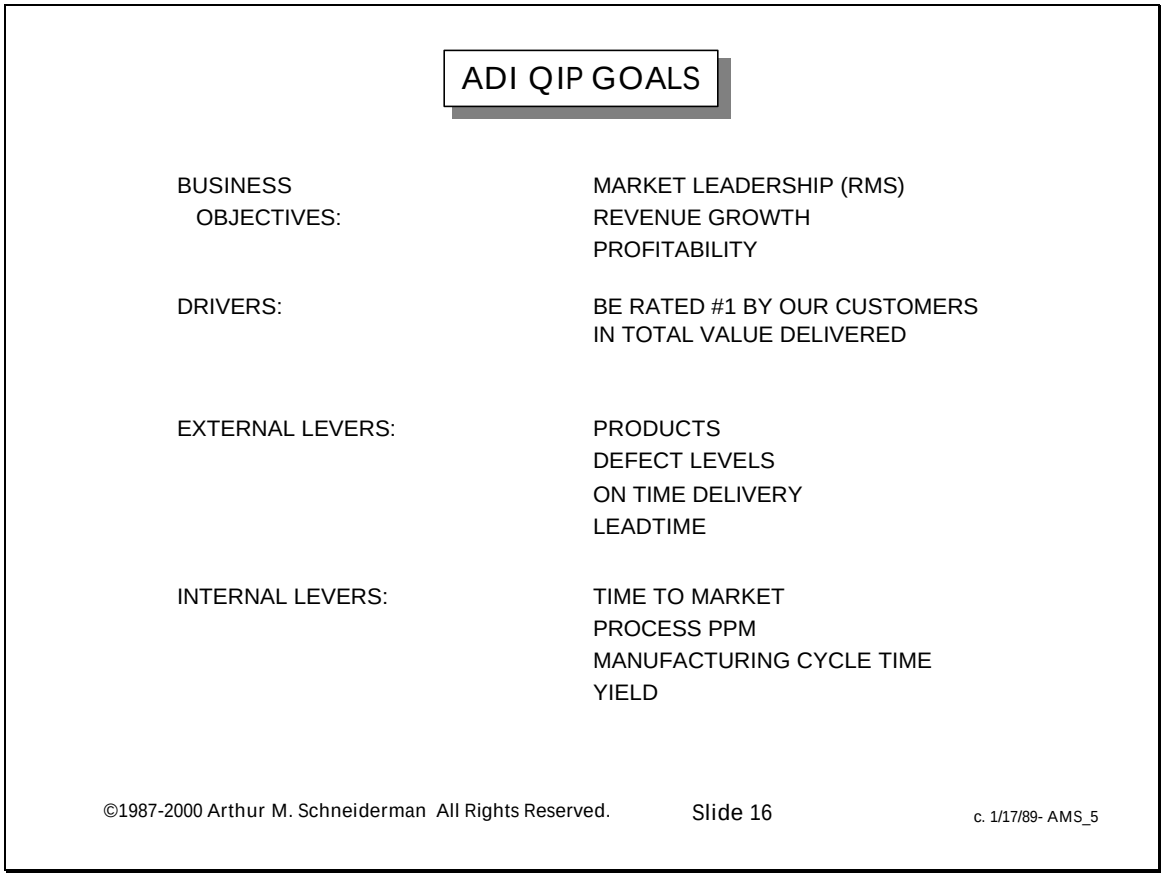


In essence what it translates down to is the recognition that Analog Devices has three major constituencies: its customers, its employees and its stockholders. Now the origins of this concept, as I said earlier were in the 1975 period, and if you back to 1975, most companies, in terms of their corporate objective, had only one of these; namely, their stockholders. They viewed the purpose of their organization to be exclusively to maximize the wealth of the stockholders. But in the mid-1970s, Ray Stata, our Chairman and founder, recognized that Analog could not achieve the level of excellence that he envisioned for the company with that one-dimensional focus. And in that Corporate Objective, he set a set of goals for us, not only in terms of our performance for our stockholders, but our performance to our customers and to our employees. And this really remains the basic trilogy that represents Analog Devices' constituencies and the overriding purpose for our being.

There are many things that we do at Analog Devices to benefit our customers, benefit our employees and benefit our stockholders. But as I move forward and talk about our quality improvement efforts, I want to focus on the area of common overlap between these three constituencies and that is our business objectives. At Analog we recognize that in order to meet the needs of our

customers, our employees and our stockholders we must achieve very aggressive business objectives. That in itself is not enough, but it certainly represents a common denominator. There are things other than business related objectives that need to be done for example in meeting employee's needs, in meeting customer's needs. But I want to talk just about the things around a subset of common objectives that we have in terms of our business objectives and show you how what we do in the area of quality improvement relates to that set of business objectives.

Slide 16



In terms of the slide I showed you earlier, you shouldn't be surprised to see that the three major objectives that Analog has in terms of the business objectives is to maintain its position of market leadership in mixed signal devices and high performance linear devices, to be a revenue growth company and to maintain the levels of profitability that are needed in order to satisfy the needs of our three constituencies. Now I'm not going to dwell on this except to tell you that these three things, as simple as they sound, represented the results of 18 months worth of effort on the part of 250 people within Analog Devices, as we went through the process of generating our 1987-1992 strategic plan. Each one of these was carefully examined by all 250 of the people that participated in this process to make sure that when we say market leadership we knew what that meant. And when we said revenue growth, we knew what that meant. So these are not simple terms. Behind each of these terms: leadership in terms of market share, revenue growth, and profitability lays a detailed plan that has been developed by a combination of bottoms-up and tops-down planning. That's the starting point.

Now in terms of achieving those business objectives, we know that there's one principle driver. Analog Devices today <u>is</u> a customer driven company.

And it is our belief that in order to achieve our business objectives we need to be rated #1 one by our customers. If we achieve that rating of #1 by a significant enough portion of our customers, then we believe we have the best shot at achieving our business objectives.

Now when you say rated #1 you imply that there's some sort of rating criteria. And in the past that rating criteria was captured in our catalog. Our customers judged us and rated us on the basis of the performance specifications of the products that we sold. But something's changed, as I'm sure you all know. And in recent years it's not simply products alone, or the specifications of products alone that sell them. There's an emerging concept in terms of what it is that customers rate us on that we at least for the moment try to capture in the word "value." To us what basically is the important thing is that we provide to our customers the best value in terms of the products that they're buying. And I'll explain a little bit more in a moment what I mean by that. But it's not just performance any more. There are more things that enter the formula. And the issue here is that whether it's done subjectively or objectively on the part of our customers, they determine the total value of what the various competitors have to offer. And they rate one #1 on the basis of "total value delivered."

Now we need to explore and understand what constitutes total value. But we know that it's not simply the one-dimensional characteristic of product performance. It use to be and so value meant products. But today, value means much more than that. Those products need to arrive defect free at our customers. They need to remain defect free through our customer's manufacturing process and they have to continue to be defect free through the useful life of our customer's products. In other words, they need to be reliable for our customer's customers. The products also have to arrive on time and on time is an ever-changing target, except that it's always changing in the same direction. On time is a narrower and narrower window.

Parts have to arrive on time to our customers because many of them have gone to just-in-time manufacturing. They want the parts to arrive within two days, in many cases, of the time they plan to use those parts. Now linked in with that on-time delivery are the shorter and shorter lead times that are also associated with just-in-time manufacturing techniques. So our customer's formula, the things that go into the calculation of value, are not only products but they're defect levels, quality levels, delivery performance, their lead-time. And we certainly know that as time goes on some of these things will disappear from this list and other things will be added to the list. But at any point in time these are the kinds of factors that customers use in computing value.

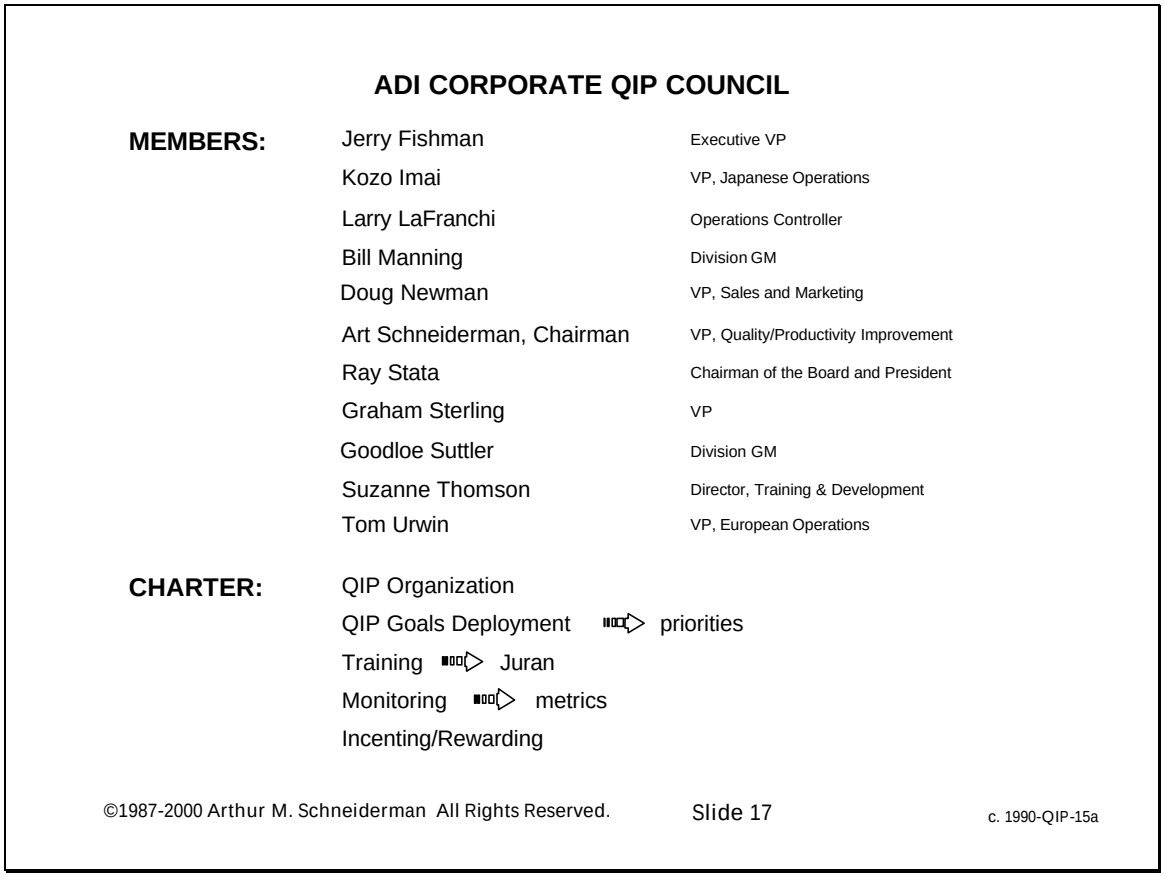
Now one of the important elements of this kind of view of things is that different customers way these things differently. For example, our military

customers tend to be much more interested in defect levels; in reliability and quality, for obvious reasons. Whereas some of our consumer products customers tend to be much more interested in on-time delivery, short lead times and what can be newly added to this list, price; purchase price. So that if you say "we want to be rated #1 in total value," that clearly depends on how one mixes in importance these different factors. With one exception: and that is no matter how you mix things, if we're #1 in products, #1 in quality, #1 delivery and #1 in lead-time, no matter what customer we're looking at, we will come out being #1 in total value. So the important thing to us at Analog is that we need to strive to be #1 in all things that are important to our customers.

That represents somewhat of a departure from traditional strategic theory which basically says that you've got to focus on one or more of these things, but we believe that the Quality Improvement Process leads to an opportunity to achieve world class performance in all of these dimensions. And that is our objective. Now having said that, it's quite obvious that there is at least one way that we could achieve world-class performance in each of these areas. We could carry very large inventories to reduce our lead-times and assure on-time delivery and we could do 100% inspection or 200% inspection or 300% inspection in order to control our defect levels. But, if we try taking that approach, we would fail in this dimension. We certainly would not be able to sustain ourselves as a business for any period of time by using inventory and inspection as ways of doing this. So we need to refocus our efforts within our facilities in order to achieve those objectives. And the way we refocus them is to look toward internal performance measurements that are linked directly to these levers, which in tern are linked directly to value and to our business success.

The internal levers are time-to-market, that's the time it takes us to develop a new product, the process capability, the inherent capability of the manufacturing process to make defect free, reliable products, manufacturing cycle time and yield. I'm going to talk in a little more about each of these things. But you can understand that as you move down the organization and have groups of people at the operator level, at the supervisor level, at the first line manager level, working on these kinds of improvements, they understand very clearly that the advances that they make in these areas will lead to advances in these areas, will lead to maximization of the total value of what we deliver to our customers and to our achievement of our business objectives.

Slide 17



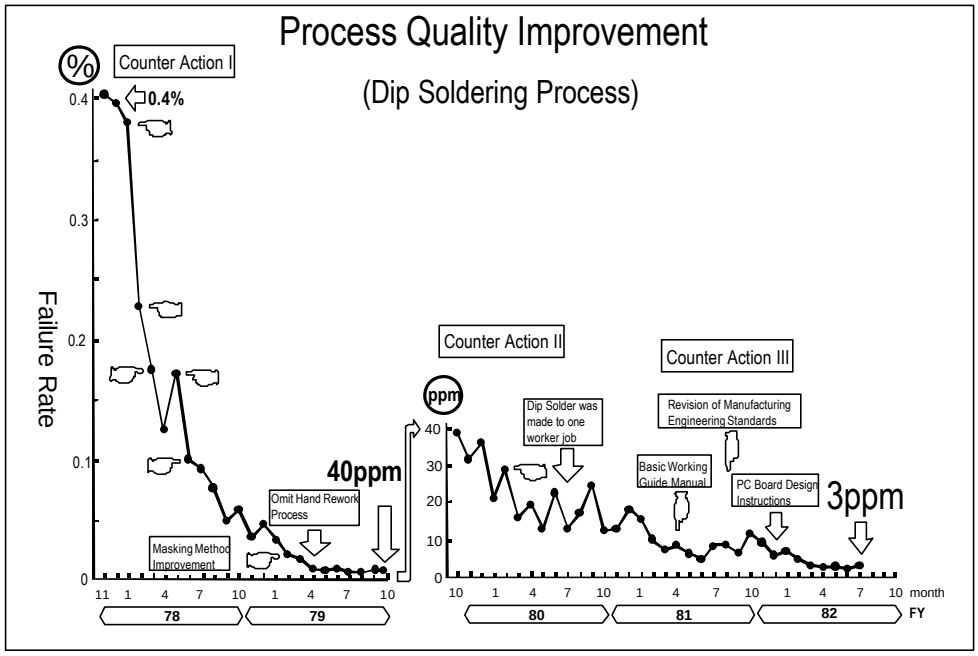
The origins of that model for linking our very specific operating performance measurement objectives to our overall business objectives is the governing body at Analog Devices with respect to our quality improvement efforts. And that is our Corporate Quality Improvement Process Council. I'd just like to point out to you the kind of membership that we have on this Council. We have Jerry Fishman who is our Executive Vice President and basically is our Chief Operating Officer; we have the Vice President of our Japanese operations; our operations Controller, who is representative of the service side of what we do, versus the manufacturing side. Bill Manning is the Division General Manager of an assembled products hybrid division; Doug Newman is our Vice President of Sales and Marketing. That's a group that I chair. Ray Stata is, as I said earlier the Chairman of the Board, the President of the company and Chief Executive Officer. Graham Sterling is another one of our Vice Presidents. Goodloe Suttler is the General Manager of our largest IC division. Sue Thompson is our Corporate Director of Training and Development, and Tom Urwin is our Vice President of European operations.

What we see here is a mix of senior executives in Analog Devices, a mix that's both geographic, that is functional, and that represents the steering group for

our quality improvement efforts at Analog Devices. Its charter consists of these five elements here. First of all it's responsible for determining how as a corporation we will be organized for quality improvement. It's also the group that was the originator of the slide that I showed you earlier in terms of coming up with our QIP or quality improvement goals and deploying those goals by setting priorities. It also is responsible for choosing our training methodology and basically our training focuses around the concepts and methodology that Joe Juran has introduced over the last thirty or forty years. It also devises monitoring systems and metrics and assures that our incentive and reward system is consistent with our quality objectives. And I might also point out that this group consists also of a majority of the members of the Executive Committee of the company and so we have a very strong overlap between the people who design the overall incentive and reward systems and this group of people.

Let me turn now to our 1992 goals. But before I do that I need to introduce a concept to you that will be important.

Slide 18



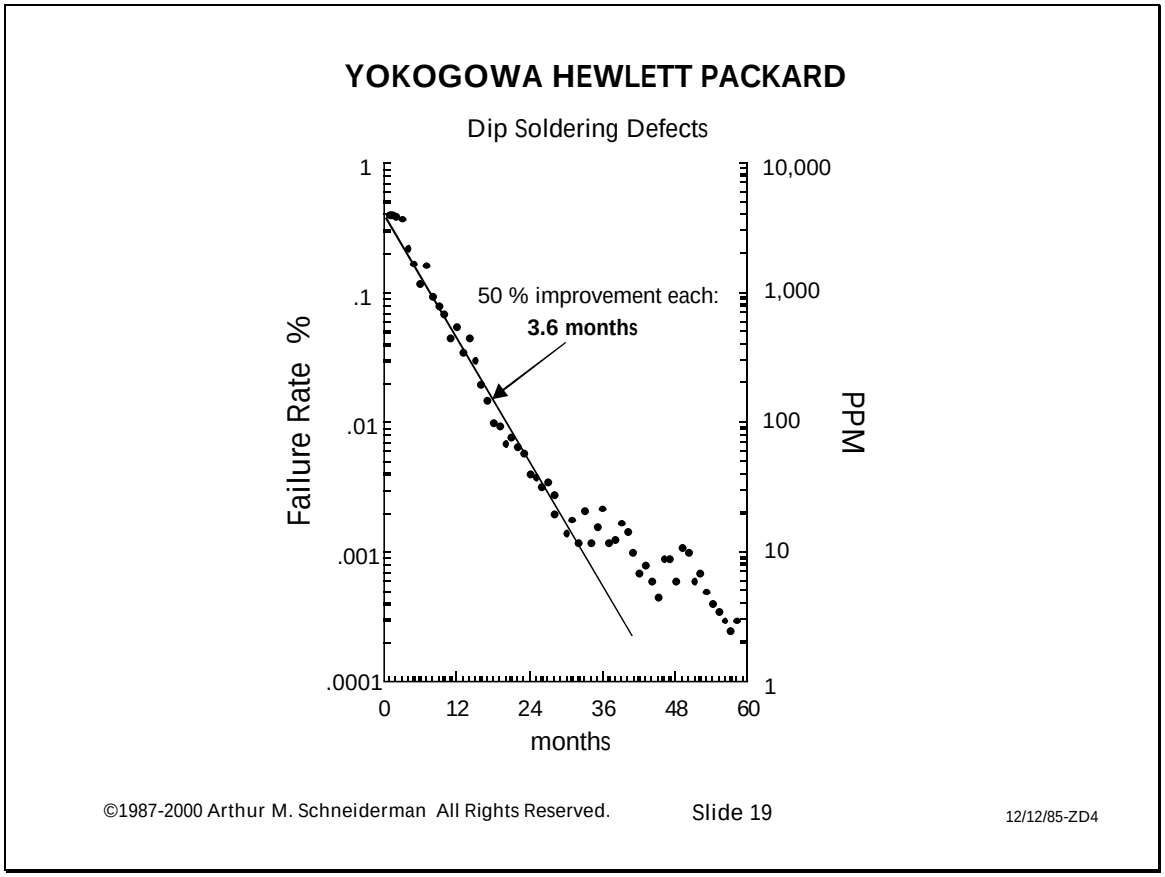
Source: Kenzo Sasaoka, President
Yokagowa-Hewlett-Packard 7/84

Slide 18

c. 1982-YHP

If I show you improvement data, this happens to be some data that was taken from Yokogawa Hewlett-Packard, and it showed improvements in their dip soldering process over the period of 1978 to 1982, you'll see a non-surprising shape to this curve. They started off at the beginning of their quality improvement efforts at about 4000 parts-per million defective, .4%, and they kind of moved down in improvement until they got to a point here where you couldn't see it on this chart so they changed the scale. And they had the same sort of a curve of improvement here. You can reformat that data and look at in a slightly different way by graphing it on what is called semi-logarithmic paper.

Slide 19



This is the same data that you saw on the previous slide graphed on semi-logarithmic paper. And the interesting thing is that we can now fit, by using this log scale, both of those charts onto a single graph; that's nice. But in addition to that notice that the data, over a three-year period of time, falls on a very good straight line.

Now one way of characterizing the slope of this straight line is by talking about the number of months that it takes to reduce the defect level by 50%. In this case, it's 3.6 months. So that if they started at .4% here, 3.6 months later they were down to .2%, or half of that. 3.6 months later, down to .1%, 3.6 months later down to .05%. Each 3.6-month period they halved the defect level from the defect level at the start of that period. And they maintained this constant rate of improvement over a three-year period of time, and over, as you can see, nearly three decades of improvement.

Now it turns out that in almost all cases the continues improvement process yields rates of improvement that are constant in terms of half-lives. And at Analog Devices, we have used this as a major planning tool in setting our goals.

Slide 20

PROPOSED HALF-LIFE MODEL VALUES

PROJECT TYPE	EXAMPLES	MONTHS MODEL HALF-LIFE	MONTHS EXPECTED RANGE
uni-functional	operator errors WIP	**3**	**0 to 6**
cross-functional	new product cycle time outgoing PPM	**9**	**6 to 12**
multi-entity	vendor quality warranty costs	**18**	**12 to 24**

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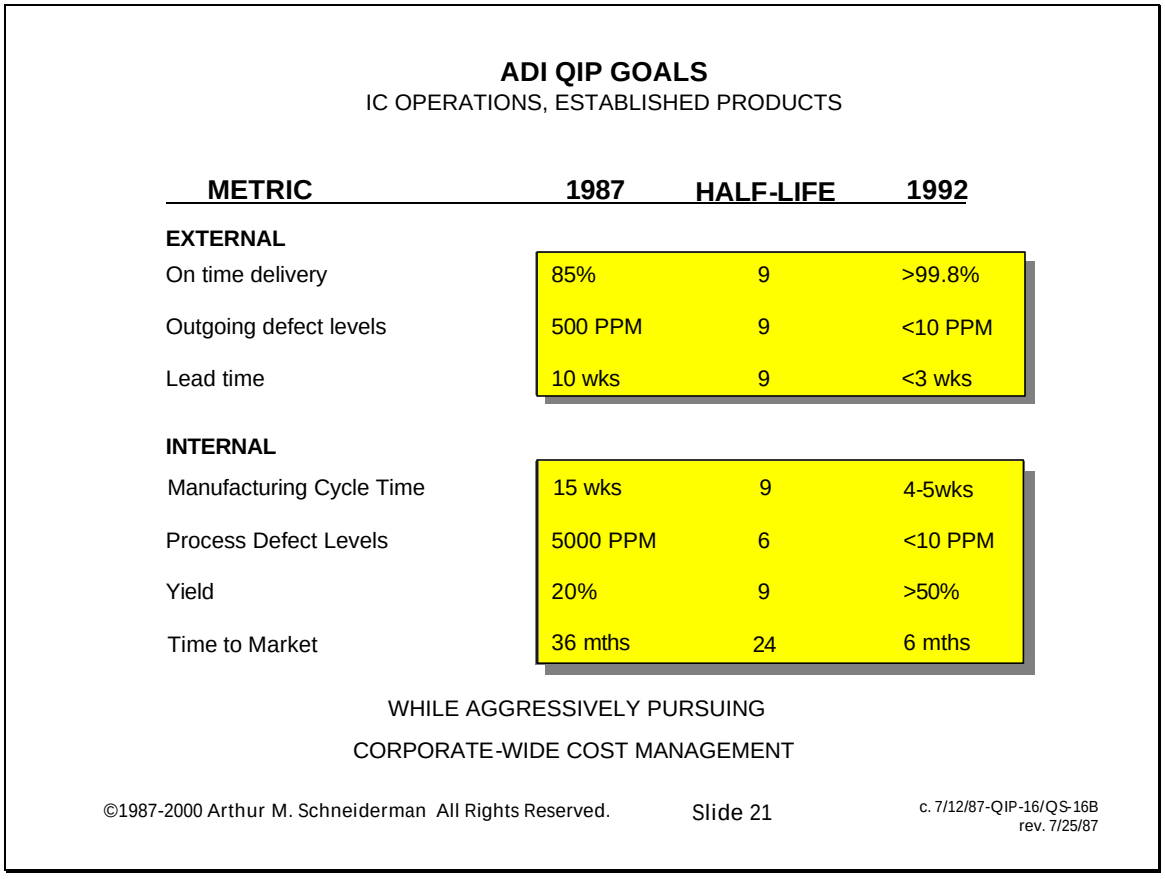
We've looked at a variety of examples, nearly a hundred examples, of this process and generalized the kind of expected rates of improvement based on the functional or organizational complexity of the problem that's being addressed. And if the problem can be solved within a single function, then we use as our model a half-life of 3 months with a range of zero to six months, depending on the technical complexity of the problem. If it's cross-functional in nature, things like new product development cycle time or outgoing defect levels, we use nine months as the half-life with a range of six to 12 months, depending again on the technical complexity of the problem. And if it's multi-entity, things like vendor quality or warrantee cost, in which different companies need to work together, then we observe that it takes longer to get 50% improvement: 18 months, with a range of 12 to 24 months. This concept of a half-life is a major element of our quality improvement process and the planning that goes along with that process. Now let me show you how we've used that.

Slide 21



(Cover numbers)

In the left hand column here, you see the external and internal measures that we talked about earlier: delivery, quality, and lead-time, from the customers perspective, and internally the things we need to drive in order to achieve improvements in this area: manufacturing cycle time, process defect levels, yields, time-to-market. Now what I'd like to do now is show you, along each of those dimensions, where we were in 1987, I'll describe to you where we are now, and tell you where we're going to be in 1992, and the half-life that we've assumed in getting between 1987 and 1992.

(Uncover 1987)

We first started our measurements of on-time delivery in 1986 and our first measurements showed on-time delivery performance at around 60%. Between 1986 and 1987 we were able to improve to 85% on time. Our outgoing quality level was running around 500 parts per million defective. Our lead-times were running around 10 weeks. I'm going to talk a little bit more later on about lead-times and show you how our thinking has changed in terms of the importance of this particular variable.

Our manufacturing cycle time was running around 15 weeks. When we first measured it in 1986, it was 26 weeks. Of the 26 weeks, we could not account for six weeks. So we could account for 20 weeks of it; six weeks of it we said the product was in limbo, it just didn't exist anywhere in the planning system. We brought the 26 weeks down to 15 weeks. Our process defect levels were running about 5000 parts per million, and to get from here to here, we were doing a lot of inspection, a lot of testing, a lot of rework. Our yields were 20%. Now, that's not yield loss, that's yield. I think that the fact that yields were so low explained a lot of what we saw here because the process defect levels in terms of quality, very low yields. I'll talk a little bit more about that in a moment. And our time to market was running about 36 months. Now in order to get to 1992, we looked at three things.

(Uncover half-life column)

First of all, we said "Where could we be, based on the assumed half-lives that you see in this column?" The second question we asked is where would our competition likely be in 1992? To answer that question, we had to define our competition. For the purposes of the things that you see here, we've taken the perspective not of the customer alone, but of the people within the customer's organization to whom these things matter. I'll give you an example.

In terms of quality levels, the thing that quality matters to are the people that are actually building the boards within or customer's organizations. We've said "what is the important way of looking at quality from the perspective of operations manager?" The answer to that is very easy, all you have to do is ask them. They are putting together boards and those boards have a mix of components on them. They have some digital ICs, they have some linear ICs, they have some passive components and active components. They have a number of different products on them. For us to compare our performance only against linear ICs makes no sense from their perspective. Their view is that you ought to compare yourself to any component that's likely to be on the same board with you. And, we share that perspective. Our objective is to make sure that when our customers do the Pareto analysis for rework of boards in their manufacturing operations that Analog Devices lies in the "other" category. It won't help us if we're the best linear supplier, but still the worst quality supplier to them in terms of their application. So we looked at our competition in a much broader way. We looked at it to be any manufacturer of components that are likely to be on the same board with us.

And we also talked to our customers and said "what are your expectations in terms of top ranked suppliers for 1992?" By doing those, we came up with the set of objectives that you see in the right hand column here.

(Uncover entire slide)

These were generated by 1987. We said that we wanted to be and could be, with a nine-month half-life, on-time more than 99.8% of the time. What that means is that we will virtually never shut down a customer's just-in-time manufacturing facility. That Analog will never be the source of an event, a destructive, catastrophic event, at our customers. Our quality levels will be below 10 parts per million, our lead-times will be under three weeks.

In order to achieve that, we have set the following internal goals. A manufacturing cycle of four to five weeks; you might say "whoops! Wait a second, you want to have a lead time of three weeks, don't you want to have a manufacturing cycle of under three weeks?" And the answer is " we would like to, but it is the nature of the IC manufacturing process that are a number of steps in the manufacture of ICs that take time, and time is fixed by the laws of physics." We believe that on average the theoretical wafer fab cycle time is around three weeks so that the theoretical time for wafer fab, assembly and test is four to five weeks, depending on whether the product is a "burned-in" product or a non burned-in product. What the implications are of this in terms of lead-times is that it is necessary that we maintain a strategic die inventory, so we operate our wafer fabs on a forecast basis and we pull from the wafer fab die bank to assemble and test to order. That's the objective there.

What's likely to happen in time is that research in the manufacturing processes for ICs and the equipment for manufacturing ICs will lead to a new generation of equipment that will allow us to manufacture in less than three weeks. That is our expectation, perhaps not for 1992, but certainly by the end of the century. Our process capability will be such that we will manufacture products at 10 parts-per-million, or under 10 parts-per-million and have no outgoing inspection. Our customers will do no incoming inspection. It won't be necessary. And the quality levels will be determined on the basis of the process capability rather than inspection.

The yields we expect will be greater than 50% by 1992. I'll get back to that in a moment because we think that that is a low number. Our design time-to-market will be under six months. Let me tell you where we are now. Our on time delivery performance in our most recent month was 97%, so we're well on the way to getting to the 99.8% objective that we have for the future. Our outgoing quality levels are around 250 parts-per-million. I'll talk a little more about leadtime in a moment. Our manufacturing cycle times today are running around seven weeks. So again, we're well on the way to the four to five week goal. And, our process defect levels are down around 1000 parts-per-million.

Yield is a very interesting one because when we first looked at these 20% yield numbers, the explanation we got from people was that that's all you can expect. We're dealing with linear ICs, not digital ICs. Demands on these

products are immense. Our most complex products are 22 mask levels, some of them with double-metal levels in them. Very complex products, which we expected could not yield at higher rates than this. But as we kept asking the question "why?" we began to make progress in yield improvement. And at our largest IC division, we succeeded in getting the yields up to 37% by the end of 1989. We believe that by the end of 1990 at our largest IC division yields will break the 50% level. And we believe that 1992 yields will perhaps be in the 60 to 70% range, and not anywhere near yet where they're going to max out.

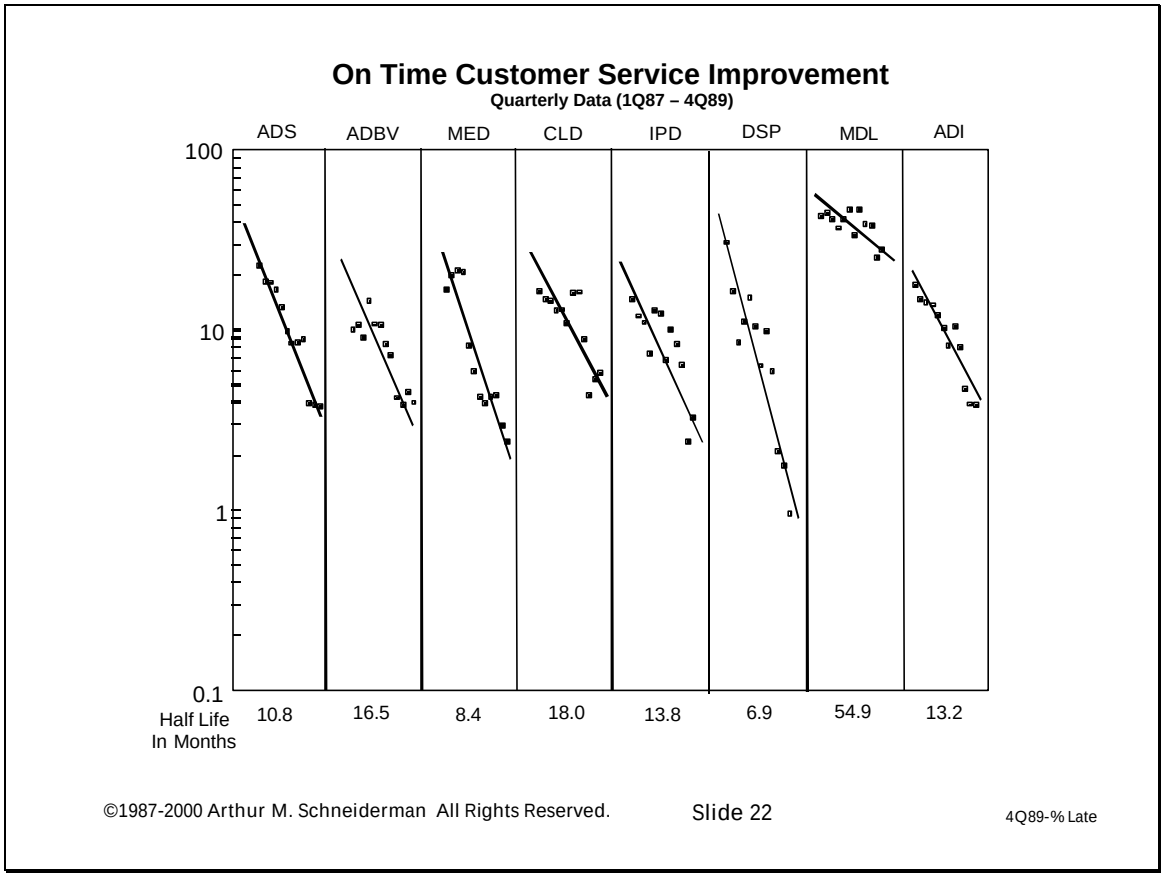
The one area that we've made really no progress at all here is time-to-market. And the only thing that we can say about that is we spend a lot of time talking to customers, talking to people who are leaders in the area of time-to-market, and we find that a lot of companies are suffering the same problem. We still are awaiting a breakthrough in this area.

Now at this point, what I usually do is I stop and ask our customers to comment on this set of goals that we have here. And I ask them the question "if we achieve these goals, based on your current thinking and your current expectations, do we have a chance to be your #1 supplier?" And the answer unanimously is "yes." In no instance has any customer said to me that "these goals are not good enough, based on what our current expectations are."

(Put up agenda slide)

Let me switch now to our performance measurement and feedback system. What I'd like to focus on there is one element of that and that is our on-time delivery performance.

Slide 22



Now the first chart that I'm going to show you, although you may think I have them reversed, is the simpler of the next two charts. But I'd like to go through this one and explain to you its format, because it will make it easier for you to understand the next chart. As you see here, the left-hand scale is a logarithmic scale and it is the percent of shipments that are not made on time to customers. So these are percentage shipments that are made late to customers: 100%, 10%, 1%, .1%. And this would be 99.9% on time, 99% on time, 90% on time. Now let's focus for a moment here on the first column. This is data for our Analog Devices Semiconductor division in Wilmington. The data in the other columns is for the other six divisions of Analog Devices. The final column is the corporate total.

The first point that you see here is ADS's performance in the first quarter of 1987; second quarter, third quarter, fourth quarter, al the way up to the fourth quarter of 1989. Now let's interpret this data. Look at the first point here, this is 10%, 20%, that would be 30%, so around 22% of the time in the first quarter of 1987 Analog Devices did not meet its commitment to its customers. This division did not meet its commitment to its customers. It was a little under 80% on time. Now in the fourth quarter of 1989, 1%, 2%, 3%, 4%, it was

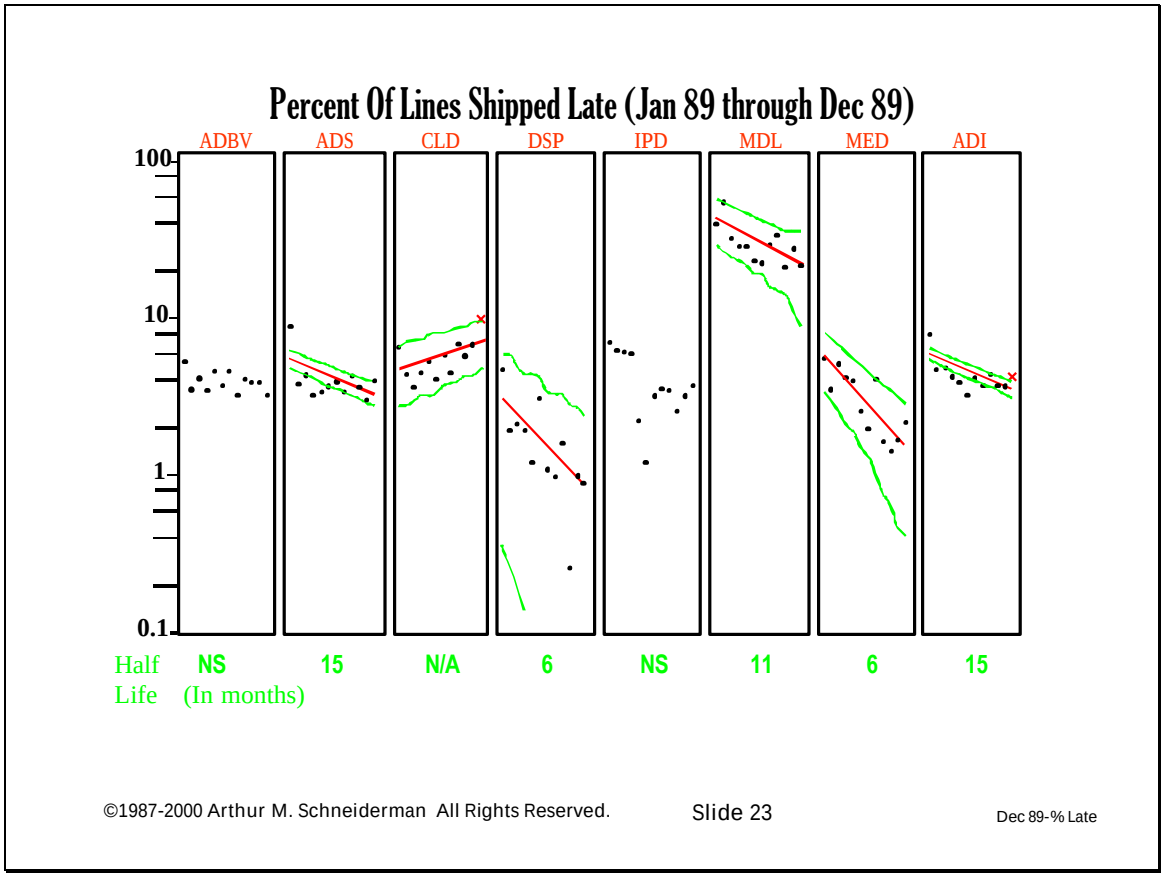
running 4% late or 96% on time in shipment to its customers. So it had gone from 78% to 96% over this period of time.

Now here you can see an example of the continuous improvement process. The data falls on a very good straight line, a remarkably good straight line. And that straight line has a half-life of 10.8 months, against a goal that you might remember of nine months. So this division has succeeded in maintaining a continuous improvement process characterized by a half-life of about 10.8 months over this three-year period of time. And as you look across the board, you see that a number of the divisions have achieved very significant improvements over this period of time. The corporate average, what you see here, going from again about 80% on time to about 96% on time by the end of 1989, with varying half-lives.

Now you might ask about this division here, It kind of stands out and it's clearly a division that has been a problem division at Analog Devices for a good number of years. What we ended up doing after a period of time in which no progress was made at that division is change general managers. We brought one of the two major product line managers from this division, moved him over to England to this division, and you can see that he has been able to make very significant progress in improving the on-time delivery performance at that division. Now as it turns out, for a number of reasons, not exclusively this reason, Analog Devices has decided to shut down the manufacturing facilities at this division and move the manufacture of that product elsewhere. Now, I said that there were many reasons that we've done that, but certainly this was one of the contributing factors to that decision, the fact that this division was not able to keep up to the rest of the divisions in maintaining a level of performance that was required by Analog Devices' customers. I can also point out that by looking down at these numbers here, there's a lot of competitive pressure that gets created between the divisions. A division with a very long half-life, or slow rate of improvement, sees a sister division or brother division improving much more rapidly and inevitably there will be discussion between the general managers of "what are you doing in order to achieve those rates of improvement?"

So this kind of a display of information is a very strong stimulus to organizational learning, across-divisional learning. Now as I said, this is the easier of the two charts. Let me move now to a more difficult chart, but only slightly more difficult, but one that is used in the organization in order to manage the improvement process.

Slide 23



The differences in this chart are first of all that it's monthly data rather than quarterly data. Secondly, it's a twelve-month period of time, so each month we add a point, and we drop a point. It's a window that we look at that is only 12 months wide. You see these red lines here? That's the half-life model statistically fit to the data. Let's look at this division; it's a better example here. The red line shows a half-life of 13 months. And so you recognize that from before. We now have two green lines on here. What are they? They're control limits. We apply the concepts of statistical quality control, the concepts that Deming pioneered in terms of rolling them out on a worldwide basis, to understand when a month-to-month variation is statistically significant. We don't react to changes on a month-to-month basis that are not statistically significant. If we were to do that, we would be chasing noise. We would be driving a manufacturing process to improve on the basis a noisy signal. So we simply look for out-of-control situations. Now on this particular chart there's one. This division here, at this point in time had a data point that was above the upper control limit. So we replaced the dot with a red + sign. If that division or another division had had a point below the lower control limit, we would replace the dot with a green + sign.

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Now you notice that the last three months have plus signs in them. We only focus on the last three months worth of data with respect to looking for out-of-control or in-control situations. Now what happens and the way that this chart is used is that within three days of the end of the month, this chart goes to the chief operating officer of the company to who each of these divisions reports. He looks at the chart, looks for red x's, picks up the phone and calls JB Archinard, general manager of CLD and says "Arch, what happened?"

Now there are right answers and there are wrong answers to that question. I'll tell first what the wrong answers are. The wrong answers are "lots of things." That's a wrong answer: lots of things. It's a wrong answer because one of the things that we learn with control charts is that an out-of-control situation has a special cause. It has one or two very specific causes; not lots of things. And so Arch has to know what the special cause was for this out-of-control situation. He has to have a plan of corrective action that involves identification of the root causes, assignment of responsibility to who has to fix that root cause, a process by which assure that the fix works and is standardized so that that problem is gone, never to reoccur. So this chart is used on an operational basis by the general management of the company to react to very specific situations. Now you can imagine the immensity of data that's contained here. If that were in a written report, as it once was, it would be 40 pages long. And it would be hopeless for a manger to pick out of 40 pages the things that he should managerially respond to. But in this format, we know the red x's and we know the green x's and we know how to react to them.

The second place in which this chart is used is at one of our two quarterly meetings of the general managers where this chart is put up and each of the general managers that has a red x of a green x has an opportunity to share their experiences with their colleagues at other divisions. Now the most beneficial ones from an organizational perspective are the green x's, the breakthrough situations in which a division has found a major improvement, a silver bullet improvement that has allowed them to make a statistically significant departure from the trend of continuous improvement that they have previously established. So this way of looking at our on-time delivery performance is an excellent way of driving the quality improvement process at Analog Devices.

I said to you earlier that our thinking on lead-time has changed a good deal and I'd I like to share with you how we now look at that. One of the difficulties in looking at average lead-time is that many of our customers give us standing orders that go on for a significant period of time.

Let's take a two-minute break now and I'll come back and show you how we look at our lead-time to our customers.

(Break)

Welcome back. During the break a question was asked of me and I'd like to answer that. If you look at this chart, this isn't the most impressive chart that I can put up. If you look at the previous chart, the one that had the quarterly data, you notice that there were very strong trends of improvement. In this chart, there aren't any strong trends of improvement and somebody said "why are you showing this chart? Why aren't you showing an older one?" And the answer is that we show the most recent data we have. The rule here in giving this presentation is we give the most recent data, this happens to be January of 1990, any time that we give this presentation. There is a message in here and the message is that we've run into a wall. We've gotten up to 96% improvement and have not been able to break through that 96% barrier. There's a lot of thinking that's going on as to what kind of structural problems, and you can see four of our divisions have run into this situation. What kind of structural problem exists within Analog Devices that tends at the moment to limit us to 97% on-time delivery? So we're really struggling with that one.

But at the same time, we recognize that that level of performance is certainly world class. 97% on-time delivery means that 100% of the quantity is shipped to 97% of our customers worldwide on or before the date that we committed to ship it. At that level of performance, we rarely get complaints from our customers in terms of late shipments. Their complaints have moved on to the issue of lead-time. And that's where we have decided to refocus our efforts. We will continue to work on this problem, but much of our efforts in the area of customer service are now in the direction of reducing our lead-times.

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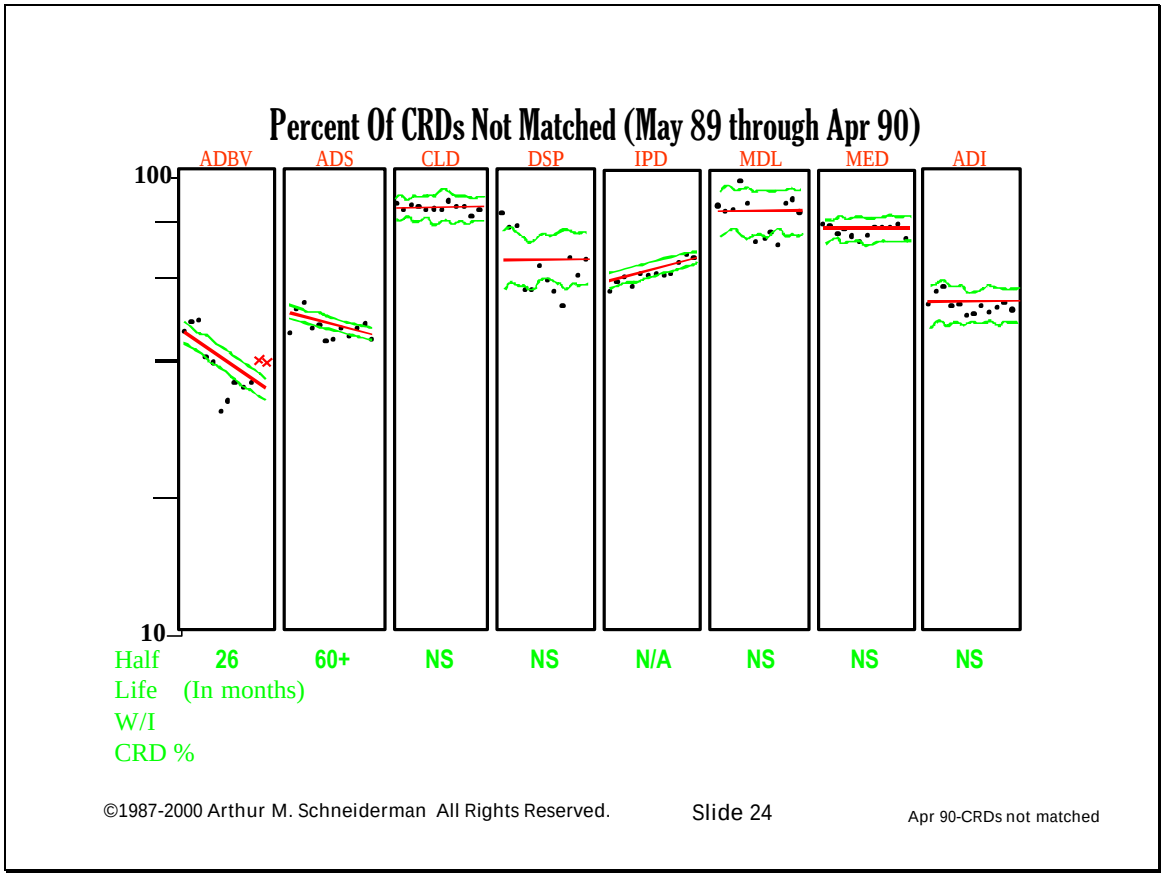
Now lead-time, as I mentioned a moment ago is a very complex issue to define. Part of our problem is that we have customers that place orders over multiple periods of time. They say "I want 50 pieces next week, and 100 pieces a week later, and 50 pieces six months later. So if we respond favorable to that, the six-month lead-time that we quote, which matches what our customers want, will very very significantly distort any sort of characterization of what kind of delivery we're offering to our customers. Instead, we've turned to a different way of looking at lead-time. And it's captured on this slide.

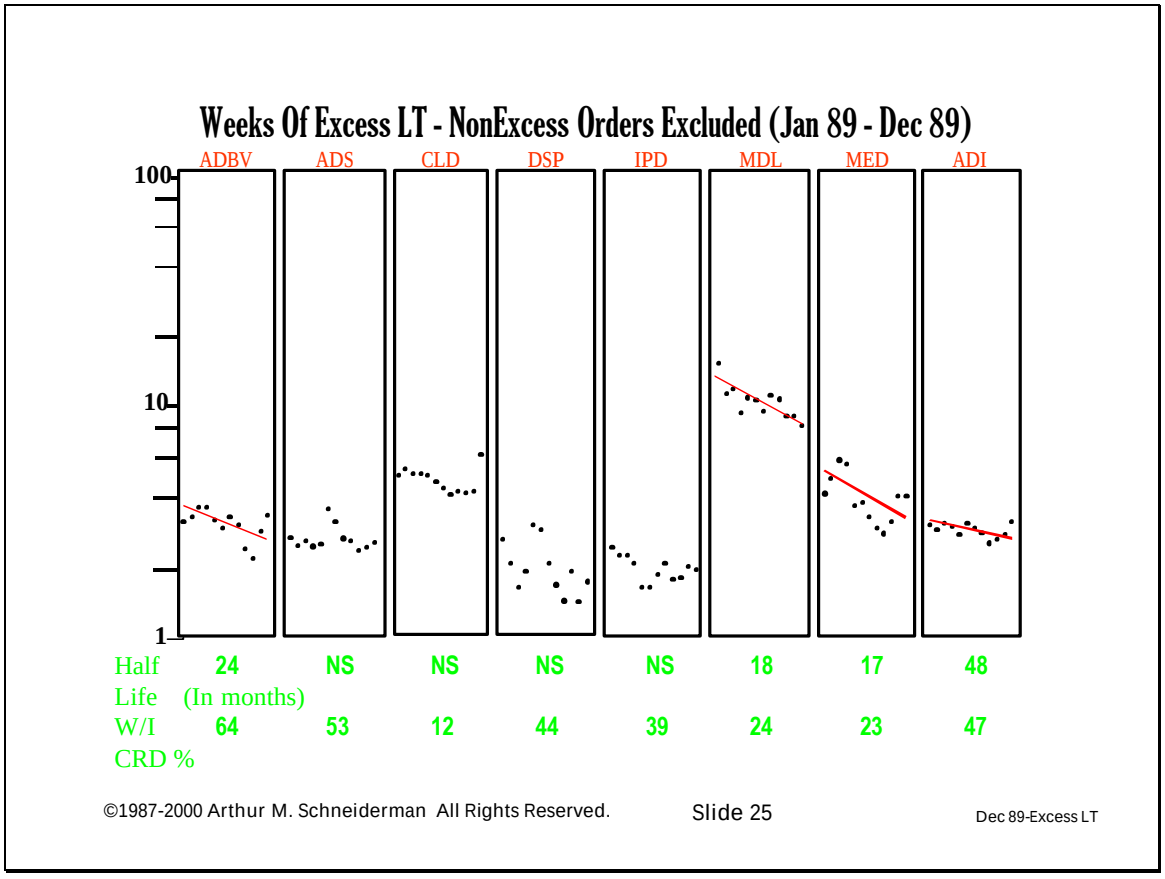
Slide 24



Again, you see very much the same sort of format, except now what we're looking at is the percent of time that we matched the customer's requested date, the customer request date. In other words, what percent of the time when our customers came to us and said "I would like a certain quantity of this product by a certain date" did we say yes? And as you can see, across the divisions, 10%, 20, 40, about 50% of the time, about 50% of the time we are matching the needs of our customers. We now want to focus our efforts at Analog Devices in getting the same sort of improvement in this as you saw on our on-time delivery performance, while maintaining or improving those levels of performance. We want to match our customer's request dates 100% of the time.

You say "that's a wonderful objective, but what happens when you fail to meet that?" And that's the second leg of the lead-time question. That second leg says when we fail to meet the customer's lead-time, how much are we missing by?

Slide 25



And this chart here shows when we do not meet our customer's lead-time request, how much do we miss by? One week, two weeks, four weeks, so you can see on average we're running about 3 weeks. 50% of the time, here's the actual number, 49% of the time when a customer comes to us and says "I would like an order on a certain date, we say you can have it on that date and 97% of the time we meet that commitment. For the other 50% of the customers that we can't satisfy, in terms of their lead-time requirement, we're missing by three weeks. And so the other leg of lead-time improvement is to increase this to 100% and decrease this to zero. And that is the major direction of our improvement efforts in the area of customer service.

Let me now put this all to a test. We have a very comprehensive measurement system in place with respect to on-time delivery. It's taken us a number of years to develop, to get the definitions right and get the organizational consensus that these in fact are appropriate measures of how well we're doing with respect to our customers. But we've got those measures in place. We measure our on-time delivery performance, we measure our lead-time performance as I've just described it to you, when we're late, we measure how late we are and we look at our late backlog to make sure that we're not

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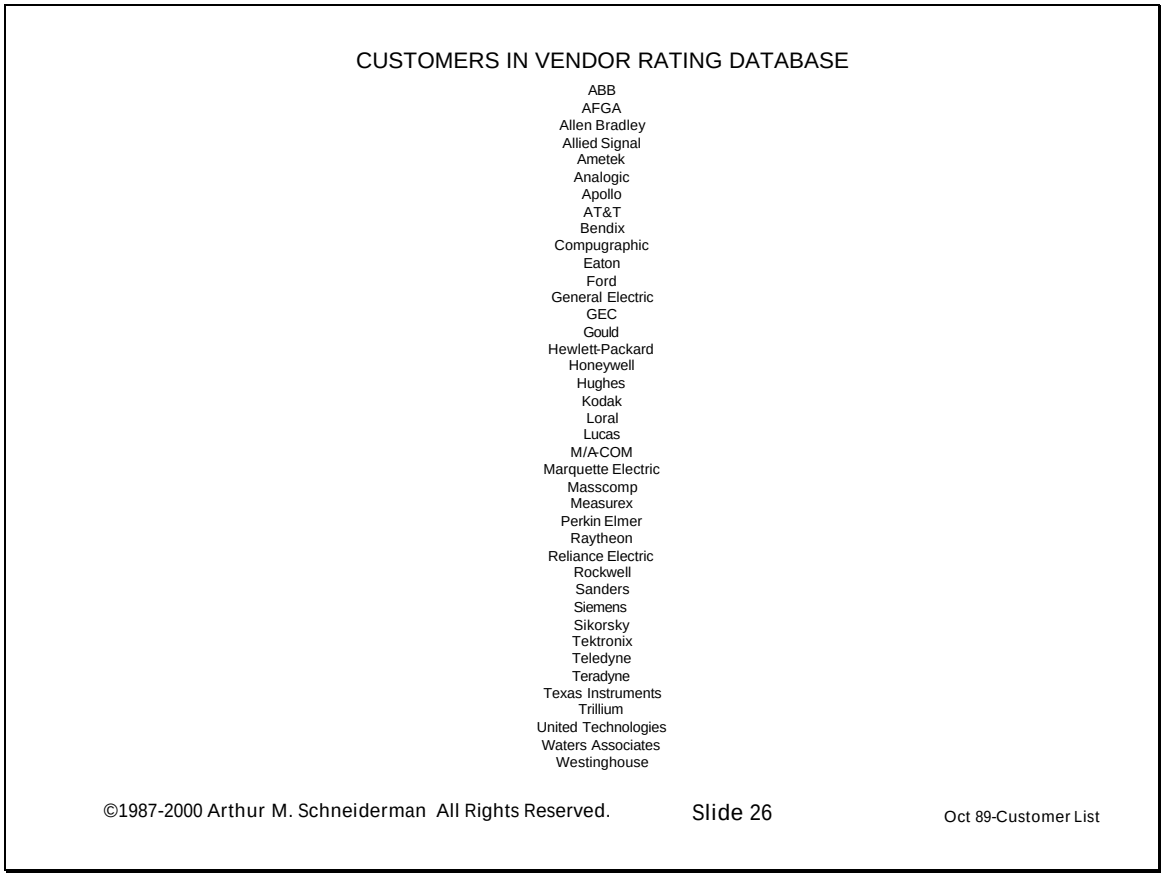
accumulating things in late backlog. So we've got all sides of the delivery issue covered with respect to our performance measurements. We could become very complacent and say that we know what our performance is to you, our customer, and we say it's great. But the real test is what do you say?

And so the final thing I'd like to share with you is our customer's measures of our performance as a truth test to this measurement system.

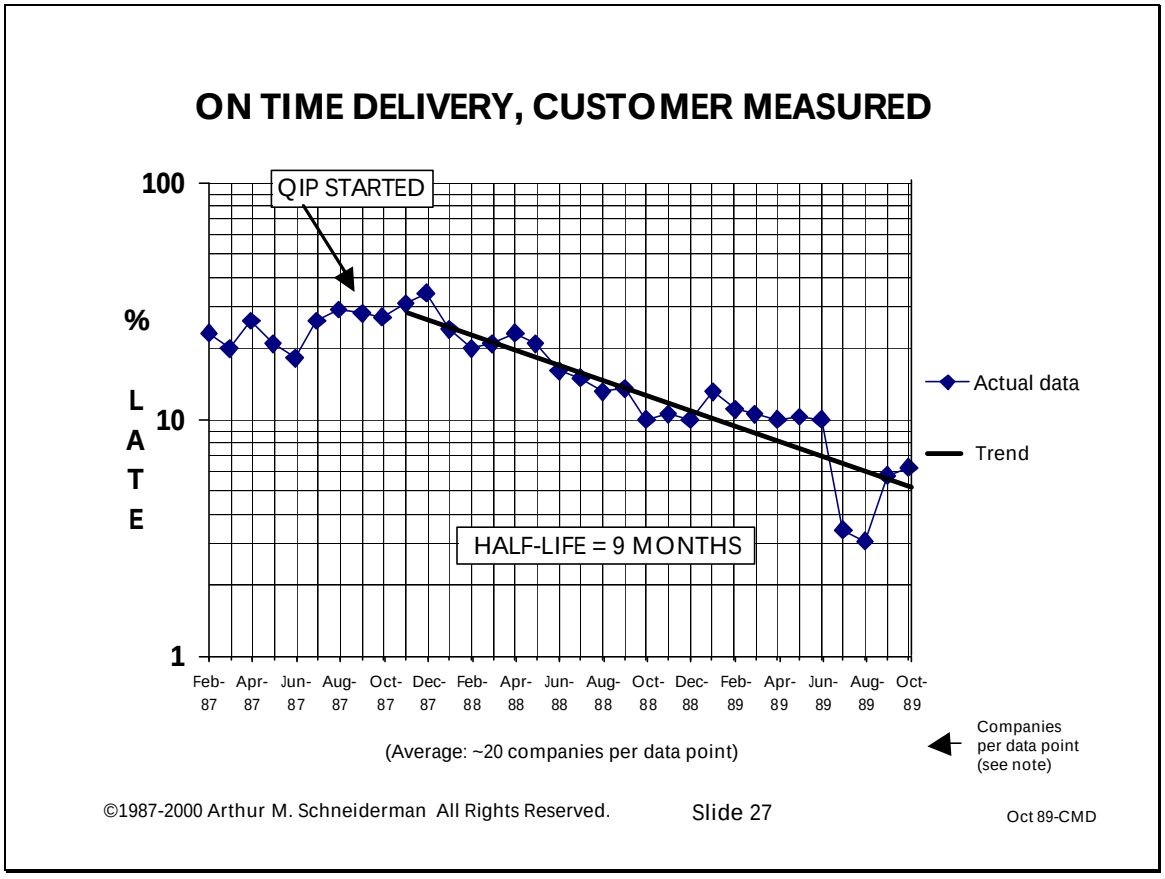
Slide 26



Many of our customers have vendor-rating systems in which they rate their suppliers in terms of delivery and quality. This is a partial list of customers that have such systems. It's partial because it represents a subset of customers that measure their supplier's delivery performance, that give that information to their suppliers and that have suppliers who have a network by which that information makes it to the right place; namely me. As you can see there are about 30 customers in that database, and it's growing.

What we do is we take the periodic reports that come from those customers and we do a straightforward averaging of their measures of our on-time delivery performance.

Slide 27

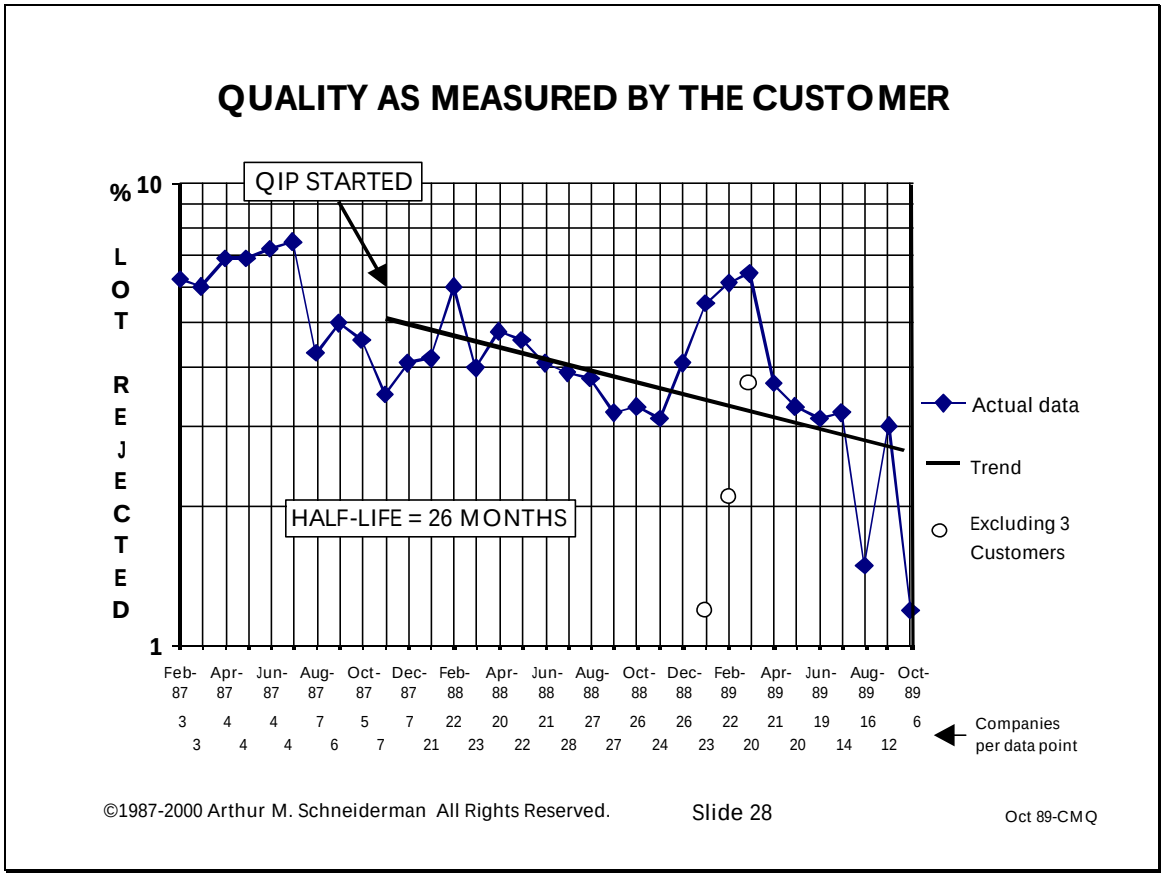


And this is what it looks like. This is your familiar percent late, semi-logarithmic scale here, and this is just a simple average of the on-time delivery measurements made by our customers of our performance and reported to us. The numbers that you see down at the bottom are the numbers of companies that go into each of the data points here. What's very encouraging about this is the correlation between our customer's measurement of our on-time delivery performance and our measures of our on-time delivery performance. You can see that they correlate in two ways. In the end of 1989, which is the latest point at which we have a reasonable number of reports that have made their way to us, our customers were measuring our performance at about 95% on time, which is very consistent with what we were measuring during that period of time. In addition to that, from the time we started our quality improvement efforts in the fall of 1987 we measure a half-life based on their data of nine months, again very consistent number, perhaps even a little more favorable, then what we've measured internally. So we feel very comfortable that we've closed the loop in terms of our on-time delivery measurements from our customers. We believe that we have a very solid understanding of our delivery performance and the evidence from our

customers says that there's a very strong correlation between what they see and what we see.

I mentioned that they also give us data in terms of quality, and here the picture is not quite as simple as it looks with respect to delivery.

Slide 28



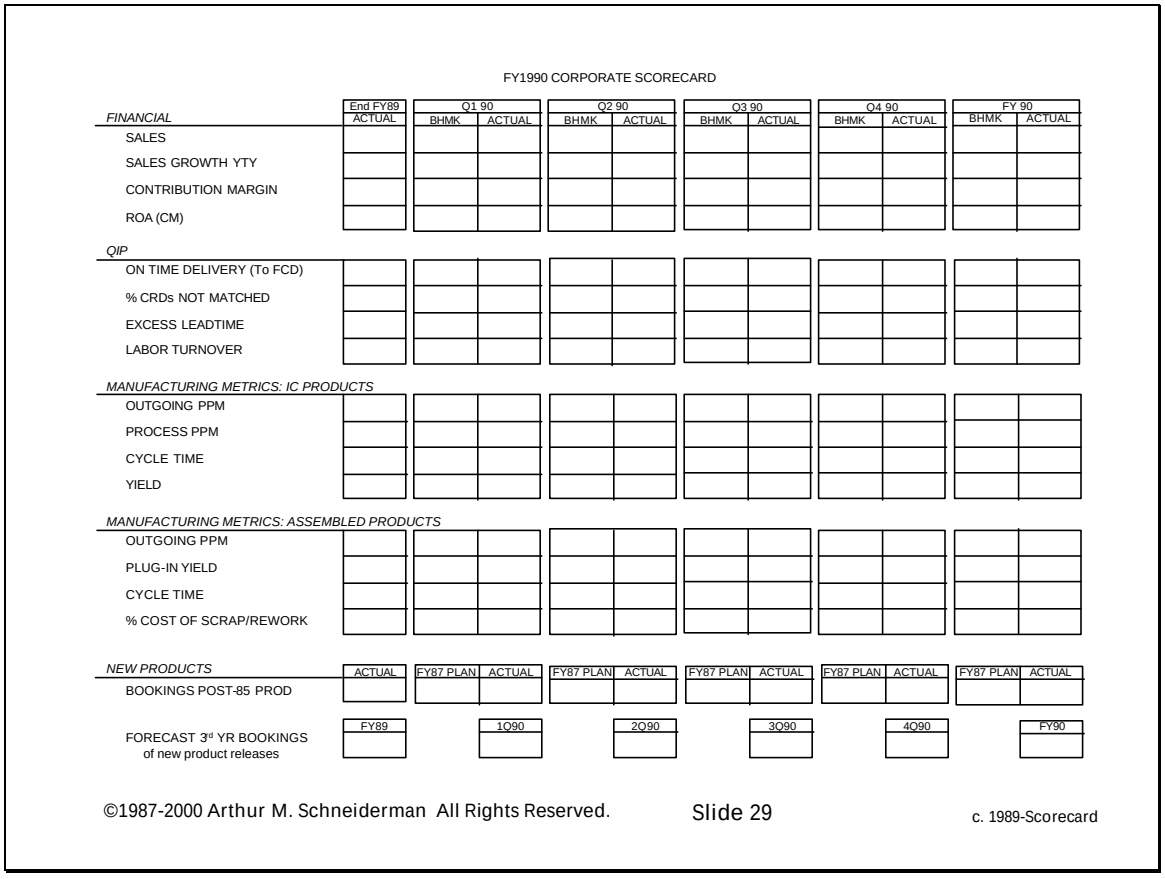
Again you see the number of customers that contributed data to each of the points. This is lot reject rate. Here the half-life is significantly longer than we would like, about 26 months, and the data is somewhat erratic. In particular there is this big blip toward the beginning of 1989 and obviously, if we put control limits on this, that would have been an out-of-control situation. So we asked the question "what went wrong?" We asked that question of ourselves. Why were these three points up so high? We found that if you excluded three customers of the 20 or so that went into each of those points, that they dropped down to these levels here; much more in line with this trend line. And we looked at the root causes for the quality problems we were having at these three customers. A very interesting common denominator evolved. And that is that the lots here were not being rejected because of product quality issues, they were being rejected because of administrative quality issues: the wrong number of parts, the wrong part, the wrong shipping container, the wrong invoicing information. So these were administrative quality problems. Whereas, back in this period of time they were product quality problems. Now that's not to say that administrative problems are not important, they are equally important from our customer's perspective. That's why they measure them in their measurement system. But what's

encouraging about it is that it is much easier to solve administrative quality problems then it is to solve product quality problems. So we're very encouraged that we'll be able to really drive this down as we start a program up of addressing administrative errors that we make and making sure that we eliminate them in the future.

(Slide off)

I think on the basis of the very strong correlation between our measurements of our performance and our customer's measurements of our performance, and the feedback that we get from them, we've been able to generate a very strong consensus within Analog Devices that we've identified the right things to measure in terms of improving the value of what we deliver to our customers. Having done that, we've also introduced a system that will provide accountability in terms of those measures. And I'd like to share that with you. We call it fondly "the scorecard," and I'd like to give you an example of what is on that scorecard.

Slide 29



FY1990 CORPORATE SCORECARD

	End FY89	Q1 90		Q2 90		Q3 90		Q4 90		FY 90	
FINANCIAL	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL	BHMK	ACTUAL
SALES											
SALES GROWTH YTY											
CONTRIBUTION MARGIN											
ROA (CM)											
QIP											
ON TIME DELIVERY (To FCD)											
% CRDs NOT MATCHED											
EXCESS LEADTIME											
LABOR TURNOVER											
MANUFACTURING METRICS: IC PRODUCTS											
OUTGOING PPM											
PROCESS PPM											
CYCLE TIME											
YIELD											
MANUFACTURING METRICS: ASSEMBLED PRODUCTS											
OUTGOING PPM											
PLUG-IN YIELD											
CYCLE TIME											
% COST OF SCRAP/REWORK											

NEW PRODUCTS	ACTUAL	FY87 PLAN	ACTUAL	FY87 PLAN	ACTUAL	FY87 PLAN	ACTUAL	FY87 PLAN	ACTUAL	FY87 PLAN	ACTUAL
BOOKINGS POST-85 PROD											

FORECAST 3rd YR BOOKINGS of new product releases	FY89	1Q90	2Q90	3Q90	4Q90	FY90

 Slide 29 c. 1989-Scorecard

The scorecard is broken down into three major sections. The first section is a very small, limited number of financial measures: sales, sales growth, contribution margin and return on assets. And then a set of QIP objectives: on-time delivery, percent CRD's not matched, excess lead-times, so you understand that both of these are measures of our lead-time or the availability of our products to our customers and our labor turnover rate, which we look at as an indicator of how well we're doing in meeting our employees needs. On the internal side of things, we look at our manufacturing metrics, divided between integrated circuit products and assembled products and there we look at outgoing defect levels, process quality levels, cycle time and yield for our ICs; outgoing PPM, plug-in yield, which is the appropriate measure for those kinds of products, cycle-time and % cost for scrap and rework. So these are a set of internal measures for these two cases that link up to the external measures that we've got there.

Now what we do is we take the half-lives that come out of our five-year objectives and we use them to generate intermediate goals. And we do that in a benchmark planning process that we go through annually. The way that process works is at the start of the process we record what our actual 1989

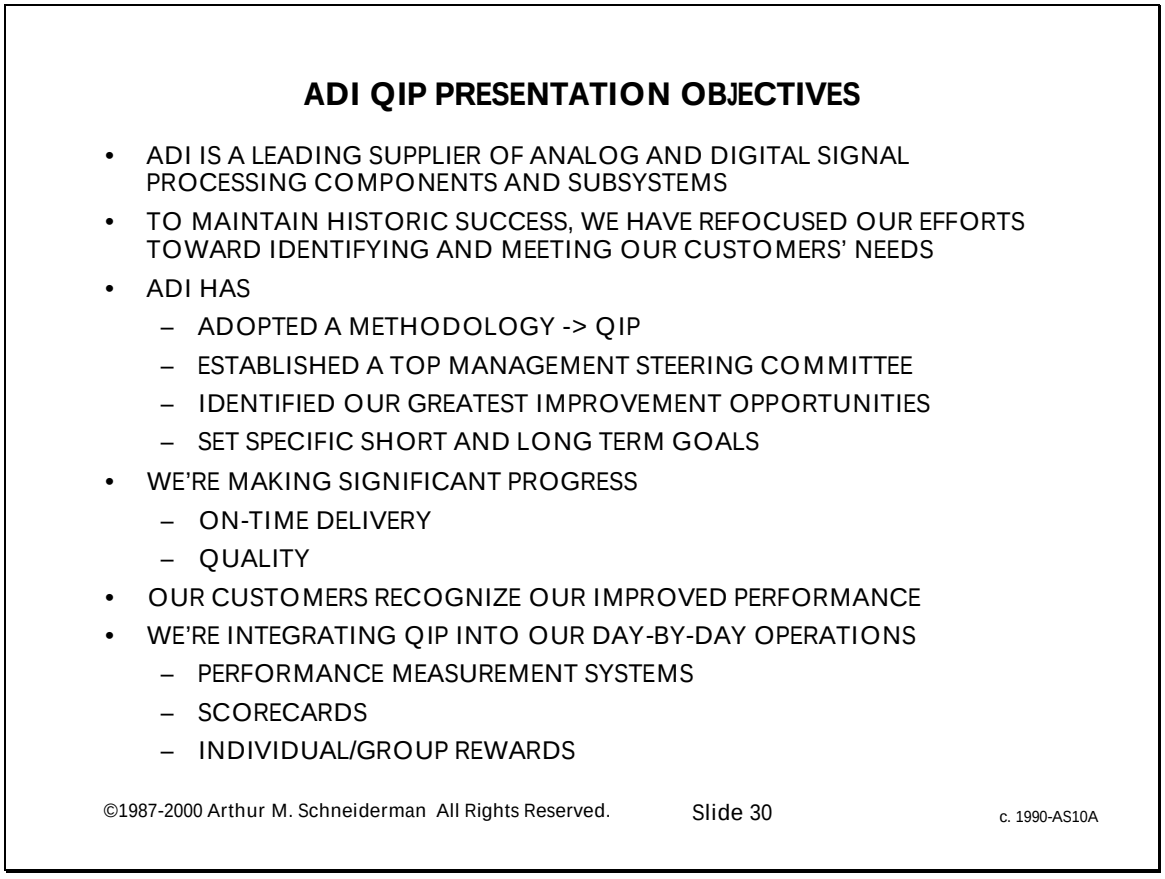
performance levels were in each of these areas. And then we send to the divisions a proposal in terms of quarterly benchmark goals and a year end goal for each of these areas here based on the half-life concept, based on the five-year plan, based on where they happen to be at the end of the previous year. And we go through a negotiation process by which they come back with a proposal, counterproposals are made and we settled in on agreed upon sets of goals. Now those agreed upon set of goals have behind them, at the levels of the divisions, planned resources needed in order to achieve those goals. But the goal setting process that's linked again back through the five-year plan to the concept of value to meeting our business objectives.

Each quarter we fill this in with the actuals and we take a red pen and a green pen, symbolism of the colors: red is bad, green is good, that's consistently the methodology we use. And we take one or two areas on each division's scorecard and use a red pen or a green pen or both if that's appropriate to circle a variance. And as I mentioned earlier, we have two general manager's council meetings a quarter and at one of them we review the scorecards. Before that meeting, each division gets a copy of the scorecard with the "suggested" areas that they should discuss and they have ten minutes to address those red or green circles; to again go through the 5W plus an H concept. What was the problem? What was the root cause of it? Who's going to fix it? When is it going to be done by? And so we have a process in place, a version of the PDCA cycle, that when we see a variance between Plan and Check, we look at that variance, we have to take corrective measures so that the variances will be closed in future time periods.

(Put up agenda slide)

As we look again at the agenda, I think you'll see that we've covered each of the areas on here and what I'd like to do now is pause for a discussion of your future needs as customers and then when we've finished that discussion I'd like to wrap things up by giving a summary of the message that I hope to give you today.

Slide 30



At the beginning of this presentation I gave you an overview of Analog Devices and I hope that you concluded from that that Analog Devices is a leading supplier of analog and digital signal processing components and subsystems. To maintain our historic success, I've demonstrated to you that we've refocused our efforts toward identifying and meeting our customer's needs. We've moved from being product driven to being market driven. We've adopted a methodology, which we call QIP, and established a top-management steering committee that has wide geographic and functional representation. We've identified our greatest improvement opportunities with the help of our customers. We've set very specific, short and long-term aggressive goals based on what we believe are continuous rates of improvement that can be achieved through the QIP methodology, using the concept of half-lives to set those goals. We've been making very significant progress with respect to on-time delivery and quality, the two greatest concerns of our customers during that period of time. Our customers recognize our improved performance. And we're integrating QIP into our day-to-day operations through our performance measurement systems, the scorecard and through individual and group rewards.

Thank you.

