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LINKING THE QSM PRODUCTIVITY INDEX WITH THE SEI MATURITY LEVEL

by

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Introduction. When the SEI Software Development Maturity Assessment Methodology started to be used to measure the software development capability of organizations, we at QSM® took a keen interest because we had been doing something similar in concept since about 1982. We gradually enhanced our capability to do meaningful quantitative productivity assessments and commercially offered these services (together with our affiliates in Europe) under two names -- SEAS (Software Engineering Assessment Service) and PEP (Productivity Enhancement Program). We developed a measurement tool (PADS® - Productivity Analysis Database System) to analyze the data and do comparative analyses related to the large database of software projects we have been collecting for more than ten years. PADS has been in service for more than ten years and is the primary tool used in conducting SEAS and PEP analyses.

The SEI Maturity Level approach was different from ours. Yet it was attempting to do much the same thing. Two independent approaches. Would they be correlated? Would they tell much the same story about an organization? Would the measures used in one relate to measures in the other?

As I began to see the early results from the SEI assessments I came to think there would be correlation. My feeling was that the primary QSM process productivity measure, the Productivity Index (we will call this the PI), would be strongly correlated with the SEI Maturity Level.

If this were so then the large body of data we had gathered and put into Productivity Index terms (along with all the other associated software management metrics we had) would be able to be expressed in SEI Maturity terms as well. This could have considerable value to those trying to get started with either method of assessment. It could be particularly valuable to QSM clients who had been using the PI/PADS assessment approach to relate their standings to the SEI assessment system.

Description of QSM's PI. The software process Productivity Index (PI) is a QSM metric. It represents the level of an organization's software development efficiency. The PI is a macro measure of the total development environment. Values from 1 to 40 have been adequate to describe the full range of projects seen so far. Low values generally are associated with poor working environments, poor tools and/or high product complexity. High values are associated with good environments, tools and management and well-understood, straightforward projects [Ref. 1, 5].

"Productivity" embraces many important factors in software development, including:

- Management influence
- Software development process and methods
- Software development tools, techniques and aids
- Skills and experience of development team members
- Availability of development computer(s)
- Complexity of application type

References 1 and 5 contain detailed explanations of the Productivity Index including how it is calculated and how it is interpreted. The significant point is that it is calculated from the size, schedule and effort that were applied to a completed project. This means that the PI is objective, measurable and capable of being compared on a numeric scale.

Histogram Distribution of PIs in QSM Database and SEI Maturity Level Distributions

A histogram showing the distribution patterns of systems in the QSM database as of 1994 is shown below.

Mixed Application types. PADS® was used to select all systems in the database and plot the Productivity Index distribution. This includes all application types from Microcode and Real Time systems at the most difficult end of the PI spectrum to Business systems at the most straightforward and well-understood end. The plot is shown below. Note that it is essentially normal. Over time the central tendency (mean) of this distribution tends to displace to the right at about one PI every three years. At each update of the database older systems are dropped off as new systems are added so that the distribution moves rather than just broadening.

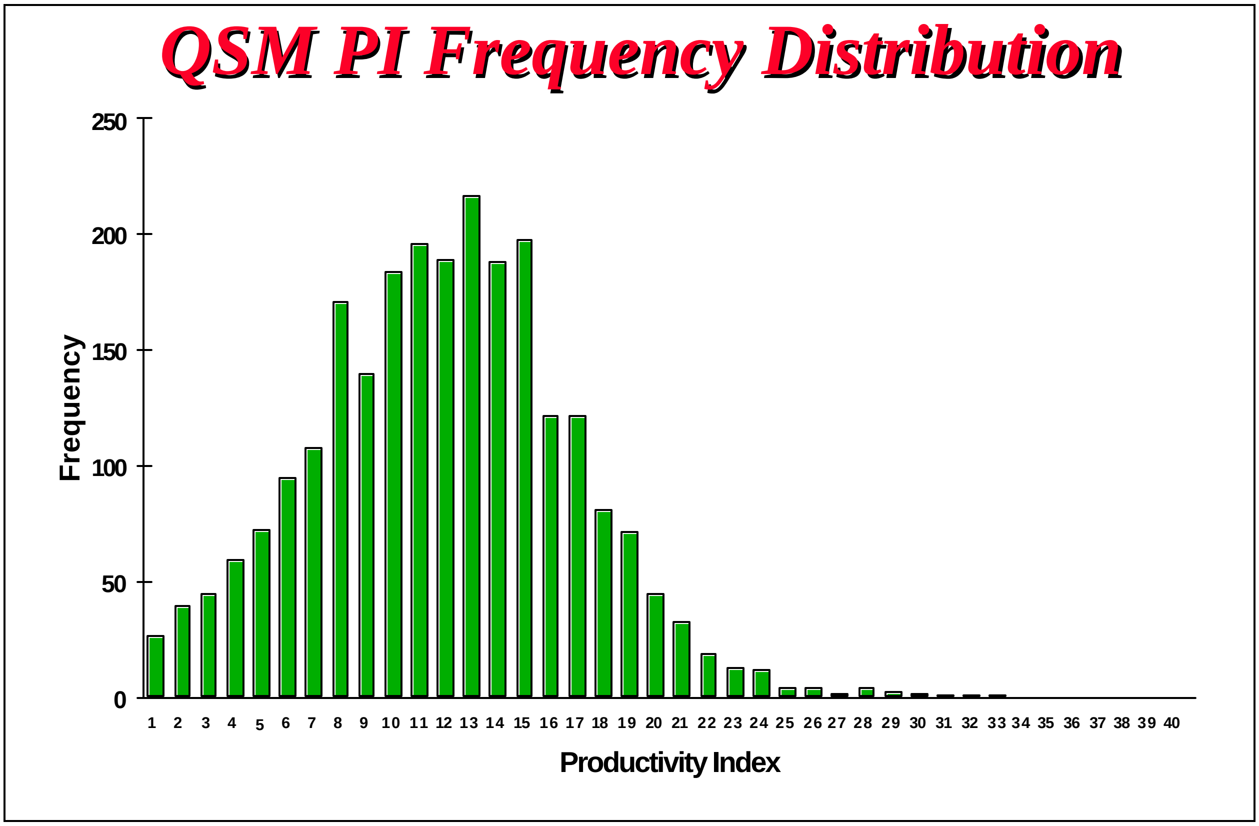

Figure 1. Distribution of all systems in the QSM PADS database as of 1990. All application types included. Mean is about PI 13.5 and standard deviation is a little more than +/- 5 PI. Distribution is approximately normal.

The figure below shows a histogram of the distribution of systems determined in the initial assessments measured by the SEI. The SEI has established five levels of maturity. Level 1 is ad hoc and chaotic with little or no reproducibility from project to project. Software development is likely to be primitive. Level 5 is at the other end of the spectrum in which a very mature process is in place and being practiced diligently on a continuous basis. Everything in the software development process is being measured against standards and continuously fed back into process improvement actions. [Ref. 2]

Note that a very large fraction of the systems is in level 1. The distribution does not appear to be normally distributed, but there is nothing to indicate that the five qualitative bins should equally divide the entire spectrum space. If one of the bins, say the first, were to contain most of the systems surveyed then such an uneven distribution would look like the one below because only five bins are too few to portray the real underlying distribution.

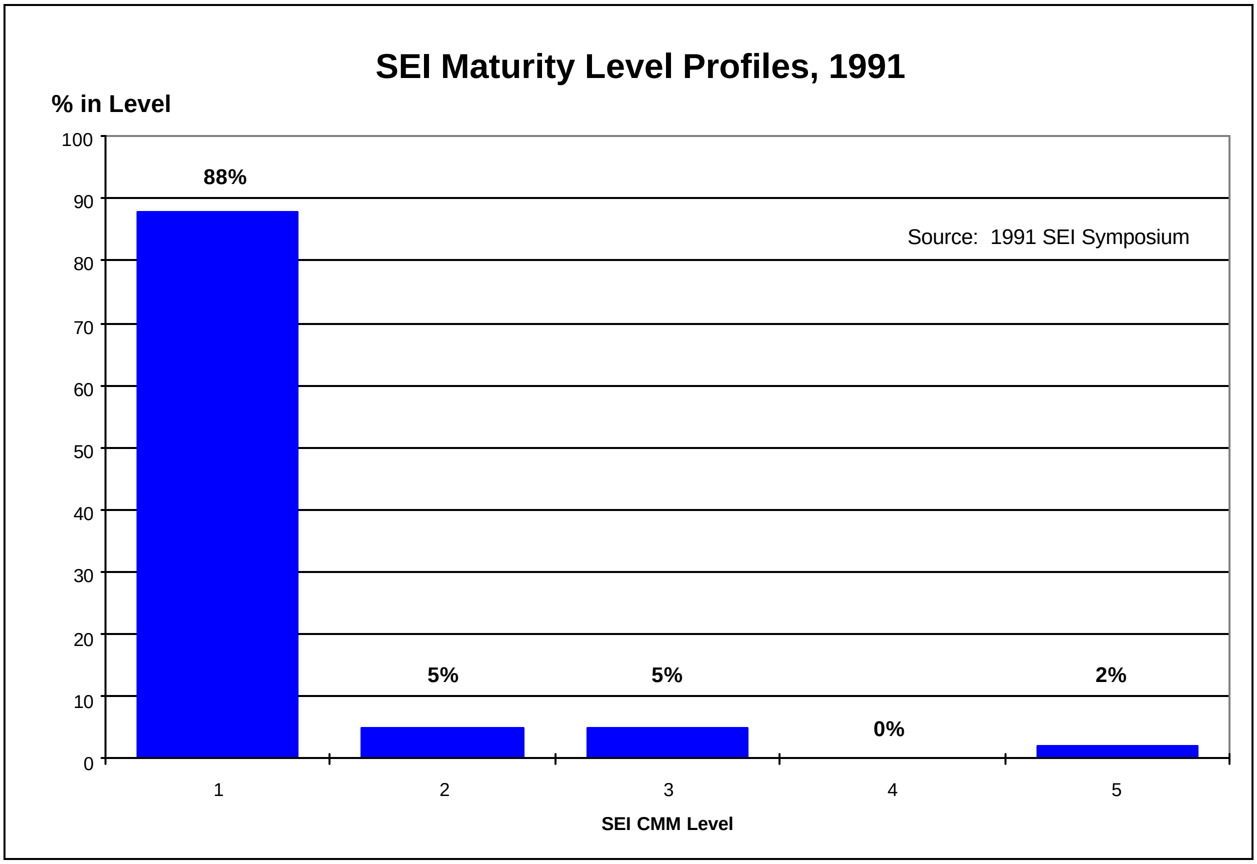

Figure 2. Distribution of systems into SEI Maturity Levels [ref. 2]. Original figure courtesy of Stan Rifkin, Master Systems.

When the normally distributed population of the QSM database (Figure 1) was carved up into five bins to approximate the results of Figure 2, then a distribution like the one shown in Figure 3, below, was obtained. In order to do this about 75% of the QSM systems had to fall into level 1 in order for the other four higher bins to approximate the SEI results of Figure 2.

This analytic comparison does establish that the two distributions can indeed be very similar to one another and represent a classification that measures process maturity in two different but complementary ways.

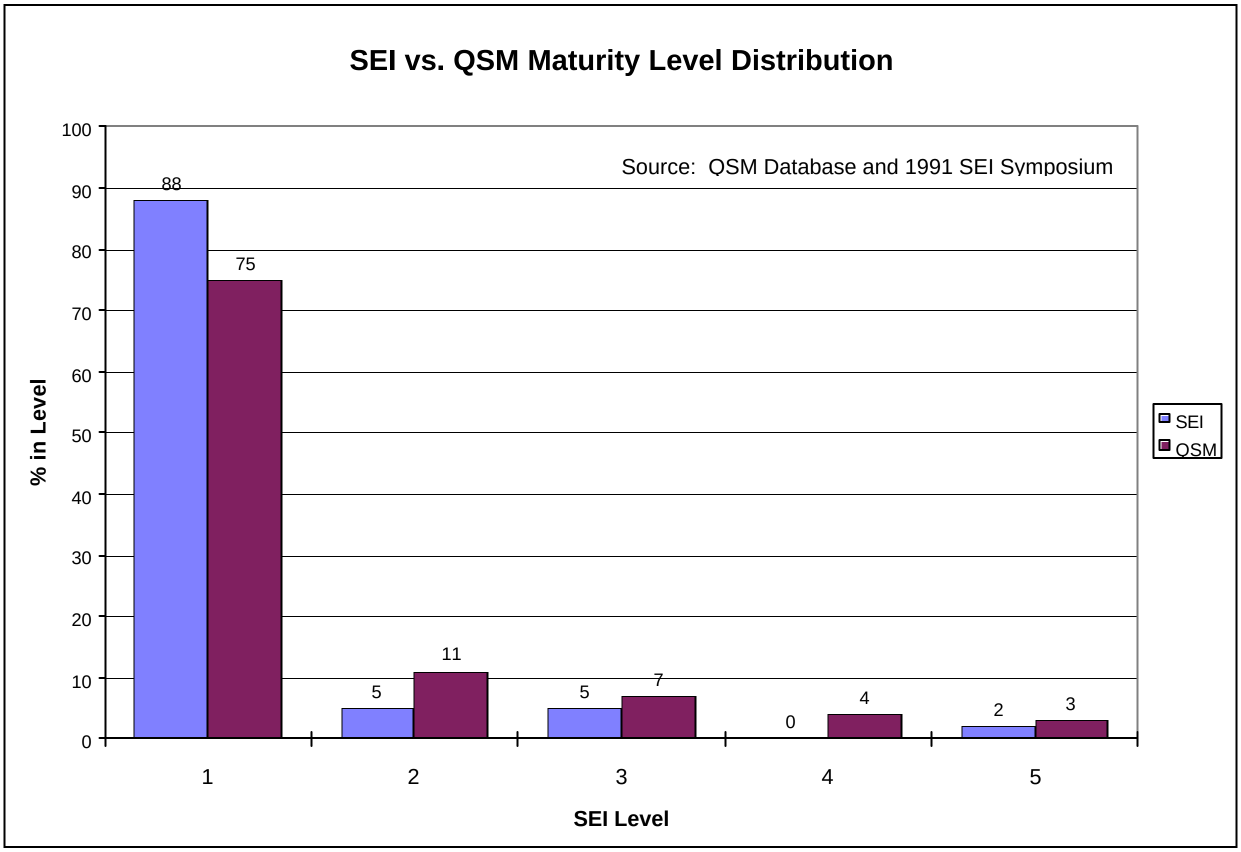

Figure 3. When the QSM database is partitioned into five bins in which a large fraction is assigned to the lowest bin then a similar pattern to the SEI distribution emerges. Original figure courtesy of Stan Rifkin, Master Systems.

The result of the SEI evaluations through 1994 is shown in the figure below. Notice there has been a migration upward from level I to level II and level III. There has been almost no movement up into level IV and V.

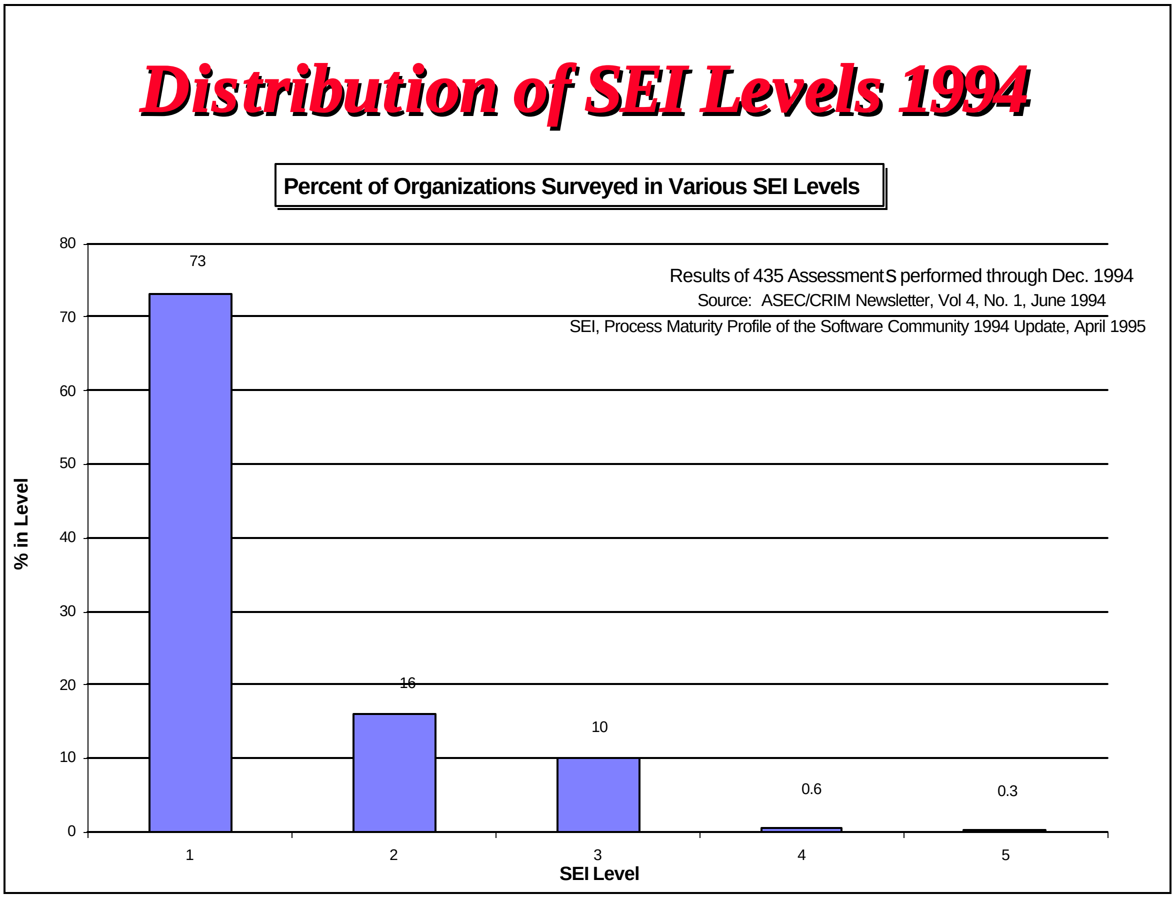

Figure 4. Results of the 435 SEI evaluations compiled through 1994.

The figure below shows the percent in the five SEI levels based on data through 1999 with projections out through 2009.

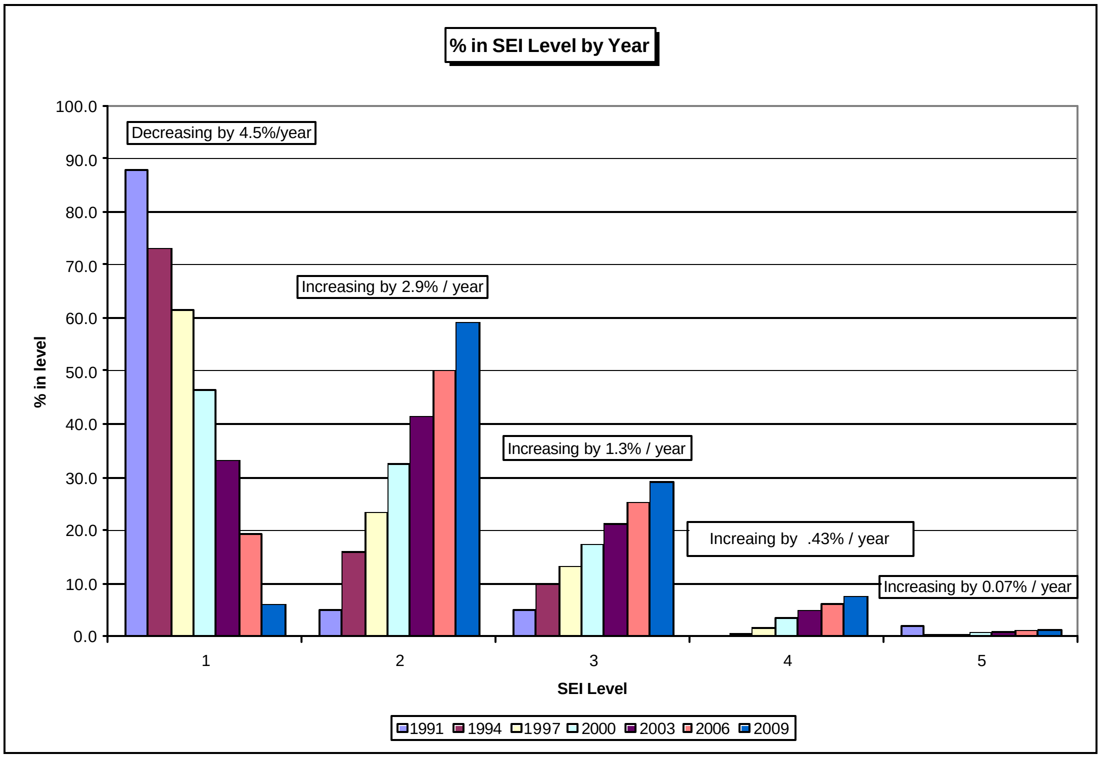

Figure 5. Percentages in SEI levels as of 1999 with projections through 2009

If we take these results and apply them to Figure 1 so as to carve it up into five bins with the distribution pattern similar to Figure 3, 4 and 5, then the transition points in terms of the PI will occur about as indicated in Figure 6 below with the overall distribution and the transition points migrating to the right at about the same rate as a function of time.

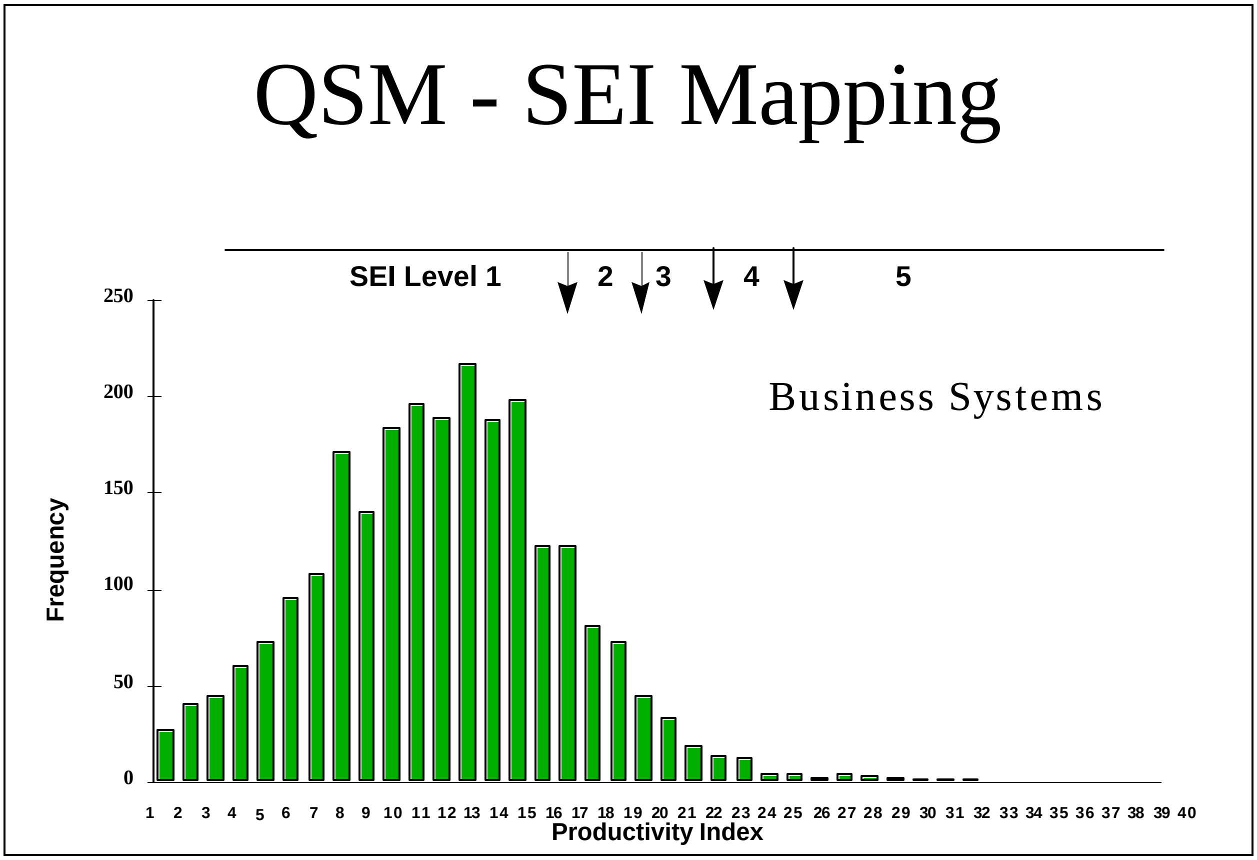

Figure 6. Approximate SEI transition Breakpoints on the QSM business systems distribution as of 1994.

Similar analysis has to be done for each application type in the QSM database base. Moreover, since the range of PIs has been shown to be quite different for real time systems, engineering systems and business systems, we would expect to see different PI transition points for each of these principal application categories. This analysis of different application types was done similarly but is not shown here for brevity. Different transition points for the different application types did emerge. The results will be shown later.

The figure below shows all the application types in the QSM database assigned to the five SEI bins and the percentages that fell into each SEI bin. Note that there appear to be a greater percentage in the higher levels for business systems than the other application categories. This is not surprising because there are more of them built and under way; and, because the complexity of these systems tend to be lower than the real time and engineering systems, more time, effort and money is being spent on process improvement because of their recurring nature and economic significance.

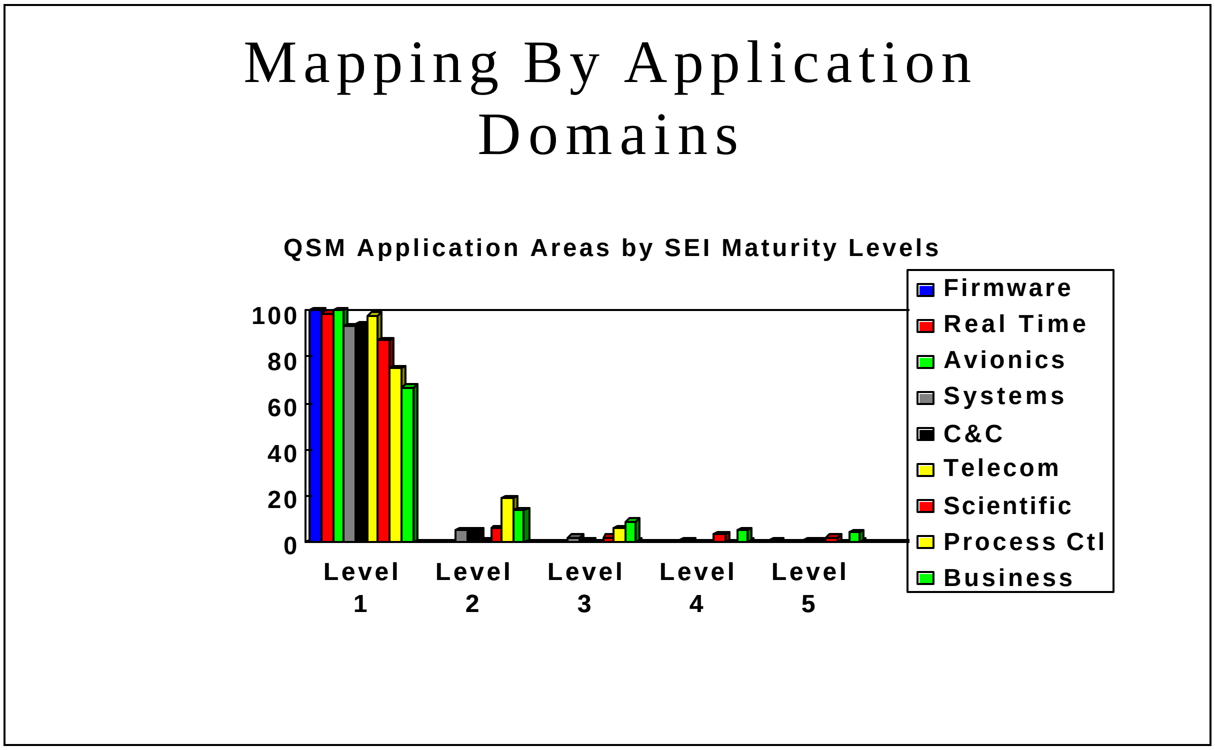

Figure 7. **Distribution of systems in QSM database into SEI Levels by application type. Original figure courtesy of Stan Rifkin, Master Systems.**

SEI Transition Breakpoints

Ideally, we would like a large body of data from the same organization, in the same time frame, and done using both the SEI maturity assessment and the numbers from those same projects so that the QSM PI could be determined. Unfortunately, such comprehensive data does not exist at present. However, there are some corroborative instances that tend to lend strong support to the hypothesis put forward in this paper. References 3 and 4 provide such instances along with an assessment of the economic value of moving up the SEI scale.

The breakpoints for transition from one SEI maturity level to the next were done somewhat heuristically. First, we noted that most of the measured observations for SEI levels have been in the Level I and II category with just a small fraction of systems in Level III. When we compare this with the distribution of all systems in the QSM database we would expect most of these to fall below + one standard deviation on the cumulative scale. I felt the 75% probability point was a good 'first cut' breakpoint for transition from SEI Level I to Level II. 84% cumulatively (+ one standard deviation) seemed reasonable for the transition point to Level III. Similarly, I thought 95% and 99% were reasonable for transition to Levels IV and V, respectively. These probability values translate to the breakpoints of the three principal application categories, Business, Engineering and Real Time, as shown below:

TRANSITION BREAKPOINTS FOR THE THREE APPLICATION TYPES

	Business Systems	Engineering Systems	Real Time Systems
Transition to SEI Level	**PI Value**	**PI Value**	**PI Value**
II	17	15	9
III	19.5	18	11.5
IV	22	20.5	14
V	25	23	16.5

We proceed now to linking the known behavior of the PI trend over time with the SEI Maturity Levels.

PI TREND LINES RELATED TO SEI MATURITY LEVELS

PI TREND LINE FOR ENGINEERING (C&C, TELECOM, SYSTEM S/W, SCIENTIFIC, AND PROCESS CONTROL SYSTEMS)

Figure 8 below shows the QSM projected trend line for increase in Productivity Index as a function of calendar time for engineering systems. This trend line is representative of five categories of application software: Command & Control, Telecommunication and Message Switching, Operating Systems, Scientific and Process Control systems. The start of the trend line is plotted at the average PI for these systems as of 1990 (at the left edge of the chart). The rate of increase per year for these systems has been about +1 PI every three years.

The standard deviation of the distribution of systems about this average is approximately +/- 3 Productivity Indices. Since the SEI Maturity Level distribution has been correlated with the PI [loosely, not rigorously] we can make reasonable probabilistic inferences about the approximate percentage of organizations likely to be in each maturity level based upon the measured rate of improvement of such organizations in terms of the Productivity Index. Figure 8 makes such an extrapolation. The extrapolation is based on data from approximately 400 completed systems in these application categories and spans 15 or more years. The rate of improvement has been stable for more than five years.

The Bell curve was tuned to the SEI percentage levels shown in Figure 4 as of the end of 1994. Think of the Bell curve as sliding upward (to the right) on the diagonal rate of improvement line to get a feel for how the changes in percentages in each SEI level are likely to occur based on what has happened through 1994. The Bell curve of Figure 8 is shown positioned at the start of 1996.

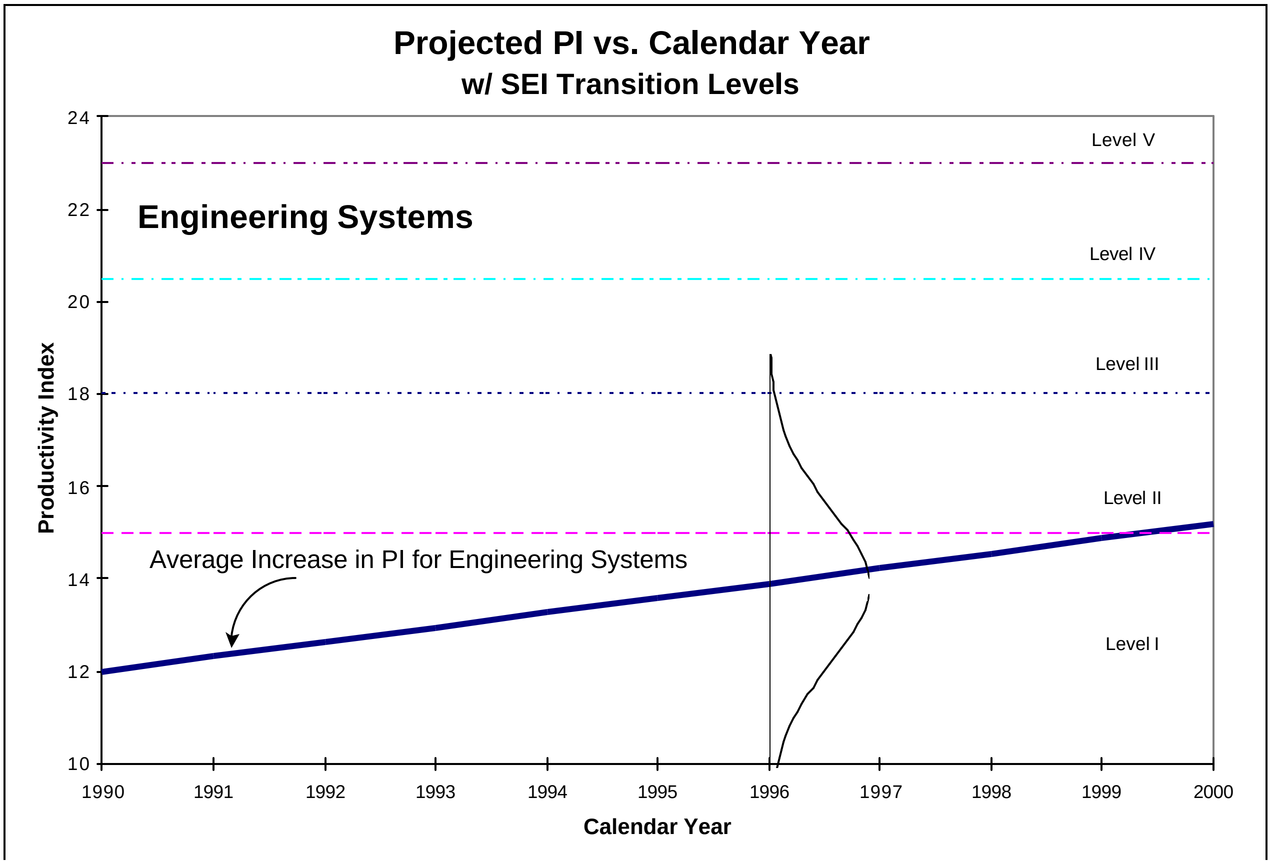

Figure 8. Trend line showing the average rate of increase in Productivity Index for Engineering systems (Command & Control systems, Telecommunication and Message Switching systems, Operating Systems, Scientific systems and Process Control systems). Based on the QSM database as of 1994. Estimated SEI Maturity Level boundaries are superimposed. Trend line is at the 50% probability level.

PI TREND LINE FOR BUSINESS SYSTEMS

Figure 9 below shows the QSM projected trend line for increase in Productivity Index as a function of calendar time. This trend line is representative of business application software. The left edge of the trend line is plotted at the average PI for these systems as of 1990. The rate of increase per year for these systems has been about +1 PI every 2 1/2 years over the last ten years.

The standard deviation of the distribution of systems about the 1994 average is approximately 4 Productivity Indices. Since the SEI Maturity Level distribution has been [loosely] correlated with the PI we can make reasonable probabilistic inferences about the approximate percentage of organizations likely to be in each maturity level. The slope is based upon the measured rate of improvement of business organizations. The extrapolation done in figure 9 is based on data from approximately 1000 completed systems.

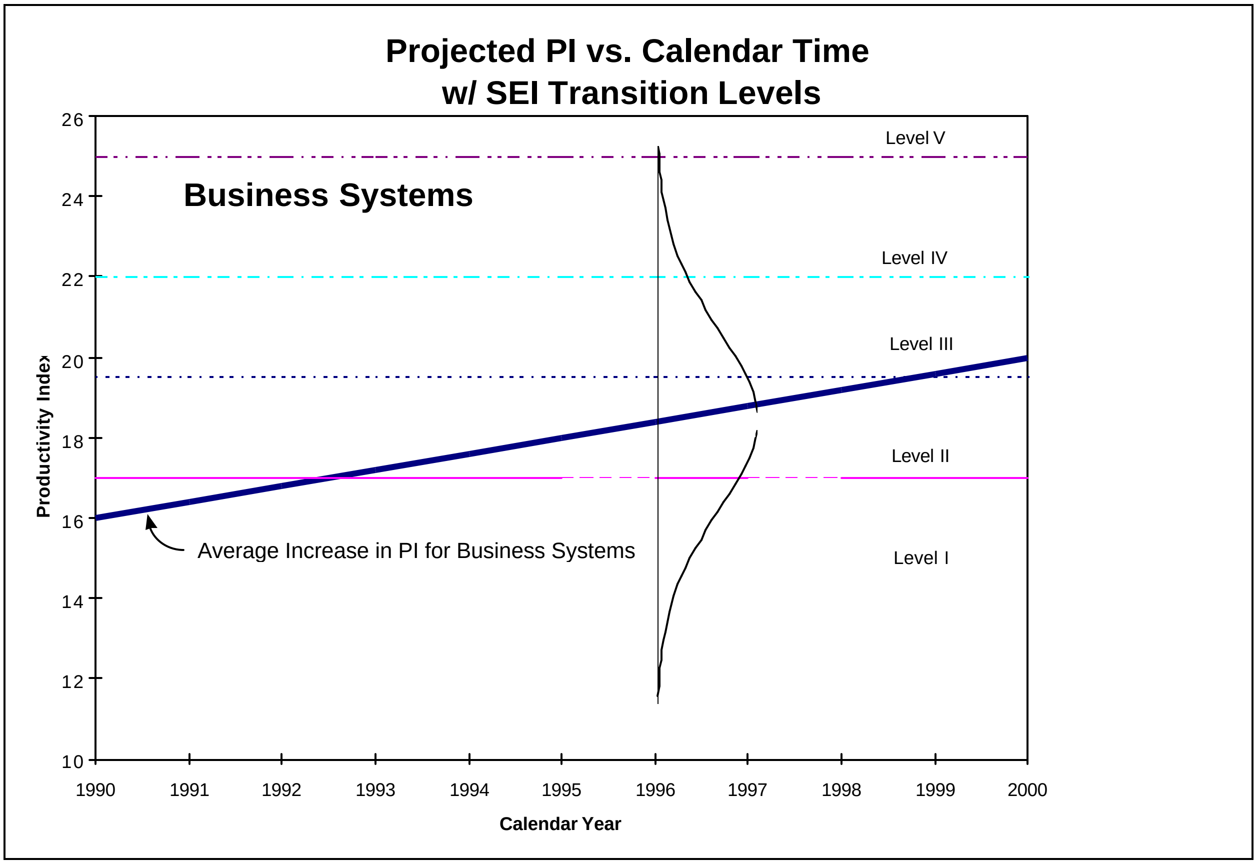

Figure 9. Trend line showing the average rate of increase in Productivity Index for business systems. The trend is based on the QSM database as of 1994. Estimated SEI Maturity Level boundaries are superimposed. Trend line is at the 50% probability level. Probability curve shows approximate percentages expected in each level as a function of calendar year.

PI TREND LINE FOR A BUSINESS SYSTEMS LEADER

Figure 10 below shows the QSM projected trend line for increase in Productivity Index as a function of calendar time. This trend line is an example of a company that is a leader in developing business application software. The trend line is plotted at the average PI for this company as of 1990. The rate of increase per year for this company has been about +1 PI every 1.4 years over the last ten years. This is the best I have seen for any company so far over a sustained period of time. This company has attacked the productivity and quality improvement process on a broad front in machine and tool investment, education, training and management enlightenment.

The standard deviation of the distribution of this organization's systems about the 1994 average is approximately two Productivity Indices. Since the SEI Maturity Level distribution has been [loosely] correlated with the PI we can make reasonable probabilistic inferences about the approximate percentage of organizations likely to be in each maturity level based upon the measured rate of improvement of this business organization in terms of the Productivity Index. Figure 10 makes such an extrapolation.

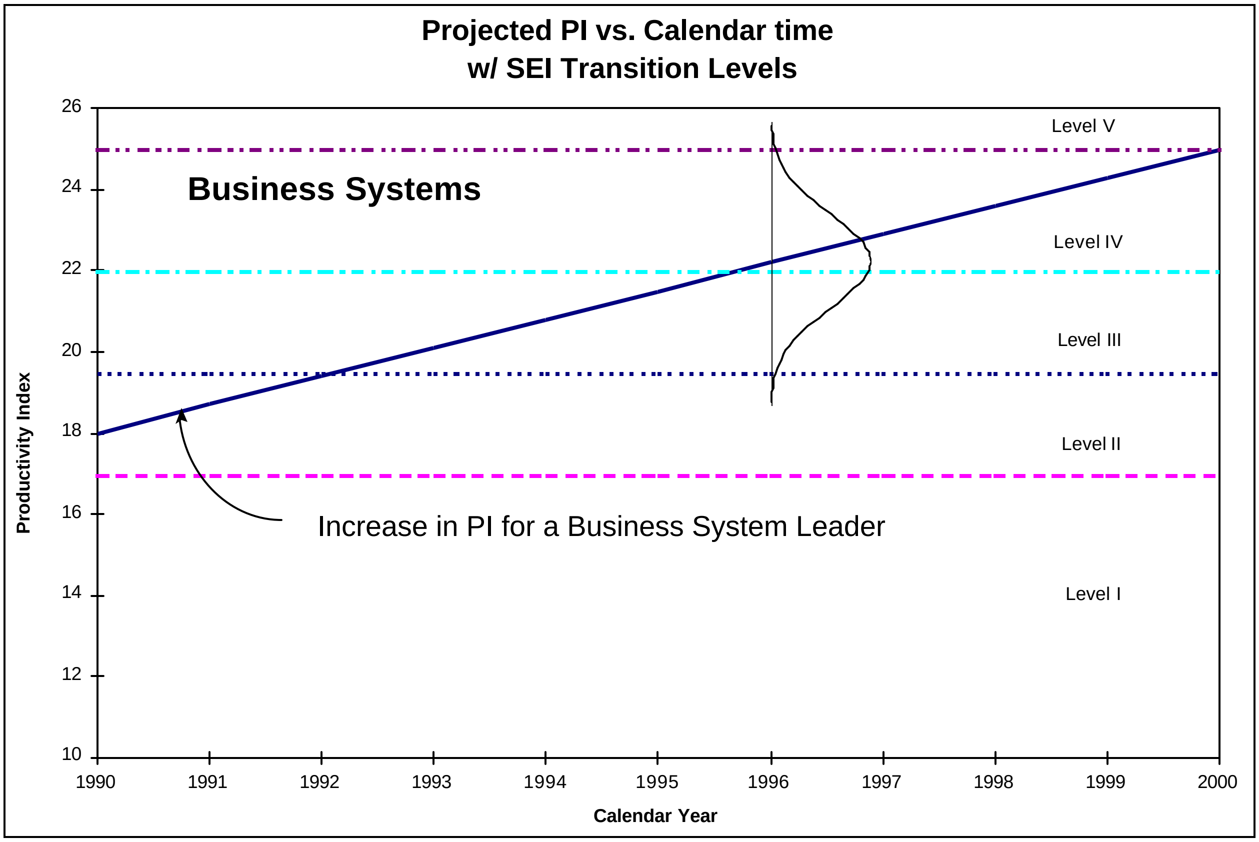

Figure 10. Trend line showing the average rate of increase in Productivity Index for a business system leader in development. Estimated SEI Maturity Level boundaries are superimposed. Trend line is at the 50% probability level. The distribution about this trend line is known as of 1994. The standard deviation of the PI is about +/- 2 PI at any point in time. i.e., in 1990 68% of this company's systems were between the range PI 16 and PI 20.

Since this company represents the very best of consistent software developers and the projection for them moving into the two highest SEI levels is only significant for the last few years of the 20th century, it would appear that it will be the 21st century before we see any significant number of companies operating at defined and optimizing levels of software development maturity. Rate of improvement appears to be agonizingly slow, or the task of accomplishing it is much more difficult than we realize; maybe both.

On the other hand there have been some encouraging signs of possible breakthroughs in the sense that quantum jumps of several PIs have occurred on projects done using some of the new tools. It should be pointed out that the sample size was very small. The applications were generated using application generators, which were part of the toolset. About 20% of the code had to be handwritten, or at least, hand re-written. These prototype systems were all straightforward business developments where the algorithms and the logic design were well understood and had existed in previous products.

Nevertheless, if organizations can improve their process and assimilate high productivity tools concurrently, then the possibility does exist for significant quantum jumps to higher PIs and maturity levels. This opportunity needs to be fostered by some of the industry leaders to see if such happenings can be made to happen by management action.

PI TREND LINE FOR REAL TIME SYSTEMS

Figure 11 below shows the QSM projected trend line for increase in Productivity Index as a function of calendar time for real time software. The left edge of the trend line is plotted at the average PI for these systems as of 1990. The rate of increase per year for these systems has been about +1 PI every 3 years over the last ten years.

The standard deviation of the distribution of systems about the 1994 average is approximately +/- two Productivity Indices. Since the SEI Maturity Level distribution has been loosely correlated with the PI we can make reasonable probabilistic inferences about the approximate percent of organizations likely to be in each maturity level. Figure 11 is an extrapolation based on data from approximately 200 completed systems in this application category and spans 15 or more years.

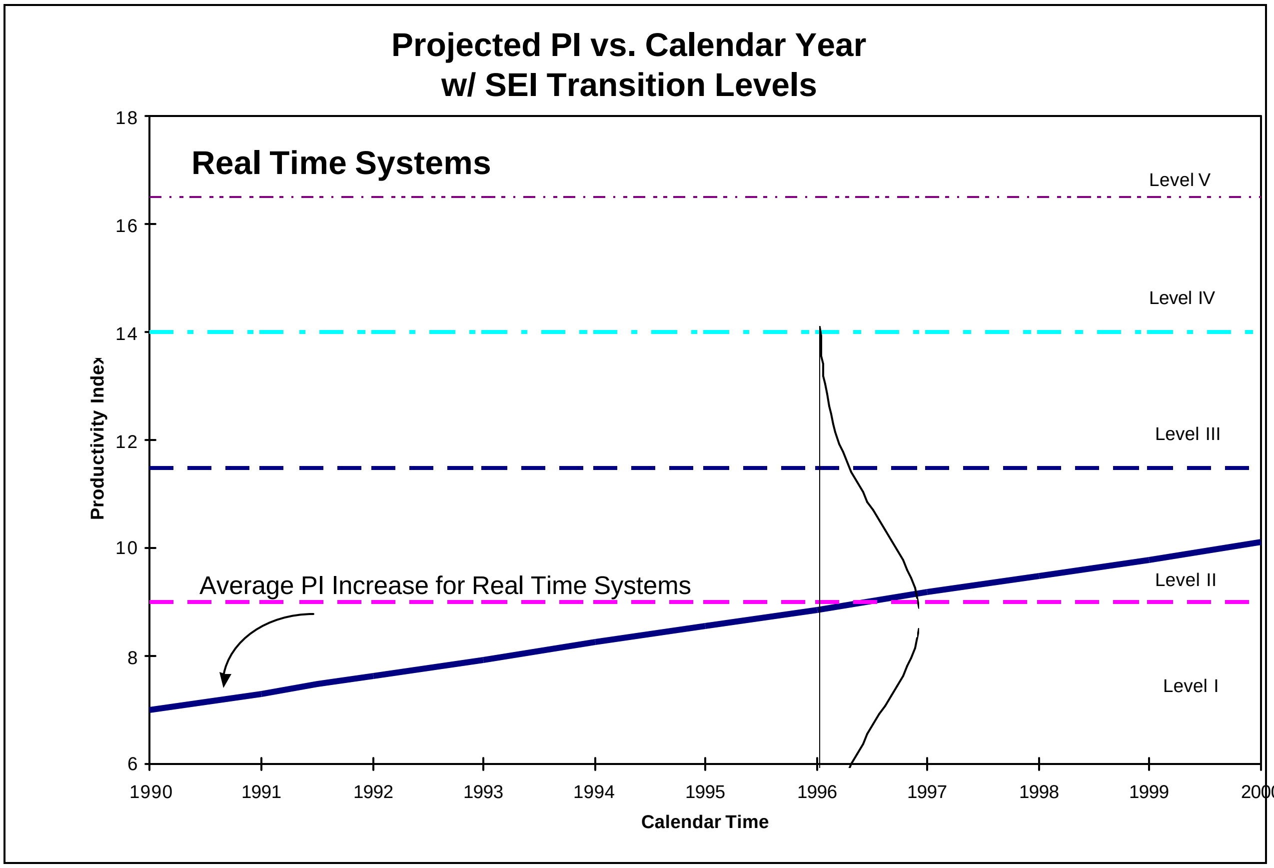

Figure 11. Trend line showing the average rate of increase in Productivity Index for real time systems. Trend line is based on the QSM data base as of 1994. Estimated SEI Maturity Level boundaries are superimposed. Trend line is at the 50% probability level.

ECONOMIC VALUE OF PROCESS IMPROVEMENT

There is substantial tangible benefit in process improvement. We have used the SLIM estimating tool to estimate the schedule, effort, cost and Mean Time to Defect for a typical system in each of the application categories we have used in this analysis. I used the average size system for the business, engineering and real time databases. I used the lowest PI for SEI level 2 and 3 for each application categories as shown in the table of breakpoints on page 9. The results are shown in the next three figures, which follow.

Economic Value of Process Improvement for Engineering Systems

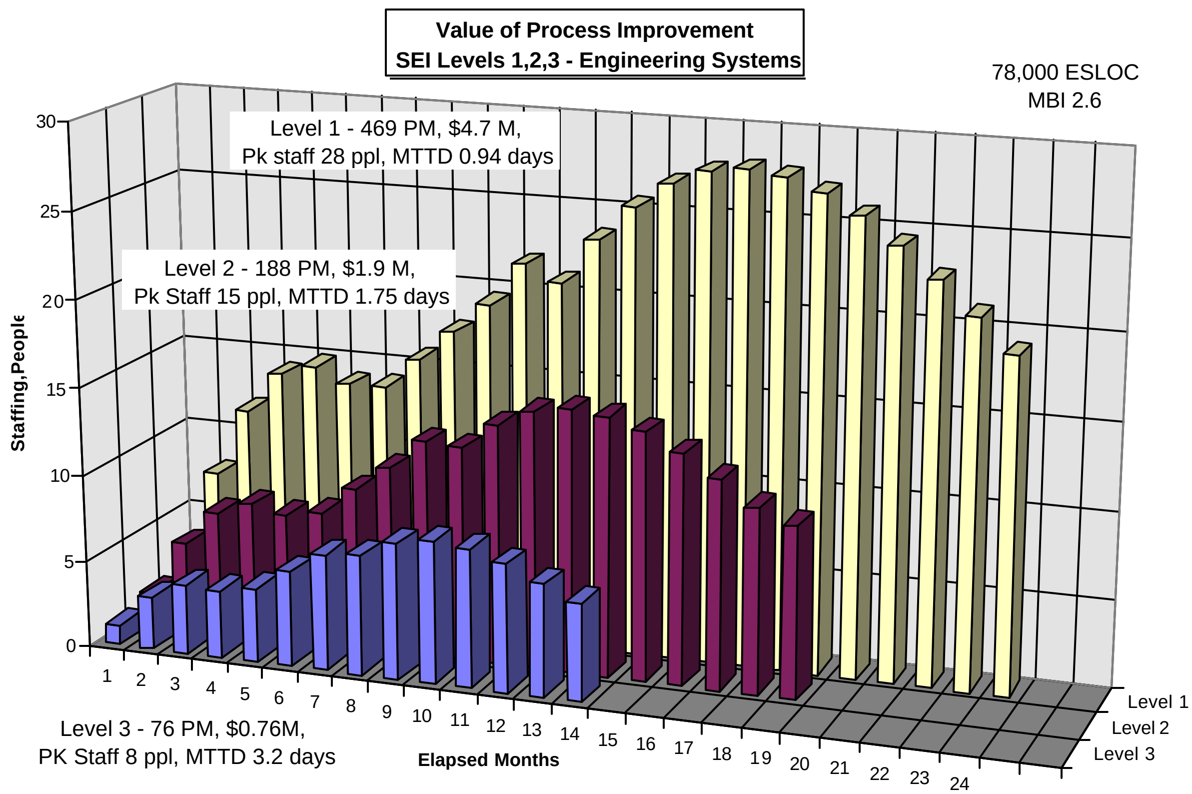

Figure 12. Economic value of moving up the SEI scale for an engineering system.

Economic Value of Process Improvement for Business Systems

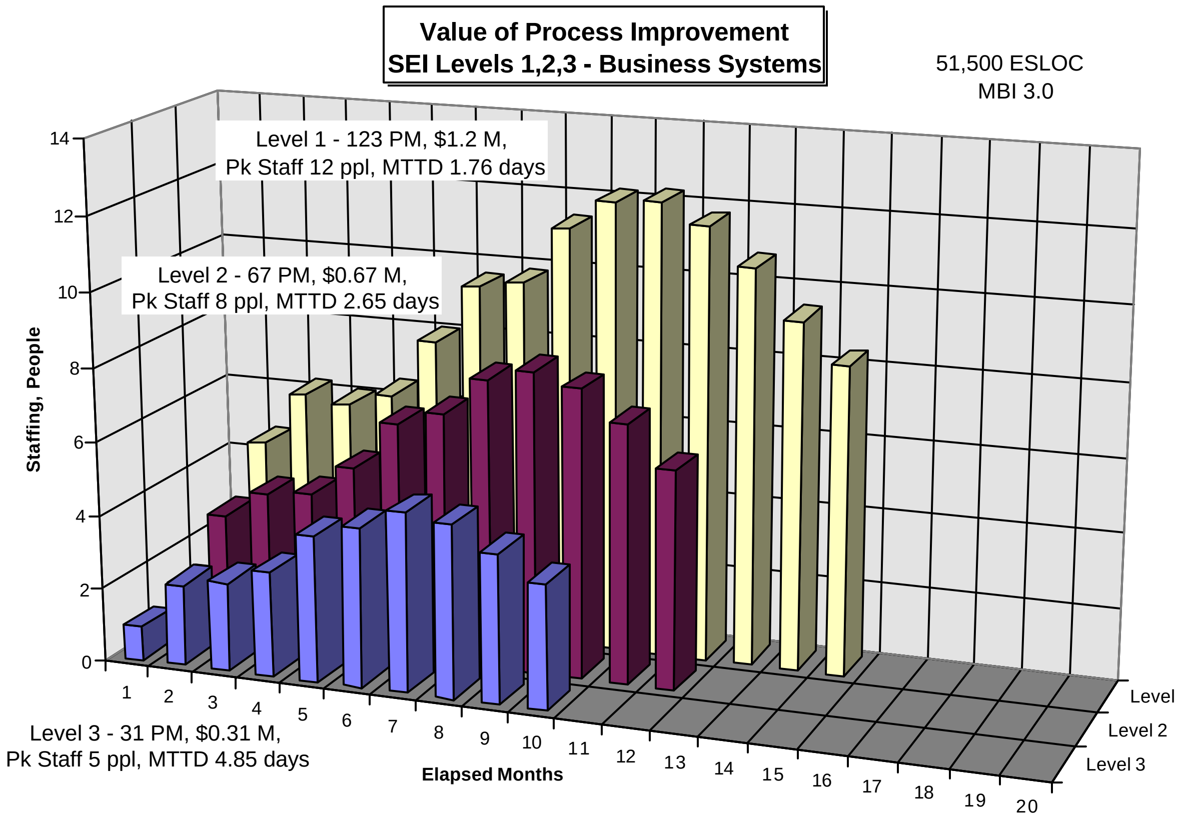

Figure 13. Economic Value of moving up the SEI scale for an average size business system.

Economic Value of Process Improvement for Real Time Systems

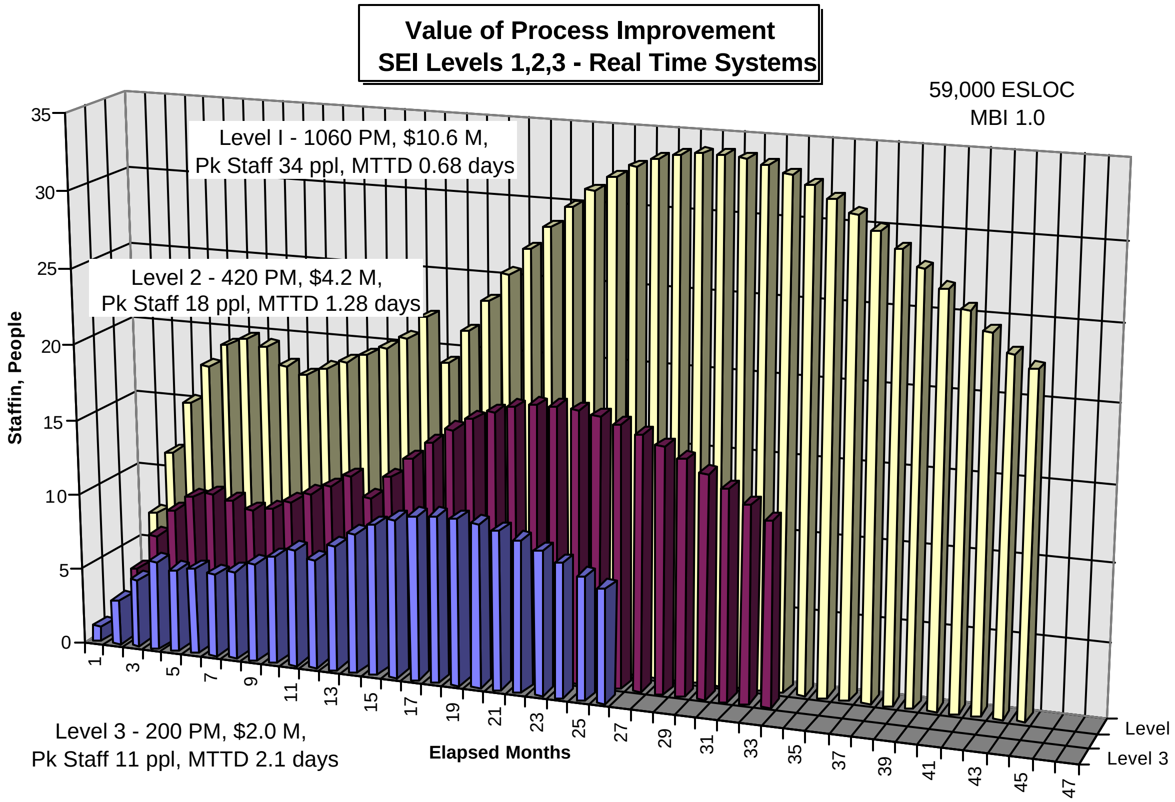

Figure 14. Economic Value of moving up the SEI scale for an average size real time system.

The savings for each of these cases are very significant. Since these savings represent only a single system it would be appropriate to multiply the savings by the average annual throughput of systems in the development organization to get a rough feel for the potential organizational savings. It is very likely that those savings would be sufficient to pay for the cost of carrying out the process improvement activities.

These three cases were taken at the average size for their respective application category. The result of moving up from one level to the next is very general, however. The magnitude of the all the management numbers tend to scale proportional to the way they look on these figures. In other words, the percentage change remains close to constant. So, if we looked at the situation where the size being compared was 500,000 SLOC, the figures would look the same at first glance; the change in magnitude would only become apparent when you looked closely at the horizontal and vertical scales of the axes.

The table below shows the percentage changes for a business system of 100,000 SLOC.

	Schedule		Staff		Effort		MTTD	
SEI Level	Mos.	% Change	People	% Change	PM	% Change	Days	% Change
I	19.3	--	24	--	309	--	1.28	--
II	16.0	**-17**	16	**-33**	168	**-46**	1.93	**51**
III	12.6	**-35**	9.5	**-60**	79	**-74**	3.23	**152**

The table below is for a business system of 51,500 SLOC corresponding to the data portrayed in Figure 13. Note that the percentage changes are nearly the same (not more than one percentage point different) as the table above at 100,000 SLOC.

	Schedule		Staff		Effort		MTTD	
SEI Level	Mos.	% Change	People	% Change	PM	% Change	Days	% Change
I	14.5	--	12	--	123	--	1.76	--
II	12.0	**-17**	8	**-33**	67	**-46**	2.65	**51**
III	9.5	**-35**	4.8	**-60**	31	**-75**	4.45	**153**

CONCLUSIONS

There does seem to be strong correlation between the SEI Maturity Levels and the QSM Productivity Index.

- Both scales seem to be measuring the process maturity and productivity capability of a software development organization although from a different perspective.

- The QSM PI measures performance on a *quantitative scale.* It is based on measurement in bottom line management terms -- time, effort, cost, manpower and defects.

- The SEI Maturity Level is determined by quantifying a binary response to a set of graded questions that reflect good software engineering practice. The more of these graded questions are answered affirmatively, the more mature an organization is presumed to be. Clearly the best companies must ultimately be able to do the things indicated by affirmative responses to the questions before they can reach the highest levels.

- When the SEI Maturity Level is linked with the rate of improvement in PI established from the QSM data base of completed projects, then projections of approximate distributions in each level can be made as a function of calendar time. The trend line projections demonstrate this.

- The charts showing the economic benefit of moving up the SEI scale clearly show the large savings possible. There is enough savings potential inherent in moving up to pay for the process improvement activities.

The analysis done for a leader in the business systems development arena clearly demonstrates that the fraction of companies that will be in the two highest maturity levels will be quite small until we are well into the 21st century unless a dramatic change in rate of improvement occurs. This possibility does exist and has been observed to happen, but so far the sample of organizations exhibiting significant quantum jump behavior is small. There is some hope more rapid improvement may occur, but it will take a combination of hard work, dedication, good management and sound investment to make it happen broadly.

That is the challenge.

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