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THE ECONOMIC IMPACT OF STARS-SUPPORTED TECHNOLOGIES

Thomas P. Frazier, *Project Leader*
Bruce N. Angier
Elizabeth K. Bailey
Philip M. Lurie
Kathryn L. Wilson

January 1992

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Director, Defense Advanced Research Projects Agency

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INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

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Thomas P. Frazier, Bruce N. Angier, Elizabeth Bailey, Philip M. Lurie, and Kathryn L. Wilson

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This document is an annotated version of a briefing that was presented in December 1991 at the STARS '91 Conference, sponsored by the Defense Advanced Research Projects Agency (DARPA). The briefing describes a model that can be used to calculate DoD software life-cycle costs and the effects on those costs of technologies being developed or supported by the Software Technology for Adaptable, Reliable Systems (STARS) program. The model estimates and tracks the amount of software that is developed and maintained, and translates that amount into effort and cost estimates. The model has parameters for the individual and synergistic effects of advanced reuse, process, and tool technologies. Four scenarios, each reflecting different assumptions about investments in software technology and the speed at which these technologies will be adopted, are analyzed, and cost estimates are presented. Though the model and its parameters are subject to change, preliminary conclusions are: small increases in the speed of technology adoption result in large savings, the STARS program appears to be cost-effective, and achieving a decrease by a factor of two in software expenditures by the year 2000 will be difficult.

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Director, Defense Advanced Research Projects Agency, under contract MDA 903 89 C 0003, Task Order A-144, issued 16 June 1990, and amendments. The work on this task is being done in support of the Software Technology for Adaptable Reliable Systems (STARS) program. One of the objectives of the task was to develop practical ways to model and measure increases in productivity, reductions in total software life-cycle costs, and effects on software quality of the STARS environment, tools, and processes. As part of accomplishing this task, IDA was to develop an abstract model to estimate Department of Defense (DoD) software life-cycle costs. This annotated briefing summarizes the current state of this modeling effort and shows examples of its use.

A version of this briefing was presented as part of the STARS '91 Conference Plenary Session held on December 3, 1991, in Tysons Corner, Virginia.

CONTENTS

The Economic Impact of STARS-Supported Technology

Outline

- **Introduction**
- **STARS Model**
- **Four scenarios**
- **Conclusions**

The purpose of this briefing is to report preliminary estimates of the economic impact of technologies being developed, enhanced, or accelerated by the Software Technology for Adaptable Reliable Systems (STARS) program. To calculate these estimates, we developed a model that connects the effects of STARS-supported technologies with their impact on the life-cycle costs of software.

This briefing is divided into four parts. The introduction reviews an economic analysis of Department of Defense (DoD) software costs that appears in Chapter 10 of the Software Technology Strategy (SWTS) [1].[1] That analysis was a collaboration between IDA and Barry Boehm, Director of the Software and Intelligent Systems Technology Office, Defense Advanced Research Projects Agency (DARPA). The model described in this briefing is an extension of that analysis.

The second part of the briefing presents a description of an automated model used to analyze the economic impact of megaprogramming technologies. It is called the STARS model because it is being developed to undertake cost-benefit analyses in support of the STARS program.

The third part of the briefing details the results from applying this model to four scenarios. These scenarios range from conservative to success-oriented.

The final part of the briefing presents a set of conclusions drawn from our work.

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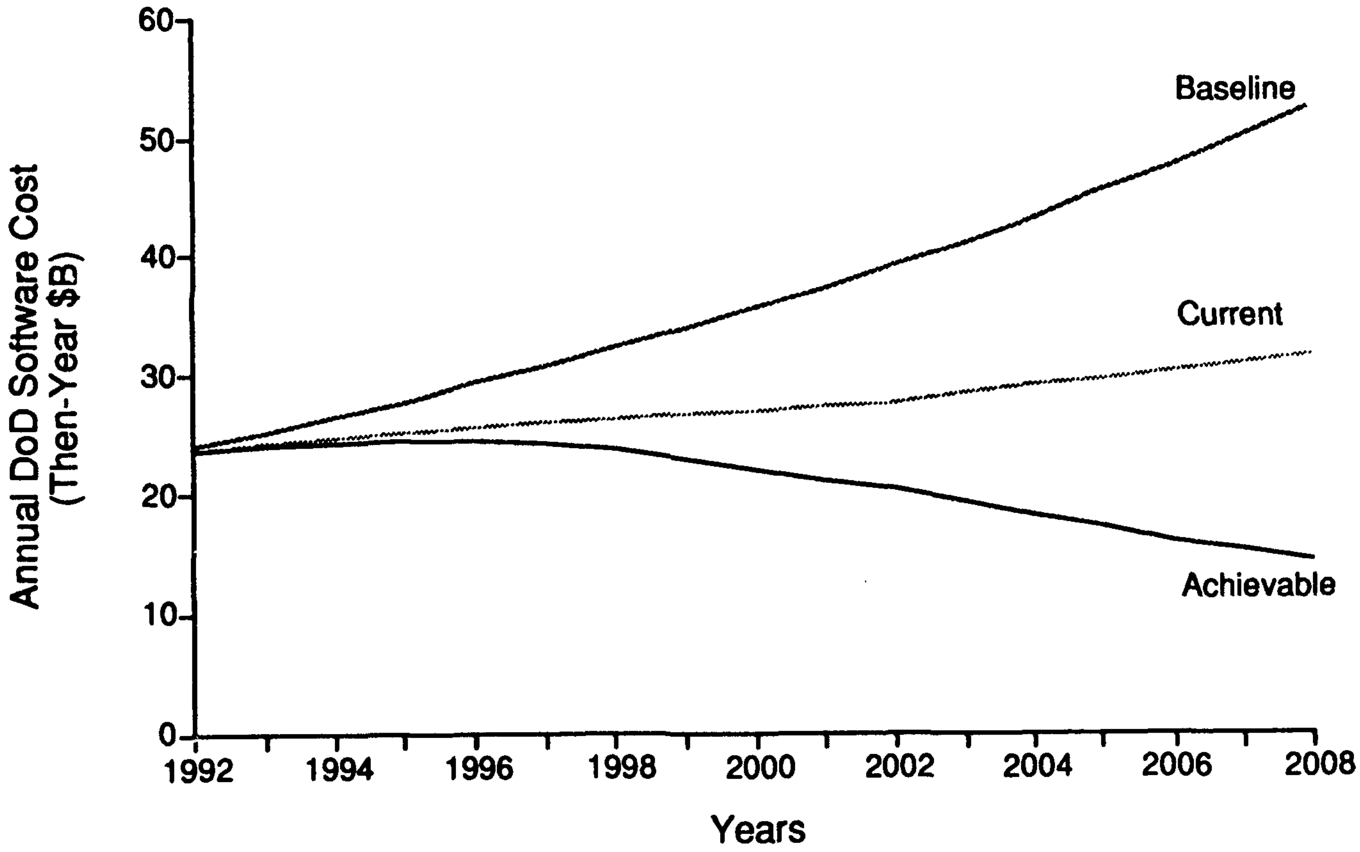
1 The SWTS is being prepared for the Director of Defense Research and Engineering (DDR&E) in partial fulfillment of the DDR&E Software Action Plan.

SWTS Cost Savings

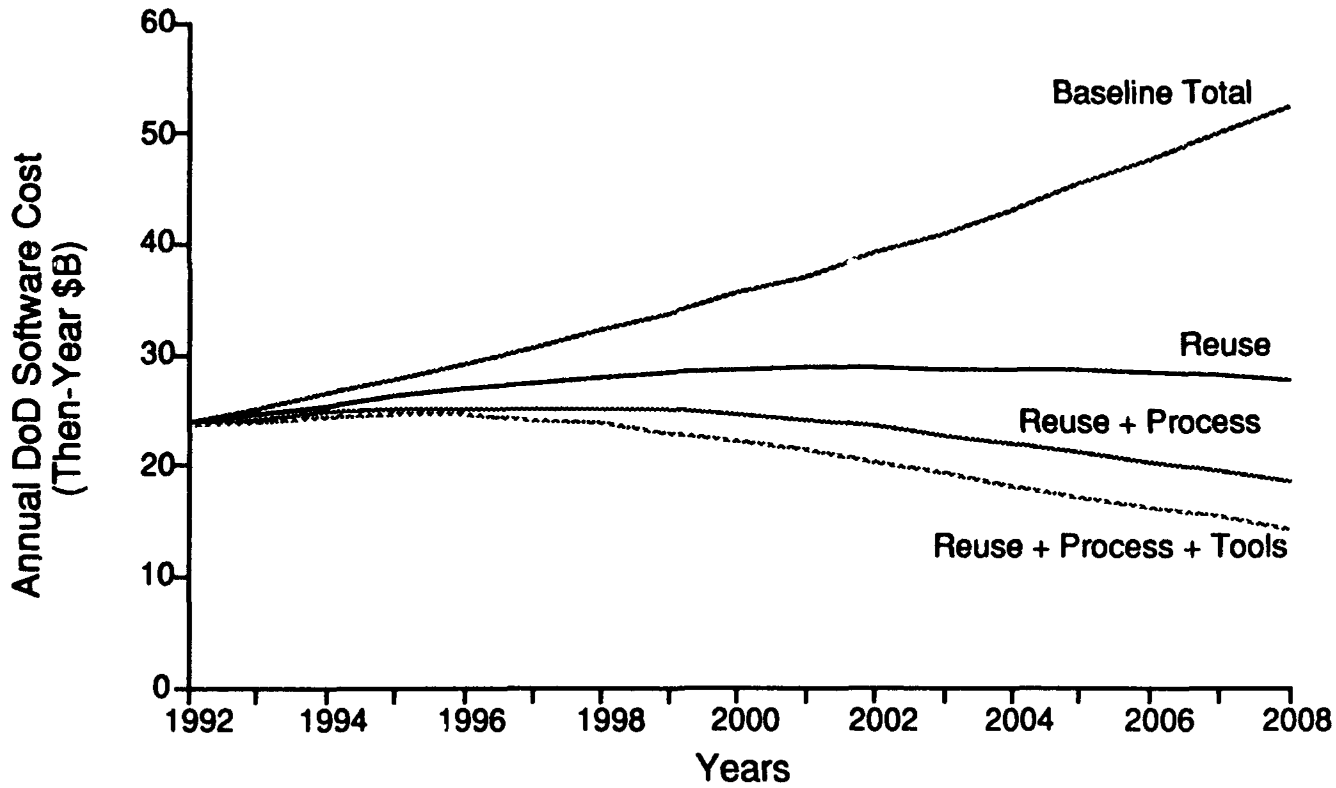


The figure above was taken from Chapter 10 of the Software Technology Strategy (SWTS) and represents the results of an earlier economic analysis that we collaborated on with Barry Boehm [1]. (An automated version of the model is described in [2].) This earlier work helps to set the stage for the presentation today, which describes a more detailed extension of that analysis. The top line (Baseline) represents the projected growth in DoD software expenditures in the absence of specific DoD technology investments. It assumes that the 1992 expenditures total $24 billion [3 through 6] and that the annual growth in demand is 4% [5] coupled with 4% annual growth in productivity as a result of advances from technologies being developed in the commercial sector, such as Computer-Aided Software Engineering (CASE) tools [7 and 8].

The middle and bottom lines (Current and Achievable) are projections based on two different investment scenarios in megaprogramming technologies. The Current scenario represents projections based on the currently planned investments outlined in the SWTS. The Achievable scenario represents further savings from increased levels of investment.

One of the goals stated for the Software Technology Strategy is to achieve a factor of two reduction in software unit costs by the year 2000. One of the questions to be explored through the economic modeling discussed here is whether this ambitious "2 X reduction" goal can be realized.

SWTS Cost Savings by Source



The analysis described in the SWTS assumes savings from three sources: reuse, process improvements, and tools or software engineering environments (SEEs). The figure above shows the contribution of each technology to the savings found under the Achievable investment scenario.

The term "reuse" is intended to apply generally to any form of work avoidance through software reuse, application generators, and commercial off-the-shelf (COTS) software. Process improvements, which include prototyping and risk management, enable projects to avoid costly rework and work smarter. Improvements in SEEs result in better, more interoperable tools that allow software practitioners to work faster.

In the analysis described in the SWTS, for each of these technologies, a time series of parameter values for each year from 1992 to 2008 represents the fraction of savings (FS) from the use of the technology and the fraction of time (FT) that the technology is actually used. The realized savings for a given year were derived by multiplying FS by FT and subtracting the product from 1. This value was then multiplied by the baseline expenditures to yield a new projection that takes into account the savings resulting from the technology. For example, if the FS for reuse in a given year is .70 and the FT is .10, then the realized savings are (.70)(.10) = .07. To get the new projected cost, subtract this value from 1 and multiply the result (.93) by the baseline costs.

STARS Economic Model

- Extends earlier model
- Includes
  - Reuse
  - Process
  - Tools
- Reflects cost of these technologies in labor rates
- Adds synergy factor
- Incorporates SEI Capability Maturity levels
- Models maintenance as inventory flow
- Includes effect of quality (defects/KLOC) on maintenance costs

Our extension to the model just described examines savings from the same three technologies. It also reflects the costs incurred in implementing these technologies via increased labor rates.

We believe that any realistic attempt to model the economics associated with megaprogramming must consider the impact of capability maturity. The model distinguishes between the five Software Engineering Institute (SEI) Capability Maturity levels. Though not explicit in the SEI framework, we believe there is a correlation between capability maturity and the level of use and sophistication of megaprogramming technologies. This correlation is reflected in the model by assuming that, for any given year, the FSs and FTs increase with capability maturity level. While the SEI is primarily responsible for facilitating the movement of software organizations to higher levels, STARS is expected to be a facilitator as well by enhancing the technologies that underlie this movement.

Additional gains are realized at higher SEI levels through the addition of a factor to account for synergy between technologies. This synergy factor is our attempt to estimate the additional fraction of savings that comes about by combining the use of advanced reuse, process, and tools. Using a hypothetical example, the use of advanced tools alone might result in an FS of .10, the use of advanced reuse concepts alone might result in an FS of .15, but the use of both together might result in a combined FS of .30. In this case, the synergy FS would be .05 (.10 + .15 + .05 = .30)

A portion of the model deals with development costs and a portion with maintenance. Maintenance is modeled as an inventory flow process and will be described in more detail in a later vugraph.

The model assumes that quality increases with increases in SEI level. Variations in code quality (defects/KLOC) affect the amount of corrective maintenance required in the model and are reflected in maintenance costs.

The Capability Maturity Model (CMM), previously called the Process Maturity Model, has been under development at SEI for several years. (For a current introduction to the CMM, see Reference [9]. For a more detailed explanation of key practices, see Reference [10].) Organizations are characterized as being at one of five maturity levels (as adapted from Reference [9], p. 8-9):

1. Initial—The software process is ad hoc, with success depending on circumstance and individual effort.

2. Repeatable—Basic management processes are in place to track cost, schedule, and functionality. Earlier successes can be repeated.
3. Defined—Management and software engineering activities are understood, standardized, and integrated.
4. Managed—Detailed process and product measures are collected and used to control both process and product.
5. Optimizing—"Continued process improvement is enabled by quantitative feedback from the process and from testing innovative ideas and technologies."

Scenarios Examined

- Megaprogramming Baseline
- STARS Value-Added
- Further Acceleration of Megaprogramming
- 2 X Reduction Goal

Our short titles for the scenarios to be modeled are listed above. A brief description of each scenario is provided in the text below. More detailed descriptions of the parameters that differentiate between these scenarios will be provided in later vugraphs.

The Megaprogramming Baseline reflects our best estimate of the rate at which the FS and FT associated with reuse, process, and tools/SEEs will change over time. Several studies have shown that the adoption of new technologies is extremely slow. Studies by IDA have shown that, on average, it takes 9 years between the introduction of a technology until it is used 50% of the time (FT = .50) and 18 years until its use approaches 100%.

The STARS Value-Added scenario reflects changes to the FTs and FSs to reflect acceleration in the adoption of these technologies and greater savings from their use.

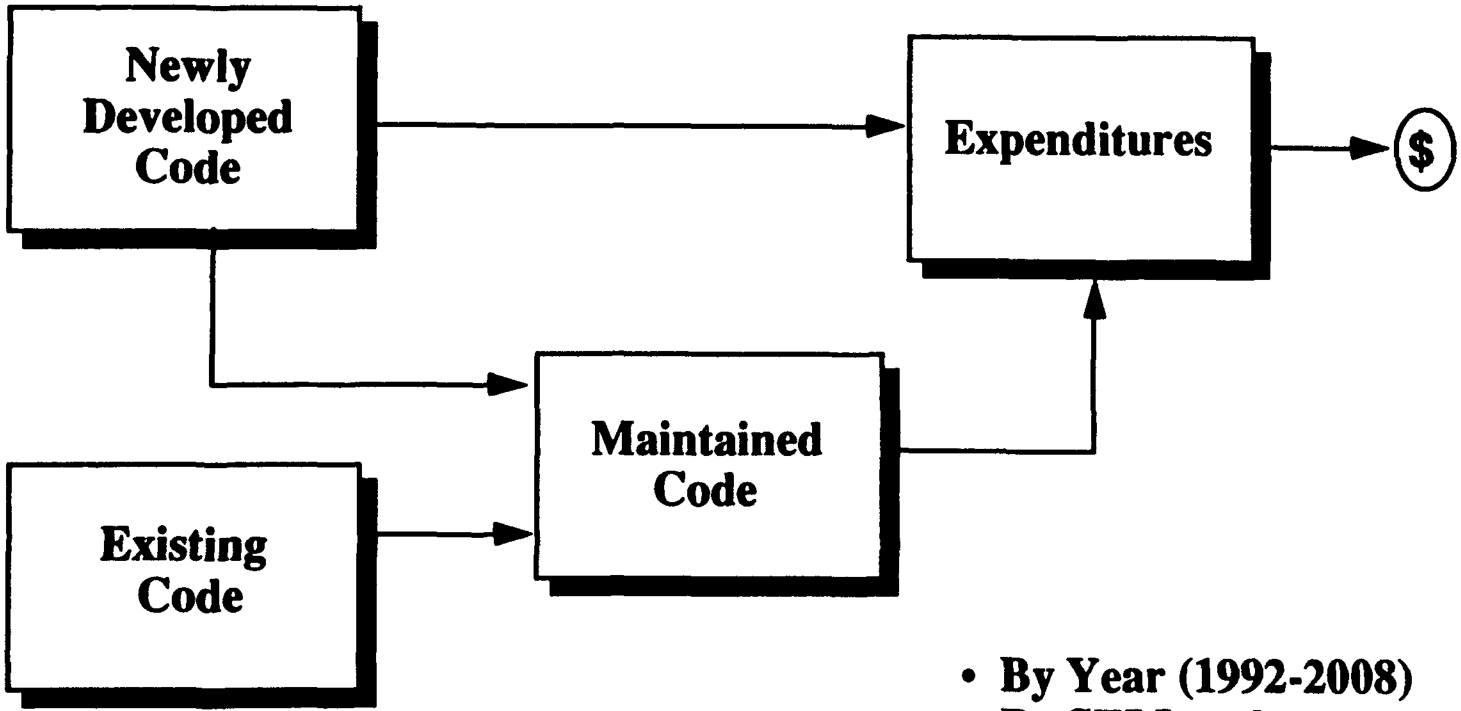
The Further Acceleration of Megaprogramming scenario looks at the impact of adopting these technologies even faster than the rate we envision with STARS.

Finally, the 2 X Reduction Goal scenario looks at a combination of model parameters that produces the stated goal outlined in the Software Technology Strategy of reducing software unit costs by a factor of two. The feasibility of meeting these parameter values will also be discussed.

For each of the scenarios, the bottom-line values of interest are the total DoD software costs for each year included in the scenario and the Net Present Value of savings in the future. The latter discounts future constant dollar savings by 10% per year and, as such, represents a conservative measure of the economic value of megaprogramming technologies.

Prior to the more detailed presentation of these scenarios, the basic structure of the model will be briefly described.

Model Overview



- By Year (1992-2008)
- By SEI Level

The model contains a development and a maintenance portion. Code is developed in a given year, and costs are estimated and then tracked through the maintenance portion of the model. Both new code and maintained code is tracked by year and by SEI capability level.

The model is implemented as an Excel™ spreadsheet containing approximately 40,000 cells. It requires about 1.2MB of disk space.

New Development Portion of the Model

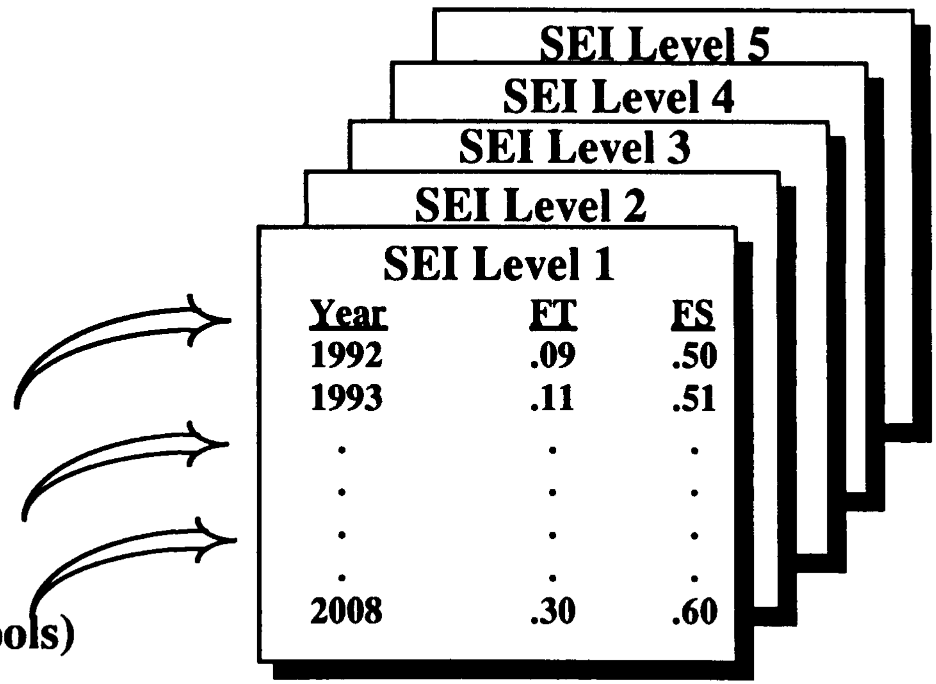
$$PM = \alpha(KDSI)^{\beta} \times Reuse \times Process \times Tools \times Synergy$$

$$Reuse = 1 - (FT \times FS)$$

$$Process = 1 - (FT \times FS)$$

$$Tools = 1 - (FT \times FS)$$

$$Synergy = f\,(Process, Tools)$$



The structure of the development portion of the model is shown above. An equation like that used in the Constructive Cost Model (COCOMO) is used to calculate effort [11 and 12]. Costs are calculated by applying labor rates to effort. Effort and cost calculations are made for each SEI level for each year from 1992 through 2008.

The equation is in the form

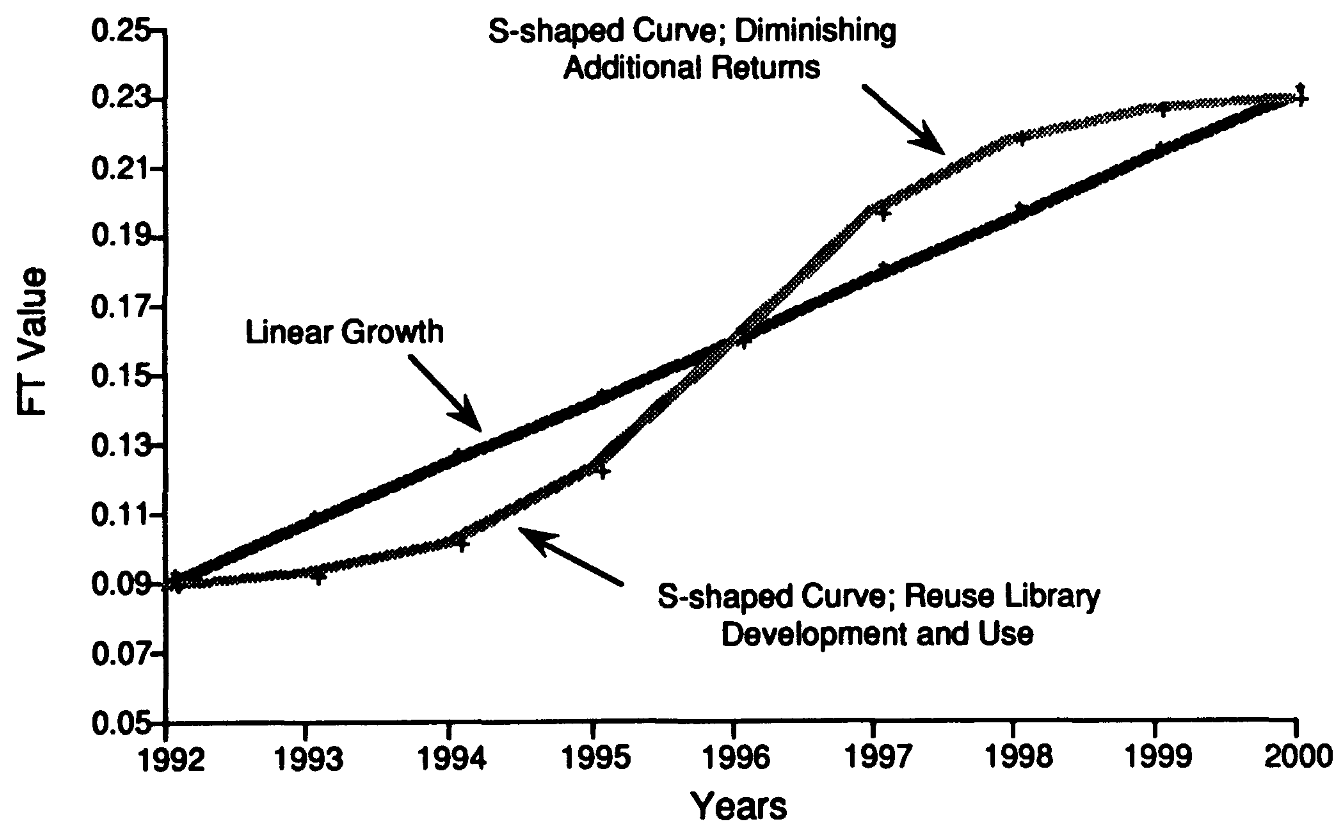
$$PM = \alpha(KDSI)^{\beta} \times Reuse \times Process \times Tools \times Synergy$$

where PM is personmonths and KDSI is thousands of delivered source instructions. The alpha and beta terms vary across SEI levels as shown below. These coefficients generate software development productivities consistent with those reported in [13].

SEI Level	α	β
1	4.75	1.06
2	2.80	1.05
3	1.50	1.04
4	1.20	1.03
5	1.00	1.02

The Reuse, Process, and Tool factors in the equation represent the product of the respective FS and FT subtracted from 1. These operate as do the Effort Adjustment Factors (EAFs) in COCOMO. The contribution of each of the three factors can be further enhanced via the Synergy factor, which is set to 1 for SEI levels 1 and 2 and between 0.9 and 1 for levels 3, 4, and 5. (Additional sources used to develop the FSs, FTs, and other model parameters are shown in the appendix to this document.)

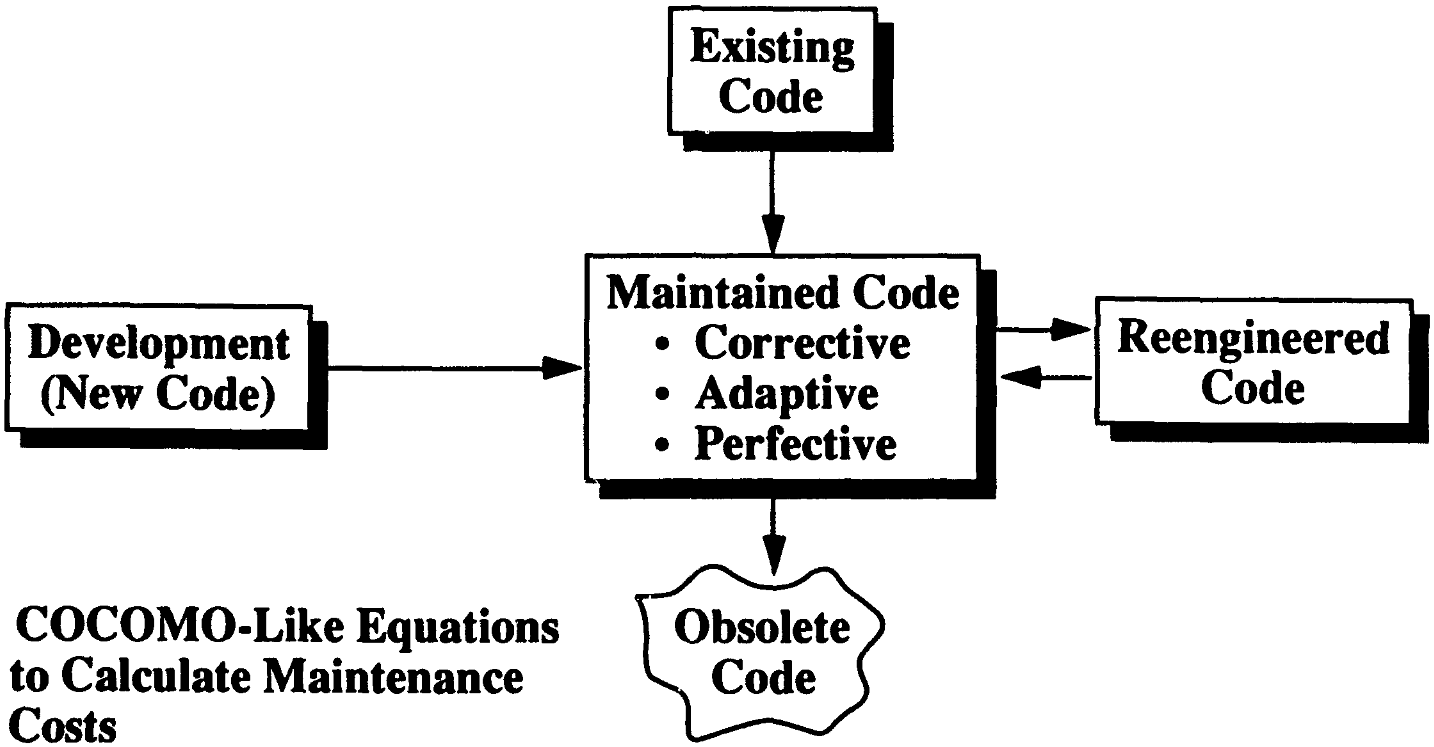
Examples of Technology Transition Paths



The incorporation of new technologies is represented by the FT parameters in the model. As described earlier, these parameters represent the fraction of software that is being developed using the megaprogramming technologies. The values of the FS and FT parameters, in a given year and over time, are key determinants of the dollar savings estimated using the model. This vugraph displays the ways we have modeled FT parameters over time.

The figure above shows two ways that the FT parameters could be modeled. The straight line shows a fixed increase every year. Although this is the simplest way to model changes in FT over time, it may not accurately reflect the path by which some technologies come into use. For example, software reuse may be associated with a substantial overhead at first as software libraries are developed and populated with components. This would result in a slow increase in the early years followed by an acceleration as libraries become more fully populated and finally a flattening out as projects reach a ceiling in terms of the proportion of software that can be developed from reusable components without additional application of techniques such as domain analysis. This technology transition path is represented by the S-shaped curve in the figure. In the model, the FTs are linear across time for process and tools/SEEs and S-shaped for reuse.

Maintenance Portion of the Model



- COCOMO-Like Equations to Calculate Maintenance Costs

The maintenance portion is modeled as an inventory flow process. Maintenance begins with a stock of existing code to be maintained. Each year, newly developed code is added to the total stock of maintained code. Some code is deleted from the total stock via obsolescence and some is reengineered. A portion of the stock of maintained code is changed as a result of corrective, adaptive, and perfective maintenance. Variations in code quality (defects/KLOC) affect the amount of corrective maintenance and are reflected in maintenance costs. The model assumes different defect densities and different maintenance productivities for different SEI levels.

Megaprogramming Baseline

- Reflects technology savings (FS) and technology use (FT) without STARS
- FS and FT increase over time and across SEI levels
- Distribution of firms across SEI Levels

SEI Level	1992	1996	2000
1	.80	59	.39
2	.12	.24	.25
3	.07	.11	.18
4	.01	.04	.14
5	.00	.02	.06

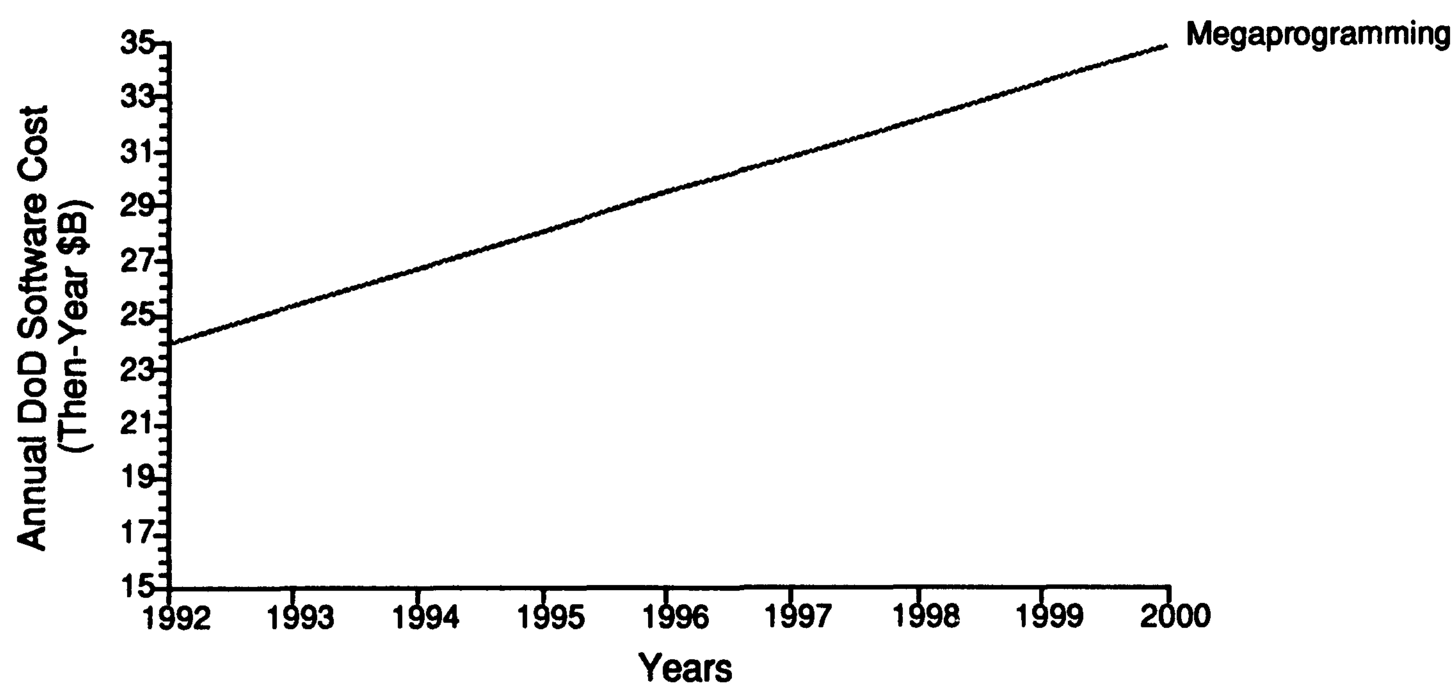
- 1992 SEI distribution from SEI assessments

The first scenario we will examine using our model represents the Megaprogramming Baseline. This scenario reflects our best estimates of the savings (FS) resulting from megaprogramming technologies and the fraction of time (FT) they would be used in the absence of STARS-related efforts to accelerate these technologies.

The distribution of projects across SEI levels is shown above. The starting values were taken from the results of the most recent SEI assessments [14]. The distribution changes annually with the proportion of projects in Level 1 declining over time and that at the higher levels increasing over time. The movement across levels represents our best estimate based on work by [13]. (The SEI currently has no such projections.)

In the Megaprogramming Baseline, the FS and FT values increase gradually over time and as one moves up the SEI levels.

Megaprogramming Baseline Results



The estimated total annual DoD software costs for the Megaprogramming scenario is presented in the chart shown above. We estimate by the year 2000, this scenario will result in annual costs of about $35 billion in then-year dollars. The results are presented in billions of then-year dollars. In constant 1992 dollars, the annual cost estimates remain fairly constant around $24 billion over the 1992-2000 time period. The main purpose of this scenario is to serve as a baseline to which the incremental effects of the STARS program or other software technology initiatives may be applied.

STARS Value-Added

- Distribution across SEI levels identical to Megaprogramming Baseline (conservative assumption)
- Higher FSs and FTs
  - 5% average difference for FSs
  - 15% average difference for FTs
- Example with FTs for External Reuse

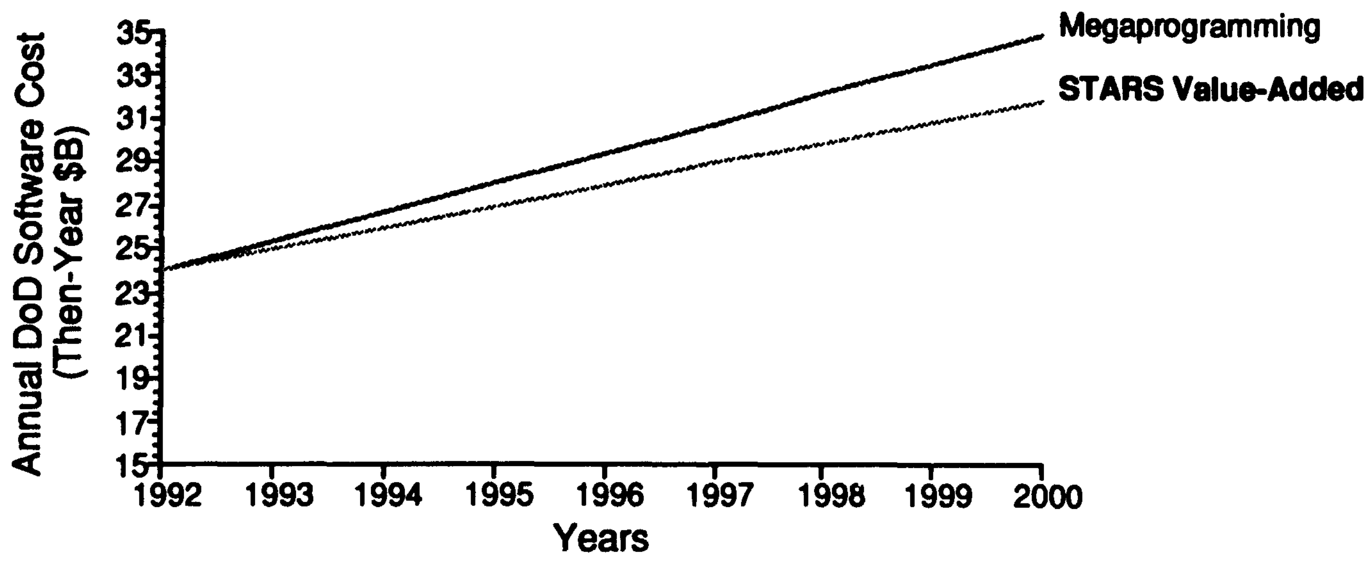
	1992	2000	2008
Megaprogramming	.09	.20	.30
STARS Value-Added	.09	.23	.38

- 10% more code can be maintained per person year

The distribution of projects across SEI levels is the same for the STARS Value-Added scenario as for the Megaprogramming Baseline. While the FS and FT values begin with identical values for the first year (1992), the rate of increase is higher for the STARS Value-Added scenario. The result is that, on average, the FS values are approximately 5% higher than for the Megaprogramming Baseline, and the FT values are approximately 15% higher. A particular FT example is shown above.

One additional difference between the two scenarios is a 10% increase for the STARS Value Added in the amount of code that can be maintained per person per year.

STARS Value-Added Results



Scenario	NPV ($B)
STARS Value-Added	$6.6

This chart presents the estimated reduction in cost (savings) DoD might realize due to the STARS program. Again, the estimates are presented in billions of then-year dollars. If we compute the value of the savings in today's dollars and also account for the time value of money by "discounting" the stream of savings, the result is a financial measure of merit called the Net Present Value (NPV). The Office of Management and Budget (OMB) guidelines specify a discount rate of 10%. This rate was used in all the reported NPV results. The NPV of the additional STARS savings is estimated to be $6.6 billion.

This is a conservative estimate of the potential savings from the STARS program for two reasons. First, many of the savings will only be realized in the first decade of the next century. For purposes of this study we ignore those savings. Second, we assume it will take some time before the full extent of the payoff from STARS technology infusion is realized. Given OMB's 10% discount rate, savings that occur in the out-years are severely discounted.

Further Acceleration of Megaprogramming (By 1 Year)

- FTs and SEI level distributions moved from 2001 to 2000
- Intermediate values interpolated

SEI Level	1992	1993	. . .	2000	2001
1	.80	.74			.35
2	.12	.14		←	.25
3	.07	.09		←	.19
4	.01	.03		←	.14
5	.00	.01			.07

The next scenario looks at the effects of accelerating technology transition. In this scenario, we have two examples. In our first example, we accelerated the rate of technology transition by one year. The STARS Value-Added scenario was chosen as the baseline for this analysis. The distribution of firms across SEI levels in the year 2001 was assigned to the year 2000. In addition, the FTs from the year 2001 were assigned to the year 2000. Values between 1992 and 2000 were interpolated.

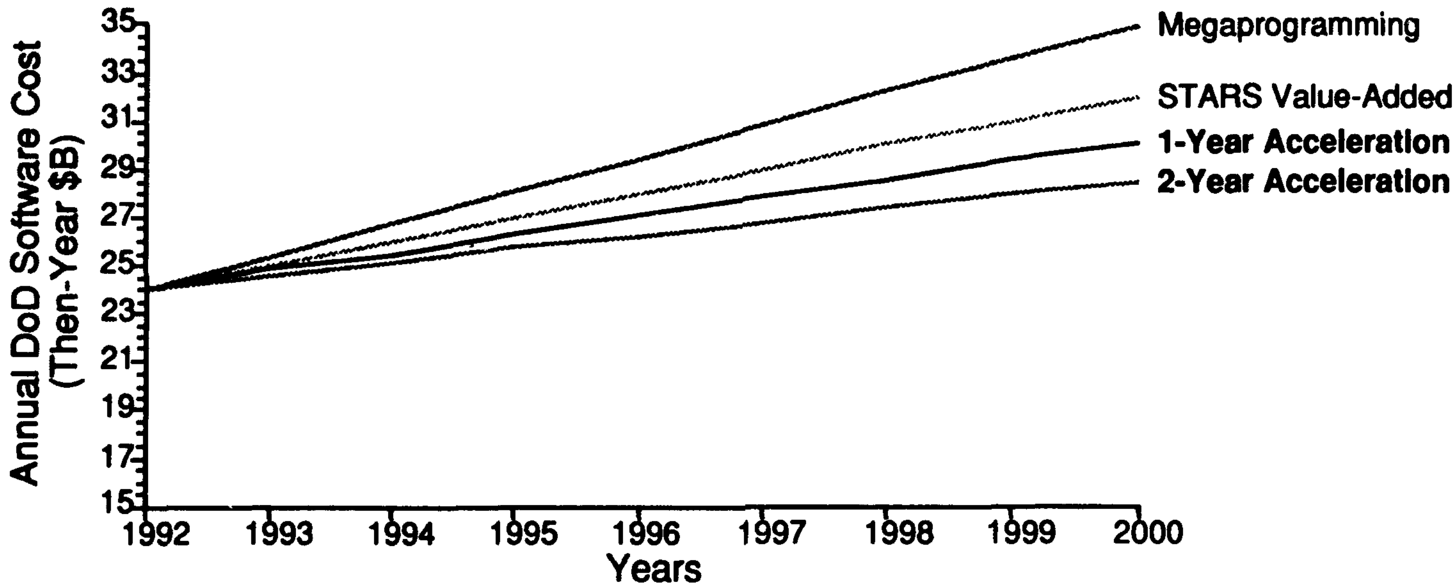
Further Acceleration of Megaprogramming (By 2 Years)

- **FTs and SEI level distributions moved from 2002 to 2000**
- **Intermediate values interpolated**

SEI Level	1992	1993	. . .	2000	2001	2002
1	.80	.74				.32
2	.12	.14		←	←	.24
3	.07	.09		←	←	.20
4	.01	.03		←	←	.16
5	.00	.01				.08

Our second example looked at the effects of accelerating technology transition by two years. The STARS Value-Added scenario was again chosen as the baseline. The distribution of firms across SEI levels in the year 2002 was assigned to the year 2000. In addition, the FTs from the year 2002 were assigned to the year 2000. Values between 1992 and 2002 were interpolated.

Further Acceleration of Megaprogramming Results



Scenario	NPV ($B)
STARS Value-Added	$6.6
1-Year Acceleration	**4.1**
2-Year Acceleration	**2.5**

This chart shows the reduction in cost that results from accelerating the pace of technology transition assumed in the STARS scenario by both one and two years. The NPV of these additional savings for a one-year acceleration is estimated to be $4.1 billion. The NPV of the incremental savings gained by speeding up software technology utilization by a second year is estimated to be $2.4 billion. The total NPV of the combined savings due to the acceleration of new technologies by two years is $6.5 billion, or about equal to the estimated savings due to STARS.

2 X Reduction Scenario

- What does it take to reduce DoD software costs by a factor of two by the year 2000?
- One approach: STARS + Accelerated movement SEI levels

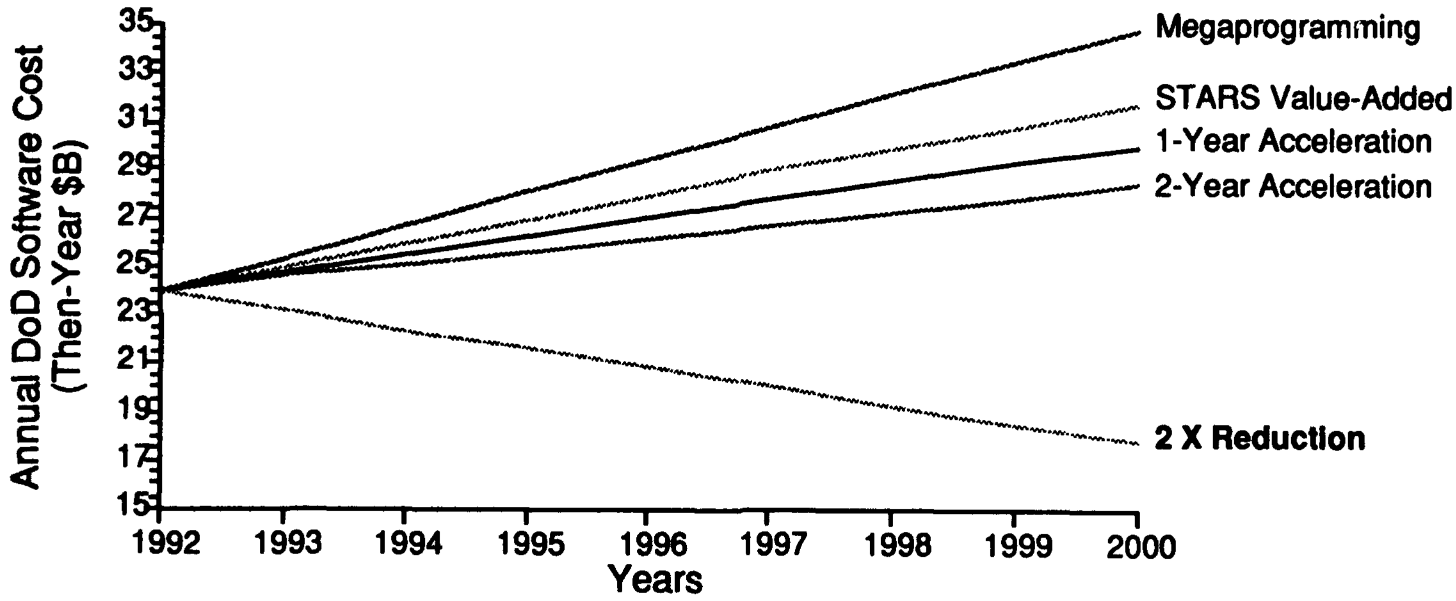
SEI Level	1992	1994	1996	1998	2000
1	.80	. 60	.40	.20	.05
2	.12	.15	.19	.22	.10
3	.07	.18	.29	.39	.50
4	.01	.05	.08	.12	.25
5	.00	.03	.05	.08	.10

- Many other approaches possible

As noted earlier, one of the goals of the Software Technology Strategy is to reduce DoD software costs by a factor of two by the year 2000. We tried various combinations of savings generated by STARS and savings generated by moving firms up SEI levels in order to ascertain if such a reduction was possible. Using the Megaprogramming Baseline expenditures of $24 billion (in constant 1992 dollars) for the year 2000, we found a combination of savings from STARS plus savings from moving firms across SEI levels that will result in expenditures of $12 billion in the year 2000.

Note that 80% of software firms are currently in level 1. This value has to decrease to 5% in just eight years to realize the 2 X reduction goal. Is it possible to move from 80% of the firms in level 1 to only 5% by the year 2000? It seems unlikely. However, without programs such as STARS, it is virtually impossible.

2 X Reduction Scenario Results



Scenario	NPV ($B)
STARS Value-Added	$6.6
1-Year Acceleration	4.1
2-Year Acceleration	2.5
2 X Reduction	**15.1**

The results of the final scenario are presented graphically above. The estimated NPV of the additional savings from this scenario is $15.1 billion.

Conclusions

- Small percentage changes in model parameters have large dollar impacts
- To the extent that STARS can effect these changes, it will have an enormous payoff
- Large savings can be captured by simply advancing technology improvement by one year
- Reducing DoD software costs by a factor of two by the year 2000 will be very difficult to achieve

Because this research is still going on, any conclusions about the particular dollar savings must be viewed as tentative. However, there are several conclusions that can be drawn.

First, the model is very sensitive to small changes in several key parameters. These include the distribution of firms across SEI levels, the values of FT, especially in the early years before their impact is dampened by discounting, and the amount of code that can be maintained by one person per year.

Second, to the extent that the STARS program can effect these changes, it will have a relatively large payoff. Even if the estimated discounted savings are cut in half, STARS is still extremely cost-effective.

Third, the model suggests that a small acceleration in the introduction of new software technologies has a large payoff.

Finally, achieving the goal of reducing total DoD software costs by the year 2000 will require significant improvements in the way DoD develops and maintains software.

APPENDIX

SOURCES OF MODEL PARAMETERS

APPENDIX

SOURCES OF MODEL PARAMETERS

Parameter Type	Source (by Reference Number)
DoD Software Spending	[3], [4], [5], [6], [15]
Discount Rate	[16]
SEI Distributions (starting)	[14], [17]
COCOMO parameters and productivity start values	Fit to material cited in [13], also [12]
Productivity Growth	[7], [8]
Reuse	
FT	[1]
FS	[18], [19], [20]
Tools	
FT	[1]
FS	[1], [21]
Process	[1], [22]
General Maintenance	[11], [13], [23]
Labor Rates	[24], [25]

Note: For additional estimates and information about many of the parameters developed here, see Reference [26].

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