Report to the National Science Foundation on

Systems Challenges for the Next Decade

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About the Institute for Systems Research

The Institute for Systems Research is a National Science Foundation (NSF) Engineering Research Center (ERC) formed in 1985 as a joint venture between the University of Maryland and Harvard University. It is one of 21 such interdisciplinary ERC's that are chartered by the NSF to increase the global competitiveness of U.S. industry. It is the only ERC with the specific mission of conducting systems research.

Foreword

In the past decade, extraordinary technological advances have been made in the fields of control, communication, computing, and sensor technologies. However, the ability to integrate these technologies into better systems has not kept pace with the advances within the disciplines themselves. Although continuing advances can be expected within each of these disciplines, their full potential cannot be realized without the ability to integrate those technologies into better products and processes.

The ability to integrate these advanced technologies has been slowed by a number of barriers. In order to achieve the advances that will be made possible by the integration of these technologies into heterogeneous systems, it is essential that those barriers be identified and overcome.

Scientists and engineers across all U.S. industrial sectors are attempting to overcome the barriers within their individual industries. However, it is increasingly clear that many of these barriers extend beyond sector boundaries and, thus, are common to many industries.

On December 8, 1994, the Institute for Systems Research hosted an industrial workshop to identify the barriers that are common across more than one industry in order to (1) focus national research efforts on removing those barriers with the greatest payoff, and (2) leverage existing industry efforts through a national networking effort.

The workshop included presentations by representatives from the automotive, communications, and semiconductor industries on the gains that can be achieved by fully integrating advanced technologies into their products and processes. These presentations were followed by a facilitated workshop in which invited participants from a wide range of U. S. industries were invited to identify the barriers that exist within their industry sectors. The participants were then asked to collaborate to identify those barriers that exist across industry sectors.

The ISR would like to thank the many companies and individuals who participated in this workshop, and, in doing so, restate the ISR's commitment to working together to address the issues discussed in this report.

— Steven I. Marcus
Director

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Executive Summary

On December 8, 1994, the Institute for Systems Research, a National Science Foundation Engineering Research Center, hosted an industrial workshop to identify the barriers that stand in the way of industry's ability to do systems integration. Participants from a wide range of U. S. industries were invited to work together to identify those barriers that were common across their industries, and, hence, would provide the greatest payoff if removed.

The working groups identified 41 specific barriers that interfered with the ability to do systems integration and which cut across industry boundaries. When these issues were consolidated and grouped by category, ten clearly identifiable issues emerged. These are listed below.

Technological Barriers

- Lack of systems integration methodology and architecture
- Lack of modeling and simulation tools and techniques
- Lack of standards
- Lack of open architectures

Human Resource and Educational Barriers

- Lack of common knowledge and vocabulary
- Lack of cross disciplinary training, horizontal & vertical

Cultural and Organizational Barriers

- Gaps between industry and academia
- Lack of means to share information across industries

Economic and Legal Barriers

- Inadequate resources devoted to systems research
- Regulatory environment

The consistent theme that runs through these issues is that engineers lack the tools and methodologies to efficiently integrate advanced technologies into heterogeneous systems. On a more fundamental level, many of today's engineers even lack the skills necessary to effectively communicate across disciplines in order to achieve those objectives. Furthermore, because research and development has traditionally been conducted within disciplines and not at a systems level, corporate cultures and federal regulations have evolved that impede systems development.

The participants concluded that they were facing a number of common issues and that inadequate resources were being devoted to addressing these issues. Despite huge gains in advanced control, communications, computing, and sensor technologies during the past decade, the full potential of those advances cannot be realized until scientists and engineers are able to fully integrate these advances at a systems level.

Systems Challenges for the Next Decade

There is a clear need for decision making tools that provide for the ability to integrate sensors, actuators, control, and diverse physical modules and then to do trade-off analysis.

Only in the last decade has the level of computing power approached that necessary to integrate and control large scale complex engineering systems.

On December 8, 1994, the Institute for Systems Research, a National Science Foundation Engineering Research Center, hosted an industrial workshop to identify the barriers that stand in the way of industry's ability to do systems integration. Participants were invited from a wide range of U. S. industries to work together to identify those barriers that were common across their industries, and, hence, would provide the greatest payoff if removed.

The working groups identified 41 specific barriers that interfered with the ability to do systems integration and which cut across industry boundaries. It is important to recognize that working groups did not limit their attention to just technological barriers; they concluded that significant barriers also existed in the topic areas of human resources and education, culture and organization, and economic and legal. The intent of this white paper is to summarize each of the issues raised within those topic areas, and, for discussion purposes, these barriers are organized within those topic areas. These barriers and the frequency with which they were identified by the working groups are presented at Appendix A.

Technological Barriers

Four key, interrelated technological barriers that prevent companies from effectively being able to accomplish their systems integration activities are—the lack of a systems integration methodology and architecture, the lack of modeling and simulation tools, the lack of interface standards, and the lack of an open architecture. While these barriers are interrelated, each should be treated as an individual issue because of the unique problems associated with it.

The first two technological barriers are closely interrelated. The lack of an established systems integration methodology and architecture is a key technological barrier in the ability to design at the systems level. Furthermore, key elements of this systems methodology, namely system modeling and simulation tools and techniques, are also lacking. The lack of these modeling and simulation tools impedes the ability of the systems designer to do trade-off analysis, and it impacts the ability to do timely prototyping. There is a clear need for decision making tools that provide for the ability to integrate sensors, actuators, control, and diverse physical modules and then to do trade-off analysis. Such integration also requires integration of the mechanisms for efficiently processing and transferring information in the system—i.e., signal processing and communication. This lack of a set of integrated tools exists across all industries and is the key technological barrier in the effort to do systems integration.

Only in the last decade has the level of computing power approached that necessary to integrate and control large scale complex engineering systems. With these advances in computing power, it is now possible to take the next step forward by fully integrating the major advances in control and communication methodologies with process knowledge and advances in sensors and computing to achieve improved efficiencies, better products, and reduced cost. The current lack of tools and methodologies represents a significant barrier to achieving those results.

A key element in overcoming these barriers will be to create and integrate hierarchical levels of control ...

A key element in overcoming these barriers will be to create and integrate hierarchical levels of control, whether that be in the manufacturing industries, communications industries, or in the process industries. This hierarchy of control begins at the local level (machine tool, communication device, or process device) and extends through process level control (production line, communications cell, or plant module), and finally to a supervisory level of control (factory or communications network). Only by integrating the dynamic elements of these levels of management can this goal be achieved. This requires that not only must the diverse methodologies of control, communication, and computing be integrated, but they must be linked in such a way that they are able to fully utilize the current and future process knowledge and the variety of sensor inputs that drive those models. Furthermore, by definition, this hierarchical control scheme dictates that this integration must occur both horizontally and vertically to accomplish this objective.

The lack of standards precludes the ability to rapidly and efficiently integrate components at the systems level.

It will be important to provide the systems engineer with some measure of his level of success in achieving his objective. Therefore, an important element of that methodology must be some sort of process metrics, especially in the areas of process and systems design, along with new optimization and trade-off analysis tools to facilitate achievement of the best system design.

The next two technological barriers are also interrelated in the way in which they address the assembling of systems. First, the lack of standards precludes the ability to rapidly and efficiently integrate components at the systems level. This lack of standards exists both at the component level and also at the level of underlying methodology for that integration. The lack of open architectures also prevents the efficient integration of heterogeneous components. The traditional means of achieving this objective is to develop interface devices to connect these heterogeneous devices, but this method is both costly and inefficient.

The nature of manufacturing and communications operations is that it has been necessary to develop new and unique control algorithms for each application. The development and prototyping of these algorithms has typically taken a significant length of time, and there has thus been a significant cost of "closing the loop". Consequently, while advanced control algorithms have often been demonstrated in the laboratory, they have much less often been used in practice. Therefore, it is essential that the development of these control methodologies keep pace with the rate of change in application, and that these highly theoretical methodologies must be developed in such a way that they are usable by those in the applications area. In keeping with this objective, there is an increasing desire to develop "plug and play" modules to minimize this historical lag in development and improve the utility and efficiency of control schema.

The drive toward reconfigurable operations means that compatibility must be achieved across manufacturers. This trend of reconfigurability extends from large scale, heterogeneous communications networks to the factory floor, where the growing interest in agile manufacturing increases the need for interoperability, both within the factory environment, horizontally across industries, and vertically to customers and suppliers.

Whereas in past operations, manufacturing facilities were tuned to remain within some prescribed limits described by statistical process control, this new view presents the opportunity to achieve superior performance and reduced cost via effective closed loop control.

These changing paradigms in the way the nation does business increasingly drive a top-down, systems level view of operations in order to achieve the agility necessary to compete in the coming decade. This new view of production and communications operations presents a real opportunity for U.S. industries to leap ahead of the competition to reduce cycle times, improve product quality, reduce cost, and improve production efficiency. Whereas in past (and current) operations, electronics and discrete parts manufacturing facilities were tuned to remain within some prescribed limits described by statistical process control, this new view presents the opportunity to achieve superior performance and reduced cost via effective closed loop control.

To achieve this goal, it will be necessary to develop a software (computing) and networking environment that will permit the integration of process models, sensor inputs, model-based control algorithms, and machine models. The effect of this goal will be the development of an operation that can not only run at peak efficiencies but also one that can provide the operator continuous feedback on the health and capacity of its operation, resulting in the ability to continuously monitor such factors as machine tool wear in a factory environment or communications traffic in a communications environment to reroute production flow or communications traffic based upon the health and capacity of the system.

Human Resource and Educational Barriers

The working groups identified two key human resource and educational barriers that impeded their ability to operate at a systems level in their industries—the lack of common knowledge and vocabulary, and the lack of cross disciplinary training.

Engineers and technicians lack the common knowledge and vocabulary to operate across systems. Whereas a unique, intradisciplinary lexicon may have been an advantage and a source of pride in the past, it now serves as a key impediment to effective interdisciplinary communication.

True systems integration requires both horizontal and vertical integration. In addition to the technological barrier created by this need, there is also an educational barrier. The typical engineer graduating from a university today simply is not prepared to work in a commercial environment in which large, complex engineering systems are being developed. Not only is that engineer ill-prepared to communicate with his peers from other disciplines, but that engineer is not trained to look at the larger system, not able to integrate across the system, and not able to examine the effect that small changes at a local level have upon overall system performance.

The day of the brilliant loner is largely over.

An important component of systems training is the development of team skills. Educational institutions typically reward students based upon individual performance; however, as Norm Augustine points out, "the day of the brilliant loner is largely over." Universities need to do a better job of educating their graduates in working in groups to prepare them for the actual environment they will face in the commercial sector.

Cultural and Organizational Barriers

Hardware and software tools need to be developed to permit systems level collaboration within and across industries.

The working groups identified two important cultural and organizational barriers—a gap between industry and academia, and the lack of means to share information within and between industries.

Much could be done to promote systems integration if the links between industry and academia were strengthened. There were several concerns in this regard. First, too often the work in academia is simply published and placed on the shelf where it lies unused. Secondly, because of the lack of communication between industry and academia, too often the research conducted in the university is not relevant to the needs of industry. Finally, the reward structure in the university environment is typically antithetical to good multidisciplinary research of relevance to industry. This situation exists for two reasons—first, faculty researchers are rewarded for their research and publications within their own specialty or discipline, and secondly, industrial problems are often not viewed as providing the level of scientific interest to engage faculty.

Similar cultural problems exist within industry. There is a lack of communication tools to share information both within and across industries. Hardware and software tools need to be developed to permit systems level collaboration within and across industries. Similarly, there is a lack of interactive ability across disciplines. While a number of collaborative tools have been developed that permit effective intradisciplinary collaboration, new tools are required to extend that collaboration across disciplines. For example, design tools are required that permit sharing between engineering and business applications that would provide the engineer and business manager feedback on cost, schedule, and risk as new products and processes are being designed.

Many of these problems are compounded by cultural barriers within the industry itself. "We've never done it that way," is a common response to many innovative ways of looking at problems. It will be difficult to overcome this inertia, because, in many cases, it is rooted in experience.

Inadequate resources are being devoted to systems research by industry, government, and academia.

Engineers lack the tools and methodologies to efficiently integrate advanced technologies into heterogeneous systems.

A final aspect of these organizational barriers is that it is difficult for people to communicate systems problems across industries. While many industry and disciplinary working groups exist, there is no single forum to discuss the systems issues that modern engineers are facing. While there has been some effort to organize systems engineering working groups, the problems being faced today go beyond systems engineering as traditionally defined by MIL STD-499. For these reasons, it has been difficult for industries to identify and solve common areas of concern.

Economic and Legal Barriers

The groups identified two significant economic and legal barriers—the lack of adequate resources devoted to systems research and a sometimes hostile regulatory environment.

First, inadequate resources are being devoted to systems research by industry, government, and academia. Systems level activities, such as those sponsored by Martin Marietta or Boeing's efforts in the development of the 777 were cited as evidence of successful industry efforts in that regard. Consistent with the cultural issues identified above, it was suggested that insufficient efforts were being taken by universities to ensure that they are adequately preparing their graduates for the multi-disciplinary environment in which they will be employed. Regarding legal barriers, several panel members cited the fact that prescriptive government regulations often stand in the way of effective systems engineering.

Conclusions

The consistent theme that runs through these issues is that engineers lack the tools and methodologies to efficiently integrate advanced technologies into heterogeneous systems. On a more fundamental level, many of today's engineers even lack the skills necessary to effectively communicate across disciplines in order to achieve those objectives. Furthermore, because research and development has traditionally been conducted within disciplines and not at a systems level, corporate cultures and federal regulations have evolved that impede systems development.

The participants concluded that they were facing a number of common issues and that inadequate resources were being devoted to addressing these issues. Despite huge gains in advanced control, communications, and computing technologies during the past decade, the potential of those advances will not be realized in the next decade until scientists and engineers are able to fully integrate these advanced technologies at the systems level.

RECOMMENDATIONS

These efforts should include devoting national resources to develop the methodologies and architectures necessary to fully integrate heterogeneous components into complex engineering systems.

While the working groups made no specific recommendations, the identification of the issues does lead to some specific recommendations from this workshop. In order for the United States to take full advantage of the progress made in advanced technologies and methodologies in control, computing, and communications, resources need to be devoted to the integration of those technologies. Specifically, the following actions should be taken.

Efforts must be undertaken on a national level to overcome the specific technological barriers identified by the workshop. These efforts should include devoting national resources to develop the methodologies and architectures necessary to fully integrate heterogeneous components into complex engineering systems. An essential component of this systems integration effort will be the development of the modeling and simulation tools that will permit engineers to do the trade-off analysis in the development of each system, and then to test/validate the design once completed.

The second major area of concern is the elimination of the human resource and educational barriers that exist to system level work.

Similarly, standards must be developed to permit the rapid exchange of information and seamless integration of components. Furthermore, the development and use of open architectures must be expanded. Ongoing standards developments, such as those led by NIST, and projects such as the NCMS open architecture project are representative of the kinds of efforts that must be expanded.

However, several obstacles stand in the way of the development of these standards. In the past, companies have often gained a competitive advantage by developing and marketing proprietary interfaces and architectures. Despite the fact that this plethora of interfaces has led to market inefficiencies and confusion in the market place, the companies that marketed proprietary interfaces will be reluctant to give up what they perceive as a competitive advantage.

It is for this reason that the development of standards is a slow, and often painful, process. Furthermore, standards once written, are often vague and subject to interpretation. Additionally, new standards often fail to address extant or legacy systems in which companies have invested. Therefore, alternative approaches that resolve the integration problem in the absence of standards, such as object oriented systems representation, may provide a more viable approach to this issue and should be vigorously pursued.

The second major area of concern is the elimination of the human resource and educational barriers that exist to system level work. For the issues raised in the workshop, the burden clearly falls upon academe; however, industry must be an active player in this effort, both to guide academia in eliminating these barriers and to upgrade the skills of their current employees.

Engineers must be provided the skills to be able to work effectively at the system level, and universities and industry trainers must work to promote the ability for the various engineering and business disciplines

It is essential to the global competitiveness of the U.S. that academic research be relevant to the needs of industry and that this new knowledge be rapidly integrated into new products and processes.

Efforts must be made to foster communication among diverse industrial sectors so that common problems can be identified and solved in a cost effective and efficient manner.

to communicate with each other. This goal may be best accomplished by presenting cross-disciplinary projects at both the undergraduate and graduate level of training. This multi-disciplinary training must be conducted in such a way that students not only work across disciplines, but also work at various levels to gain an appreciation for the overall systems nature of any problem. An essential component of this training will be the development of team skills.

A major challenge in overcoming these cultural and organizational issues is bridging the gap that exists between industry and academia. The building of these bridges will require the concerted effort of both industry and academia. It is essential to the global competitiveness of the U.S. that academic research be relevant to the needs of industry and that this new knowledge be rapidly integrated into new products and processes. An important element of the solution will be reviewing the reward systems in both industry and academia to ensure that they promote the interaction between the two groups. The National Science Foundation's Engineering Research Centers program is cited as an outstanding example of a government program that serves to promote this objective, and which could serve as the model for other programs to emulate.

In addition to bridging the gaps between industry and academia, efforts must be made to foster communication among diverse industrial sectors so that common problems can be identified and solved in a cost effective and efficient manner. Agencies such as NIST have done an excellent job of bringing cross-industry groups together to address specific industry problems, but there have been few attempts to bring cross-industry groups together to resolve the larger issues associated with systems integration across diverse and complex engineering systems. This industrial workshop was cited as an example of the leadership role that the National Science Foundation Engineering Research Centers can play in breaking down this barrier.

The participants believed that national resources would be required to achieve the objectives of the workshop. NSF, ARPA, and other government agencies have increasingly sponsored multi-disciplinary research projects, but few resources have been specifically devoted to the underlying methodologies that facilitate the integration of these technologies. It is essential that resources be devoted to this effort.

APPENDICES

A—Table of Barriers

B— Workshop Agenda

C— Keynote Address,
Mr. Norman R. Augustine

D—Distribution

APPENDIX A

TABLE OF BARRIERS

TOPICS	WORK GROUP 1	WORK GROUP 2	WORK GROUP 3	WORK GROUP 4
TECHNOLOGY				
Lack of systems integration methodology & architecture	✓		x	
Lack of ability to integrate sensors, actuators, & control			✓	x
Lack of decision-making tools				x
Lack of design and integration tools		✓		x
Lack of methods for trade-off analysis		x	✓	
Lack of a set of integrated tools				x
Lack of software integration tools		x		
Lack of timely prototyping capability	x			
Lack of modeling and simulation tools and techniques	x	x	x	x
Lack of simulation and prototyping tools		x		
Lack of timely prototyping capability				x
Lack of standards		x		x
Interoperability and methodology—lack of standards	x	✓	✓	
Lack of open architectures		x	✓	x
Lack of open system hybrid models	x			
Lack of integration environment architectures—modules		x		
HUMAN RESOURCE/EDUCATION				
Lack of common knowledge and vocabulary		x		
Common understanding and terms needed	x		✓	
Unsuccessful technical communication	x			
Lack of cross disciplinary training, horizontal & vertical		x	✓	✓
Lack of process [systems] engineering education		x	✓	x
Lack of training		x		✓
Lack of team skills				x
CULTURAL/ORGANIZATIONAL				
Gaps between industry and academia			x	x
Lack of market focus				x
Lack of ability to share info'n. [within]/across industries				x
Lack of communication tools			✓	x
Lack of interactive ability				x
ECONOMICAL/LEGAL				
Inadequate resources devoted to systems research	✓	x		x
Regulatory environment				x
Intellectual property				x
Product liability				x

Legend: **x identified as cross-industry problem by work group**
✓ identified by work group as industry-specific problem

Appendix B

ISR Industry Workshop Agenda

ISR Industry Workshop
Systems Challenges for the Next Decade

Agenda

8:30–9:00 a.m.	Registration and Continental Breakfast
9:00–9:10 a.m.	Welcome to the University of Maryland at College Park William E. Kirwan, President
9:10–9:30 a.m.	Keynote Address Norman R. Augustine, Chairman and C.E.O. Martin Marietta Corporation
9:30–10:00 a.m.	Systems Overview Steven I. Marcus, Director Institute for Systems Research
10:00–10:30 a.m.	Perspectives on Government's Role in Support of Systems Integration Robert J. Bonometti Office of Science, Technology and Policy
10:30–10:45 a.m.	Break
10:45–11:15 a.m.	Predictive Process Control for Manufacturing Richard J. Furness Ford Research Laboratory
11:15–11:45 a.m.	Process Control in Semiconductor Manufacturing Jimmy W. Hosch SEMATECH
11:45 a.m.–12:15 p.m.	Systems Aspects of Wireless Communications Gerard J. Foschini AT&T Bell Laboratories
12:15–1:30 p.m.	Lunch
1:30–3:30 p.m.	Facilitated Discussion
3:30–4:00 p.m.	Wrap-up

Appendix C

Keynote Address

Norman R. Augustine, Chairman & C.E.O.

Martin Marietta Corporation

Good morning and welcome to this annual Industry Workshop, hosted by the Institute for Systems Research. I very much wanted to join you this morning, but a scheduling conflict prevents me. So I asked if I might say a few words to you by videotape.

Actually, my being on videotape might be an advantage over seeing me in person. I once overheard an audience member critique my speaking style saying: "He starts off slowly, then sort of tapers off." In light of that, I'll try to keep my remarks brief and to the point.

First, let me note that Martin Marietta has been a strong proponent of the Institute for Systems Research since its inception in 1985. The Institute has grown enormously in stature over the last decade, becoming a nationally recognized center of thought and research in the area of systems engineering — which I believe will be critical to our nation's competitiveness as we enter the 21st century.

Many of you have heard me say that modern engineering projects almost always represent the combination of diverse disciplines rather than the application of a singular expertise. This is of course what systems engineering is all about — the ability to integrate a number of different engineering capabilities into one successfully functioning project.

We are all familiar with the maxim that 70% of a project's cost are fixed at the time of its design. If the designer doesn't understand the requirements or isn't aware of possible efficiencies that could be "built in" from the beginning, chances of a successful outcome become very small indeed.

Systems engineering brings the diverse areas of engineering - and even other fields such as economics - together so that the end product reflects all the skills of all the parties who need to be involved.

As far as I know, systems engineering was originally created to facilitate the development of complex systems for use in defense. Today, the need for systems engineering is felt in virtually every industry or area of commerce in American life.

For example, the days of the "disposable society" are over. Today, people demand products that last much longer, that perform much better, that cost much less — and that also have some sort of "afterlife." That is, they can be recycled into new products or alternative uses. Today, the greatest challenge in many industries is avoiding, at all cost, a product whose final resting place is the landfill.

This is usually not a problem that any single individual in the design and production "food chain" can remedy. It will require the dedicated efforts of mechanical engineers, computer scientists, materials engineers, software engineers, waste specialists, industry executives, marketing experts, and a lot of other people, working together, to resolve.

As we ponder the systems engineering of the future and the future of systems engineering, we need to be sure we don't fall into the past traps of not understanding what is the final objective or that we look too narrowly at the approaches of obtaining that objective.

Looking at systems engineering — working in partnership between academia and industry — is what you're here to do and it is also where I believe our future has the potential to be its brightest.

You are all familiar with the traditional role of systems engineering - but this morning, I'd like to mention two related areas in which I believe we need to invest so we can create the environment that permits systems engineering to have its maximum impact. Let me touch on these briefly.

First, we need to improve our team skills. The day of the "brilliant loner" is largely over insofar as engineering is concerned... if indeed it ever existed. Even Wernher von Braun, one of the greatest engineering talents of our century, required a team of tens of thousands to successfully carry out the Apollo moon project.

Most future engineering undertakings will require the interaction of thousands or millions of components and hundreds or thousands of people who understand those components. There will of course continue to be important exceptions to this rule, but the majority of engineers of the future are likely to find themselves working as part of a group.

Second, we need to develop our communications and selling skills. Most major engineering projects of today are limited as much by the laws of humans as by the laws of physics. Living in a "sound bite" world, those involved in systems engineering must learn to communicate effectively. In my judgment, this remains our greatest engineering shortcoming today — particularly insofar as written communication is concerned. It is not sensible to continue to place our candle under a bushel as we too often have in the past. If we put our trust solely in the primacy of logic and technical skills, we will lose the contest for the public's attention — and in the end, both the public and the systems engineer will be the loser.

Finally, we need to learn the political process. One must ask why, in today's technology-based society, the voices of the engineer and the scientist and the technician are so seldom heard along with those of all the others who choose to express their views on technological issues?

We must equip engineers of the future to present their cases in almost every forum imaginable — from town meeting to state legislature, from The New York Times to Sixty Minutes, from the Congress to the Oval Office. To do so requires a grounding in such distinctly non-engineering fields as government, history, economics, business, and political science. This of course greatly expands the definition of systems engineering - but it's all part of the task of engineering new systems. The job is not done if the idea dies for lack of understanding by the Congress, for example.

It is not easy to explain why we need a superconducting supercollider in 17 words... but, on average, that's exactly how many words you get when you appear on the network evening news. As Admiral Hyman Rickover, himself a great engineer, once observed, "The best engineers are those who, in addition to technical expertise, have had good training in the liberal arts and understand the world around them."

So finally, allow me to draw on the words from the opening sentence of Winnie-the-Pooh, the book by A.A. Milne: "Here is Edward Bear, coming downstairs now, bump, bump, bump, on the back of his head, behind Christopher Robin. It is, as far as he knows, the only way of coming downstairs, but sometimes he feels that there really is another way... if only he could stop bumping for a moment and think of it."

The time has come for us to stop bumping our heads and embrace systems engineering in its fullest definition so we can lead our country and our economy into the twenty-first century.

Now, let me say thank you for affording me this opportunity to say a few words and wish you a very successful workshop.

Appendix D

Distribution

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